

Photogrammetry, 3D modelling and printing: The creation of a collection of archaeological and epigraphical materials at the university

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ABSTRACT

The aim of this contribution is to present the *Experimenting Digital Antiquity* Project undertaken at the Complutense University in 2021–2022. The initiative consisted of encouraging new teaching methodologies by creating a collection of copies of ancient finds printed with 3D technology. This required a series of carefully organised steps that can be summarised as training students in the skills needed to carry out the photogrammetry of artifacts preserved in museums and ultimately printing the 3D models they prepared. The results, an initial collection of 21 artifacts, laid the foundations for work that has continued since then.

1. Introduction

Traditionally, access to archaeological exhibits has been practically vetoed for History, Archaeology and Art History students, especially in the earliest stages of their learning. Due to the rarity of such objects and their fragility, their use with younger students was not recommended either. The *Experimenting Digital Antiquity* project (known originally in Spanish as *Experimenta la Antigüedad Digital*)¹ attempted to overcome these challenges by creating a collection of archaeological finds in 3D –both digital and printed formats– using photogrammetry, 3D design and 3D printing as tools for scientific use. The process included training our students in how to use this technology accurately for research with the aim of developing a closer relationship with the archaeological artifact.

3D technology provides a new paradigm for professors and students. It can make classes more interesting and dynamic and provides the

opportunity to experience the interactivity that is usually lacking with traditional methodologies. Thus, students who eventually participate in actual archaeological fieldwork and other related activities will have acquired a series of skills that allow them to put the tools they have learned into practice. This will be even more important if some of them eventually work as professional archaeologists, since they will have a more comprehensive knowledge of the composition, materiality and nature of these finds. They will also have expertise in the field of heritage virtualisation.

In the first year of the *Experimenting Digital Antiquity* Project we focused on the Classical World –Greece and Rome– including finds from the Iberian Peninsula in a colonial context.² The activity aimed to create a strong bond between the students and the material culture of antiquity through first-hand experience. This can solve the problem of rarity and fragility and provide students with a new set of tools to benefit their future research, reconstructing items and artifacts and replicating their

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¹ The project was accepted in the 2021 Innova-Docencia call for proposals (No. 361) of the Complutense University of Madrid, a yearly call that promotes the application of new teaching approaches and methodologies. The project was undertaken during the 2021–2022 academic year.

² A second project is currently under development in the 2022–2023 academic year. Entitled as *From the Museum to the Classroom: Archaeology and Heritage in 3D (Del Museo al Aula: Arqueología y Patrimonio en 3D)*, it was accepted in the 2022 Innova-Docencia call for proposals (No. 339) of the Complutense University of Madrid. This time, we have expanded the subject to Egypt, the Near East, Prehistory, Protohistory, and American Anthropology and Archaeology.

structure. Furthermore, the low cost of the printing process allows the production of more than one copy without notable additional costs.

2. Overview of photogrammetry in archaeology and education

This idea emerged from precedents in the scientific literature on the uses of photogrammetry in this field. By the 19th century photogrammetry was already contributing to the documentation of cultural elements (Albertz, 2007: 504–506; El-Brahim, 2016). The first example comes from K. F. Stolze, who used photogrammetry in 1874 in the excavations of Persepolis and the Mesdjid-e-Djumä mosque in Persia. He applied the image superposition technique using a stereoscopic camera. The foundation of the Royal Prussian Institute of Photogrammetry (*Königlich Preussische Meßbildanstalt*) in 1885 entailed the creation of an archive of monuments documented with photogrammetry to preserve them in case of a potential threat (Foramitti, 1976). As time went by, technological innovations related to the development of vectorised maps based on photogrammetry (El-Brahim, 2016) and the double projection and optical rectification of photography (Bervoets, 1969) laid the foundations for a new phase of photogrammetry (Marín-Buzón et al., 2021). In 1910, the International Society for Photogrammetry was founded. A few years later, in the proceedings of its first conference –held in Vienna– we can see the beginnings of the analogical system of photogrammetry. Other advances in both measurement cameras and stereometric analysis can be observed in the documentation of archaeological sites such as Stonehenge in 1907 (Capper, 1907: 571). However, this system became too complex and the invention of computers, which were better at making these calculations, gained more popularity (Sanjib, 1988; Karara, 1989). Due to the high level of specialisation needed in the creation process, photogrammetry was not included in the methodological practices of archaeological documentation until the Second World War. The destruction of a number of monuments, historic sites and artistic works during that conflict led to the drawing up of the *Venice Charter for the Conservation and Restoration of Monuments and Sites* in 1964 and its acceptance by the International Council on Monuments and Sites (ICOMOS). This was followed by the establishment of the International Committee of Architectural Photogrammetry (CIPA) in 1968.

