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PROTOTYPING AN EGYPTIAN REVIVAL. LASER SCANNING, 3D PRINTS AND SCULPTURE TO SUPPORT THE ECHOES OF EGYPT EXHIBITION

1. Introduction and aims

The exhibition *Echoes of Egypt: Conjuring the Land of Pharaohs*, which was on display at the Yale Peabody Museum of Natural History in New Haven, CT (USA) from April 2013 to January 2014, also served as the basis for a fully online collection of objects that narrate our three thousand year obsession with ancient Egypt (http://echoesofegypt.peabody.yale.edu/). Exploring its different sections, the website provides a wide range of examples through which the legacy of Egyptian culture impacted the art, architecture, and literature of later civilizations. Hieroglyphs, Mummy-Mania and Egyptosophy are three themes within the exhibition that complement the section "Looking through the Pylon", a chronological overview of "Egyptomania" through the ages. From mummification rituals, artefacts and architecture to cinematographic revival, the website offers a permanent repository that is important not only because it allows an easy access to the information but also because it preserves the identity of the exhibition, a significant achievement with installation. The purpose of the present article is to supplement what is available online, describing in a more detailed manner what would otherwise remain hidden among the preparatory stages of all those activities necessary to realize the results that are eventually displayed for the public. In our opinion, this justifies choosing an older project to highlight some technical aspects that deserve a more in depth treatment especially because this project involved technologies that are still relevant and exist in a developmental stage. Therefore, this article can be a further example of the potential of 3D scanning and printing in museum exhibits.

While "Egyptomania" is rarely identified in medieval art, a sphinx of Paschalis Romanus is one of the best examples of Egyptian revival art during the European Middle Ages[1]. The original sphinx, located at the Museo Civico of Viterbo (Italy)[2] was thus an ideal fit for *Echoes of Egypt*, but its size and the expense of transport precluded shipping the statue from Italy to the United States. With 3D scanning and printing, however, we were able to include the

[1] The 3D model is available on https://echoesofegypt.peabody.yale.edu/overview/sphinx.

[2] We would like to thank the Director of the Museum, Orsola Grassi, for her collaboration and logistic support.

sphinx sculpture in the exhibit, placing the object within the larger context of Egyptian revivals, including a fascinating juxtaposition with a medieval Arabic manuscript that includes an early attempt to translate hieroglyphs: Bibliothèque Nationale de France MS Arabe 6805, Ibn Wahshiyya (ca. 860-935 CE), *Book of the Long-Desired Fulfilled Knowledge of Occult Alphabets*[3].

2. 3D printing and Cultural Heritage

The techniques of 3D printing satisfy many needs within the field of cultural heritage, including specific areas such as conservation, restoration, and exhibitions, both commercial and educational. Shipping an artefact, especially if unique, is always problematic due to security procedures, costs and bureaucratic issues. Moving an object from its storage location entails a risk, and conservators seek to limit, as much as possible, physical contact with the object. Accidents are unfortunately possible causes of partial and complete damage of museum objects. The example of the Canova panel "The Killing of Priamus", destroyed while moved for a temporary exhibition in Assisi (Italy), is a famous example among the many recorded by the media and available online (Table 1). From this perspective, digital-based 3D prints can be very helpful in allowing the creation of customized cases by printing the negative volume of the scanned object using appropriate materials (Scopigno *et al.* 2015).

Subject	**Reference**
San Bernardo Anonymous (sculpture - XIV century): damaged during the setting up of "Benedictus Pater Europae" exhibition in 1981.	Roger Marijnissen, *Laissez-nous le Bruegel!* «Museum International» (Edition Française), 38, 4, 249-252, 2009.
La Danse Henri Matisse (painting): damaged during transportation in 1993.	Leonard W. Boasberg, *Matisse in Barnes Tour is damaged, Court told an expert testifying for opponents of the Tour couldn't say When Harm Occurred*, «The Inquirer», December 30, 1993.
Le Tre Grazie Antonio Canova (sculpture): damaged during transportation in 1994.	*Crack Found in Famed "Three Graces"*, «Associated Press», March 6th, 1998.
Irish miniature Book of Kells (XIV century): the manuscript was damaged during transportation in 2000.	*Book of Kells is damaged*, «The Guardian», April 15th, 2000.
Slavers throwing overboard the dead and dying - Typhoon coming on Joseph Mallord William Turner (painting): damaged on the way back from a temporary exhibition in 2003.	Dalya Alberge and Jack Malvern, *Masterpiece by Turner damaged on loan to Tate*, «The Times», October 28th, 2003.

