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INTANGIBLE HERITAGE?...NOT ANYMORE FROM PHOTO TO 3D PRINTED CULTURAL HERITAGE ASSETS REPLICAS THE TWO MISSING IRON DISCS FROM THE DACIAN HILLFORT OF PIATRA ROȘIE (ROMANIA)

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Abstract: Cultural heritage domain has started to adopt various modern technologies to improve their visitor's user experience within various museum exhibitions. There are a wide variety of academic papers that present various workflow that enable the digitization of various cultural heritage assets, starting from small objects up to entire buildings and fortifications. This paper is focused on the development of 3D models that are suited for 3D printing using budget 3D printers as well as open-source 3D modelling software to enable the physical reconstruction of tangible cultural heritage assets. The case study presented within the paper has been done on the Dacian ornamental discs that has been looted from the Dacian hill fort from Piatra Roșie (Luncani, Hunedoara County, Romania) and the only references are a set of images that have appeared online at an action house from United States of America. Researchers are currently making new materials 3D printable expanding their category from plastics and metals up to composite materials that combine multiple materials to get the best properties of each. Along with these new materials, a wide variety of 3D printing technologies have been developed, these technologies have the potential to become a vital component in cultural heritage empowering the research, documentation, and preservation for a wide variety of cultural heritage assets.
Keywords: *cultural heritage, 3D reconstruction, 3D printing, tangible assets, museum exhibitions.*

1. INTRODUCTION

The recent technological evolution of both 3D modelling software as well as the popularity of 3D printing equipment has enabled the development of tangible artefacts for museum exhibitions. As presented by Ballarin, Balleti and Vernier[1] museum and cultural heritage related institutions have started to adopt modern technologies such as virtual reality and augmented reality application or 3D printed tangible replicas within their exhibitions. The use of modern technologies has changed

[1] BALLARIN/BALLETTI/VERNIER 2018.

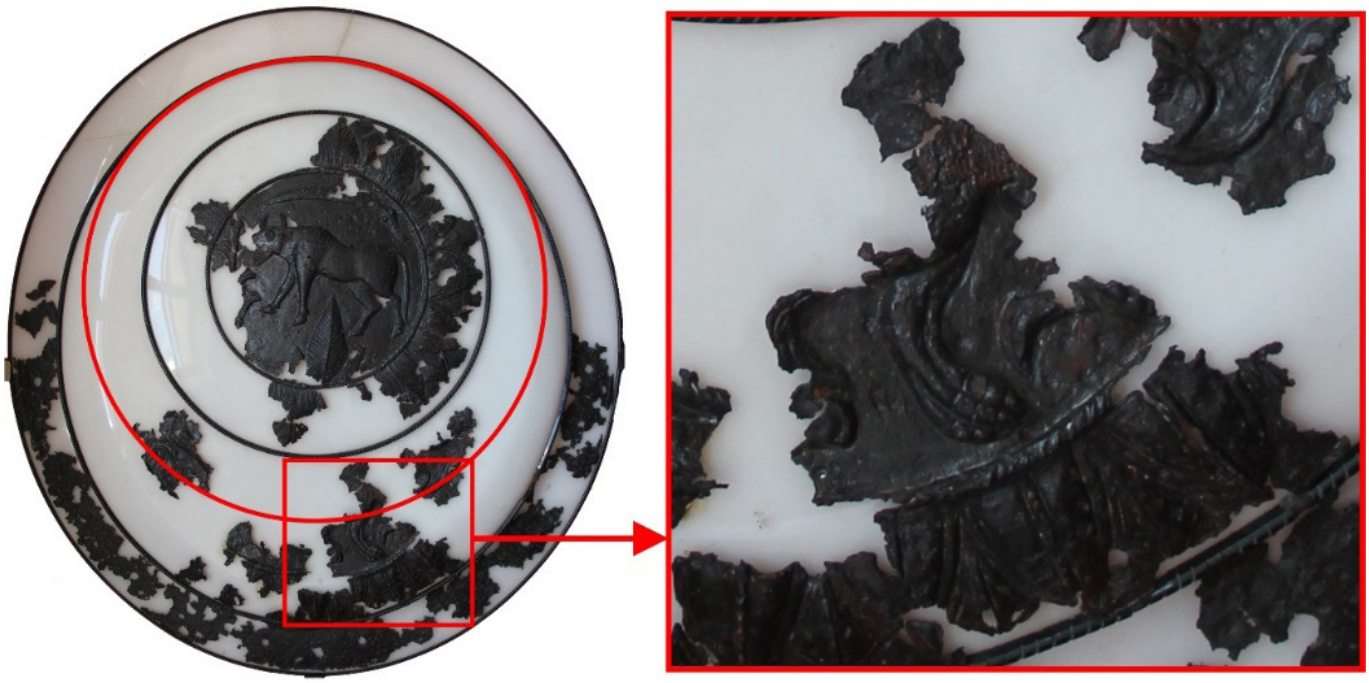

Fig. 1. The fragmented Dacian ornamental disc found at Piatra Roșie hill fort, the fragments are exhibited at the National Museum of Transylvanian History from Cluj-Napoca

museum visits allowing visitors to interact better with the exhibition. Defining digital applications and tangible 3D reconstructed have transformed the experience towards a multi-layer and multi-sensorial experience. A wide variety of digital screens, natural gesture acquisition sensors, head-mounted display, and physical replicas have been integrated within the exhibition changing the way users' approach and interact with the cultural heritage assets. The original cultural heritage assets are displayed in traditional glass display cases allowing users to observe the intricate details and texture.