Despite the use of photogrammetry as a documentation method in archaeology, due to its cost it did not play an important role in this field until the beginning of the digital era. However, since the end of the 20th century, digital photography has allowed the use of conventional cameras that are not as expensive as calibrated metrical cameras to undertake this sort of task (Gonizzi Barsanti, Remondino and Visintini, 2013: 146; Pérez et al., 2014: 108–124; Marín-Buzón et al., 2021: 2). Calibration was no longer a manual procedure, as software able to process all the data became available (Clement et al., 2012: 314–325; Clement et al., 2013: 75–81).

Today there are plenty of methodologies and tools available to document and virtualise our heritage.³ There are more uses than the mere “virtualisation” of sites (Gonizzi Barsanti, Remondino and Visintini, 2013; Galeazzi, 2016; Sapirstein and Murray, 2017). Bewley (2003) used digital photogrammetry from aerial orthophotos to build virtual models of sites and topographic surveys. With this development, archaeologists were able to examine with more accuracy the different structures of the Roman camp of Cawthorn (Bewley, 2003: 284). Similarly, but on a smaller scale, Bujakiewicz et al. (2006) suggested using virtualisation with photogrammetry to reconstruct, model or visualise archaeological artifacts for their dissemination in museums or interpretation centres. The Guidi and Remondino, (2012) applied new

techniques in photogrammetry to obtain more precise measurements of small 3D shapes in archaeological finds, offering better results than conventional drawings and standard photography.

In recent years, laser scanners have become increasingly popular for the documentation of archaeological sites and/or artifacts. In this respect, photogrammetry has led to a new phase in which we are able to develop a mesh that documents different features more accurately. Nevertheless, this technique lacks integrated high-definition cameras, which ultimately presents some issues in the interpretation of textures and colours (Fazio and Lo Brutto, 2020). Lo Brutto and Dardanelli (2017), as well as López-Martínez et al. (2019), have suggested a complementary use of high-definition cameras and 3D orthophotos to improve analyses on surfaces such as mosaics, frescoes, soils and decorated walls. Likewise, photogrammetry can be linked to Geographical Information Systems (GIS) to generate 3D models of structures and georeferenced sites, thus obtaining more possibilities to document and examine less accessible spaces (Kolbl et al., 2000: 446–452).

The diverse techniques available have led to new uses of photogrammetry in heritage conservation, reconstruction and dissemination (Tucci et al., 2017). Cerrillo-Cuenca and Sanjosé (2013: 43) used aerial photogrammetry for the analysis of prehistoric landscapes and the preservation of information in case the heritage suffered any kind of damage or alteration. A good example of this purpose can be seen in the archaeological site of Palmyra (Syria) after its partial destruction by DAESH (Denker, 2017), or in places where heritage can be affected by anthropic or natural elements, as in Itanos in Greece (Ercek et al., 2010) or the theatres of Byblos in the Lebanon (Younes et al., 2017) and Taormina in Italy (Gabellone et al., 2017). In the case of Ulaca (Spain), accessibility to the site is a major issue due to the orography; here, the 3D photogrammetric reconstruction can bring it to everybody, preserving and disseminating its most remarkable monuments (Maté-González et al., 2022, 2023; Rodríguez-Hernández et al., 2021, 2023).

Together with the “photogrammetric archaeology” techniques, teaching of the uses of photogrammetry have developed in recent years, although this technology for educational purpose is still scarce in Human Sciences, partly because many scholars tend to consider a 3D model just as an investigative tool (Kuroczyński et al., 2023). However, there are different approaches and examples that prove the value of this methodology. The virtualisation of heritage has made teaching easier when explaining sites and artifacts and has increased student interest in the subject. They are now able to better understand our archaeological, historical and artistic materials (Behan, 2008; Mota et al., 2009; McLean and Verneman, 2018; Tucci et al., 2020). Drap et al. (2007) used photogrammetric digitalisation of underwater archaeological sites for their classroom exhibition, given that, for obvious reasons, access to those locations is very difficult. Similarly, Ioannides et al. (2016) applied 3D modelling and photogrammetry to show UNESCO heritage monuments in the classroom. It is also possible, with more advanced technology, to create virtual realities (VR) as a pedagogical tool to present landmarks that students can “visit” (Dai, 2021; Cieri et al., 2021), such as the sanctuary of Delphi in ancient Greece (Liritzis et al., 2021). There have also been notable steps in the introduction of 3D modelling with archaeological materials in the classroom (Chapinal-Heras et al., 2023a) or, more specifically, as an activity within a complete excavation methodology for archaeology students (Derudas and Berggren, 2021).

