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3D Scanning, CAD Optimization and 3D Print Application in Cultural Heritage: An Example on Statue from the Ancient Salona

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Abstract: Modern technologies applied in industry and manufacturing can also be very useful in the preservation and popularization of cultural heritage. Some of the monuments or sculptures can be time-consuming for the academic sculptor to produce a true copy. Today, the process of reversible engineering can be applied, which is a significantly faster process and also more cost effective In this paper, the application of reversible engineering is presented on the example of important historical heritage from the ancient Salona dated to the 2nd century.

Stručni rad

Sažetak: Suvremene tehnologije primijenjene u industriji i proizvodnji također mogu biti vrlo korisne u očuvanju i popularizaciji kulturne baštine. Neki od spomenika ili skulptura mogu od akademskog kipara zahtjevati dosta vremena da se stvori istinska replika. Danas možemo primijeniti proces reverzibilnog inženjeringa koji je ujedno znatno brži i isplativiji postupak. U ovom radu primjena reverzibilnog inženjerstva predstavljena je na primjeru važne povijesne baštine iz drevne Salone iz 2. stoljeća.

1. Introduction

The technology of 3D print was developed by the Massachusetts Institute of Technology (MIT) in USA where terms 3D printer and 3D printing were coined [1]. 3D printing can be defined as a manufacturing of 3D products from various materials using from digital files [2]. Today, various techniques of 3D printing can be used, such as: Stereolithography – SLA; Selective Laser Sintering – SLS; Fused Deposition Modeling – FDM; Laminated Object Manufacturing – LOM; Polyjet; Electron Beam Modeling – EBM, and Solid Ground Curing – SGC [3, 4, 5]. Very widely used and very cost effective is FDM, which uses wire shape plastomers which are heated and extruded through nozzle (controlled by a computer which dimensions read as coordinates) layer by layer thus forming the 3D shape [5, 6].

FDM printers use two different materials, one for modeling and one as support. FDM has several advantages, such as less energy consumption, it does not use the laser beam, no special demands for cooling and ventilation, small maintenance costs, several prototypes can be manufactured at once. On the other hand, the limitation is the limited number of materials that can be used for production; the lines between layers are visible, etc. [7, 8, and 9].

Materials that are usually used in FDM are polylactide (PLA), acrylonitrile butadiene styrene (ABS), Polyetylentefeftalat – polyester (PETG), Nylon, and others [10, 11, 12, and 13].

Although any designed model can be printed, in cultural heritage application, usually 3D printing preceded 3D scanning and CAD optimization. A 3D scanner is a device used for scanning an object or environment by collecting data about its dimensions and outer appearance (such as texture or color) [14, 15]. Thus collected data is used for building 3D objects. 3D laser scanners have high precision and using the tools for reverse engineering 3D model can be obtained relatively fast.

Building the prototype has several steps: computed product construction (design) or 3D scanning of the real object; transferring CAD model to STL file; preparation for printing; printing of model; and final processing of printed model.

After designing or scanning of the object, the STL file of a model can be edited in several program packages such as Zprint™ or Autodesk ® Meshmixer™ [16, 17]. Using these methodologies the manufacturing lasts from two to three days, which is drastically shorter than the classical approach.

2. Materials and methods

The sculpture (head) known as the “Girl from Salona” or Plautila (Figure 1) is dated to 2nd century AD, and the scanning was ordered by the museum “Dom kulture Zvonimir” in Solin, Croatia [18]. The head was scanned in situ using DAVID SLS-3 3D Scanner [19] (Figure 2, 3 and 4).

Figure 1. “Girl from Salona“ or Plautila
Slika 1. “Djevojka iz Salone” ili Plautila

Thus, reverse engineering has found its application also in cultural heritage preservation and popularization, especially taking into consideration that it is an undestructive method.