The research team from the 3D scanning and 3D measurement laboratory of Technical University of Cluj-Napoca has worked with various museum and institutions from Romania with the goal of creating innovative exhibitions that make use of modern digital technologies.

As presented by Rahaman, Champion and Bekele[2] the cultural heritage domain is on the verge of adopting these technologies, not only to enhance user experience but to satisfy the more enthusiastic and tech-savvy visitors. There are various ways that can be used to add additional information to a physical cultural heritage displayed within a museum glass display. The most popular option adopted by various museums around the world is to use an audio guide system or position a QR code near the object allowing museum visitors to use their own smartphones to access the additional information and even the 3D digitized artefacts allowing the user to rotate and scale the object to visualize the intricate details and inscriptions. 3D digital reconstruction of damaged and fragmented objects that can be visualized both on their smartphone or various monitors and projection screen are widely available in modern museum exhibitions. For some cultural heritage assets, these 3D models have been integrated in virtual reality environments allowing users to immerse them self within a digital environment where they can interact with the objects either by using virtual reality controllers or natural gestures that are interpreted by specific sensors such as Kinect or LeapMotion.

Another important aspect of digitally reconstructed assets and physical 3D printed tangible is represented by their scientific purpose, allowing a better analysis of fragmented archaeological findings that can be study and measured digitally to better understand their original shape.

There is another important aspect regarding the possibility of creating tangible cultural assets. Anastasiadou and Vettese[3] highlight that 3D printing technologies creates new opportunities regarding the personalisation and creativity of cultural heritage souvenirs by transforming visitors' intangible encounters they experience within a museum exhibition/archaeological site into tangible memory linked to the visited places.

2. AIM OF THE RESEARCH

The purpose of this article is to present the advantages of using 3D printing technologies to recreate missing cultural heritage assets based on the shape and dimensional features and properties of similar known assets. The case study has been done for two Dacian ornamental discs that have been looted from the Dacian Fortress from Piatra Roșie.

The most important aspects that have been considered for this research initiative was to create realistic tangible assets that have the details and touch feeling (embossed details) of the original ornamental discs starting with the dimensional constraints of other similar Dacian ornamental discs that have been discovered at Piatra Roșie

[2] RAHAMAN/CHAMPION/BEKELE 2019

[3] ANASTASIADOU/VETTESE 2019

Fig. 2. Luncani Piatra Roșie hill fort, part of the Dacian Fortresses complex from Orăștie Mountains[4]

hill fort and which are currently located at the National Museum of Transylvanian History from Cluj-Napoca[5] and National Museum of Romanian History from Bucharest[6]. The reference of the fragmented disc from National Museum of Transylvanian History from Cluj-Napoca is presented in Fig.1.

As an integral part of the of Dacian fortresses complex from the Orăștie Mountains, the hill fort from Luncani Piatra Roșie (Fig. 2) came to the attention of the scientific world in the first half of the 19th century. Rumours about the discovery of impressive coin hoards attracted to the area not only representatives of the Austrian tax authorities but also several scholars, intrigued by the nature of the ruins discovered in the mountains south of Orăștie city. Located near the source of the Luncani Valley, the fortress of Piatra Roșie, is part of a large defensive system meant to defend the capital of the Dacian Kingdom, controlling the access to the politico-military centre of the Dacians from West and South-West.

Although systematic archaeological excavations at this site were limited to a large-scale campaign in 1949, which resulted in the publication of the archaeological monograph a few years later[7], and a few small verification campaigns between 2003-2005, the richness and diversity of the discovered archaeological material place it among the most interesting Dacian fortresses around the capital of the Dacian Kingdom. Among the exceptional pieces discovered during the archaeological excavations but also because of the actions of recovery of the stolen archaeological patrimony from the Orăștie Mountains area, the iron discs with zoomorphic and phytomorphic representations stand out.

The first piece of this kind was discovered in the 1949 campaign, in a building with an apse located inside the large enclosure (the second fortress) from Piatra Roșie. The edifice, built in wood and clay, was based on rows of shaped limestone blocks, access to it being facilitated by a road, in turn paved with shaped limestone slabs[8]. Near the wall of the apse room, the remains of an "ovoid iron plate with embossed ornaments" were discovered[9], plaque that would enter the literature with the name of "parade shield from Piatra Roșie"[10]. In the early 2000s, at the same site, archaeological poachers discovered a whole series of wrought iron discs with embossed decorations. On-the-spot checks showed that the parts probably came from the immediate vicinity of the building where the 1949 piece had been discovered, in a pit dug by poachers several remains of one or more such iron discs were identified[11]. The exact number of pieces discovered and trafficked by poachers is not known exactly, so far three ornamental discs have been recovered (two in the patrimony of MNIR and one specimen in the patrimony of MNIT)[12]. On the basis of the archaeological context and historical background, the discs have been dated in the chronological segment preceding the last Dacian war of AD 105-106[13].

They prove, if necessary, the advanced knowledge of metalsmithing of the Dacian craftsmen, their production involving the mastery of rather complicated procedures of beating the iron sheet, in the technique *au repoussé*, as well as engraving the details on the obverse of the pieces. To these are added the special artistic talent of those who made them, being impressive regarding their care for proportions, for details as well as the accuracy of the representations[14].