Related to this, teaching-in-museum education is considered as a tool for developing students’ notions of historical temporality (Pinto, 2011, 2020; Santacana and Llonch, 2012; Santacana and Martinez, 2013; Chapinal-Heras et al., 2023b). The creation of this kind of collection is in fact linked to a former system of education in European and North American universities, in which replicas of artifacts have been made since the 19th century. At that time, plaster replicas of sculptures provided a useful teaching resource in a period when photography was in its infancy and only sketches were used for teaching in Archaeology and Art History. Here we should mention the excellent and impressive collection of glass flowers at the Harvard Museum of Natural History. There are

³ There are different instruments –digital cameras, 3D scanners, integrated total stations, drones, etc.– to apply photogrammetry in archaeological studies, depending on the needs of each specific case (Karara, 1989; Bujakiewicz et al., 2006; Remondino and El-Hakim, 2006).

also very interesting examples in Europe, such as the Museo dell'Arte Classica of the Sapienza Università di Roma (Barbanera, 1995) and the Gypsotheca at the University of Seville's Faculty of Philology (Beltrán Fortes and Méndez Rodríguez, 2005; Ruiz-de-Lacanal, 2018).

A project undertaken in Afghanistan by the Oriental Institute of Chicago University shows us how 3D technology can physically bring museums into the classroom. One of the activities of the aforementioned project has consisted of creating a 3D printed collection of the finds kept at the National Museum of Afghanistan, as well as visiting schools – focusing on those for women and girls – to teach them about their own heritage and past using those artifacts, among other resources (Stein, 2019). Another successful and useful approach is to print out fragments of vessels, display them in a simulated archaeological site, teach students how to excavate and guide them through the complex process of assembling the fragments to reconstruct the whole vessel (Montusiewicz et al., 2015). It is also possible to digitise and print archaeological sites or parts of them in 3D, as has been done with the Muslim tower of Cástulo in Spain (Arias et al., 2022). Learning about buildings and other large-scale structures can be easier if we use 3D techniques to decompose such structures and focus on specific architectural elements, as has been done with part of the heritage of Lublin, Poland (Montusiewicz et al., 2021); in fact, this project involved the creation of a board game based on a selection of the city's historic buildings, using playful materials to raise players' awareness of heritage (Montusiewicz and Milosz, 2021).

The potential of learning through 3D printed artifacts is even more evident in the case of impaired people, where the leading cognitive factor is touch, as demonstrated by a test conducted with a group of people with simulated pattern dysfunction and a blind person, who interacted with 3D printed materials produced through the decomposition of a minaret of the Ulugh Beg Madrasa in Samarkand (Montusiewicz et al., 2022). Another case study involved the use of a collection of 22 replicas of skulls of the major species in human evolution (Díaz-Navarro and Sánchez de la Parra-Pérez, 2023) or the creation of tactile replicas for the Piraeus Archaeological Museum (Kantaros et al., 2023).

In the working place of most of our team at the time of performing this project – Department of Prehistory, Ancient History and Archaeology at the Complutense University of Madrid – we have had the opportunity to deal with real archaeological artifacts from excavations in which different teachers have conducted fieldwork (Ulaca, Campo de Trigo and other small sites) (Maté-González et al., 2022; Rodríguez-Hernández et al., 2023). There used to be a collection of actual archaeological artifacts used for teaching about Cyprus (España-Chamorro and Varas Mazagatos, 2021) and other areas that had been donated to the National Archaeological Museum in Madrid. Currently, the only materials available are the “Numismatic Collection” and the “American Archaeology and Ethnology Museum”, both in the Faculty of Geography and History (San Andrés Moya, 2015), as well as some plaster copies, especially those from the historical plaster copies at the Faculty of Fine Arts (Terrón Manrique and Blanch González, 2015).

3. Materials and methods

The idea of the *Experimenting Digital Antiquity* Project was based on the aforementioned challenges: teaching with finds that can be touched and handled is infrequent, mainly because they are scarce and fragile. The use of originals or historical replicas requires extreme care, and the teacher must always keep an eye on the students to avoid any breakages. The original is irretrievable if broken and replicas made of the same material or even plaster are very expensive. Likewise, there is usually just a single piece of each kind, even when using replicas. This makes it difficult for all the students to have access to it simultaneously, especially in large classes. These challenges mean that the experience is not the same for all of them, which ultimately leads to a possible reluctance to carry out this type of practical teaching. How can we take advantage

of the digital technologies to teach about the importance of our heritage through a collection of antique artifacts? One answer is to create a collection of 3D replicas of them using photogrammetry.