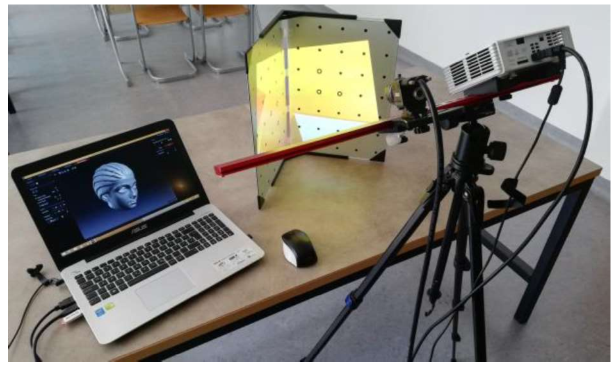

Figure 2. DAVID SLS-3 3D Scanner
Slika 2. . DAVID SLS-3 3D skener

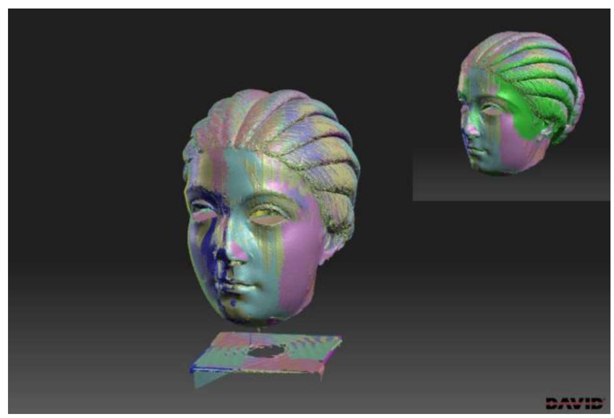

Figure 3. Scanned model of the sculpture
Slika 3. Skenirani model sculpture

Figure 4. Scanned model of the sculpture after fusion the texture and silhouettes
Slika 4. Skenirani model sculpture nakon fuzije teksture i silueta

The model was exported to STL file, but it needed optimization before printing as 3D model had more than million dots (3 million triangles). The number of dots resulted in a file larger than 700 MB which was not suitable for 3D printing. Thus CAD optimization was used to reduce unnecessary detail that will not be visible on the replica and to turn the models into simpler models for 3D print. Also, models need to be optimized to remove the irregularities made by 3D scanner and removal of generic irregularities of the model (scans cannot lap perfectly which produces irregularities on model), and all of that to improve the process of 3D printing. The model was post-processed using software Autodesk ® Meshmixer™ using various options [17]. First, the number of dots was optimized that object contained using tool Reduce. The reduction of the number of dots by 90 % reduced the total number of dots to 150,000. In the other step, the tool Smoother was used to remove the irregularities from specific surface parts using different parameters from this tool. Additionally, other tools were used when needed, such as Draw (to fulfill the empty places on the object), Flatten (to remove bulges from object) and Drag (to create bulges on the object). Also, option Analysis was used to analyze object characteristics (holes, dimensions, thickness, stability) as well as Overhangs (which detects parts of an object that would need support during printing).

The model was printed on 3D printer CubePro Duo [20] (Figure 5) and afterward manually treated for final finish to remove irregularities caused by the printing process.

Figure 5. 3D printer CubePro Duo
Slika 5. 3D printer CubePro Duo

3. Results

The 3D model of the scanned head before optimization is shown in figure 6.

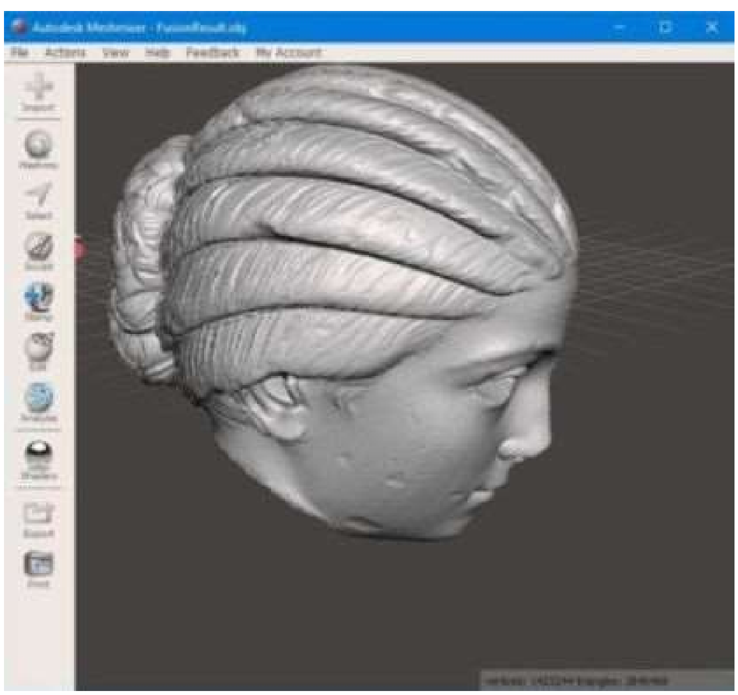

Figure 6. Model of the scanned head before optimization
Slika 6. Model skenirane glave prije optimizacije

The optimization of the number of dots that object contained using tool Reduce revealed that the model had sufficient quality for 3D print (Figure 7).