The pieces stand out through the complex decoration rendered on the obverse. In all cases the ornaments are arranged in concentric registers, starting from a central medallion in which is usually rendered a real or fantastic animal, surrounded by a register with plant decoration and finally an outer band, often smooth, provided with holes for attachment on a wooden support or on a wall. Usually, the registers are delimited by a twisted ornament (string or "twisted rope").

The central element of all discs is represented by the image of an animal, arranged in a medallion, and sometimes

[4] CETĂȚI DACICE 2012.
[5] EUROPEANA 2018.
[6] CAPODOPERE 2019.
[7] DAICOVICIU 1954.
[8] DAICOVICIU 1954, 64-65.
[9] DAICOVICIU 1954, 65.
[10] DAICOVICIU 1954, 119. Starting from C. Daicoviciu's interpretation, according to which the piece would represent an ovoid parade shield, I. Korodi combined at the time of the restoration, fragments that most likely came from at least two different pieces, including in the ornamentation of the piece a so-called register semilunar; KORODI 1967. Subsequent analyses and analogies offered by the discovery of other ornamented discs showed that the fragments of the decorated iron plate came from two different discoidal pieces, one with a bour in the central medallion and the other most likely a feline, the crescent register being in fact part of the central medallion of a second disc. FLOREA/FERENCZ 2004-2005, 50.
[11] If the building itself had a sacred function, then it is possible that the pit in which the discs were stored was a *favissa*. FLOREA/FERENCZ 2004-2005, 47-48.
[12] BORANGIC/BĂDESCU 2017, 114.
[13] FLOREA/SUCIU 1995, 60.
[14] FLOREA/CRISTESCU 2016, 146.

associated with plant elements. Thus, in the central medallion of the piece discovered in the excavations from 1949, a bour/bison was rendered walking to the left, above it being represented another zoomorphic element, most probably a snake (?). Two vegetal elements appear in the same medallion: a small tree towards which the ox is heading, and three sharp palms represented at the bottom of the medallion[15]. A similar animal appears on one of the discs kept in the MNIR collections, stating that this time the bour/bison is shown moving to the right and the vegetal elements that complete the decoration are much more complex: an ivy twig that runs behind, above and probably in front of the animal and a flowering plant shown under and between the feet of the bour[16]. On other discs the central place is occupied by a griffin, a lion or a deer, and in these cases the zoomorphic representations being accompanied by vegetal elements.

Fig. 3. The gryphon zoomorphic ornamental disc is presented to the left of the figure. The bour zoomorphic ornamental disc is presented to the right of the figure.

As for the second register, the one that surrounds the central medallion, it is made exclusively from plants, which show acanthus leaves and / or nested lotus petals. In addition to these elements, the decoration of the discs is sometimes completed with a series of small eggs separated by incised lines, glued to the corded ornament that separates the vegetal register from the flat edge of the discs. The border of the pieces, about 5 cm wide and undecorated, was provided with holes in which decorative targets were probably inserted with the help of which the discs were fixed on a support, so that this external register could also be ornamented. With such targets, also decorated with plant motifs, was provided for example the disc that had a griffin in the central medallion[17].

Most likely, the representations on the central medallions of the discs discovered at Piatra Roşie had some symbolic significance for the Dacian world, at least for the communities in the region of the capital of the Dacian Kingdom. The preference for certain animals (bour/bison, lion, griffin), which appear not only on iron pieces, but also on painted pottery or more recently on the bronze mould discovered at Sarmizegetusa Regia, shows the importance of these animals in the ancient imaginary universe. It is therefore probable to interpret these pieces rather as objects involved in various ritual practices (offerings, images of worship or associated with worship, etc.), than as pieces of armament as they entered the literature. Not only the complex decoration on them but also the place of discovery, in a probable cult building and in a *favissa* located in the immediate vicinity of this building, plead for this interpretation[18].

The other references used within digital reconstruction are presented in Fig. 3, these are the two ornamental discs recovered by the authorities, they are located at the National Museum of Romanian History. One of the discs has a gryphon zoomorphic element in the middle while the other has a bour. These discs are similar to the previously presented fragmented disc, but their conservation status is good having no missing fragments indicating the roundness shape of the Dacian ornamental discs.

3. DIGITAL RECONSTRUCTION

The fragmented disc presented in Fig. 1 has been digitized using two scanners, a laser scanning (ViuScan) and a structured light scanner (GoScan 50). We have closely analysed the two resulting meshes and the laser scanning offers the best accuracy which is important since the metal fragments have a thin surface with various intricate details. The scanner has been calibrated to the smallest possible scanning volume (a cube with the side of 100 mm) enabling us to achieve the highest resolution (0.1 mm) that can be acquired by the ViuScan scanner (Fig. 4).

The resulting mesh have been imported in Blender [19] along with the reference image of the two looted Dacian Ornamental discs presented in Fig. 5. The shape of the bour profile is very similar and follows the same shape on both shields, the bour is rendered walking to the left and the legs position are very similar defined. The major differences are the vegetal elements from the main register, on the fragmented shield the bour has a tree rendered to the left and three leaves palm ornament at the bottom.