The methodologies applied to university education in recent years have evolved towards the incorporation of new technologies in the classroom. The aim of this project was to physically involve students in “Digital Antiquity”, but with three secondary objectives: 1) to experience the real object before the process; 2) to acquire the basic knowledge for the creation of the 3D model; 3) to experiment with the artifact during the creation of the digital model and the final printed product. This is part of what we mean by teaching engagement; we expect both the teacher and the student to be an active part of the learning and knowledge construction process. It is a reciprocal relationship in which, in the case of our project, knowledge is built up through exercises that must include a significant digital load where these activities are performed physically.

The project requires the use of a number of materials for the different stages of the process of photogrammetry: for the photographic session, wooden rotatory disks on which to place the artifacts, cameras and mobile phones. It is worth mentioning that, although it is essential to have high-quality cameras for professional photogrammetry studies, the nature and scope of our activity make it feasible to undertake the task with mobile phones. Moreover, the quality of these devices is currently high enough to be able to take sufficiently accurate photos to create 3D models for teaching and other non-professional purposes. For the virtualisation of the finds, it was necessary to use personal computers and laptops with several programs, including Meshroom, Instant Meshes, Metashape and Blender. Ultimaker Cura was the preferred software for turning the 3D models into printable files. Finally, for this last step, the materials required were the 3D Printer –a Creality Ender 3– and PLA filament reels. In terms of human resources, we recruited thirty students from the History and History of Art degrees.

Although the project was selected in the 2021 Innova-Docencia call for proposals, it received no funding. For this reason, we decided to turn to the GoFundMe crowdfunding platform as a way of acquire the materials needed.⁴ These expenses were mainly for the 3D printing technology, i.e. the 3D printer and PLA filament. We used different social media to reach out to more people for funding. In this respect, we set up a Twitter account (@proyexperimental) to report on the progress made from the outset, that also proved useful for crowdfunding purposes. The successful campaign allowed us to raise 360€. With that amount, we bought a Creality Ender 3 3D printer, three PLA filament reels and four wooden rotatory disks.

We gained access to the archaeological and epigraphic artifacts thanks to a collaboration with two institutions: the Museo Arqueológico Nacional (National Archaeological Museum, hereinafter MAN)⁵ and the Real Academia de Bellas Artes de San Fernando (Royal Academy of Fine Arts of San Fernando, hereinafter RABASF). These partnerships afforded us not only the possibility of processing and 3D modelling some of their archaeological exhibits, but also allowed us to undertake the photogrammetry sessions in their facilities. It is time now to briefly explain the methodology used for the practical implementation of our project. Once this is done, the following section will delve into the specific development of each of the steps of the activity.

After two years without social relations and no practical teaching

⁴ <https://www.gofundme.com/es-es> [last entry on April 4, 2024]. The specific link of the campaign is https://www.gofundme.com/f/proyecto-experimenta-la-antiguedad-digital?utm_campaign=p_cf+share-flow-1& [last entry on April 4, 2024].

⁵ Department of Greek and Roman Antiquities (Chief Curator Ángeles Castellano Hernández and Curator Margarita Moreno Conde), Department of Protohistory and Colonisations (Chief Curator Alicia Rodero Ríaza, Curator Susana de Luis Mariño and Technician Esperanza Manso Martín) and Department of Documentation (Felipa Díaz).

such as excursions or field trips due to the pandemic, the undergraduates requested a return to face-to-face activities. This included museums, but the number of attendees was very limited due to the rules derived from the health situation. With this in mind and aiming to promote the use of digital technologies to achieve a closer approach to our heritage, we decided to bring the museum to the classroom.

Once the idea had been developed, cooperation agreements with the institutions confirmed and the project selected, we were able to start work at the beginning of September 2021. The following months were focused on recruiting volunteers among the students and training them in the photogrammetry of small and medium-sized artifacts, as well as 3D modelling. The software used was Agisoft Metashape and Blender. We initially expected to use Meshroom, Instant Meshes and Blender, all license-free programs. However, the tests performed before proceeding to train the students showed that Meshroom required personal computers or laptops with a 32 GB RAM Memory and a NVIDIA GeForce GTX 1070 GPU, among other aspects. Such advanced computers are expensive for a non-professional context and very few students had them. For this reason, we decided to use Agisoft Metashape, which is less demanding in terms of computer resources – 16 to 32 GB RAM Memory and NVIDIA or AMD GPU with 1024+ unified shaders GPU. Owing to the fact that our funding was very limited, we could not afford student licenses and we had to take advantage of the 30-day trial version. When needed, Blender was used to correct minor details in the 3D models.

