3D scanning, reverse engineering, digital model, digitisation of museum objects

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SELECTED METHODS OF MAKING THREE-DIMENSIONAL VIRTUAL MODELS OF MUSEUM CERAMIC OBJECTS

Abstract

The paper presents available three-dimensional scanning technologies with a particular focus on the digitisation process of ceramic objects. Of the research carried out show that in digitising ceramic objects with concave ornamentation by the Roland PICZA LPX-600 scanner the method of scanning by planes should be used. While digitising such objects with the ZScanner ® 700 one should use the resolution of 0,4 mm. The paper also shows the suitability of reference imaging in recreating the shape of the object in constructing 3D models. This shape can be used in virtual assembly of the shells of broken ceramic vessels.

1.1. INTRODUCTION

Three-dimensional digitisations of objects from Polish museum collections have been made from the beginning of this century, e.g. by a team led by professor R. Sitnik, but they are still incidental activities. In the available literature one can find some suggestions formulated in relation to the three-dimensional scanning process, but they are more verbal in nature, and different authors are putting forward their own opinions. Kuśmidrowicz-Król [1] points out the fact that the technical aspects of the digitisation process not only require specialised equipment, but also a team of people well prepared to handle them. Issues concerning creation of low-budget jobs in 3D scanning and the training of people can be found in the works of Sansoni [2], Kęsik, Montusiewicz and Żyła [3, 4]

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and in Reznicek and Pavelka [5]. Pavlidis et al.’ paper [6] presents a number of techniques of aquiring 3D images in the area of cultural heritage. In the book edited by Stanco, Battiato, Gallo [7] this subject is extended and completed, and Remondino’s [8] paper reviews the actual optical 3D measurement sensors and 3D modelling techniques, with their limitations and potentialities, requirements and specifications.

Klak [9] describes the use of laser scanners for three-dimensional digitisation of museum objects, while Bunsch and Sitnik [10] devote more space to the advantages of scanning by using structured light, also discussing other non-contact scanning techniques. Skabek and Kowalski discuss the practical effects of applying selected scanner models using a laser beam in building 3D models [11], whereas Li, Luo and Zha [12] show practical realisations of 3D scanning. Kłos and Nowacki [13] discuss the practices that should be used in the process of 3D digitisation of museum collections. An original approach to creating cyber-archaeology is presented by Forte, Kurillo and Matlock [14], while Tyszczuk [15] considers his own ideas and practical solutions in this area.

The purpose of creating virtual 3D models of museum objects can be [15]: archiving the collected items to keep them as objects of cultural heritage, the ability to perform metric analyses of these objects, the ability to conduct comparative studies, including typological analyses, the use of models for the verification of the behaviour and determination of the authenticity of monuments, the ability to perform replicas of objects (rapid prototyping using 3D printing), reconstruction of destroyed or damaged items, as well as the possibility of using virtual assembly of fragmented objects, e.g. shells or ceramic sculptures. In addition, having digitised three-dimensional museum objects allows public access to virtual collections, which may contribute to the increased interest in specific museums and places where they are located.

The main problem addressed by the research team from the Department of Programming and Computer Graphics at the Institute of Computer Science, Technical University of Lublin, aims to develop algorithms and tools that will support virtual assembly of vessel shells found during archaeological excavations. The prepared technology will be tested among others on shards of vessels kept in the Alisher Navoiy Scientific-Experimental Museum-Laboratory of the Samarkand State University in the Uzbekistan. The created algorithms and prepared computer program will allow in the future to assemble these objects independently of where they might be kept. The presented phase of the study concerns the preparation of experimental material whose shape we know (creating three-dimensional digital records of the object as a whole and all its fragments when broken). In solving real-world problems we usually have shells that come from many dishes, whose shapes and sizes are not fully known, and in addition there is a deficit of the assembled components.

The aim of this work is to present the application of laser scanners Roland PICZA LPX-600 and ZScanner ® 700 in creating three-dimensional models of complete ceramic objects and objects broken into parts and to determine their suitability to scan these types of exhibits. Digitisation was performed using equipment from the Department of Thermodynamics, Fluid Mechanics and Aviation Propulsion Systems, Faculty of Mechanical Engineering. Moreover, procedures for 3D modelling in AutoCAD 2013 are provided that can be used to perform a complete model of an object based on its reference photo and use it during the virtual assembly of digital shells.