The 3D reconstruction of the ornamental discs has

[15] FLOREA/SUCIU 1995, 54-57.
[16] BORANGIC/BĂDESCU 2017, 116, fig. 108; FLOREA/CRISTESCU 2016, fig. 13.
[17] BORANGIC/BĂDESCU 2017, 114-115, fig. 107; FLOREA/CRISTESCU 2016, fig. 13.
[18] FLOREA/SUCIU 1995, 57; FLOREA/FERENCZ 2004-2005, 47-48; FLOREA/CRISTESCU 2016, 146.
[19] BLENDER 2021.

Fig. 4. Laser scanning of the fragmented disc using ViuSCAN.

Fig. 5. The two Dacian ornamental discs that have been stolen from the archaeological site of Piatra Roșie and presented at an auction in USA.

been done using a polygon-by-polygon modelling technique. The first step was to define the outer circle diameter using the reference of the existing Dacian ornamental discs available. The two reference Dacian ornamental discs presented in fig. 5, are made from iron, and have the same texture as the ones recovered by the authorities and presented in fig. 3. The fragmented disc presented in fig.1 has a black texture since the iron material was very thin and was corroding thus required to be preserved using specific conservator-restorer techniques to prevent and slow the corrosion and deterioration of the fine intricate details of the surface.

The first step of the polygon-by-polygon modelling technique involved the creation of the outer circle that will define the disc, the case study presented within this paper with screen captures has been done on the disc with the bour zoomorphic representation (Fig.6).

The Dacian ornamental discs are composed using three adorned registers. The outer circle diameter has been set to 420 mm for the reconstructed bour disc, as the existing reference disc from MNIR. These are the following references and dimension of the existing bour disc[20] from MNIR museum presented in Fig. 3. The outer register has 12 circular holes circularly aligned to the middle of the disc. The outer register is merged with the middle register using an ornament that is defined a twisted rope, in relief with a width of 5 mm. The middle register is adorned with two rows defined with 19 triangular relief leaves. The inner register also known as the central medallion has a diameter of 18.5 mm and the entire space is occupied by the animal and vegetation decoration. Under the bour chin there`s a triangle bear pointing down. The body of the bour is

[20] CAPODOPERE 2019.

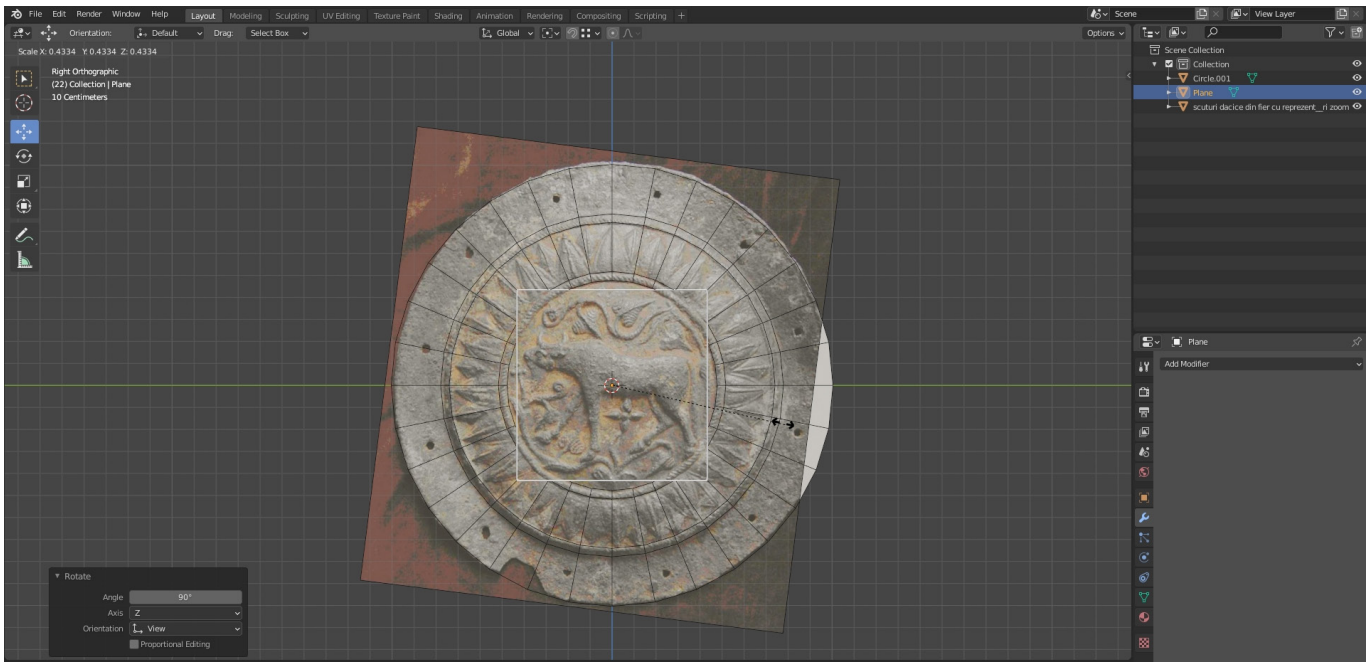

Fig. 6. Defining the reference circle size and subdivision of the model to follow the shape of the disc with the three registers separated using twisted rope embossed elements.

decorated with multiple rows of short lines representing the fur. For the reference bour disc, the animal`s forehead is poorly preserved, being rusted. All three known bour Dacian discs have similar elements, starting with the profile of the zoomorphic representation up to the vegetation decoration circularly aligned around the middle register with twisted rope elements separating the disc registers. This ornamental reference disc has a maximum diameter of 420 mm and was realized using the hot hammering technique. It has a thickness that varies from 1 mm up to 1.8 mm and a maximum height of 5 mm. The overall weight of this disc is 1.5 kg. The other reference ornamental disc presented in Fig.3 with a gryphon zoomorphic representation has a maximum diameter of 418 mm, a thickness between 1.8 up to 1.9 mm and a maximum height of 5 mm. The weight of this disc is around 1.6 kg.

