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Application of reverse engineering and rapid prototyping resources for digitalization of works of art

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Abstract: The article presents the process that was carried out to digitize the work of art Atlacatl by the Salvadoran sculptor Valentín Estrada, located in the Pinacoteca of the Don Bosco University. For this purpose, rapid prototyping technology from the Center for Innovation in Industrial Design and Manufacturing was used, which is normally used for reverse engineering and analysis, within professorships, research, and services to companies in the manufacturing sector.

The procedure used is the one followed for the digitization of structural engineering parts, incorporating care for the work of art, and using the software for managing the point cloud of organic parts. At the end, the verification of dimensional deviation is included, which corroborates that a high level of dimensional accuracy was obtained in each detail of the computer drawing.

Keywords: 3D prototyping, reverse engineering, digital cultural heritage, three-dimensional modelling.

1. Introduction

Since 2015, the Pinacoteca has existed at the Don Bosco University of El Salvador, in the building of the former Rafael Meza Ayau library, which houses different works by national and foreign artists. Among the works you can see paintings, sculptures in different materials such as metal, plaster, cement, etc. Works of art are a cultural heritage [1] that must be shown to people in different generations throughout history.

With the interest of studying ancient artistic works and protecting them from deterioration due to manipulation, creating replicas, and even documenting ancient archaeological works, different digitalization techniques such as photogrammetry are used. With this, the advantages achieved with digitalization are taken advantage of, such as contributions to conservation and scientific dissemination [2], graphic documentation [3] [4], texturing mapping [5], and precise 3D measurements [6]. And consequently, 3D replicas are obtained, they can be examined in detail by many more people as virtual access to the collections is enabled [7], for example.
According to Parada et al [8] the digitalization of archaeological objects allows them to be explored and then studied without being altered, so photogrammetry [9] is used, with which archaeological pieces [10] [11], archaeological sites [12], archaeological sites [2], crafts [13], cultural assets [7] [14], pre-Columbian pieces [15], in short, everything that is important to heritage [16] are digitalized and documented.

Similarly, Magnani [17] establishes that “the visualization and analysis of 3D data can be incorporated into museum exhibits”, and with the application of digital tools, there are already possibilities to observe digitalized objects in museums and for visitors to manipulate them on interactive computer screens within virtual reality environments [18] such as rotating them, zooming in to see details, and they can even be incorporated into augmented reality tours.

Another characteristic of digitalization in the 3D scanning process is the high precision obtained in the point cloud and in computer designs [19], whether from small objects to large structures, which can be used to present printed replicas to children of different ages, young people, adults and people with visual disabilities [20].

2. Materials and methods

The work consisted of carrying out the entire process of digitizing the work of art Atlacatl by the Salvadoran sculptor Valentín Estrada. The original work is in the park of the Colonia Atlacatl in San Salvador, and this replica (Image 1) is in the Pinacoteca of the Don Bosco University in El Salvador.

Image 1. Replica of the Atlacatl sculpture that was digitized using 3D scanning technology. According to the history of the conquest of El Salvador, the indigenous Atlacatl resisted the troops of Don Pedro de Alvarado, in the lordship of Cuzcatlán.

For the process, the replica of the Atlacatl sculpture was selected as the object of digitalization. The decision to select it was based on its cultural importance within the history of the time of the Salvadoran conquest and the need to preserve it in a digital format that would allow its study and dissemination. The work, which is in the Pinacoteca of the Don Bosco University, represents a significant national historical symbol for El Salvador.

In the 3D scanning process, an EinScan pro HD scanner was used, with the texture configuration, 0.02 mm resolution and the color pack for color detection. With this configuration, the scanner can detect the textures and colors of the object being scanned, which allows the detection of surfaces to be much more precise, saving time and optimizing the use of resources.