2. DESCRIPTION OF MAKING DIGITAL THREE-DIMENSIONAL OBJECTS

2.1. Three-dimensional scanning

Currently, there are several methods that have found practical application in the creation of three-dimensional models of museum objects. These are the methods of digitisation which, through the use of reverse engineering, create a virtual image of the currently available real object as well as three-dimensional modeling, which can be done on the basis of the reference images of the object to which we do not have direct access (in the extreme case, the object may no longer exist). It is clear that only the reverse engineering methods allow us to create a faithful digital image of an existing object.

The existing methods of 3D digitisation can be divided into contact and non-contact scanning. Among the latter are distinguished [2, 16]:

- laser triangulation,
- photogrammetry (passive method),
- flight of the beam time method (used for large and very large objects),
- structured lighting method (used just as in laser triangulation method).

Because the study examined the usefulness of scanners using laser triangulation, only this method of digitisation will further be presented. The idea of laser scanning can be reduced to the principle of laser distance measurement from a point of known spatial coordinates for the points test and the designation of their position in the adopted system of spatial polar coordinates. This method utilises laser beams as points or lines, and its use is restricted to dispersion surfaces not exceeding two meters. When scanning surfaces which are transparent, reflective or refracting light, one should use a substance adhesively sticking to the surface and with light-scattering properties (talc, titanium oxide or acrylic medium). Once digitised, the object should be wiped or washed with water, which may be unacceptable for many works of art. One advantage of this method is the ability to digitise in daytime as the laser beam has a high energy efficiency. The measuring system of the scanner consists of: a low-power laser emitting orange-red or infrared light, a mirror allowing control of the direction of the laser beam and a high-resolution CCD sensor. During the scan, a camera fitted with a filter transmitting only the laser light, record the place illuminated by the projected laser beam. Both cameras operate synchronously, i.e. to make a video recording, the laser beam must intersect on the scanned surface. Because they are positioned relative to each other at a distance and at an angle, it is not always possible to register the image from both cameras, and it is only possible to scan under this condition. The data on the geometry of the scanned object are obtained by calculating the most intensely illuminated points on the CCD and connecting them with information about the inclination of the mirror. As a result of this conversion a point cloud with coordinates (x, y, z) is obtained, which is a computer representation of the surface of the measured object.

To allow the scanning of an object it is placed on from every side on a computer controlled rotary table (in the case of stationary scanners) or, in the case of handheld scanners, the object placed on a stationary surface is scanned from every side. In the latter case it becomes necessary to place the object markers (tags affixed in the form of circles with a diameter of about 5 mm), which allow the moving scanner to locate reference points so that the obtained distance measurements could be related to points obtained earlier. Tyszczuk [15] believes that the laser light locally heats the surface of the scanned object, which can be dangerous for many objects requiring conservator's protection, but this finding is not supported by research.

Of the many data saving formats the one most commonly used in rapid prototyping methods are text files (extension *.txt*). The text file creates a point cloud which is a set of points with coordinates (x, y, z) and contains information about the intensity of the reflection. Most CAD software also provides the option to save in the *.stl* format, which is a triangulation (triangular) representation of the geometry of surfaces in three-dimensional space. Each area is divided into small triangles, and each vertex of the triangle is described by three points representing their location in relation to the coordinate axes. The resulting triangle mesh can also be saved in formats: *.igs*, *.dwg* and *.wrl*.

2.2. Three-dimensional modelling

A sample method of modelling the selected geometry using the scanning data obtained with a CAD program is shown in Figure 1.

After importing the data in the form of a point cloud (I) one should define an area for further processing (II) to eliminate unnecessary points created during the scan (which are erroneous data) from the object's surroundings. In the next step, based on the control points a polygon mesh (III) is generated as the image of the scanned geometry in the form of a NURBS surface (Non-Uniform Rational B-Spline). Only then can it be converted into a surface model (IV). Finally, it should be replaced it with a solid model by giving thickness to the existing surfaces (V), or in the case of closed surfaces by filling their interior. It is the solid model which most accurately reflects the virtual model of the scanned object.