[3] See the essay about Ibn Wahshiyya by Isabel Toral-Niehoff in http://echoesofegypt.peabody.yale.edu/hieroglyphs/kitab-shauq-al-mustaham-fi-ma-irfat-rumuz-al-aqlam-long-desired-fulfilled-knowledge.

Subject	Reference
Madonna dei Pellegrini Michelangelo Merisi da Caravaggio (painting): damaged during the "Caravaggio e l'Europa" exhibition in 2006.	Renata Mambelli, *Caravaggio torna sfregiato da Milano*, «La Repubblica», February 20th, 2006.
Marzia Domenico Beccafumi (painting): heavily damaged during the dismantling of the "Reinassance: art for a city" exhibition in Siena in 2008.	Martin Bailey, *National Gallery drops Renaissance painting, splitting it in two*, «The Art Newspaper», June 1st, 2008.
When it starts dripping from the ceiling Martin Kippenberger (art installation): damaged during cleaning in 2011.	Helen Pidd, *Overzealous cleaner ruins £690,000 artwork that she thought was dirty*, «The Guardian», November 3rd, 2011.
Pintura sobre fondo blanco para la celda de un solitario. Joan Mirò (painting): damaged by a man that fell on it in 2011.	Martin Bailey, *Miró on loan damaged at Tate Modern*, «The Art Newspaper», January 8th, 2013.
Impronta Luciano Fabro (sculpture): destroyed during an exhibition in 2013.	*Crash! E l'Impronta di Luciano Fabro va in frantumi. Accident at the opening of the exhibition "Meno Uno" in Lugano (Italy). Il colpevole? Uno sbadato giornalista*, «Exibart», September 8th, 2013.

Table 1 – Selection among well-known cases of accidents.

The use of 3D printers for restoration and preservation has provided promising results and is growing quickly, even though the field itself is still developing. Thanks to a new generation of printing devices that can use a mixture of synthetic and natural material, it is possible to prototype *ad hoc* those parts that could be used to integrate missing or broken areas of artifacts or architectural components (Antlej *et al.* 2011; Bigliardi *et al.* 2015).

Museums are increasingly utilizing 3D printing technology, not only for exhibition-related purposes, but also to create new modes of interaction between the public and collections, also through the Internet. Two of the most spectacular examples of this new synergy are projects developed by the Smithsonian Institution and the British Museum that allow files to be downloaded for personal 3D printing of replicas from an available online selection of artefacts (https://3d.si.edu/).

The increasing affordability of 3D printing is having an equally beneficial effect on business and educational institutions. Private individuals can now buy 3D printers for home use or access online services that will print a file for a reasonable price. This trend is visible also inside of universities and other research-related institutions, such as services that enable students to develop and print their own projects, not necessarily related to Cultural Heritage[4]. Also from a medical perspective, 3D printing enables individuals with low vision to appreciate an "objet d'art" (Jafri *et al.* 2015); several museums

[4] http://digitalmedia.architecture.yale.edu/printingplotting/3d-printing-farm.

and associations are working in this direction, offering touchable replicas that allow a person with vision deficits to experience the idea of the original object (Neumüller *et al.* 2014; Stanco *et al.* 2017). Using similar techniques, such projects are also becoming possible for bi-dimensional objects, such as paintings and photographs (Reichinger *et al.* 2011, 2012).

The benefits of 3D printing are also positively impacting research in archaeology and the development of a wide group of related studies. Almost any type of artefacts, damaged or intact, can be recorded in 3D and processed through specific software to produce printable versions that can be used to fulfill several research needs. Digital restoration methods based on computer graphics allow the reconstruction of broken objects in their original shape and their printing in 3D for scientific, educational or marketing purposes (Antlej *et al.* 2011; Stanco *et al.* 2017)[5]. Its application to ceramics is well documented and usually incorporates more affordable solutions (Barreau *et al.* 2014). By using data coming from other types of sources such as texts, drawings, images or negative supports (molds or casts), it is also possible to formulate reconstructive hypotheses and so, create prototypes that can offer a more realistic experience with the objects (Scopigno *et al.* 2011, 51).