The scanning environment was prepared with special care to ensure optimal data capture conditions. The preparation prior to scanning consisted of analyzing the available lighting, so a space was selected where sunlight does not enter directly onto the object or onto the floor, because the condition of reflection and variation of light is detected by the scanner as an unstable condition, which does not capture information and automatically interrupts image processing. To reduce the brightness of the pieces, unscented industrial talc was applied to them, moistening the surface of the work and then applying the talc very carefully with a brush (Image 2). It is worth mentioning that no developer spray, as normally used in the prototyping laboratory, was used, because the pressure inside the can is high, the sprayed product spreads through the atmosphere and could damage nearby works. The brightness must be controlled, since the 3D scanner emits a strong light with its projector, to detect surfaces, however, excess reflected light is counterproductive, and the software perceives it as a hole. After scanning, the talcum powder was carefully removed using a damp cloth and a clean brush, a task carried out by the person in charge of maintenance of the works.

Image 2. The space in the Art Gallery is prepared for 3D scanning. The space prepared for carrying out the work can be seen, with the scanner software active, capturing information, and preparing the surface of the work where information is missing.

For the processing of the point cloud, the GeoMagic Design X program was used for working with organic shapes. It is important to emphasize that space in the Art Gallery was used where the sunlight enters indirectly, so as not to affect the scanning work. In addition, the lights that illuminate the works of art can be turned off, always with the aim of attenuating the areas of high illumination that can negatively affect the scanning process.

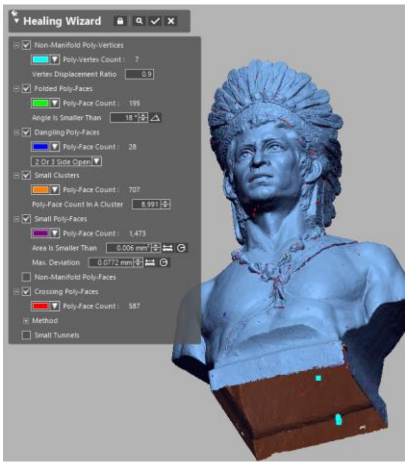
In image 3, the area illuminated by the 3D scanner projector can be seen, and which allows the optical sensors to capture each relief, with its shapes, distances from each lens, with which the equipment and software determine the depth of each point in space, the reference surfaces with respect to each other that are being captured, the changes in surface angles, and which constitute the volume of the sculpture in the digitalized image.

After the maximum amount of information was captured, the point cloud was post-processed with the scanner's own software. This action cleans up out-of-place surfaces, filling empty spaces in accordance with how the point cloud was captured. The use of advanced 3D scanning technology at this time, allowed for the capture of every detail of the sculpture, from the most subtle reliefs, aspects of the headdress, shapes of the indigenous necklace, including details of the hair that the author of the work captured in detail, and his signature on the bottom of the base.

Image 3. Scanning process of the sculpture, projecting a beam of light that is detected by the 3D scanner sensors. The area illuminated by the projector is tracked by the scanner's optical sensors, which involves manually moving the scanner at different angles so that the surface information of the model is recorded.

The file was then loaded into the GeoMagic Design X software, which removed any unnecessary loose information from the point cloud that was still left over from the previous operation. As shown in image 4, there were small holes and the base had no surface information, as it was not scanned on purpose because it was a flat bust base, which had no restrictions on being created by computer.

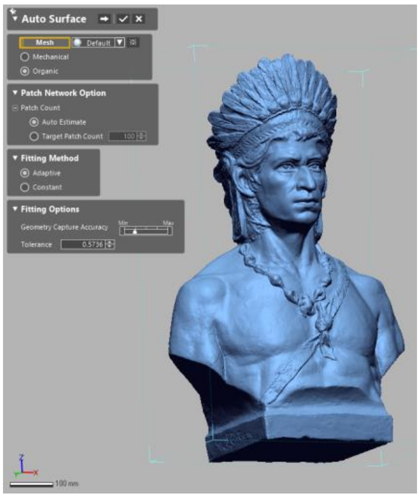
The next operation is to use the "healing wizard" function, shown in image 4, with the aim of having the small holes filled automatically, with the help of the computer, taking advantage of the intuitive potential of the program. Once the small holes were filled, the edges of the base were trimmed to make it uniform, and then it was completed with the "healing wizard" tool that completed it in a single step (Figure 5), leaving the object as shown in Figure 6, complete on the entire surface, including the base.