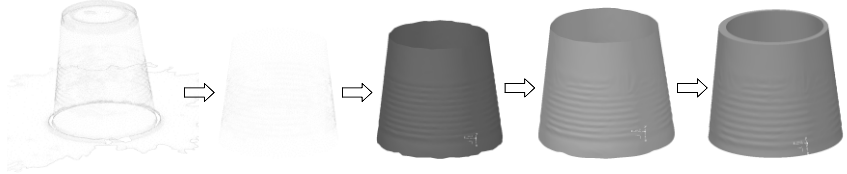

Fig. 1. A sample procedure for geometric modelling using the scanning data [source: own study]

For three-dimensional modelling of the actual exhibit, one can use the reference image of the same object. The basis for the selection of modelling tools is an analysis of the shape and geometrical properties of an object. One should find a plane of symmetry, the axes of symmetry, repetitive elements, their arrangement, rounded and chamfered areas. Such an analysis allows for proper selection of basic objects from which one can start modelling (so-called primitives) and tools for their conversion. More complicated objects are obtained by assembling elementary ones using Boolean operations (difference, sum, product) and locating the characteristic points of objects. Modern 3D modeling programs allow for the conversion of planar objects into solid ones, which greatly enhances the modelling techniques used and gives the designer more freedom of action and triggers his creativity. In this paper AutoCAD 2013 was used for the modelling process.

3. 3D DIGITISATION WITH LASER SCANNERS

3.1. Description of objects for digitisation

The selected objects are two jugs with significantly different shape, made of the same light diffusing material and coated in part with the same ornamentation. The jugs were formed manually as evidenced by a high degree of deviation of the actual cross sections obtained during the measurement of the adjacent circles. For example, the diameter of the foot of the jug shown in Figure 2 was 110 ± 0.1 mm, while the upper part from 110.9 to 120.3 mm. At this stage of the study the objective was the preparation of research material for testing algorithms supporting the virtual assembly of broken dishes. Scanning these vessels will give us their digital description when they were whole and after breaking. Information about the original shape and appearance of these vessels will facilitate the identification of shells and allocate them to a particular jug, while the identical ornamentation will make this process more difficult, especially when the broken fragments are not too large. Thus, the scanning process will include the digitisation of the vessel before and after the breakdown.

A B

Fig. 2. Jug scanning and modelling: A – jug 1, B – jug 2 [source: own study]

3.2. Scanning with the Roland PICZA LPX-600 scanner

Depending on your needs and the size of the scanned object two types of 3D scanning devices can be distinguished: portable (handheld) and stationary. Digitsed objects have been scanned using both the stationary and portable scanner. As a desktop scanner Roland PICZA 3D LPX-600 was used, which is shown in Figure 3 together with selected data in Table. 1.

Fig. 3. Roland PICZA 3D Laser Scanner LPX-600 [17]

Tab. 1. Detailed scanner Roland PICZA 3D Laser Scanner LPX-600 [17]

NAME	DESCRIPTION
Table size	Diameter 254 mm (10 in.)
Maximum scanning area	Plane scanning: Width 254 mm (10 in.), height 406,4 mm (16 in.) Rotary scanning: Diameter 254 mm (10 in.), height 406,4mm (16 in.)
Scanning pitch	Plane scanning: widthdirection 0,2 to 254 mm, heightdirection 0,2 to 406,4 mm. Rotary scanning: circumference 0,18 to 3.6 degrees, height direction 0,2 to 406,4 mm
Repeat accuracy	±0,05 mm (This figure reflects standard scanning conditions established by Roland DG)
Maximum table load weight	5 kg (11 lbs)
Laser	Wavelength: 645 to 660 nm Maximum output: less than 0,39 µW (maximum output of the laser light emitted inside housing is 0,1 mW)
Sensor	Non contact laser sensor
Scanning method	Spot-beam triangulation
Operating speed	Table rotation speed: 9 rpm, head rotation speed: 4,48 rpm, Maximum head movement speed: 37 mm/sec.
Interface	USB (compliant with Universal Serial Bus SpecificationRevision 1,1)

The Roland LPX-600 laser scanner is widely used in the trade by designers, artists, animators and game developers. They have thus the ability to scan objects to the computer in a highly automated manner. The user-friendly handling comes down to placing the object inside and setting the required scanning parameters. It does not call for any complicated setup or technical knowledge. Users enter only the required scanning resolution, area and mode (rotary or planar). Scans are performed automatically and unattended. The result of scanning are data in the form of a point cloud.