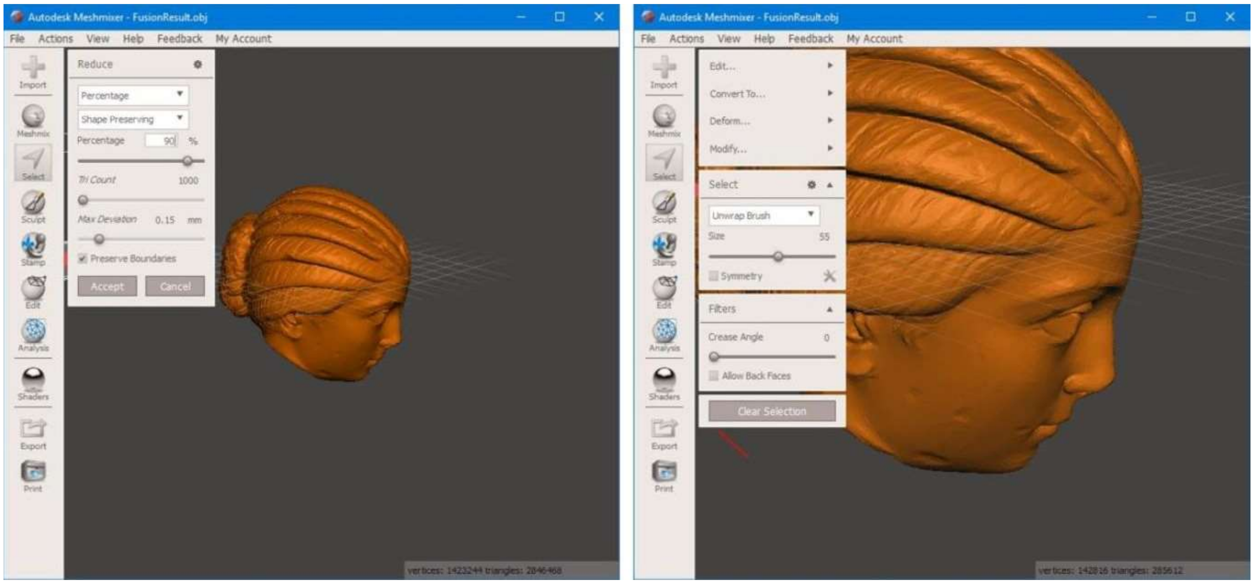

Figure 7. Optimization of the number of dots
Slika 7. Optimiranje broja točaka

The difference in model quality before and after the application of tool Reduce on Autodesk ® Meshmixer™ (Figure 8 and 9).

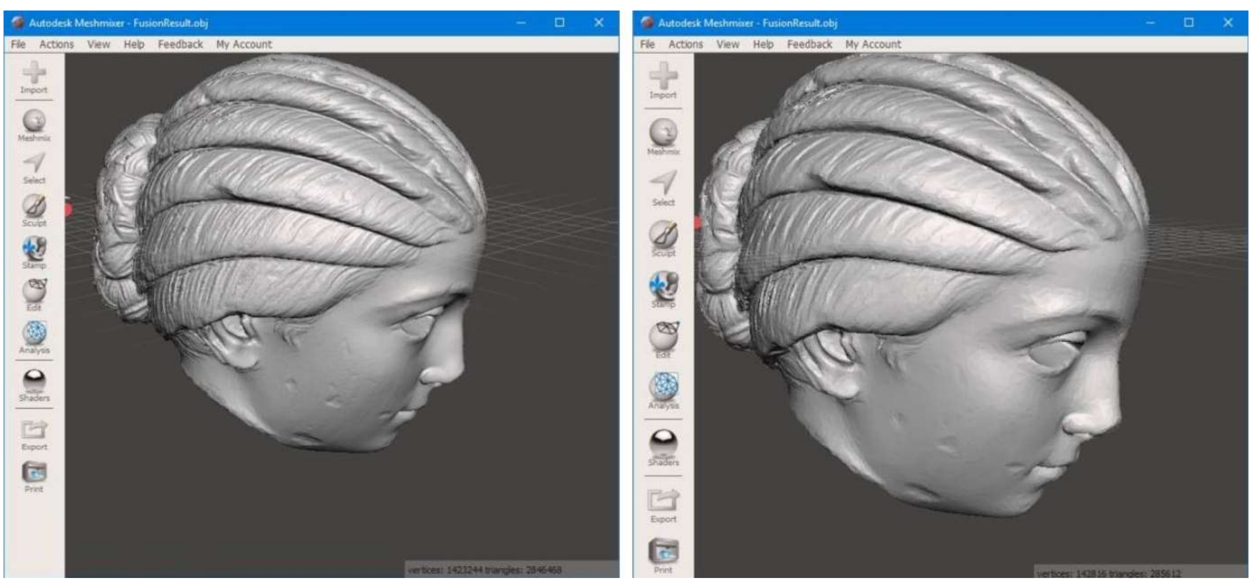

Figure 8. 3D model with 1.5 mil. dots (left), and 3D model with 150 000 dots (right)
Slika 8. 3D model s 1.5 mil. točaka (lijevo) i 3D model s 150 000 točaka (desno)