The following step was the 3D modelling of the vegetation leaves that are circularly aligned around the middle register of the disc. This step was done using the same polygon-by-polygon modelling technique closely following the shape of the reference within the image while considering the height of the details according with the values from the disc with bour shape presented in Fig. 3. The result is illustrated in fig. 7. The number of vegetation leaves circularly aligned has be done according to the reference image, the image presents a total of 20 vegetation leaves circularly patterned, while the reference disc from MNIR[21] has only 19.

The twisted rope elements that separate the three registers of the ornamental disc have been modelled using the same polygon-by-polygon technique having each section twisted and digitally multiplied, the end vertices have been

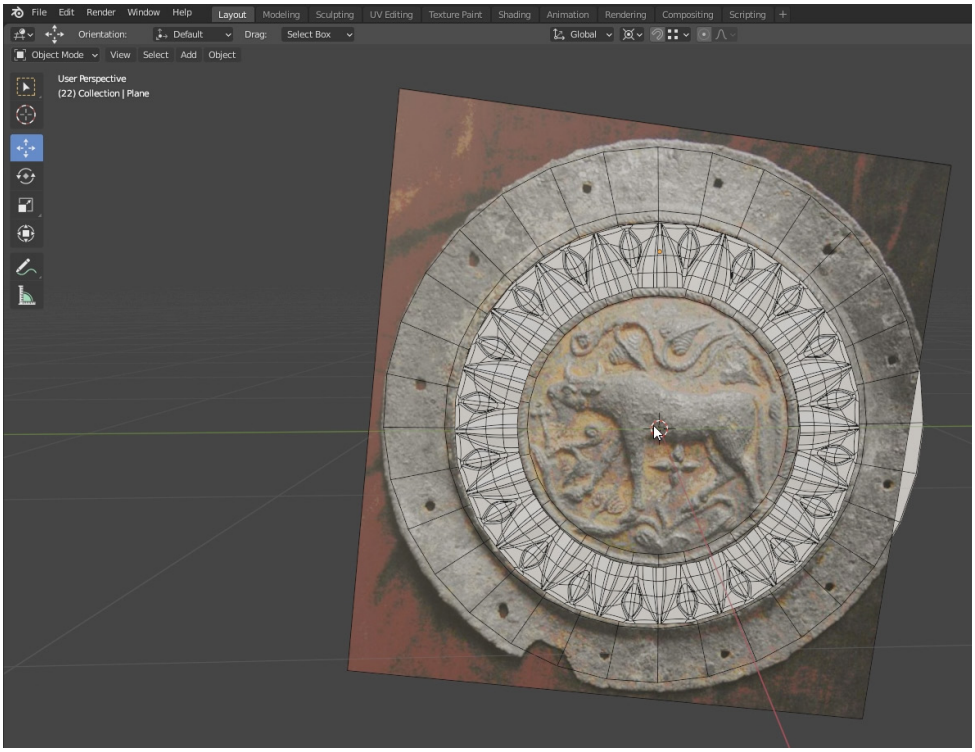

Fig. 7. The 3D modelling of the vegetation leaves around the middle register of the disc.

[21] CAPODOPERE 2019.