Scan files are further processed using programs such as CAD (Computer Aided Design). For this purpose, Roland offers an internal software package called EZ Studio, which creates an .stl format model. For more advanced work may require such software packages as Geometry Systems, Rapidform or Geomagic. These programs allow users to customise the scanning and processing of complex data to create animation formats.

Thanks to the movable head, the Roland PICZA 3D LPX-600 scanner allows two types of scanning techniques: rotary (rotary scanning) and planar (plane scanning), Figure 4. Rotary scanning is dedicated especially to objects that are nearly spherical or cylindrical and have smooth curves. In other cases, it is recommended to scan by planes. Using this technique, we have fewer constraints associated with the shape of objects.

A B

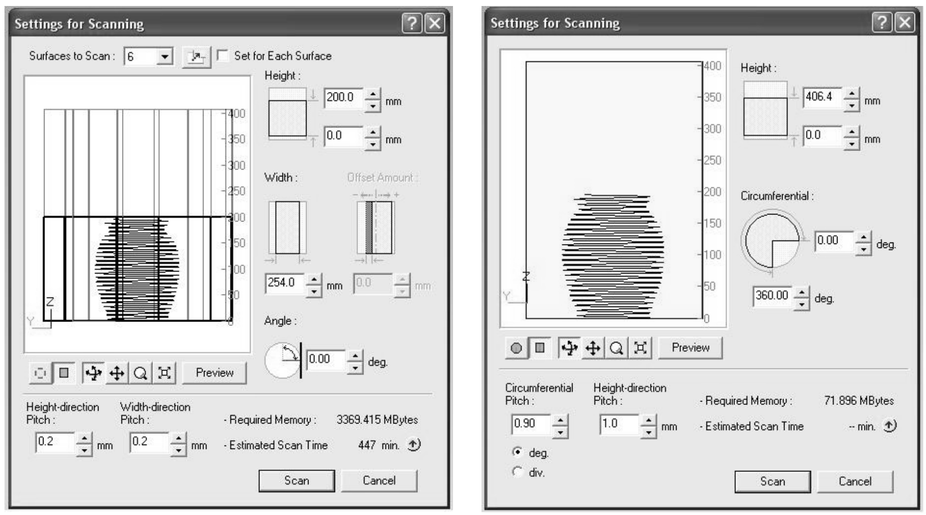

Fig. 4. Scanning settings: planes (A) and rotational (B) [source: own study]

When scanning by planes (Figure 4A), in the Surfaces to Scan field one enters the number of planes in which the object will be scanned; in the Angle field – the angle for the currently selected scan area; in the Height and Width fields the dimensions of the scanning area are introduced, regarding respectively the height and width (the scan area may also be implemented separately for each area). With specified settings a simplified preview of the print area is possible by clicking Preview. A more detailed look at the geometry is allowed by the features accessible through the icons placed under the preview window of the object being scanned.

Both scanning techniques allow to obtain a digital form of both the entire object and its separate fragments. In examining the usefulness of the Roland PICZA scanner in digitising museum objects a scan was performed of jug 1 of Figure 1 by using the two available techniques: rotating and planes.

Rotary scanning

The rotary scanning technique is made by introducing the digitisation accuracy of 0.4 mm. The image of the scanned fragment of the digitised jug (about 65% of the scanning process) is shown in Figure 5. The scanning time was about 85 minutes.

Analysis of the obtained digital image of a jug reveals that the scanning technique used is not appropriate, because the fragments in which the surface of the jug was covered with ornaments is discontinuous – the appearance of the effect of a "sieve". There are explicit see-through effects, with the peering blue background on which the digital recording is generated.

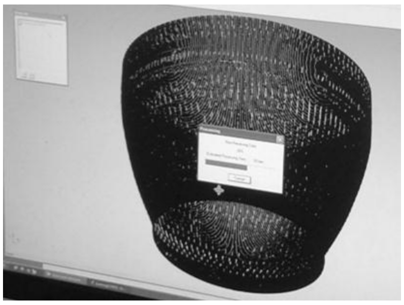

Fig. 5 is a partial view of the jug after scanning by the rotational technique [source: own study]

Scanning by planes

When scanning in this technique, six active surfaces were introduced. A jug surface was obtained consisting of six fragments shown in Figure 6. Because of the angle of covering the object with one plane and the number of planes, individual pieces overlap to form a continuous surface. This technique allows to scan the entire surface producing very well-mapped surface structures. Ornaments which decorated the jug are properly mapped and do not create holes, as was seen when scanning by rotation.