In an Iron Age site in Scotland, the UHI Archaeology Institute recreated jewelry through the reconstruction of the molds found onsite[6]. Last generation devices can print different materials and colors (Chen *et al.* 2016)[7] allowing the production of faithful replicas, either in real or scaled dimensions, that are not secondary if we think about preservation of the original artefacts. It is understandable that this is having success as means to spread knowledge within museums, archives and other institutes (Di Giuseppantonio Di Franco *et al.* 2015). Some excavation projects are digitizing everything that comes out of the stratigraphy, layers, structures and artefacts that are also printed in 3D (Forte 2014). Thanks to the experimentation in different fields, i.e. medical and engineering, the application of 3D printing technology to the study of human and animal remains is well documented. Scientists from the National Museum in Rio (Brazil) were able to print body parts of Egyptian mummies using non-invasive recording techniques based on CT and X-ray scans, in order to preserve the mummified state of the original (McKnight *et al.* 2015)[8]. In another case, a burial discovered

[5] See also https://www.wired.com/2012/12/harvard-3d-printing-archaelogy.

[6] http://www.bbc.com/news/uk-scotland-north-east-orkney-shetland-37481840.

[7] See also http://sustainablearchaeologyuwo.blogspot.com/2014/03/3d-printing-testing-size-and-colour.html.

[8] Another example is available on https://www.3ders.org/articles/20160822-face-of-ancient-egyptian-mummy-recreated-through-3d-printing.html.

in Virginia and documented by CT-scanning was printed in 3D, revealing the bodies of four men buried during the XVII century[9].

Architecture and sculpture in archaeology, pertinent to the case study that we are presenting in this paper, are often very connected and 3D printing is providing significant support for study in these fields. The popular 1:3 scaled replica of the Palmyra Arch made by the Institute of Digital Archaeology (IDA) and funded by the Dubai Future Foundation (https://3dprint.com/192138/3d-printed-palmyra-arch-award) is a perfect example that shows how 3D printing can help the restoration and reproduction of ancient architecture that are in areas under threat. In addition to this case study, others demonstrate similar uses of 3D prints to restore ancient buildings, sculptural elements and decorations. Often sculptures and decorative components reach us with partial or total losses that now, thanks to the application of these technologies, can be reintegrated or reconstructed (Zhou *et al.* 2016; Xu *et al.* 2017). The Cathedral of Cologne in Germany is a good example of restoration of sculptural elements using 3D scanning/printing. The goal of the project was to produce replicas of the sculptures of the Michael portal, which were printed in PMMA material (polymethyl methacrylate), which reproduces the appearance of the sandstone in the sculpture. Upon completion, similarly to what we did with the Paschalis Romanus sphinx, these copies were sent to be cleaned, and the surface impregnated with epoxy resin[10]. The virtual reconstruction of the East pediment of the Greek temple of Zeus at Olympia (Patay-Horváth 2011, 242; Scopigno 2013) demonstrates how challenging it can be to create hypotheses when so much of the original is not extant. Such reconstructions must involve all available source material, such as historical documents, which then bring in a host of additional interpretive issues (Stanco *et al.* 2017). Taken as a whole the benefits of 3D technologies for restoration purposes are obvious, and represent a viable alternative to traditional casting techniques (Di Paola *et al.* 2017, 178). The interesting work done on the colossal statue of Zeus Enthroned, conserved at the Archaeological Museum "A. Salinas" in Palermo (Italy), is another example that offers a clear overview of these advantages, especially focusing on those that relate to conservation and communication matters (Di Paola *et al.* 2017, 182-183). The projects mentioned in this paper are only few among the many that have been undertaken around the world, but provide another example that demonstrates how 3D scanning and 3D printing continue to be effective methods for the promotion of Cultural Heritage.

[9] Available on https://3dprint.com/93342/3d-scan-jamestown-graves.

[10] See https://www.voxeljet.com/unternehmen/news/3d-druck-in-der-denkmalpflege/ and https://alunar3d.wordpress.com/2017/06/08/the-application-and-development-of-3d-printing-in-architecture-have-changed-peoples-life/.

