3D Scanning of Porto Alegre Museum Artifacts: The Crockery of the Rocco Bakery

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3D Scanning of Porto Alegre Museum Artifacts: The Crockery of the Rocco Bakery
Antiques usually require careful handling, so these objects cannot be made available to the general public and are handled only by restoration specialists. This article focuses on the preservation of antiquities in terms of cultural heritage and the availability of these objects for access by visitors, it describes and evaluates the development of a method to support the digitisation of objects considered solids of revolution. The artifacts were provided by the Museu Joaquim José Felizardo in the city of Porto Alegre, Brazil, and were used to set the table in the former Confeitaria Rocco (bakery). The 3D process consisted of the following steps: laser scanning, data processing of the coordinates obtained from the surface of the object into point clouds, creation of the virtual model, creation of a physical model using additive manufacturing, and evaluation of the physical model in comparison with the original artifact. The obtained results show that highly accurate models can be created using the proposed method. Therefore, virtual data can be obtained for the conservation, restoration and creation of replicas for studies and accessibility.

Keywords: 3D digitisation, cultural heritage, historical artifacts, solids of revolution

INTRODUCTION

The possibility to bring and incorporate 3D techniques into museums is a valuable and significant addition to protect and interact with heritage and art objects. 3D technologies capture small objects' asymmetries and marks of time that would be difficult to accurately reproduce using other techniques. In this sense, the use of 3D techniques is a good way to preserve cultural and historical heritage and, moreover, to make these objects accessible by offering a unique experience to visitors, including those with visual impairments. Therefore, the development of a precise and reliable method for the 3D reconstruction of pieces considering them solids of revolution becomes a useful tool. 3D technologies call for interdisciplinary studies concerning the cultural heritage, and on the other hand, may also be used as an interaction tool.[1] According to Turner et al., 3D tools provide an interface where participants, including children, may have contact with museum spaces and objects.[2]

The Joaquim Jose Felizardo Museum is a reference for accessibility in southern Brazil and has various aids and an accessibility area that is being developed with the support of a dedicated team. The museum's collection includes utensils from Confeitaria Rocco, a bakery that served the population of Porto Alegre between 1912 and 1964.[3] The selection criteria for the digitised pieces were the state of conservation and the cultural relevance for the city.

Three main reasons influenced the decision to conduct this study:

It should be considered that within the historical heritage there are many fixed objects of revolution, for example, vases, bowls, jars and decorative objects. Despite their similarity, these pieces have small differences and traces of the period, which should be accurately reproduced.

In the context of cultural dissemination, a detailed 3D model not only helps in virtual accessibility, but also in cataloguing and restoration in case of damage.

Making accurate replicas allows physical contact with objects that cannot otherwise be touched or handled because of the original's value.

The aim of this paper is to present a method for the 3D scanning of, and the development of 3D models of, artifacts with slightly asymmetric solids of revolution. The second goal is to contribute to the generation of 3D models of solids of revolution to enable the reproduction of accurate replicas.

THE MUSEUM AND THE BAKERY

The museum is currently housed in the Solar Lopo Gonçalves, a historic building built between 1845 and 1855, located at 582 Rua João Alfredo in the Cidade Baixa neighbourhood of Porto Alegre, capital of the state of Rio Grande do Sul. It was built as a weekend home for the family of Lopo Gonçalves Bastos (1800–1872), a Portuguese merchant who was active in business and politics in Porto Alegre.[4] In 1979, the Museum of Porto Alegre or the Municipal

[1] GALEAZZI Fabrizio. 3D recording, documentation and management of cultural heritage. In: *International Journal of Heritage Studies*, 23(7), 2017, pp. 671–673.

[2] TURNER, Hannach et al. Using 3D Printing to Enhance Understanding and Engagement with Young Audiences: lessons from Workshops in a Museum. In: *Curator: The Museum Journal* 60(3), 2017, pp. 311–333.

[3] SOSKA, Gabriela Barbosa. Confeitaria Rocco: instituto de gastronomia [Rocco bakery: gastronomy institute]. Senior thesis in architecture at the Federal University of Rio Grande do Sul, Porto Alegre, 2018, 32 pp., accessed October 19, 2020, http://hdl.handle.net/10183/182815[In Portuguese].

[4] Site da prefeitura de Porto Alegre [Porto Alegre City Hall website, RS, Brazil]. *Cultura - Museu de Porto Alegre Joaquim Felizardo* [Culture - Museum of Porto Alegre Joaquim Felizardo], accessed May 10, 2022, https://www2.portoalegre.rs.gov.br/smc/default.php?p_secao=278 [In Portuguese].

Museum was created, and the building in question underwent two years of restoration to later become the seat of the museum. Joaquim José Felizardo (1932–1992) was a writer and professor who founded the Porto Alegre Municipal Cultural Department (SMC) in 1988. In his memory, the Historical Museum of Porto Alegre was named after him in 1993 (Figure 1). In 2010, the accessibility sector was created with the main objective of widening, qualifying and democratising access for the general public and the integration of people with disabilities.[5]

Figure 1: *Exterior view of the building of the Museum Joaquim José Felizardo.*
Source: free stock photos bank. https://bancodeimagens.portoalegre.rs.gov.br/imagem/31489

The museum has a digital collection room with about 5,000 photographs of Porto Alegre in the nineteenth century, as well as three important collections on the history of the city: a photographic collection consisting of about 20,000 photographs collected at Fototeca Sioma Breitman to create an image database, a large part of which will be restored and conserved to be later digitised; an archaeological collection including 120,000 pieces, including fragments and whole objects related to prehistoric and historic settlement sites in the city of Porto Alegre – these are pieces made of ceramics, stone, porcelain, glass, metal, leather and bone; a historical collection including about 1,300 pieces that were donated by Porto Alegre citizens in the late nineteenth and twentieth centuries. These are objects of various types that belonged to Porto Alegre citizens, with the pieces from the old Confeitaria Rocco standing out.[6] Therefore, the tableware from the former Confeitaria Rocco is an important part of the urban memory of the city of Porto Alegre.