In parallel, we chose the archaeological finds and proceeded to prepare the documentation for permission to work with them. With the permits in hand, we arranged the photogrammetry sessions at each institution and the students undertook their tasks. The museums visits also made it possible to give a new life to the finds beyond their traditional ambience in order to intervene in heritage and – as suggested by Riegl – give them a contemporary value. The students prepared the 3D models at home and sent them to us. Then, using the Ultimaker Cura software, the 3D figures were adapted to the printing parameters required for our Creality Ender 3. We ended up printing a total of 21 items⁶ and rounded off the project with an exhibition of the collection at the Faculty of Geography and History of the Complutense University of Madrid. The entire process entailed numerous benefits for both students and teachers. Table 1 lists those we consider most relevant.

4. Calculation

It is now time to further describe how the project was developed and resulted in 21 smaller 3D replicas from the Graeco-Roman world and the colonial-period Iberian Peninsula. Firstly, it was necessary to form the team of personnel from the university who would work on it. As this activity offers a highly interdisciplinary approach, the team would also show this diversity by engaging with people from different backgrounds,

⁶ From originals preserved at the MAN: 1) Appliqué with female head shape (34886), 2) marble bust (37912), 3) female bust (2776), 4) Centaur of Royos (18536), 5) ceramic pot (1986/46/40), 6) ceramic jar (1986/46/40), 7) lamp (1923/60/740), 8) dagger (10490), 9) bull (1981/109/1), 10) figurine of Nike (32637), 11) funerary inscription 1 (38336), 12) funerary inscription 2 (38338). At the RABASF (all of busts from the cast collection of the Villa of the Papyri in Herculaneum): 13) Archidamus (V-139), 14) Demetrius I Poliorcetes (V-838), 15) Philaetorus of Pergamon (V-138), 16) Heracles or an athlete, by Polycleus (V-113), 17) herma of Dionisos (V-153), 18) Greek man of letters (V-082), 19) Ptolemy II (V-148), 20) Terentius (V-085), 21) Zeus/Iuppiter Ammon (V-141).

primarily Ancient History, Archaeology or Art History.⁷ Together we prepared and submitted the application for the 2021 Innova-Docencia call for proposals.⁸ Three months later, the final decision was published and we were one of the approved projects.⁹ Although no funding was provided, through the aforementioned GoFundMe crowdfunding we were able to collect enough money – 360€ – to purchase the required materials: a Creality Ender 3 3D printer, three PLA filament reels and four wooden rotatory disks.

The project officially began in September 2021. During that month, we began to look for students willing to take part in the activity. Since some of the team members taught courses in History and History of Art degrees, we made an open call in those classes for anybody who was interested. In this way, a group of thirty students joined the project. Most of them came from Art History studies, although there were also some from the History degree.

The following phase consisted of training in the entire process of photogrammetry, i.e. to take accurate photographs and prepare 3D models with them. The training was organised in two steps, first with the project members who had no expertise in this field, and afterwards with the students (Figs. 1 and 2). In both cases, the members in charge of the training sessions were C. Díaz-Sánchez and M. E. Rey-Álvarez Zafiria. We used plaster replicas available from the Department of Prehistory, Ancient History and Archaeology of the Faculty of Geography and History. Students had to take among 40 to 80 photographs of the artifacts, in JPEG format. The same parameters were followed in the subsequent sessions in the museums. For the 3D modelling, as explained above, the software employed was finally Agisoft Metashape and, for minor modifications, Blender. In order to ensure that the training could be remembered, we prepared video tutorials for the students to refer to when they had any doubts.

Simultaneously, we worked on the selection of artifacts from the collaborating institutions and the applications for the permits to undertake the photogrammetry. Initially, the students were given the option of choosing the figure they preferred.¹⁰ This increased their engagement with the activity, as they were able to choose the finds they considered most appealed to their personal interests. In this respect, the main advantage was that we could quickly send the institutions the list of pieces chosen. As some of the students were less familiar with archaeological practice, a factor that could have conditioned their choice, the project members provided some assistance, with the additional aim of obtaining a varied selection of artifacts. Nevertheless, there were eventual setbacks that slightly altered this procedure. On the one hand, some of the items from the MAN were too fragile and the risk of damage was too great. Therefore, the staff at that institution selected other more manageable artifacts that were in some way related to the originals. On the other hand, at the RABASF it was necessary to restrict the materials to the Cast Collection from the Villa of the Papyri in Herculaneum, i.e. busts of important Greek, Hellenistic and Roman individuals. In general, the materials chosen were small and medium-sized, none of them exceeding 50 cm in height, width or depth.