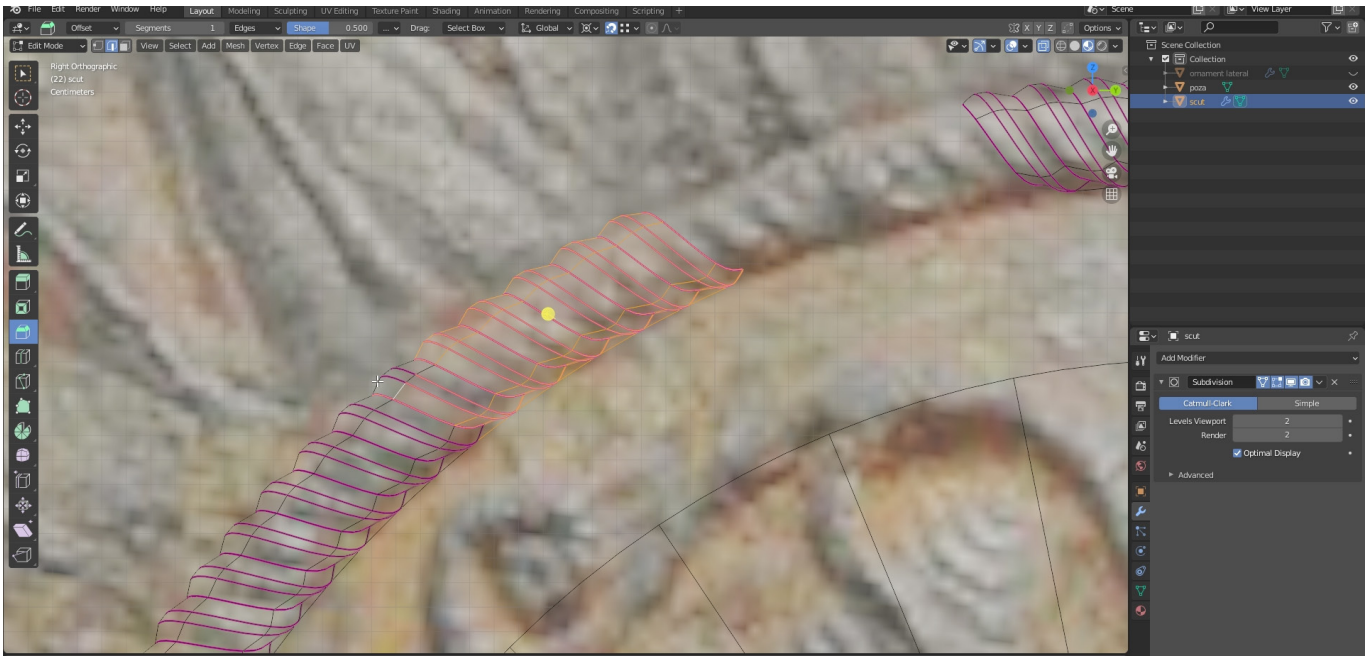

Fig. 8. 3D modelling of the twisted rope elements.

merged to define the filled surface where the two sections are being merged, this step is illustrated in fig.8.

The same modelling technique has been applied to all the elements of the disc using the reference image and dimensional values of the reference shield from MNIR[22]. The final resulting mesh of the 3D digitally reconstructed bour disc using polygon-by-polygon modelling technique has been then transferred to the Sculpt Mode within Blender to reduce the crease of the final model. The resulting mesh of the disc is presented in fig. 9.

4. 3D PRINTING

The two digitally reconstructed Dacian ornamental shields have been 3D printed using additive manufacturing technology within the Makerspace laboratory from Technical University of Cluj-Napoca. PLA filament has been chosen mainly because this is the most affordable material for additive manufacturing, and it is an easy material to work with in comparison with ABS. The semi-crystalline polymer has a melting temperature of 180 °C and the final product can be sanded and treated with acetone to define a smooth surface.

Other researchers such as Ballarin, Balleti and Vernier[23] highlighted the possibility of using online printing services that give the users the possibility to upload their 3D model, choose between a wide variety of 3D printing technologies and materials and have the resulting 3D printed model delivered to any part of the world. Our main goal was to digitally reconstruct the missing discs and create the reconstructed looted discs using affordable materials and commonly available commercial 3D printers. Using online 3D printing services enables the use of more complex materials and 3D printing technologies such as SLM(Selective Laser Melting) LPBF (Laser Powder Bed Fusion) and DMLM (Direct Metal Laser Melting) to melt and fuse metallic powder using a high power-density laser, but these technologies are very expensive for larges pieces such as the Dacian ornamental discs. For future research projects we consider using these technologies that will enable the reproduction of the Dacian ornamental discs using metallic powder since researchers are constantly developing these technologies, which in 2021 are still very expensive for large parts such as the ornamental disc with a diameter of 420 mm since most 3D metal printing equipment have a much smaller build size volume.

For the case study done within this article, the Ultimaker Cura[24] software was used to define the slicing of the two reconstructed shields using an 0.1 mm fine printing profile and an infill of 20% (Fig. 10). With these parameters each reconstructed shield required almost 5 days to allow the printer extruder to recreate the shape and about 700 g of PLA. The printing settings made use of support materials to allow the 3D reconstructed model to maintain its thickness. The support material has been removed from the bottom side of the ornamental shield using a pair of pliers.

The final 3D printed discs were treated with acetone to highlight their reconstructed details and were coloured black using an aerosol spray can. The resulting discs are presented in fig. 11.

5. CONCLUSIONS

This pluridisciplinary approach, involving fields of history, archaeology together with engineering, VR and 3D printing may take the Heritage Studies to a new level. If earlier scholarly and professional activities were focused 'narrowly on the architectural or archaeological preservation of the monuments and sites'[25] with the new available technologies, we may offer to the public a past that has been

[22] CAPODOPERE 2019.
[23] BALLARIN/BALLETTI/VERNIER 2018.
[24] ULTIMAKER CURA 2021.
[25] LOGAN/SMITH 2009, xii.