A B C

Fig. 6. View of the partial results of scanning jug 1: A – one plane, B – two planes, C – six planes (complete surface) [source: own study]

The quality of the scanned object is strictly dependent on, among others, the set accuracy of the scanning process. An important factor in the practice of digitisation is also the time of the process, which in turn is a function of the accuracy. For this reason, the scanning parameters are introduced individually for each object depending on the desired requirements. The Roland PICZA scanner allows to scan with the accuracy of 0,2 mm with value gradation of 0.2 mm, both along the width and height. For estimated scan times a simulation of the digitisation process was done, changing the precision values of scanning. The experiment was performed while scanning jug 1, and the results are given in Table 2 and Figure 7. It was found that in scanning by planes an increase in the accuracy along the width does not affect the scanning time.

Tab. 2. Time values of scanning by six planes while changing process accuracy along the height coordinate [source: own study]

Lp.	Height [mm]	Width [mm]	Time [min]	Time shortening [%]
1.	0,2	0,2	437	-
2.	0,4	0,2	221	49
3.	0,6	0,2	148	33
4.	0,8	0,2	113	24
5.	1	0,2	91	19

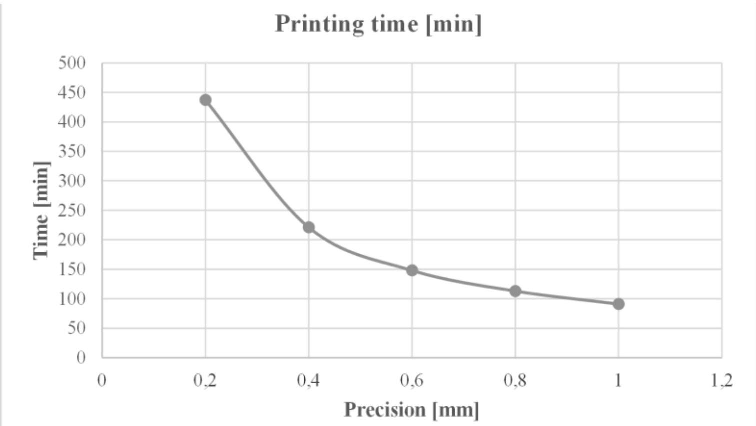

Fig. 7. Impact of accuracy on digitisation time in scanning by six planes along the height coordinate [source: own study]

A thorough analysis of the results of the simulated time values in scanning with six planes shows that halving the height accuracy from 0.2 mm to 0.4 mm reduces the time by 49%. Further reduction in the accuracy by the value of 0.2 mm (i.e. three times less than the initial value) shortens the time of digitisation threefold. Ultimately, the obtained results show that an n-fold decrease in accuracy reduces scanning time about n times. Thus the scanning duration with the accuracy of 1 mm is 90 minutes.

3.3. Scanning using a handheld scanner ZScanner ® 700

The ZScanner ® 700 shown in Figure 8A, the details of which are given in Table 3, is a handheld scanner. Using it requires sticking on the object markers enabling the automatic submission of individual scans. Thanks to these markers, after a change of the scan area (displacement of the device relative to the object), the scanner detects the positions relative to the previous surface. Markers are used normally in objects larger than the volume of the measuring scanner, Figure 8B.