☑ Non-Manifold Poly-Vertices
Poly-Vertex Count : 7
Vertex Displacement Ratio 0.9
☑ Folded Poly-Faces
Poly-Face Count : 195
Angle Is Smaller Than 18 °
☑ Dangling Poly-Faces
Poly-Face Count : 28
2 Or 3 Side Open
☑ Small Clusters
Poly-Face Count : 707
Poly-Face Count In A Cluster 8,991
☑ Small Poly-Faces
Poly-Face Count : 1,473
Area Is Smaller Than 0.006 mm²
Max. Deviation 0.0772 mm
☐ Non-Manifold Poly-Faces
☑ Crossing Poly-Faces
Poly-Face Count : 587
Method
☐ Small Tunnels

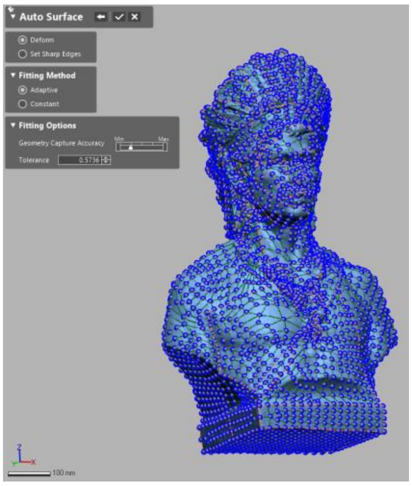
Image 4. Work to fill empty spaces in the point cloud using the healing wizard option provided by the software. Some spaces that were not filled automatically were worked on and corrected individually by the program user.

Point cloud post-processing is essential to ensure the integrity and accuracy of the captured data, and involves a stage of thorough analysis by the software user, which may require the application of additional techniques such as manual edge trimming, surface smoothing, hole punching, and manual filling to remove imperfections. During this phase, it is common to encounter challenges that go beyond simply filling in empty spaces or correcting small holes. For example, discrepancies in data quality may arise due to varying reflection of the scanned surfaces or the presence of artifacts that distort the captured information. In such cases, it is necessary to resort to additional strategies, such as segmenting the point cloud into more manageable regions or applying advanced filtering algorithms that are included within these programs, to remove unwanted noise. Noise in 3D scanning refers to the appearance of loose surfaces, elongated surfaces, in the point cloud, that do not actually exist on the scan object or on the supporting surfaces. The "healing wizard" tool, used to automatically fill small holes in the point cloud, represents one part of the tools available in the three-dimensional data processing program. In addition to this function, there are other processing and reconstruction methods that can be applied according to the specific needs of the scanned object and the characteristics of the data obtained. For example, the use of surface elaboration in the form of bridges, bays, which help to join two separate surfaces, surface smoothing algorithms, surface optimization tools or curve and surface adjustment tools, all of which help in the process of improving the visual quality of the resulting digital model, reducing the presence of irregularities or unwanted details that can alter its definition and precision. In some cases, it may be necessary to make manual adjustments to correct imperfections or inconsistencies in the generated digital model, that is, even with the development of the intuitive level of the programs, the intervention of the designer is still necessary to correct and optimize the graphic data. Once the empty spaces of the object being processed have been completed, and in this case the point cloud of the bust of the Indian Atlacatl, the "autosurface" tool is applied, as shown in image 5, and it is worth mentioning that it does not operate if the software detects discontinuities on the surface such as holes. This tool collects data from each surface aspect and represents it as a continuous mesh.



Auto Surface
Mesh — Default
○ Mechanical
● Organic
Patch Network Option
Patch Count
● Auto Estimate
○ Target Patch Count 100
Fitting Method
● Adaptive
○ Constant
Fitting Options
Geometry Capture Accuracy
Tolerance 0.5736

Image 5. Selecting the autosurface option to convert the point cloud into a continuous surface. This operation can be performed once there are no discontinuities on the surface, such as holes, discontinuous edges. If the requirement is not met, the autosurface operation sends an error message, and the designer must re-check and correct the discontinuity problems of the point cloud that are indicated.