Confeitaria Rocco, founded in 1772 by Portuguese from the Azores islands,[7] is a renovated historic building in the city of Porto Alegre, located at the corner of Riachuelo and Dr Flores

[5] ATOLINI, Thanise Guerini. *Oficina de Acessibilidade Conhecendo Porto Alegre através dos sentidos: Educação Patrimonial no Museu de Porto Alegre Joaquim José Felizardo. Experimentações em lugares de memória: ações educativas e patrimônios*. Porto Alegre/RS: Selbach & autores associados, 2015, pp. 335–348. [In Portuguse].

[6] Site da prefeitura de Porto Alegre [Porto Alegre City Hall website, RS, Brazil], ref. 4.

[7] Site oficial da prefeitura da cidade de Porto Alegre [Porto Alegre City Hall official website, RS, Brazil]. *Conheça Porto Alegre* [Discover Porto Alegre],accessed August 3, 2021, https://prefeitura.poa.br/gp/projetos/conheca-porto-alegre [In Portuguese].

streets, next to Praça Conde de Porto Alegre. It was an important meeting point for the aristocratic society of Porto Alegre (RS, Brazil). It was built in 1912 and belonged to the Italian Nicolau Rocco (1861–1932). It was a meeting place for rio-grandense society because of the quality of its services and products, because of the external beauty of the building with its masonry made of adobe bricks and facades decorated with beautiful details on staircases, balconies and columns, and because of the splendour of the interiors, which were furnished with luxury and refinement. Its banquets and sweet and savoury pastries, as well as the service, installations and utensils, became famous. The bakery property was officially proclaimed a historical landmark by the municipality of Porto Alegre in 1997.[8]

THE PROJECT

From the outside, the four-story building of 1,560 m2 has an Art Nouveau style and is made of clay brick masonry and ornate facades with beautiful details on the stairways, balconies and columns.[9]

The interiors were as luxurious and sophisticatedly decorated as the utensils used for serving. The tableware used for serving at the table included two sets: a dessert service with a silver holder and glass bowl (Figure 2A) and a ceramic cup and saucer (Figure 2B). Both sets feature intricate details, curves and organic shapes. The glass bowl is composed of pieces of varying thicknesses with refined embossed floral details.

It should be noted that the cultural heritage objects had to be handled with special care and could not be modified, changed or in any way damaged.[10] Acquisition protocols were far stricter than those required for the scanning of objects for industrial applications.[11]

Figure 2: *Tableware from the former Confeitaria Rocco, on display at the Museu Joaquim José Felizardo in Porto Alegre/* RS. Dessert service consisting of a silver saucer and a glass bowl (A). Ceramic teacup and saucer (B)

Materials such as wood, stone, marble, glass, ceramic and metal, including copper alloys,

[8] SOSKA, Gabriela Barbosa, Confeitaria Rocco: instituto de gastronomia...

[9] PALOMBINI, Marco Antônio de Lima. O processo recente de revitalização na área central de Porto Alegre: uma análise acerca do papel da Universidade Federal do Rio Grande do Sul [The recent revitalisation process in dowtown Porto Alegre: an analysis of the contribution of the Federal University of Rio Grande do Sul]. Master's thesis, Postgraduate Program in Economics, Federal University of Rio Grande do Sul, Porto Alegre, 2015, 119 pp., accessed March 10, 2022, http://hdl.handle.net/10183/147473 [In Portuguese].

[10] KUZMINSKY, Susan C., and GARDINER, Megan S. Three-dimensional laser scanning: potential uses for museum conservation and scientific research. In: *Journal of Archaeological Science*, 39(8), 2012, pp. 2744–2751

[11] Ibidem; PAVLIDIS, George et al. Methods for 3D digitization of Cultural Heritage. In: *Journal of Cultural Heritage*, 8(1), 2007, pp. 93–98.

silver, gold and different grades of steel, are commonly used on historical sculptures or antiques.[12] Great efforts have been made to preserve cultural heritage objects and make them accessible to citizens. This is a relatively delicate matter related to the democratisation of cultural heritage through the 3D digitisation of artifacts and spaces.[13] Therefore, multidisciplinary research lines are emerging in order to reproduce and store precise information on patrimony.[14]

Three-dimensional scanning stands out as a technology that is used to accurately capture the contours of the object surface.[15] It captures 3D images and data using computer tools to obtain highly accurate details of surfaces, textures and the object as a whole.[16] It is possible to create photorealistic 3D models or prototypes to explore and disseminate historical and cultural heritage from 2D paintings to 3D sculptures, from big buildings to very small objects.[17]

Moreover, research by Lee et al. has shown that 3D scanning and printing equipment, processes and materials are interdependent. Biomaterials, composites, electronic materials and smart materials are interesting alternative choices. Smart materials using, for example, water or heat, have the ability to change their geometry, making them ideal for 4D printing.[18]

Technological advances also underscore the importance of the technology in the fields of archaeology[19] and biological anthropology.[20]

Findings from testing different 3D scanners for cultural heritage showed that, due the technical complexity of 3D scanning variables, no method alone meets the necessary specifications