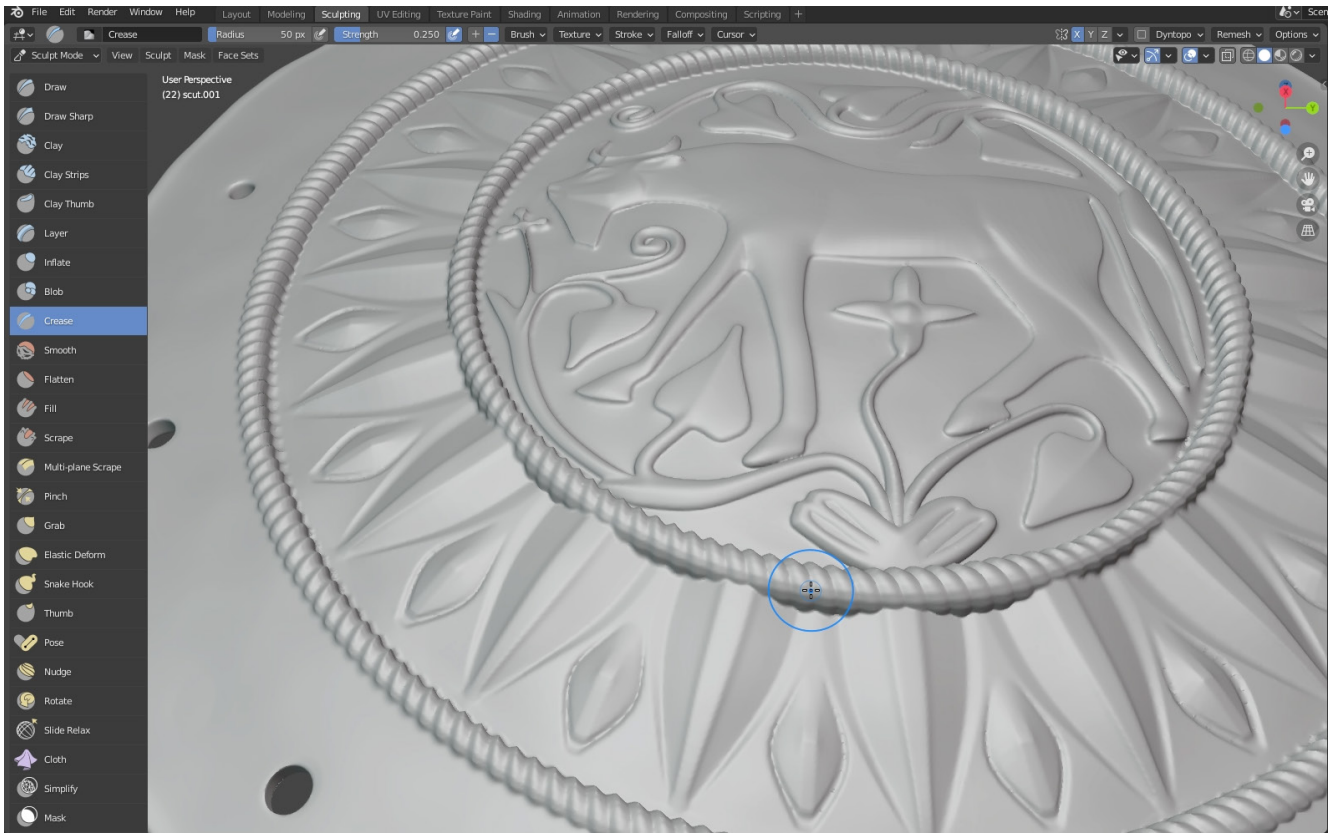

Fig. 9. Crease tool feature available within the Sculpt Mode from Blender software.