⁷ At that time, most of the members were affiliated to Complutense University of Madrid. Listed in alphabetic order: D. Chapinal-Heras (PI; currently at the Universidad Autónoma de Madrid), C. Díaz-Sánchez, S. España-Chamorro (currently at Sapienza Università di Roma), J. García-Sánchez, N. Gómez García, M. Parada López de Corselas (previously, at Valladolid University; currently at the Complutense University of Madrid), L. Pagola-Sánchez, M. E. Rey-Álvarez Zafiria and R. Yáñez Jato.

⁸ <https://www.ucm.es/proyectos-de-innovacion-2021-2022> [last entry on April 4, 2024]. Call opened on 16 March 2021.

⁹ The provisional decision was published on 16 June 2021; the final one on 23 July 2021.

¹⁰ <http://ceres.mcu.es/pages/SimpleSearch?index=true> [last entry on March 9, 2024]. In the case of the RABASF, the absence of a complete on-line catalogue, with both materials in exhibitions and in the collections that are not open to the public, we agreed to choose the artifacts during an in-person visit.

Table 1Main benefits of the *Experimenting Digital Antiquity* Project.

Socialising in academic environments after two years of digital relationships
Experimenting with original archaeological artifacts
A real engagement with the content of some university subjects
Acquisition of new digital skills linked to the photogrammetry of artifacts
Closer contact with the 3D model and the printed version
Sharing the outputs in social media
Providing a collection of archaeological materials for the Department of Prehistory, Ancient History and Archaeology at the Complutense University of Madrid

**Fig. 1.** Training in photogrammetry. Photography session.

Next we provided the students with a worksheet so they could note specific data about their artifact. This worksheet included the following points: author of the document, typology, material/medium, technique, dimensions, date, place, current location, inventory number, historical information, cultural context, description, bibliography and, finally, a blank space for a picture of the piece. This thorough list aimed to help the students acquire knowledge of how to catalogue archaeological material and obtain in-depth information on the background of the piece of their choosing.

Once the students had been trained in the complete process of photogrammetry and we had been granted the permits to work in the collaborating institutions, it was possible to proceed to one of the most crucial steps in the project. In photogrammetry, taking accurate photographs is very important. If the pictures are not of suitable quality (some details not properly included, shadows, poor illumination, etc.), it is very difficult to prepare a good-quality 3D model. With this in mind, we coordinated the students to attend the museums on specific days. The first sessions took place at the RABASF (Fig. 3), followed by the MAN, as the permits for the latter arrived a little later. The artifacts were placed on wooden rotatory disks. Since the light was deficient and we did not have special tools to correct it, we applied an alternative mechanism:

other students would illuminate the specific area of the artifact that was being photographed with the torch function of their mobile phones. At each session there was always at least one member of the project responsible for resolving any situations that may arise. Students had to take between 40 and 80 images, enough to produce 3D models for printing. The required formats of these archives were .obj and .stl. The latter is particularly important because it is the one that 3D printing software can recognise.

The last stage of the process dealt with the 3D printing. The program used for this purpose was the free software Ultimaker Cura, which allows the setting of the specific parameters of the 3D printer, in our case the Creality Ender 3 (Fig. 4). With this application, which generates a .gcode archive, the format required for 3D printing, we were also able to adjust the size of the figure, its scale position on the printing bed, and the infill, e.g. whether it is almost totally empty inside or whether one of the various infill modes was preferable. Depending on these aspects, the required time and material – PLA filament in our case – is more or less. Typically, 3D printed objects have ranged in size from 8 to 16 cm in height and width. In some cases, the dimensions are exactly the same as the original artifact, but in most cases the result has been scaled materials. The chosen sizes took between 2 and 7 h to print. In order to reduce



Fig. 2. Training in photogrammetry. Software session.



Fig. 3. Photography session at RABASF.

the time and the amount of filament used, we chose to design the parts with a hollow interior by selecting the “Lightning” option in the “Filling” section of the printing parameters. Afterwards, the printing task was undertaken by the PI, Diego Chapinal-Heras, as the activity requires the 3D printer to always be in a fixed location and therefore must be undertaken by someone who can have frequent access to it (Fig. 5).