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[12] Ibidem; ANDRADE, Beatriz Trinchão et al. Digital preservation of Brazilian indigenous artworks: Generating high quality textures for 3D models. In: *Journal of Cultural Heritage*, 13(1), 2012, pp. 28–39; GOMES, Leonardo, BELLON, Olga R. P., and SILVA, Luciano. 3D reconstruction methods for digital preservation of cultural heritage: A survey. In: *Pattern Recognition Letters*, 50(C), 2014, pp. 3–14 BRUNO, Fabio et al. From 3D reconstruction to virtual reality: A complete methodology for digital archaeological exhibition. In: *Journal of Cultural Heritage,* 11(1), 2010, pp. 42–49; FOWLES, P. Stephen et al. The laser recording and virtual restoration of a wooden sculpture of Buddha. In: *Journal of Cultural Heritage*, 4(1), 2003, pp. 67–371; YOUNAN, Sarah, and TREADAWAY, Cathy. Digital 3D models of heritage artefacts: Towards a digital dream space. In: *Digital Applications in Archaeology and Cultural Heritage*, 2(4), 2015, pp. 240–247.

[13] TAYLOR, Joel, and GIBSON, Lara Kate. Digitisation, digital interaction and social media: embedded barriers to democratic heritage. In: *International Journal of Heritage Studies*, 23(5), 2016, pp. 408–420.

[14] ANDRADE, Beatriz Trinchão et al.Digital preservation of Brazilian...

[15] SHORT, Daniel B. Use of 3D Printing by Museums: Educational Exhibits, Artifact Education, and Artifact Restoration. In: *3D Printing and Additive Manufacturing*, 2(4), 2015, pp. 209–215; GOMES, Leonardo, BELLON, Olga R. P., and SILVA, Luciano. 3D reconstruction methods for digital preservation...; BRUNO, Fabio et al. From 3D reconstruction to virtual reality...; FOWLES, P. Stephen et al. The laser recording and virtual restoration...

[16] PAVLIDIS, George et al.Methods for 3D digitization...; ANDRADE, Beatriz Trinchão et al.Digital preservation of Brazilian...; GOMES, Leonardo, BELLON, Olga R. P., and SILVA, Luciano. 3D reconstruction methods for digital preservation...; BRUNO, Fabio et al. From 3D reconstruction to virtual reality...; FOWLES, P. Stephen et al. The laser recording and virtual restoration...

[17] BRUNO, Fabio et al. From 3D reconstruction to virtual reality...; FOWLES, P. Stephen et al.The laser recording and virtual restoration...; GILLESPIE, Susan D. – VOLK, Michael. A 3D model of Complex A, La Venta, Mexico. In: *Digital Applications in Archaeology and Cultural Heritage*, 1(3-4), 2014, pp. 72–81.

[18] LEE, Jian-Yuan, AN, Jia, and CHUA, Chee Kai. Fundamentals and applications of 3D printing for novel materials. In: *Applied Materials Today*, 7, 2017, pp. 120–133.

[19] ANDRADE, Beatriz Trinchão et al.Digital preservation of Brazilian...; no. 3D reconstruction methods for digital preservation...; BRUNO, Fabio et al. From 3D reconstruction to virtual reality...; FOWLES, P. Stephen et al. The laser recording and virtual restoration...; GILLESPIE, Susan D. – VOLK, Michael. A 3D model of Complex A...

[20] KUZMINSKY, Susan C., and GARDINER, Megan S. Three-dimensional laser scanning...; WEBER, Gerhard W. Another link between archaeology and anthropology: Virtual anthropology. In: *Digital Applications in Archaeology and Cultural Heritage*, 1(1), 2013, pp. 3–11.

required in each project.[21] Furthermore, associated with the appropriate 3D scanner, the proper 3D digitisation procedure is equally important.[22] The combination of laser scanning and photogrammetry techniques has proven its effectiveness in reproducing precise and pleasing 3D models of historical cities.[23]

Typically, a 3D scanning process generates point clouds, which are sets of thousands of coordinates from the surface of an object. Different point clouds need to be aligned and merged to form a 3D mesh. To scan solids of revolution aiming at the reproduction of textures and asymmetric details in cyclic surfaces can be very challenging. In other words, these objects, even though they have similar sides, feature simple differences that should be accurately reproduced. Greater difficulty occurs while building the point clouds measured by the scanner because the software tends to overlap similar surfaces, interfering with the point clouds' resolution. The definition, constraints, quality and level of the information withdrawn from the point cloud is relevant. The cloud's resolution is directly related to the points – a greater number of points results in a smaller variation in the cloud points, therefore refining the model.[24]

A detailed 3D model offers the possibility of archiving geometric details and object surface conditions such as corrosion, wear and other characteristics.[25] Digital files are durable and unchangeable and can be used as references for monitoring the degradation and restoration of artifacts, among other benefits.[26] In the context of cultural dissemination, researchers have been scanning the collections of museums around the world providing people with greater access to digital objects.[27]

For real-time visualisation purposes, low-resolution meshes and image maps are used for the representation of surface details.[28] Therefore, a high level of detail in a low-resolution model can be obtained with little processing effort. However, only a model with a high-resolution mesh is capable of representing details and textures with the use of 3D printing.[29]

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[21] DI ANGELO, Luka et al. An AHP-based method for choosing the best 3D scanner for cultural heritage applications. In: *Journal of Cultural Heritage*, 34, 2018, pp. 109–115.

[22] BUDAK, Igor et al. Development of Expert System for the Selection of 3D Digitization Method in Tangible Cultural Heritage. In: *Technical Gazette*, 26(3), 2019, pp. 837–844.