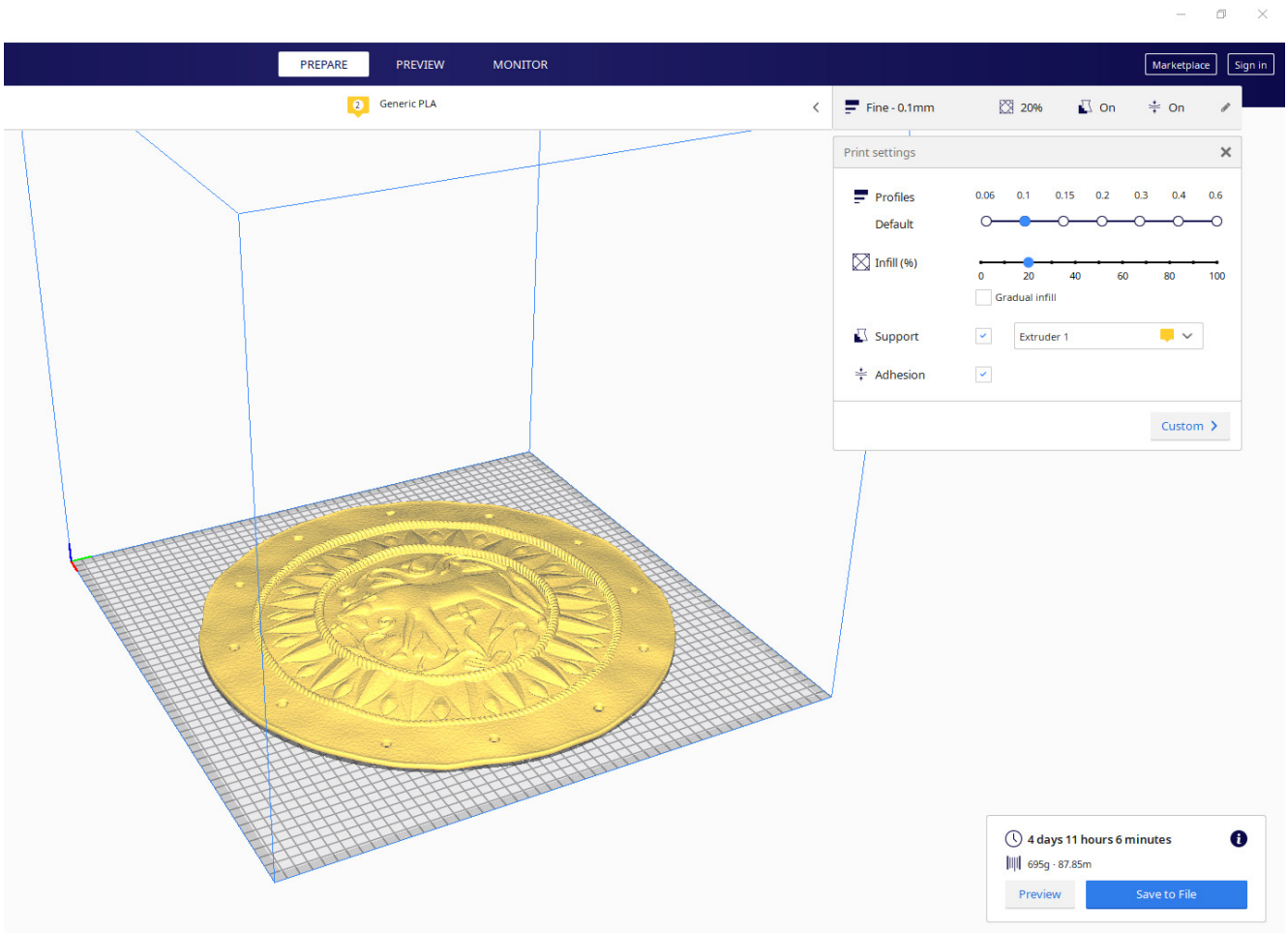

Fig. 10. The slicing and the printing parameters used for both reconstructed discs.

Fig. 11. The two 3D printed Dacian ornamental discs.

frequently considered as being lost.

The present case study reveals a very exciting and attractive way with multiple benefits for the public, academic environment, institutions in charge with the safeguarding of Cultural Heritage and marketing, as well.

Above all, 3D printing will allow visitors to touch and feel objects previously behind glass. It 'will help people to connect with the objects on an extra level and perhaps gain a deeper understanding. The implications for visually impaired visitors are exciting too.'[26]

There are already few projects involving the 3D printing technology running at prestigious museums.

The Science Museum London is displaying 3D printed organs, prosthetic limbs and reconstructive surgery.[27]

Already, in 2018, the Manacor Museum of History, Spain opened an exhibition with artefacts printed in 3D. The visitors were encouraged to interact with these models, 'to hold them and feel them'.[28]

As Charlotte Coates clearly pointed out there is a large variety of benefits that this technology can offer to museums and the public. 'It gives museums the ability to make collections available to more people. Blind and visually impaired visitors can experience exhibitions in a new way. Curators can have the opportunity to take 3D models out to schools, hospitals, retirement homes and more. This will help to reach people who might not otherwise visit the museum. 3D printing can also be used as an extra method of preserving and safeguarding collections.

This technology can help with education, conservation and research. When used alongside existing tools and expertise, 3D printing can add great value to a museum collection.'[29]

Certainly, this technology may also have some downside aspects that we must be aware of. The material used for printing it is not the same as the original artefact is made of. At the same time, the quality of the material used for printing may as well the device involved also may affect the quality of the products.

For the academic environment and the safeguarding of the cultural heritage the 3D printing technology can be a great benefit.

In 2012, scholars from The Semitic Museum, Harvard University used the 3D modelling and printing techniques to recreate a 3,000 years ceramic lion found at the Mesopotamian city of Nuzi (nowadays, in Iraq) and smashed in pieces.[30]

As for the case study done within this paper, the two artefacts are still on the Interpol wanted list, the only illustrative available information were the two photos. Together with the comparative analysis with the similar recovered artefacts allowed the reconstruction of a 1:1 scale 3D model of each of the two artefacts. Once all the discs, known at the moment, will be printed in 3D will allow both scholars and authorities to find out the more details on the production technique, decoration, functionality, and, implicit, to decipher the mentality of a 2,000 years community that was capable of creating such masterpieces of work in iron.

It may also offer the possibility to complete the decorations of the two previously discovered discs, back in 1949. Their poor state of preservation has been misleading restorers and scholars for decades to consider those fragments as one disc/shield, until recently when it has been demonstrated that we are dealing with fragments coming from two or more different artefacts.[31]

At the same line, a comparative analysis of all these discs in front of you, at a 1:1 scale, with the possibility to observe all the details, also knowing the archaeological context/site where the discs were found, it may offer a clue whether there could have been even more discs found and trafficked that we were aware of. At the time when these

[26] COATES 2020.
[27] COATES 2020.
[28] COATES 2020.
[29] COATES 2020.
[30] FLAHERTY 2012; COATES 2020.
[31] FLOREA/FERENCZ 2004-2005, 50.

artefacts were both trafficking and recovery targets for smugglers and authorities, there was already an impressive list of stolen and recovered ancient artefacts from Romania, such as: 700 gold Koson coins; 253 silver Koson types; three iron discs of the similar category with the ones discuss in this paper; 31 pseudo-Lysimachus gold coins; a golden necklace and earrings; 13 Dacian gold spirals, etc.[32]

At the end, maybe, the most important aspect that the present study may help us to understand is one of moral, cultural and sentimental nature. Imagine how many valuable artefacts which we know them only from photos has been lost (e.g. the Amber Room, the Kamakura sword, some of the Fabergé eggs) may be recreated and touched again.

On this way, we hope that at least part of the *intangible heritage* may be *tangible* again!

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