Auto Surface
● Deform
○ Set Sharp Edges
Fitting Method
● Adaptive
○ Constant
Fitting Options
Geometry Capture Accuracy
Tolerance 0.5736

Image 6. Result of the autosurface work. The point cloud processing program can be configured with different mesh sizes; when the meshes are smaller, on the order of 1 mm or less, better quality and more accurate surfaces can be obtained, but this implies greater use of the computer's data processing memory.

Image 6 shows that the program interpreted the information in the previous step, and as it found no problems, it was able to generate the mesh and in the same process convert the mesh into a solid. The transformation of the point cloud into a continuous surface, as is done by the "autosurface" tool, requires careful analysis of the topology by the software, interpreting the points and the geometry of the scanned object. It is worth mentioning that, with the development of the versions of point cloud management programs, computers with greater capacity and more powerful performance are required for data and image processing.

After generating the surface, it is convenient to thoroughly review the generated mesh, to detect any possible anomaly. That is, human supervision should not be ruled out at each stage, no matter how advanced the computer program used in point cloud processing is. This follow-up may involve direct editing of the resulting polygonal mesh, applying remeshing operations to optimize its structure and improve its quality, and resizing the resulting mesh, which may prove useful in the future when operating the model in computer-aided design programs.

3. Results and discussion

In GeoMagic Design X software the correct mesh is transformed into a solid, see image 7, suitable to be recognized by computer programs such as CAD CAM CAE (Computer Aided Design, Computer Aided Manufacturing and Computer Aided Engineering).

Image 7. Conversion of the point cloud and closed surfaces into a solid body. Organic figures like this artwork are the result of a complex mesh that results in precise shapes and dimensions faithful to the original model.

The conversion of the point cloud and closed surfaces into a solid body is the last step in the processing of the data captured with the 3D scanner. The scanning process provides the most complete, consistent, fast and accurate representation of the scanned object, which cannot be achieved with the methodical process of generating planes, straight and curved lines, and surfaces. This scanning and scanning process applies to organic parts as in this documented case, and applies to parts with complex geometries that require a lot of time for the measurement and determination of radii, angles, change of reference planes, etc.

Once the object with solid characteristics is available on the computer, it can be exported to a format for reading in other computer programs, or in a format for 3D printing where replicas can be reproduced in different scales without the need for molds.

It is important to note that this process of digitizing organic parts may introduce certain surface characteristics or approximations, which after exporting it to other computer-aided design (CAD) programs may affect the creation of new drawings from this model, since new drawing plans must be generated from the surfaces and meshes generated from the resulting model. For example, when generating a solid from a polygonal mesh, it is possible that plans with different orientations to the available reference system are generated.

In this case of digitization, an analysis of the dimensional deviation of the final object with respect to the initial point cloud was carried out, as indicated in image 8, which shows that the digital replica has faithful details and precise dimensions with respect to the scanned model of the art gallery. The area represented in green indicates a dimensional deviation (dd) that meets 0.1<dd<0.2 of 0.0 mm, a measurement that is almost imperceptible to the human eye, but which in an organic figure can be considered within acceptable limits. Similarly, the yellow dots and areas indicate a deviation of +0.2 mm, and the light blue areas indicate a deviation of -0.1 mm, which is also acceptable for an organic model approximately 1 meter high.

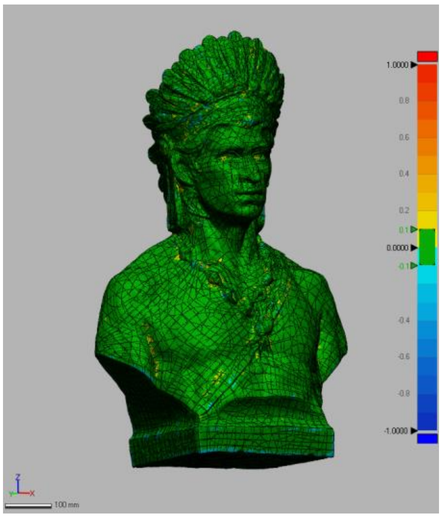


Image 8. Verification of the dimensional deviation of the solid surface with respect to the point cloud. The deviations determined by the software vary between -0.1 mm and 0.2 mm, which is acceptable for organic models, given that it is a replica of a work of art made and finished by hand.