[23] BALSA-BARREIRO, José, and FRITSCH, Dieter. Generation of visually aesthetic and detailed 3D models of historical cities by using laser scanning and digital photogrammetry. In: *Digital Applications in Archaeology and Cultural Heritage*, 8, 2018, pp. 57–64; LERONES, Pedro Marín et al. A practical approach to making accurate 3D layouts of interesting cultural heritage sites through digital models. In: *Journal of Cultural Heritage*, 11(1), 2010, pp. 1–9.

[24] FRYSKOWSKA, Anna, and STACHELEK, Julita. A no-reference method of geometric content quality analysis of 3D models generated from laser scanning point clouds for hBIM. In: *Journal of Cultural Heritage*, 34, 2018, pp. 95–108.

[25] PAVLIDIS, George et al.Methods for 3D digitization...; ANDRADE, Beatriz Trinchão et al.Digital preservation of Brazilian...; GOMES, Leonardo, BELLON, Olga R. P., and SILVA, Luciano. 3D reconstruction methods for digital preservation...

[26] ANDRADE, Beatriz Trinchão et al.Digital preservation of Brazilian...; PIERACCINI, Massimiliano – GUIDI, Gabriele – ATZENI, Carlo. 3D digitizing of cultural heritage. In: *Journal of Cultural Heritage*, 2(1), 2001, pp. 63–70.

[27] KUZMINSKY, Susan C., and GARDINER, Megan S. Three-dimensional laser scanning...; BRUNO, Fabio et al. From 3D reconstruction to virtual reality...; FOWLES, P. Stephen et al.The laser recording and virtual restoration...; PIERACCINI, Massimiliano – GUIDI, Gabriele – ATZENI, Carlo. 3D digitizing...; KOLLER, David, FRISCHER, Bernard, and HUMPHREYS, Greg. Research challenges for digital archives of 3D cultural heritage models. In: *ACM Journal on Computing and Cultural Heritage*, 2(3), 2009, Art 7, pp. 1–17.

[28] AKENINE-MÖLLER, Tomas, HAINES, Eric, and HOFFMAN, Naty. *Real-time rendering*. 3rd. ed. Natick, Massachusetts: A K Peters, 2008.

[29] FOSTER, Shaun, and HALBSTEIN David. *Integrating 3D modeling, photogrammetry and design*. London: Springer, 2014.

The 3D reconstruction of cultural heritage objects requires accuracy and precision with respect to texture to capture small details.[30] 3D scanning and 3D printing combined are efficient techniques in cultural heritage preservation and the reproduction of elements and architectural features.[31]

The construction of accurate replicas allows a physical contact with objects which is essential to the accessibility of cultural heritage to people with visual impairment.[32]

PROJECT PHASES

The present study consists of five coordinated and interrelated phases detailed in Figure 3.

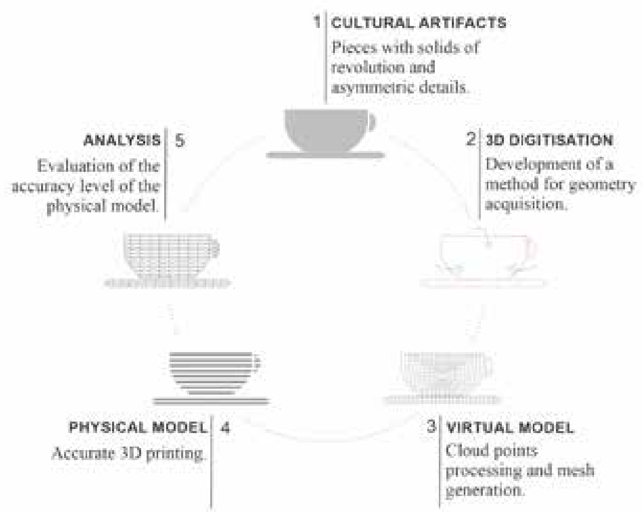

Figure 3: *Flowchart of the experimental procedure consisting of 5 steps: (1) selection of cultural artifacts (rotating bodies); (2) development of a 3D scanning method; (3) data processing and generation of a virtual model; (4) construction of a physical model with 3D printing; and (5) comparison between the original piece and the model*

[30] ANDRADE, Beatriz Trinchão et al.Digital preservation of Brazilian...; GOMES, Leonardo, BELLON, Olga R. P., and SILVA, Luciano. 3D reconstruction methods for digital preservation...; NEELY, Liz – LANGER, Miriam. *Please Feel the Museum: The Emergence of 3D Printing and Scanning*. The annual conference of Museums and the Web. Portland, OR, USA, April 17–20, 2013; NEELY, Liz – ROZNER, Elory. *Museum3D: Experiments in engaging audiences using 3D*. The annual conference of Museums and the Web, Chicago, IL, USA, April 8–11, 2015; LAPP, Eric, and NICOLI, Joe. Exploring 3D modeling, finger print extraction, and other scanning applications for ancient clay oil lamps. In: *Digital Applications in Archaeology and Cultural Heritage*, 1(2),2014, pp. 34–44.

[31] XU, Jie, DING, Lieyun – LOVE, Peter E. D. Digital reproduction of historical building ornamental components: from 3D scanning to 3D printing. In: *Automation in Construction*, 76, 2017, pp. 85–96.

[32] YOUNAN, Sarah, and TREADAWAY, Cathy. Digital 3D models of heritage artefacts...; EVREINOVA, Tatiana G., EVREINOV, Grigori, and RAISAMO, Roope. An alternative approach to strengthening tactile memory for sensory disabled people. In: *Universal Access in the Information Society*, 5(2), 2006, pp. 189–198; BALLETTI, Caterina, BALLARIN, Martina, and GUERRA, Francesco. 3D printing: State of the art and future perspectives. In: *Journal of Cultural Heritage*, 26, 2017, pp. 172–182; ROSSETTI, V., et al. Enabling Access to Cultural Heritage for the visually impaired: an interactive 3D model of a cultural site. In: *Procedia Computer Science*, 130, 2018, pp. 383–391.