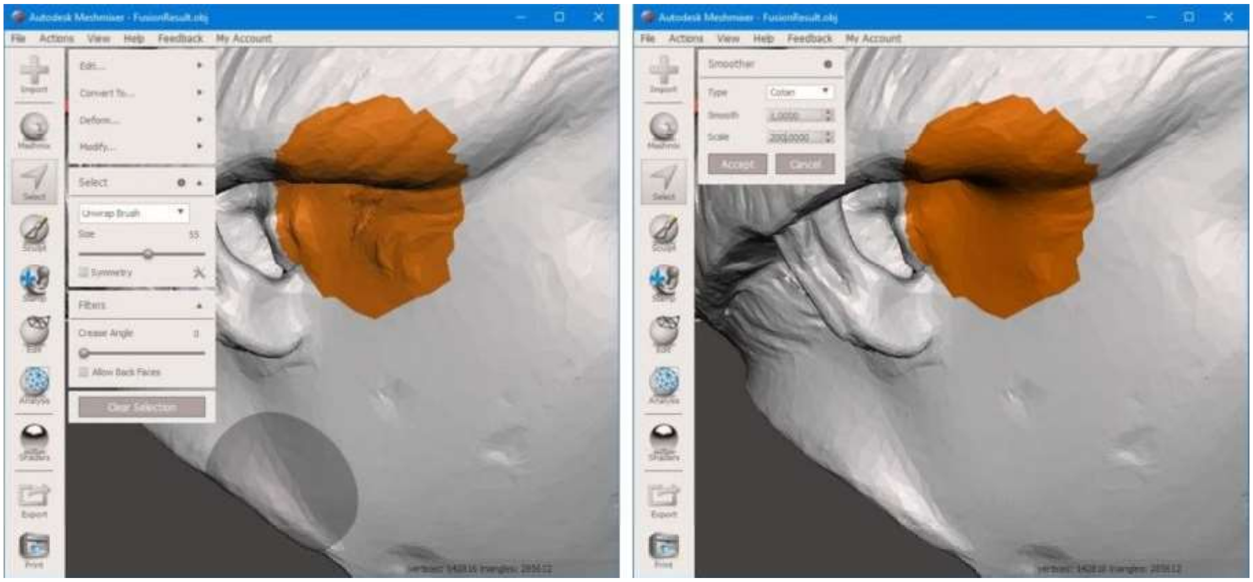

Figure 9. Smoothing the surface of the model that contains significant irregularities
Slika 9. Zaglađivanje površine modela koja sadrži značajne nepravilnosti

The result of the 3D print final product is shown in Figure 10.

Figure 10. 3D printed model that need to be manually treated for final finish to remove irregularities
Slika 10. 3D isprintani model kod kojeg je potrebno ručno ukloniti nepravilnosti do završnog izgleda

After manually treatment the 3D printed model and removing the irregularities the model of the head was used to produce the molds which were done by the "Dom kulture Zvonimir" in Solin (Figures 11 and 12).

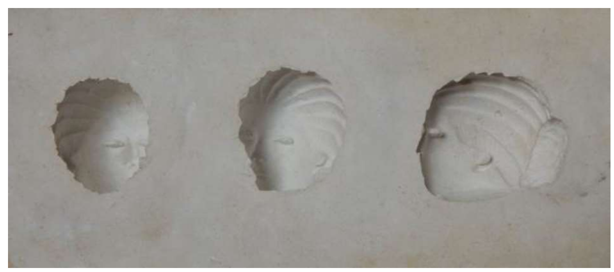

Figure 11. Molds made out of 3D model
(courtesy of museum "Dom kulture Zvonimir" in Solin)
Slika 11. Kalupi izvedeni od 3D modela
(ljubaznošću muzeja "Dom kulture Zvonimir" in Solin)

Figure 12. Souvenirs made out of plaster
(courtesy of museum "Dom kulture Zvonimir" in Solin)
Slika 12. Suveniri napravljeni od gipsa
(ljubaznošću muzeja "Dom kulture Zvonimir" in Solin)

4. Discussion and conclusion

Use of 3D scanner, optimization of the model with Autodesk ® Meshmixer™ and 3D printing revealed that this approach presents a complete solution for optimization of 3D models. The advantage of the freeware Autodesk ® Meshmixer™ is its compatibility with most of the 3D printers which enable the printing from that software. The approach of 3D scanning, optimization and 3D printing in for cultural heartache purposes showed that the principles used in manufacturing can be transferred to other fields, in this case, preservation and presentation of cultural heritage. The project resulted in the successful production of souvenirs and the two of the souvenirs made by additive technology are presented in Figures 13 and 14. These souvenirs help museum to earn funds which are absolutely needed for the preservation of the cultural heritage. Since the whole process of the souvenir development was low-cost, it represents a sustainable solution for the commercial activities of the museums.