A B

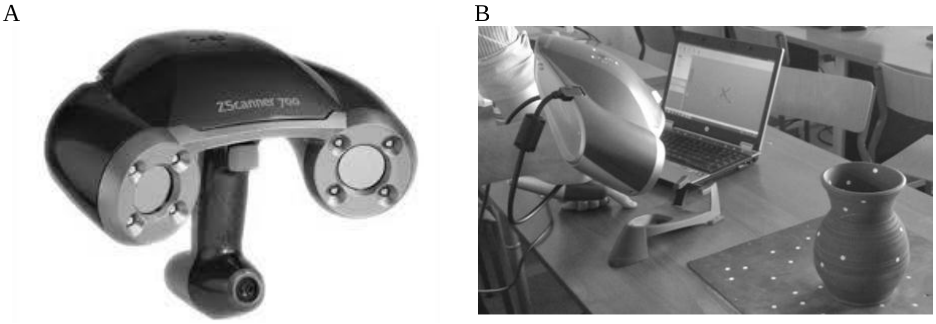

Fig. 8. The ZScanner ® 700: A – general view [18], B – the scanning process of jug 2 (cf. Fig. 1); visible white markers stuck to the object [source: own study]

Tab. 3. Details of the ZScanner ® 700 [18]

NAME	DESCRIPTION
Weight	1.3 kg
Dimensions	172x260x216 mm
Speed	18000 measurements/s
Laser class	II (safe for the eyes)
Cameras	3
Accuracy XY	50 µm
Resolution	0.1 mm in axis Z
Texture resolution	50 to 250 DPI
Depth of measurement	30 cm
Exported formats	*.DAE, .FBX, .MA, .OBJ, .PLY, .STL, .TXT, .WRL, .X3D, .X3DZ, .ZPR*
Certificate	CE
Data transfer	FireWire

A handheld scanner, due to its ability of movement relative to the object, allows one to scan the interior of an object so that the inner surface is generated. This capability significantly increases the use of this scanner compared to a desktop scanner and turns out to be very useful when scanning small items.

In examining the suitability of the ZScanner ® 700 to digitise exhibits, scans of jug 2 of Figure 1 were done, beginning with the digitisation of the entire object, and then after breaking it into eight parts, of the individual components, Figure 10. Breaking the jug results in several large components, some very small fragments and ceramic dust, whose total weight was about 5% of the weight of the complete jug (the total weight was 1176.9 g).

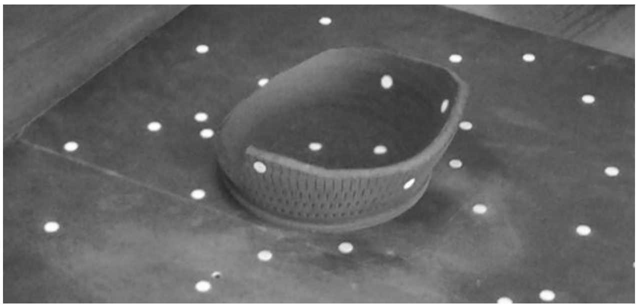

Fig. 10. Scanning the base of jug 2 by using the ZScanner ® 700 [source: own study]

The digitisation of the jug was made with the scanning accuracy set to 0.4 mm. Attempts to scan the sample were also conducted with the maximum accuracy of 0.2 mm, which, however, failed. The process of obtaining a digital fragment lasted a very long and the resulting image of the scanned area was characterised by a large discontinuity and was not fit for use.

Examples of the digital images of elements of jug 2 are shown in Figure 11. The drawing shows that the resulting scans show slight defects arising in the process of digitisation, which should be corrected during postprocessing.

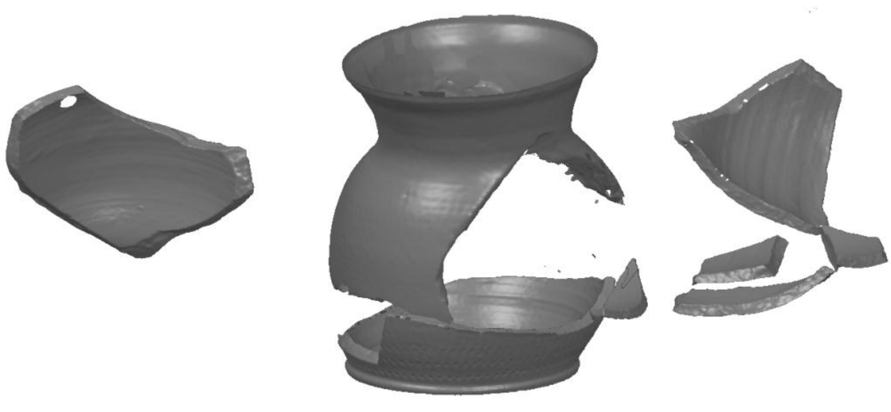

Fig. 11. View of scanned fragments of the broken jug 2 using ZScanner ® 700 and the process accuracy = 0.4 mm [source: own study]