METHODS AND PROCEDURES

3D Scanning and Printing

Complex shapes or large amounts of surface detail are preferably captured using laser scanners.[33] To digitise the artifacts a laser scanning system (Digimil 3D Tecnodrill®) was used. It was a CNC (computer numerical controlled) device with a laser source that emitted light in the form of a line or pattern over the objects and extracted thousands of points. A computer file with the extension "TXT" was created containing the coordinates x, y, z of each point of the scanned external surfaces. The accuracy is determined by the selected lens, and the resolution or the distance between the points can be controlled depending on the desired image quality.

The main parameters of the laser scanner used were: a lens with a focal length of 150 mm, a resolution of 0.1 mm and an accuracy of 0.035 mm.

The system for generating the 3D shape is based on conoscopic holography. It consists of emitting a laser beam onto an object, which returns and passes through a birefringent crystal and is then detected by a charge-coupled device (CCD). A CCD imager consists of a large number of light-sensitive elements. Therefore, the relationship between the emitter and the projection of the laser beam onto a material surface is determined by the calibration process, which is performed separately for each lens.

After point clouds were acquired from each object surface, the data were organised and entered into Geomagic Studio software. First, the point clouds were acquired based on the common areas between each surface. The point clouds were then converted into a mesh of triangles. Small errors in the meshes were carefully repaired to maintain the accuracy and original features of the model.

To verify the quality of the digitisation, one of the models was exported as an STL file, a file used in additive manufacturing. The Objet350 Connex3™ 3D printer was used to produce the saucer. It produces parts with a minimum layer thickness of 0.016 mm.

The resin used in our experiment was VeroWhite, which preserved the glossy surface of the top. The printed piece was also 3D scanned and compared to the scan of the original piece. For this purpose, the two virtual models were lined up and the distances between the surfaces were measured.

3D Scanning Procedure

The present study was carried out to develop a method to facilitate the digitisation of 3D solids of revolution. The scanning method was optimised while the first parts were scanned; i.e., the first scanned part allowed feedback on the procedures to facilitate the digitisation of subsequent parts. The data collection and the development of the physical model were evaluated.

At first glance, the parts appeared to be symmetrical, meaning both sides were the same. However, in the case of an old artifact, the geometry was not exactly identical. Another important feature was the surface texture. These pieces had an embossed texture that was unevenly worn in some places due to time or use. Because of these factors, it was not possible to scan a single piece so that it could be cut at an angle as if it were symmetrical.

So, the experimental procedure began with scanning the dessert harness, as shown in Figure 4. A schematic was created to determine the direction of rotation. The numbers show the order of digitisation and the arrows show the direction of incidence of the laser light on the object.

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[33] NEELY, Liz – ROZNER, Elory. *Museum3D*...

The same procedure was used to analyse the back side of the object.

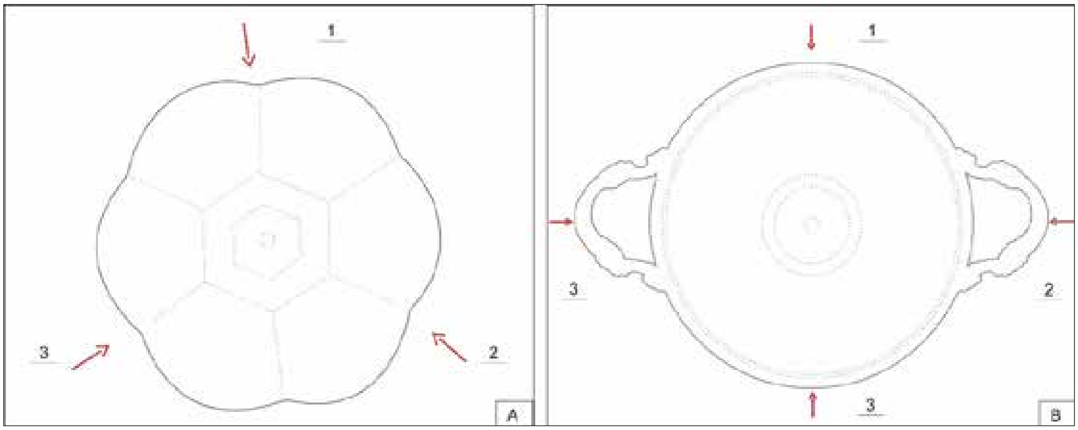

Figure 4: *Illustration of the scanning process (top view): (A) glass dish, (B) silver slide. The numbers show the order of digitisation and the arrows show the direction of incidence of the laser beam on the object. The dashed lines represent the geometry of the parts*

The procedure continued with the scanning of the saucer (Figure 5A) and the cup (Figure 5B). To minimise the difficulty of matching the point clouds, a problem observed in the previous pieces, some paper labels (with easily removable acrylic adhesive) were applied in different geometric shapes.

The raised design of the label was detected by the laser and allowed accurate identification of the directions. These labels were placed in the four quadrants of the saucer and in the three quadrants of the cup. The handle of the cup helped identify one of the quadrants.