Finally, by means of an exhibition we attempted to disseminate the project in our university community, primarily at the Faculty of Geography and History (Fig. 6). This exhibition lasted one month, from late September to late October 2022. The event allowed the team to explain the main goals of the project and how they were achieved. Furthermore, as a way of thanking them for their involvement and motivation, the students who participated and therefore contributed to adding figures to the collection received a small replica of their pieces. Our donors in the crowdfunding campaign also received a figure of their choice.

5. Results and discussion

Experimenting with ancient artifacts and a real mediation with material culture have been defined as “the basic principles of analysing an artifact” (Andreotti 1993, 21). Archaeological and heritage is a cultural product with a great deal of information that cannot be perceived from a simple picture of a single moment. Experiencing archaeology through material culture needs time to learn about and interpret the practical and social functions of the items (Pinto 2020, 136). This helps us to understand the context, condition, purpose and technology. That is the real purpose of the project to create 3D models of archaeological finds. In this respect, the activity has been successful. We never intended to create an immense collection of life-size pieces. Our purpose was to complete a virtual printed collection of educational material to use as a powerful teaching and learning tool, not only taking advantage of the final product, but also engaging students in the creation process. The

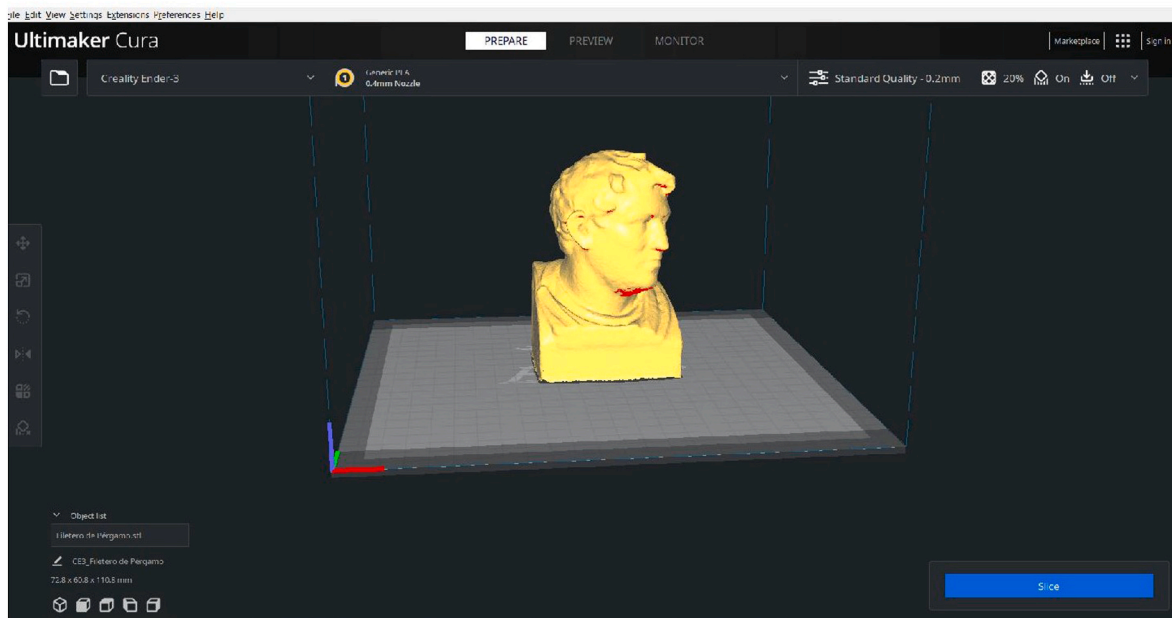


Fig. 4. 3D model of Philetaerus of Pergamon (RABASF) in Ultimaker Cura.