4. 3D MODELING USING AutoCAD PROGRAM

The modelled jug 2 of Figure 1 is a rotating solid, so the best method of modelling it is plotting its left or right contour (for this purpose, spline objects were used) based on a reference photo and using the command to rotate this contour around the indicated axis (click Rotate around the Z axis 360 °). Thus, the outer surface of the jug was obtained. In practice, in modelling the external shape of the jug both contours were used, introducing other colours (purple and grey) for contrast. Since the jug was made by hand, the two contours are slightly different from each other. This is shown in Figure 12 by applying both modelled surfaces onto each other.

A B C

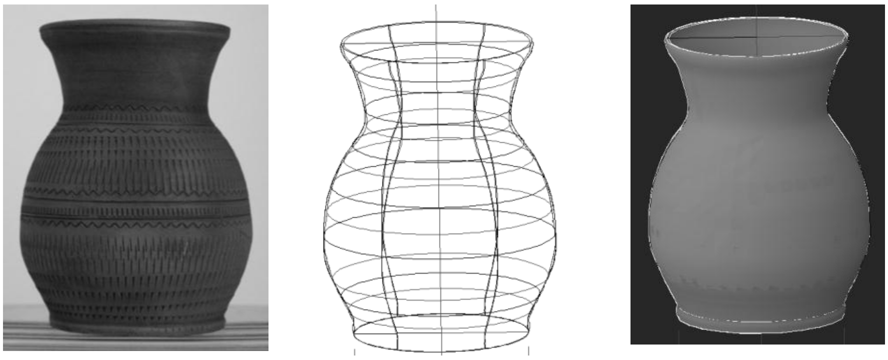

Fig. 12. Jug 2 and its model: A –reference image, surface models, B – overview edge, C – a conceptual overview [source: own study]

The colour penetration shown in the figure is due to a difference between the contours obtained by the outline of the left and right edges of the photographed jug. Obtaining a solid model was achieved by converting the surface model to a solid structure using the command Bold with the appropriate options and parameters, Figure 13.

Fig. 13. Fragment of a solid model of jug 2 [source: own study]

The presented modelling process does not afford ornamentation present on the surface of the jug in geometric form. In order to obtain a photorealistic visualisation one would have to map the model with the texture derived from a photo of the actual surface of the jug, and then perform the rendering.

The implementation of a virtual jug shows that the resulting model is only a digital approximation of the actual object, but may be useful in the process of virtually assembling the digitised items, because it can be placed in a three-dimensional scene and it shows the shape of the object.

5. SUMMARY AND CONCLUSIONS

Ceramic shells from excavations are objects that do not have sharp edges, but many small cavities. This causes that elements from the breakdown of a larger piece in time will not adhere to each other over the entire cross-sectional area of the shell. Thus, the requirements for the digitisation of such objects are characterised by a certain peculiarity, in which maximisation of the accuracy of the scan is not a priority. Generating large files would cause virtual assembly to require the use of equipment with large calculation capacities and would be very time-consuming.

From the work carried out it appears that:

1. The use of a desktop scanner Roland PICZA LPX-600 is justified in carrying out digitisation of complete objects, because the process is carried out automatically and does not absorb personnel time.
2. The stationary scanner is not suitable for scanning the shells of a broken jug (they form hypersurfaces) due to the continued coverage of their interiors. Obscured fragments will form breaks in the digital representation of the scanned surface.
3. In digitising by the Roland PICZA LPX-600 scanner, to obtain a correct image structure on the surface of an object, one should scan by planes and not by rotation.

4. Scanning with maximum accuracy takes too much time (over 400 min.) and the size of the files created varies from 30 to 140 MB, depending on the recording format.
5. The handheld ZScanner ® 700 is well suited for scanning the shells of a broken jug after introduction of the scanning accuracy of 0.4 mm. Then the digitisation process goes pretty quickly, and the resulting scan is characterised by good quality.
6. Creating AutoCAD digital models of complete vessels will be useful in the process of virtual assembly of elements created after their breaking. Saving the resulting files in various formats makes their use independent of the various programs for the treatment of three-dimensional objects.