4. Conclusions

In the development of this scanning and digitization work, rapid prototyping digital engineering tools were used to obtain a faithful, compatible and precise model of the replica, which can be worked with other computer programs for drawing, analysis and computer-aided manufacturing. In this sense, the staff in charge of the art gallery expressed their interest in making smaller 3D printed copies, which will be shown to children from rural schools in the country, who find it difficult to visit museums in the capital city, an action of the "development of educational suitcases" project with an initiative of ICOM (International Council of Museums) through the company LERO Estudio.

In this case, the art gallery collaborated to digitize a work of art, which will then be printed to scale in 3D, so that said replica can be transported throughout the country and shown to children from different schools. This initiative motivates us to carry out more similar actions with more works of art, which have the permission of the artists, and can be replicated to be shown to the public who cannot visit museums or cultural centers, and in the future these replicas can even be shown in other countries.

Another possibility that opens up is in the line of inclusivity, because the replica can be available to people with visual disabilities, who will be able to explore the replica of the work of art by touch. An example is that the 3D printed replicas can be presented to people from associations for the blind, study centers for blind children, and family groups where a family member has a disability. With this example, more ideas and challenges arise to be able to create an inclusive museum, where printed works of art are available for blind people of all ages, or to create a mobile museum that travels throughout the country so that people of all ages can learn about the cultural wealth in each country.

There are cultural assets that cannot be displayed to the public, due to the damage, erosion they have and their age, in addition to being unique pieces; and with prototyping tools, replicas can be digitized, reconstructed and displayed to showcase the cultural wealth that exists and that until now is only known to cultural technicians.

The process of digitizing objects using engineering technologies, such as laser scanning or photogrammetry, is a constantly evolving field that requires a combination of technical skills and specialized knowledge of computer-aided design, optics, metrology, and spatial logic skills. From data acquisition to processing and generation of digital models, each stage of the process presents unique challenges that must be addressed carefully and methodically. However, with the continued development of data processing technologies and techniques, the digitization of cultural heritage and other three-dimensional objects is expected to continue to advance, opening new opportunities for the conservation, research and dissemination of cultural heritage throughout the world.

References

1. UNESCO, "Los Pueblos y su cultura", 1982. Disponible en: https://unesdoc.unesco.org/ark:/48223/pf0000074720_spa
2. B. Conte, y A. Robledo, "Aplicación de tecnologías 3D en sitios arqueológicos del valle de Ongamira, Córdoba, Argentina. Fotogrametría en excavaciones y morteros arqueológicos", Revista Del Museo De Antropología, 13(1), 273–280. 2020. Disponible en https://revistas.unc.edu.ar/index.php/antropologia/article/view/23900
3. P. O. Coder, Museo Virtual Hiperrealista, Virtual Archaeology Review, 3(7), 23-26. 2012.
4. M. Krzemień, "Ceremonial vases from the collection of Museo de Arqueología in Nebaj, El Quiché, Guatemala", Estudios Latinoamericanos, 38, 7-25. 2019. Disponible en https://doi.org/10.36447/Estudios2018.v38.art1
5. B. M. Alonso, S. Barba, y A. Á. Tordesillas, "Documentación del patrimonio cultural. Método basado en la fusión de técnicas fotogramétricas y de escaneado óptico de triangulación". EGA Revista de Expresión Gráfica Arquitectónica, 21(28), 236-245. 2016.
6. A. Davis, D. Belton, P. Helmholz, et al, "Arte rupestre de Pilbara: escaneo láser, fotogrametría y reconstrucción fotográfica 3D como herramientas de gestión del patrimonio". Herit Sci 5, 25. 2017. Disponible en
7. https://doi.org/10.1186/s40494-017-0140-7
8. D. Ávido M. Vitores, "Archivo fotográfico para la reconstrucción tridimensional. Arqueometría Argentina. Metodologías científicas aplicadas a bienes culturales. Datación, caracterización, prospección y conservación". Compiladores Pifferetti Andrián y Dosztal Irene, editorial Aspha pp.: 223-232. 2015.
9. R. Parada, A. Vera, K. Rincón Parada y E. Badwin, "Modelado de objetos arqueológicos: una propuesta usando fotogrametría digital", Revista Ingenio, 7 (1), 143–149. 2014. Disponible en https://revistas.ufps.edu.co/index.php/ingenio/article/view/2043
10. A. M. Charquero Ballester, "Práctica y usos de la fotogrametría digital en Arqueología", colecciones DAMA, documentos de Arqueología y Patrimonio Histórico - 2016, N. 1, ISSN 2530-2345. 221-236. 2016. Disponible en https://rua.ua.es/dspace/handle/10045/59158