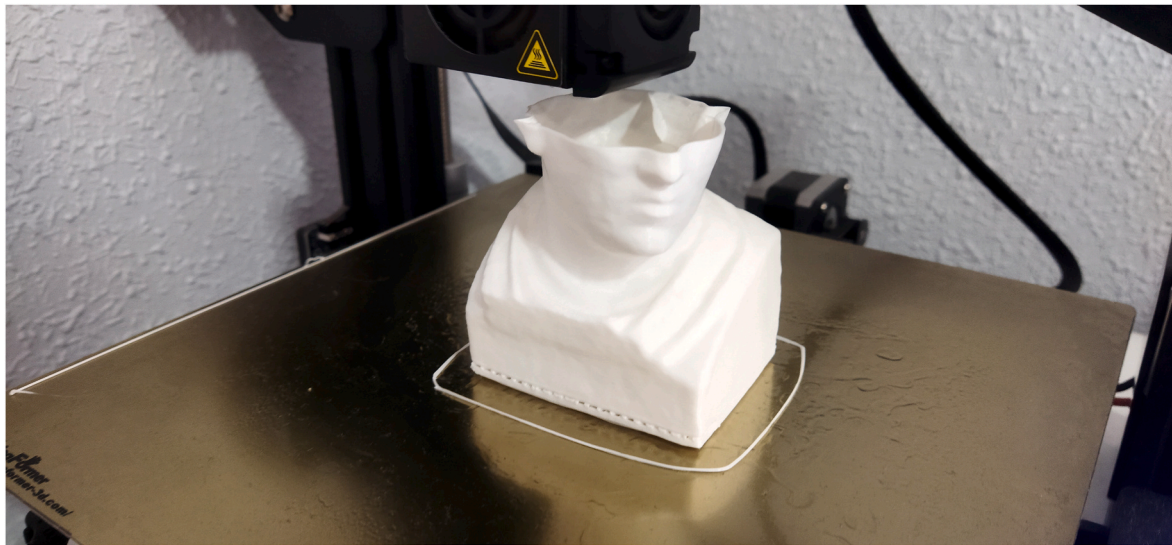


Fig. 5. Printing a smaller replica of Philetaerus of Pergamon.

results, therefore, have been enormously satisfactory. The Department of Prehistory, Ancient History and Archaeology now has a collection of 21 artifacts, with smaller size than the originals in most of the cases, and both groups of professors and students have benefited from holistic training based on the materiality, digital processing and reproduction of the studied artifacts.

Digital Humanities are gradually becoming more popular and are proving to what extent they are useful for the preservation of our heritage. One question emerges here: if their application in research is a growing trend, should not we do the same in the field of teaching? The *Experimenting Digital Antiquity* Project attempts to contribute to this issue. The use of originals and replicas is well known. However, by creating a circular system that allows us to easily create new materials for teaching and, at the same time, train our own students in skills that will probably be very useful in their future careers, we are transforming university teaching. This is just a first step in this relatively new field. Its potential is enormous. It ranges from the expansion of the collection to

the material culture of different civilisations and territories to the development of new methodologies.

6. Conclusions

Undertaking this project has attempted to demonstrate how the 3D virtualisation of archaeological objects has various benefits for both students and professors. On the one hand, the acquired methodological training in both photogrammetry and 3D printing, which is not a common practice in the regulated studies of History, Archaeology or Art History. The promotion of these digital skills in Human Science degrees is an incentive in their educational and professional curriculum related to the fields of Archaeology and Heritage, as there is a tendency to generate virtual documentation for the safeguarding or exhibition and dissemination of archaeological sites and artifacts. Likewise, the contact with actual archaeological finds, obtained thanks to the project's collaborating institutions, can increase the students' interest in them



Fig. 6. Exhibition of the collection.

and their cultures. This kind of active training proved to be very positive as some final year students decided to continue their studies with MAS focusing on the virtualisation of archaeological heritage.

On the other hand, the teachers acquired a collection of archaeological and artistic replicas for use in the classroom. This contributes to delivering more dynamic explanations and obtaining greater attention from the students. There is no need to take excessive care with the pieces, as the replicas are easily replaceable. Furthermore, implementing virtualisation and subsequent 3D printing as an educational resource makes it possible to break down some of the physical barriers for students with visual challenges. They can now touch what they are studying, allowing them to better understand and assimilate the knowledge presented in the classroom. Therefore, we consider the development of the *Experimenting Digital Antiquity* Project can go beyond the current limited and somewhat rigid methodology for teaching archaeological subjects in Spanish universities. It can open up a new approach, offering the forms of virtualisation as an alternative to traditional studies in the Human Sciences.

CRedit authorship contribution statement

Diego Chapinal-Heras: Writing – original draft, Writing – review & editing. **Díaz-Sánchez Carlos:** Writing – original draft. **Gómez-García Natalia:** Writing – original draft. **España-Chamorro Sergio:** Writing – original draft. **Pagola-Sánchez Lucía:** Writing – original draft. **Parada López de Corselas Manuel:** Writing – original draft. **Rey-Álvarez Zafiria Manuel Elías:** Writing – original draft.

Declaration of competing interest

The authors declare the following financial interests/personal

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