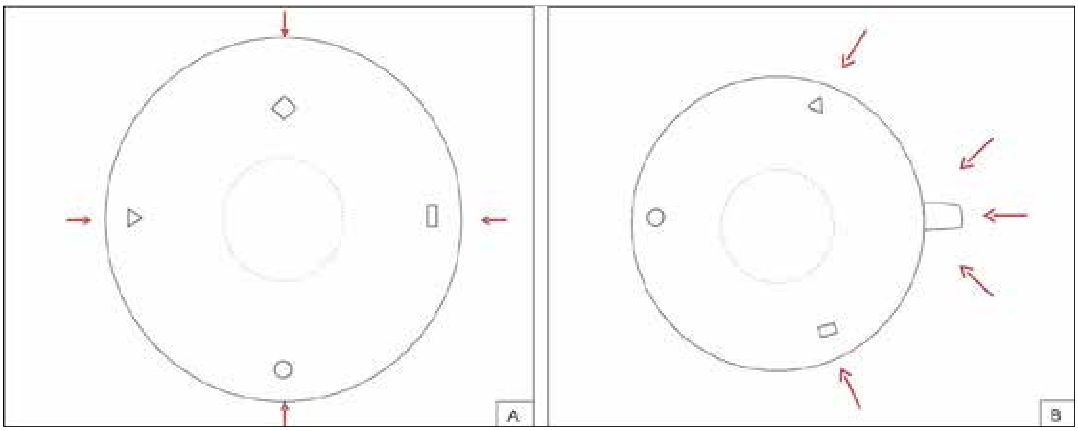

Figure 5: *Schematic representation of the scanning process (top view): (A) ceramic saucer, (B) ceramic cup. The numbers show the sequence used for digitisation and the arrows show the direction of incidence of the laser light on the object. The geometric shapes show the position of the adhesive labels. The dashed lines represent the geometry of the parts*

The surface properties of the materials used to manufacture the tableware must be taken into account in the 3D scanning process. Silver artifacts have reflective properties that make point cloud acquisition difficult. The laser beam passes through a clear liquid crystal glass that is not detected by the scanner.[34] Therefore, the surface of the material had to be covered, a common procedure for reflective materials. For this reason, Metal-Chek D-70 was used, a non-aqueous wet developer for penetrant testing. It consists essentially of calcium carbonate in isopropyl alcohol. After application, the alcohol evaporates, leaving micrometric calcium carbonate particles that make the surface of the objects opaque. After scanning, the developer powder was removed with a bristle brush.

RESULTS AND DISCUSSION

The proposed method was used to create virtual models of two artifacts from the crockery of the former Confeitaria Rocco.

Figure 6 and Figure 7 show the digitised 3D reproduction of the cup and saucer from the Confeitaria Rocco tableware. The comparison of Figure 2(B) with Figures 6(B) and 7(B) shows that the technique can provide a good 3D representation of the pieces. However, a high quality mesh is required to produce physical replicas. Meshes with a large number of triangles allow accurate reproduction of fine surface details, especially embossments with organic morphology, such as those present on the mount of the silver handle and around the rim of the saucer.

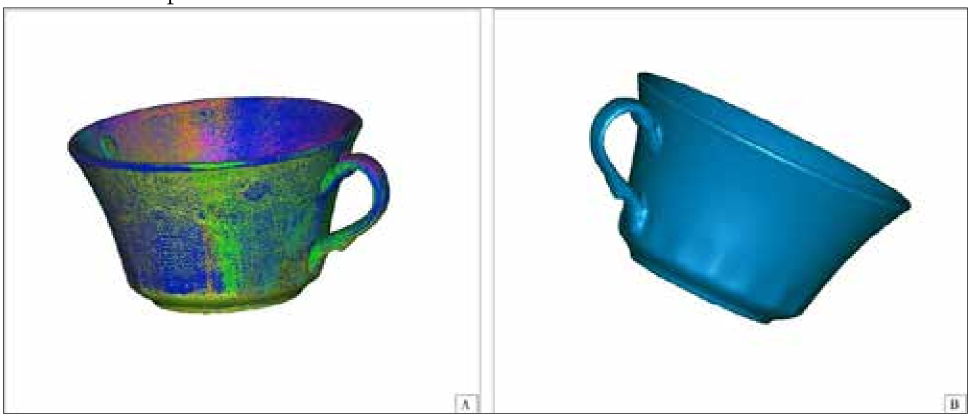

Figure 6: *Digital reproduction of the cup: (A) registered point clouds and (B) final mesh from the fusion of point clouds*

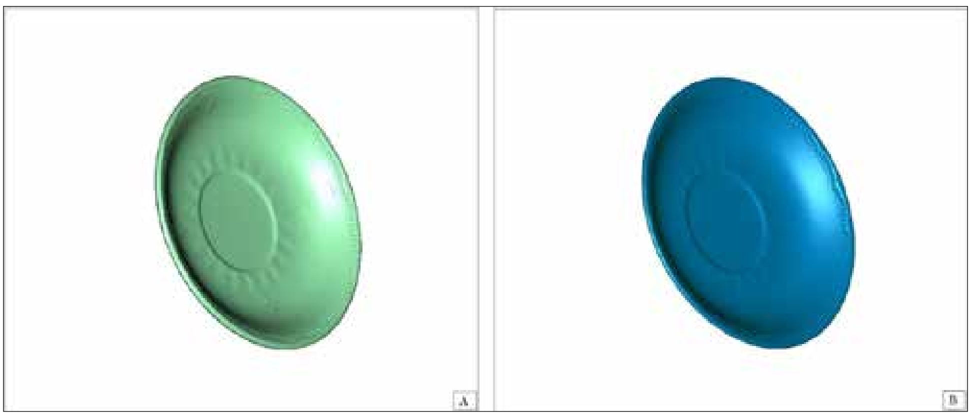

Figure 7: *Digital reproduction of the saucer: (A) shaded view defined by the point clouds and (B) final rendered 3D surface*

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[34] PAVLIDIS, George et al.Methods for 3D digitization...; BRUNO, Fabio et al. From 3D reconstruction to virtual reality...