11. Y. S. Ventura Aguilar, "Diseño de protocolo para digitalización de patrimonio cultural salvadoreño, implementando realidad virtual, fotogrametría y procesos de manufactura aditiva". Ciencia, Cultura Y Sociedad, 8(1), 11–24. 2023. Disponible en https://doi.org/10.5377/ccs.v8i1.15594
12. M. T. Sebastián, "Escaneado en 3D y prototipado de piezas arqueológicas: las nuevas tecnologías en el registro, conservación y difusión del Patrimonio Arqueológico", Iberia. Revista de la Antigüedad, 8, 135-158. 2013.
13. P. Codificador Ortiz, "Digitalización automática del patrimonio arqueológico a partir de fotogrametría", Revista de Arqueología Virtual, 4 (8), 46. 2015. Disponible en
14. https://doi.org/10.4995/var.2013.4287
15. Carlos Córdoba-Cely, "Hacia la artesanía generativa. Caso de estudio de la técnica artesanal del barniz de Pasto (Colombia) y la impresión 3D", Artnodes, núm. 27. 2021. Disponible en https://doi.org/10.7238/a.v0i27.375112.
16. S. Santos Gómez, "El empleo de las tecnologías 3D en la conservación del patrimonio y su aplicación en la realización de reproducciones de bienes culturales". Observar. Revista electrónica de didáctica de las artes, (11 (1)), 97-114. Universidad Complutense de Madrid. 2017.
17. E. M. Múnera, J. F. R. Salazar y J. W. Bedoya, "Construcción de un modelo digital 3D de piezas precolombinas utilizando escaneo láser", Revista Avances en Sistemas e Informática, 7(1), 197-206. 2010.
18. M. Flores Rodríguez, "Propuesta metodología para documentación y evaluación de elementos patrimoniales dentro del complejo histórico de la Alhambra (Granada) mediante modelización tridimensional". Trabajo de fin de máster, Universidad de Almería, 2015.
19. M. Magnani, M. Douglass, W. Schroder, J. Reeves y D. Braun, "The digital revolution to come: Photogrammetry in archaeological practice", American Antiquity Review, 85 (4), 737-760. 2020. doi:10.1017/aaq.2020.59
20. A. E. Marambio Castillo, J. M. Corso Sarmiento, J. Lucena Salas y J. Roca Cladera, "Nuevas formas de accesibilidad a través de aplicaciones con realidad virtual y aumentada en el museo marítimo de Barcelona: proyecto PATRAC, subproyecto 3". ACE: Architecture, City and Environment, 5(13), 145-160. 2010. Disponible en https://doi.org/10.5821/ace.v5i13.2497

I. Moreno Blanco, "Escaneados 3D de alta precisión en la investigación numismática", tesis de máster, Universidad Politécnica de Madrid, 2019.

21. Á. D. Martín-Blas Cifuentes, "La impresión de figuras en 3D como incentivo a la lectura para personas con discapacidad visual". Integración: Revista digital sobre discapacidad visual. 2019.