REFERENCES

[1] KUŚMIDROWICZ-KRÓL A.: *Standards, Procedures and Other Challenges – Works of the Team of Experts on the Digitalisation of Museum Exhibits at the National Institute of Museology and Collections Protection (in Polish)*. Muzealnictwo, No. 52, 2011, pp. 29-36.

[2] SANSONI G., TREBESCHI M., DOCCHIO F.: *State-of-The-Art and Applications of 3D Imaging Sensors in Industry, Cultural Heritage, Medicine, and Criminal Investigation*, „Sensors" No. 9, 2009, pp. 568–601.

[3] KĘSIK J., MONTUSIEWICZ J., ŻYŁA K.: *Low-cost 3D Scanning Methods as Tools for Virtual Heritage Expositions (in Polish).* Pomiary Automatyka Kontrola, Vol. 60, No. 8, 2014, pp. 664–667.

[4] KĘSIK J., ŻYŁA K.: *Low-cost 3D scanners in training museum workers responsible for digitalization of resources – possibilities of usage (in Polish)*. Logistyka, No. 6, 2014, pp. 5385–5394.

[5] REZNICEK J., PAVELKA K.: *New Low-Cost 3d Scanning Techniques for Cultural Heritage Documentation*. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVI, Part B5, Beijing 2008, pp. 237–240.

[6] PAVLIDIS G., KOUTSOUDIS A., ARNAOUTOGLOU F., TSIOUKAS V., CHAMZAS C.: *Methods for 3D digitization of Cultural Heritage*. Journal of Cultural Heritage, No. 8, 2007, pp. 93–98.

[7] *Digital Imaging for Cultural Heritage Preservation: Analysis, Restoration, and Reconstruction of Ancient Artworks*. [eds.] F. Stanco, S. Battiato, G. Gallo, CRC Press, Taylor & Francis Group, 2011.

[8] REMONDINO F.: *Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning*. Remote Sensing, No. 3, 2011, pp. 1004–1138.

[9] KLAK P.: *Practical Digitalisation of Historical Monuments and Museum Exhibits (in Polish)*. Muzealnictwo, No. 52, 2011, pp. 54–60.

[10] BUNSCH E., SITNIK R.: *The 3D Digitalisation Process – from Assumptions to Digital Documentation (in Polish)*. Muzealnictwo, No. 52, 2011, pp. 48–53.

[11] SKARBEK K., KOWALSKI P.: *Building the Models of Cultural Heritage Objects Using Multiple 3D Scanners*. Theoretical and Applied Infor., Vol. 21, No. 2, 2009, pp. 115–129.

[12] LI R., LUO T., ZHA H.: *3D Digitization and Its Applications in Cultural Heritage*. [in] Ioannides M. (Ed.): EuroMed'2010, Proceedings of the Third International Conference on Digital Heritage, Springer-Verlag Berlin, Heidelberg 2010, pp.381–388.

[13] KŁOS M., NOWACKA A.: *Good Digitalisation Praxis upon the Basis of the Experiences of the DigMuz Inter-Museum Digitalisation Group (in Polish)*. Muzealnictwo, No. 52, 2011, pp. 61–72.

[14] FORTE M., KURILLO G., MATLOCK T.: *Teleimmersive Archaeology: Simulation and Cognitive Impact*. [in] Ioannides M. (Ed.): EuroMed'2010, Proceedings of the Third International Conference on Digital Heritage, Springer-Verlag Berlin, Heidelberg 2010, pp. 442–431.

[15] TYSZCZUK S.: *Alternative Archaeology. Techniques of research and documentation in archaeology and anthropology (in Polish) Archeologia alternatywna. Techniki badań i dokumentacji w archeologii oraz antropologii*. Last accessed on 10.10.2014, http://www.archeotyszczuk.republika.pl/muzealnictwo.htm.

[16] SITNIK R.: *Light System for Automated 3D Documenting of Cultural Heritage*, Lasers in the Conservation of Artworks, Vol. VIII, 2011, pp. 203–207.

[17] *Roland, 3D Laser Scanner LPX-600*. Information brochure, RDG-416003699 '05 NOV. A-4 G-S, 2010.

[18] *ZCorporation, Versatile and user-friendly 3D scanners*. Information brochure 3D Lab., 2010.