Table 1 presents data from the point clouds acquired and from the meshes generated for each of the four scanned parts. Due to the geometric complexity of the silver support, there was no significant reduction in the number of triangles generated. The symmetric ceramic parts were acquired with greater overlapping of surfaces, resulting in a large number of redundant points, which were reduced during their conversion into mesh.

	Piece 1	**Piece 2**	**Piece 3**	**Piece 4**
Pieces	Bowl	Support	Saucer	Cup
Material	Glass	Silver	Ceramic	Ceramic
Point clouds	5	8	6	8
Total of points acquired	1,533,113	3,247,706	4,762,502	4,060,989
Resulted mesh triangles	1,452,034	5,228,608	837,472	752,402

Table 1: *Data from the point clouds and meshes generated for each of the four scanned pieces.*

Figure 8 shows the photorealistic rendering of the models obtained. The 3D models can be viewed and manipulated interactively at the following links: A) https://www.ufrgs.br/ldsm/3d/?p=1273 and B) https://www.ufrgs.br/ldsm/3d/?p=1228.

Figure 8: *Photorealistic rendering of the models:* (A) bowl and support (conjunto para servir) – http://www.ufrgs.br/ldsm/3d/?p=1273, (B) cup and saucer – (jogo de chá) –http://www.ufrgs.br/ldsm/3d/?p=1228

During the processing of the point clouds of the first scanned part (bowl), it was observed that the matching of data obtained from different viewing directions was complex as there was no method for the identification of sides with great similarity. For this reason, adhesive labels were used, as described in the experimental section. The labels facilitated the process of assembling the subsequent parts. This procedure is similar to that used in photogrammetry methods; however, it was possible to use a reduced number of labels. Due to the scanner's high accuracy, the embossed geometry originated by them was captured and had to be removed during the editing of the point clouds for mesh generation. An in-depth analysis of the saucer was conducted due to the greater difficulty in scanning symmetrical parts.

The procedure for the identification of pieces was essential because they were not exactly symmetrical, particularly those with relief details. Moreover, these original pieces were affected by time marks, which should be accurately represented while dealing with objects of heritage value. The comparison of details between the original piece and the 3D model obtained from a rendering technique is shown in Figure 9.

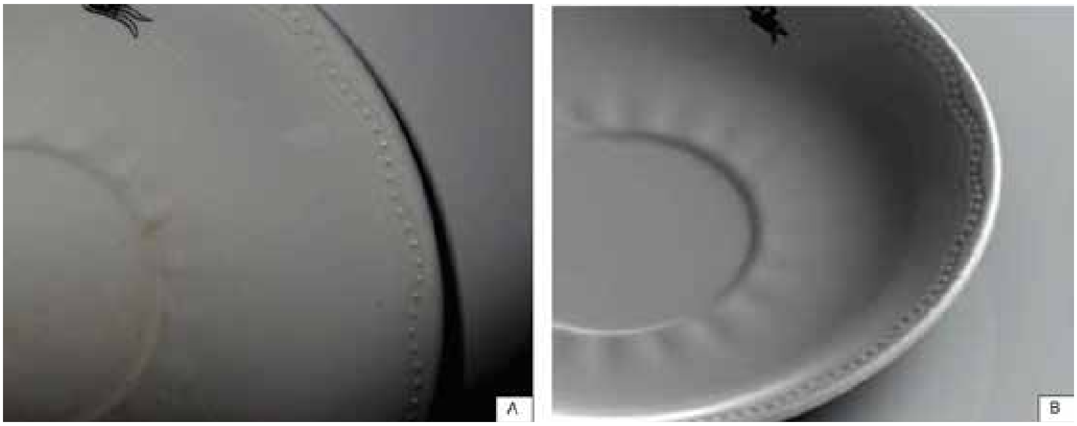

Figure 9: *Comparison of details with emphasis on the surface structure of the ceramic saucer. Original object (A) and virtual model rendered and completed after scanning (B)*

To exemplify an accurate representation of the piece, and to compare it to the original, a precision prototyping process was also required. Figure 10 shows the comparison of details between the original piece and the 3D model. With the naked eye, the geometry is very similar. Differences in the colours of the original object were noticeable due to degradation. The texture was well defined, including the worn parts around the rim of the original piece and the embossed central details. The shiny finish on the upper side provided a similarity with the original ceramic piece.

Applications of 3D scanning technologies include the analysis of real-world objects to collect data on their shapes and appearances and also the monitoring of the deterioration of objects. Thus, it was possible to analyse the results obtained following the reproduction of the scanned object.

Figure 10: *Comparison of details focusing on the surface structure of the original ceramic saucer (right) and the printed physical model (left). With the naked eye, one can see the quality of the physical model compared to the original, especially in terms of details of texture and size*

The printed model was scanned from a top view to be compared with the original piece. Figure 11 shows the result of the dimensional evaluation performed from the overlapping images of two 3D models, and the measurement of differences between their surfaces. The cold tones (blue) indicated the areas where the scanned model was smaller. The warm colours (red) indicated the areas that were larger than the original model. The green colour indicated the areas where the difference between them was below 0.05 mm.