Figure 13. Magnet of head the "Girl from Salona" (courtesy of museum "Dom kulture Zvonimir" in Solin)
Slika 13. Magnet glave "Djevojka iz Salone" (ljubaznošću muzeja "Dom kulture Zvonimir" in Solin)

Figure 14. Statue of the head the "Girl from Salona" (courtesy of museum "Dom kulture Zvonimir" in Solin)
Slika 14. Statua glave "Djevojka iz Salone" (ljubaznošću muzeja "Dom kulture Zvonimir" in Solin)

REFERENCES

[1] Sachs, E., Cima, M., Brancazio, D., Curodeau, A., & Shalon, T., (1990), *Three Dimensional Printing. Rapid Fabrication of Molds for Casting*. Advances in Integrated Product Design.

[2] Gebhardt, A., (2012), *Understanding additive manufacturing: rapid prototyping-rapid tooling-rapid manufacturing*. Carl Hanser Verlag GmbH Co KG.

[3] Grimm, T., (2004), *User's guide to rapid prototyping*. Society of Manufacturing Engineers.

[4] Jacobs, P. F., (1992), *Rapid prototyping & manufacturing: fundamentals of stereolithography*. Society of Manufacturing Engineers.

[5] Wong, K. V., & Hernandez, A., (2012), *A review of additive manufacturing*. ISRN Mechanical Engineering, 2012.

[6] Zein, I., Hutmacher, D. W., Tan, K. C., & Teoh, S. H., (2002), *Fused deposition modeling of novel scaffold architectures for tissue engineering applications*. Biomaterials, 23(4), 1169-1185.

[7] Mohamed, O. A., Masood, S. H., & Bhowmik, J. L., (2015), *Optimization of fused deposition modeling process parameters: a review of current research and future prospects*. Advances in Manufacturing, 3(1), 42-53.

[8] Peko, I., Krolo, J., Bagavac, P., Đurić, S., Kostić, N., & Bašić, A., (2017), *Modeling and Optimization of Tensile Strength of ABS Parts Manufactured by the Fused Deposition Modeling Process*. In International conference "Mechanical Technologies and Structural Materials".

[9] Grimm, T., (2003), *Fused deposition modeling: a technology evaluation*. Time-compression technologies, 11(2), 1-6.

[10] Novakova-Marcincinova, L., & Kuric, I., (2012), *Basic and advanced materials for fused deposition modeling rapid prototyping technology*. Manuf. and Ind. Eng, 11(1), 24-27.

[11] Singh, R., & Singh, S., (2014), *Development of nylon based FDM filament for rapid tooling application*. Journal of The Institution of Engineers (India): Series C, 95(2), 103-108.

[12] El-Farahaty, K. A., Sadik, A. M., & Hezma, A. M., (2007), *Study of Optical and Structure Properties of Polyester (PET) and Copolyester (PETG) Fibers by Interferometry.* International Journal of Polymeric Materials, 56(7), 715-728.

[13] Novakova-Marcincinova, L., & Novak-Marcincin, J., (2013), *Verification of mechanical properties of abs materials used in FDM rapid prototyping technology*. Proceedings in manufacturing systems, 8(2), 87-92.

[14] https://www8.hp.com/us/en/campaign/3Dscanner/overview.html?jumpid=va_t1345uf8k6 [accessed 26.8.2018]

[15] Boehler, W., & Marbs, A., (2002), *3D scanning instruments.* Proceedings of the CIPA WG, 6, 9-18.

[16] https://www.3dsystems.com/software/3d-sprint [accessed 26.8.2018]

[17] http://www.meshmixer.com/ [accessed 26.8.2018]

[18] Buzov, M., (2009), *Plautilla, sudbina jedne princeze*. Archaeologia Adriatica, 2(2), 473-488.

[19] https://www8.hp.com/us/en/campaign/3Dscanner/overview.html?jumpid=va_t1345uf8k6 [accessed 26.8.2018]

[20] https://www.3dsystems.com/shop/support/cubepro/videos [accessed 26.8.2018]