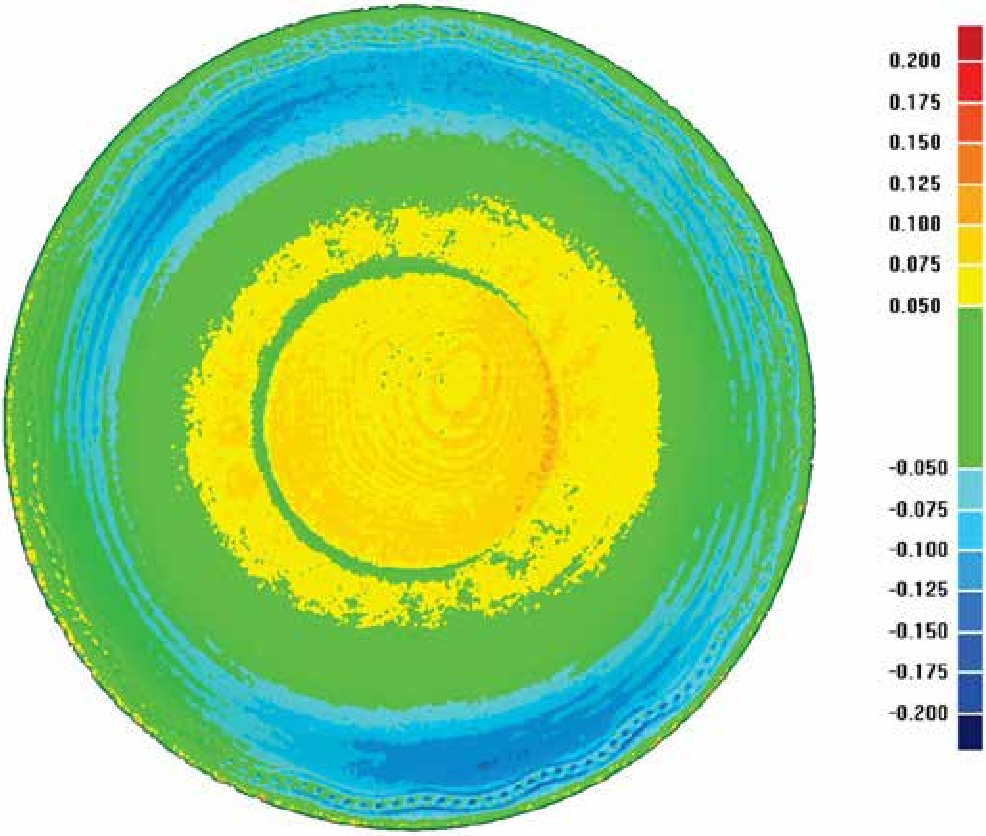

Figure 11: *Alignment calculation analysis using the Global Registration tool in Geomagic Studio to evaluate the accuracy between the artifacts scanned from the original and the artifacts scanned from the replica. The blue tones correspond to the points that are below the average surface. The reddish tones represent points that are above it, and the green color indicates areas without significant dimensional errors. The units are in mm*

Based on the colour pattern shown in Figure 11, it was possible to determine that the scanned model had a slight deformation characterised by a slightly raised centre and slightly lower edges compared to the original model. This feature is seen in one of the scanned axes and not on the entire circumference of the piece. The traces left by the build-up of the layers during 3D printing can be seen mainly in the central part (yellow). Although the maximum difference was 0.18 mm, the mean difference between the surfaces was 0.05 mm, with a standard deviation of 0.06 mm. No significant differences were found in the textured area or around the edge of the saucer.

CONCLUSIONS

In this study, a method was proposed to obtain models of historical artifacts considered as a rotating body for the reproduction of accurate replicas. Four 3D virtual models of historical and cultural artifacts were created to verify the accuracy of the method. These objects are part of the local museum collection. One physical model was produced using the 3D printing of a polymer material.

The proposed 3D digitisation method enabled the acquisition of highly accurate virtual models. Since 3D laser scanning technology is non-contact, the risk of damage to delicate historical objects is minimal. However, further studies are needed to digitise objects made of opaque materials (such as metal and glass) without coatings.

The high accuracy of the laser scanner allowed the detection and obtainment of superficial details such as small asymmetries and traces of time, which are important from a historical point of view. Although the method is not able to capture hidden surfaces / internal geometries, it can be used with other complementary technologies such as ultrasound or tomography to obtain more comprehensive data.

Thus, the limiting factor for obtaining accurate replicas was the reproduction technology, i.e., 3D printing. However, the physical model obtained in this study had a satisfactory surface quality. By touch and with the naked eye, the geometric differences between the original and the scanned object were not visible, only the differences in materials.

The digitised objects presented in this study are essentially a showcase for the potential and wide range of digitisation techniques to preserve the identity of cultural objects from time, wear, weather or vandalism. 3D scanning and 3D printing are effective means of producing replicas and prototypes for museum purposes and preserving the original for further study.

The ability to 3D scan pieces with complex geometries and fine surface details offers the museum the advantage of documenting the objects in its collection while making them available virtually. The 3D models can be used in virtual reality and/or augmented reality applications to bring the public closer to the museum and the diversity of its historical collection, connecting it with people from around the world.

By combining the virtual model with the high-precision 3D printing process, it is possible to reproduce the parts with a better surface quality than with conventional processes. This is because there are very few objects in the museum that users can touch. Touching physical objects on site is therefore a new experience for all museum users, including visually impaired people who rely on the sense of touch.

These methods show the importance and versatility of the technological interaction of museums to offer visitors enjoyment and different levels of experience. The point is to offer a new and interesting way of interacting with the object (touching and handling) without damaging the original.

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AUTHOR DISCLOSURE STATEMENT

Andresa Richetti, Fabio Pinto da Silva and Liane Roldo declare that they have no conflict of interest with the existing project, financial, social or otherwise.

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