3. The artefact

The marble statue represents a human-headed lion bodied creature, bearing an inscription stating its artist (Paschalis Romanus) and the date of its creation in 1286 (Fig. 1). Romanus belonged to the school of Thirteenth century artists known as the *Cosmati*, whose interest in antiquity presaged the later Italian Renaissance; renowned for their inlaid colored marble floors, several other lions and sphinxes derived from Egyptian prototypes belong to the Cosmatesque school (Curran 2007, 45-47; Lo Sardo 2008, 137-41). While the combination of human and leonine features certainly derives from an ancient Egyptian sphinx (or a Roman copy thereof), the exact inspiration of Romanus' work remains unknown – medieval features are imposed upon the earlier template: the turned head transforming a frontal pose; the human hair filling the place of a *nemes*-headdress; the fully carved underside (including the testicles) of the leonine body differing from the filled negative space of Egyptian sphinxes[11].

The statue, which measures 84×54×23 cm, belonged to a larger monument that was part of the tomb of Pietro Vico, an important *Praefectus Romae* during the Thirteenth century. Originally located in the church of Santa Maria in Gradi in the city of Viterbo (Italy), Romanus' sphinx is now one of the most important pieces to survive the destruction of the Second World War.

3.1 *Digital acquisition*

Our first step was a preliminary study of the object and its environment to define the best workflow to follow (timing, equipment, operators, software and logistics). Paschalis Romanus' sphinx stood on a wooden base centered in its assigned room. With the permission of the museum, we set up a temporary work station and agreed to terms and condition to ensure the safety of the statue and the occupancy of the room during visiting hours. Through a technical evaluation of the morphometric characters of the sphinx, we defined the strategy of acquisition.

We employed a scanning technology based on a Multi Triangulation Laser (MTL) using a low cost device called NextEngine. We recorded the entire surface of the object by shooting a series of laser strips after a prior calibration of the array. We could move around the statue in a safe way holding the scanner on a solid tripod and using a swivel head to facilitate the positioning of the scanner in the right angle facing the sphinx. Each stationary point was selected according to the desired details and the

[11] http://echoesofegypt.peabody.yale.edu/overview/sphinx.

Fig. 1 – Pasquale Romanus Sphinx exhibited in the Museo Civico of Viterbo.

geometry of the areas (Fig. 2). The acquisition process was continuously monitored though a laptop connected to the scanner that was operated using the dedicated software Scan Studio, which can record simultaneously metric data (point clouds) and graphic data (images) due to its sensor and the 3 Megapixel integrated cameras. At the end of each scanning session the RAW data was transferred to another laptop to perform a first alignment in order to check the quality of the acquired data. Using Rapidform XOR_2, a specific software for reverse-engineering, it was possible to align all the scans afterward obtaining a single points cloud (Fig. 3).

Keeping 50-60% of overlapping area among the scans, we increased the control to ensure a high quality alignment, especially important to solve complicated geometries, undercuts and small cracks. The smooth surface of the sphinx's body gives way to more complex and detailed surfaced in the head and legs, which necessitated a different technical approach for the acquisition of data in those areas. In order to record properly the lightly sculpted details of the face, those thinner and dense in the braid and inscription incised in the base, we used a higher scan resolution. The inner part of the back legs was not easily reachable by the laser array and a few small spots could not be recorded and needed to be patched digitally afterward. Even in the smooth areas of the body, the reflection from the stone created problems in the reconstruction of the geometry. In each case, we had to remain flexible in the recording of each portion of the statue, so as to avoid loss of information.

Fig. 2 – The Next Engine scanner during an over-hanged shooting to capture the top of the statue.

The whole acquisition stage lasted 16 hours (two working days). To cover the entire surface of the sphinx 124 scans were needed: 110 of them were taken in wide mode (range: 34.29×25.65 cm) and the other 14 were done in macro mode (range: 12.95×9.65 cm) to produce a high resolution model of the inscription on the base of the statue. The distance between the scanner and the statue ranged from 45-50 cm for the wide mode to 12 cm for the macro mode (Fig. 4). We did not record the entire statue in macro mode because it

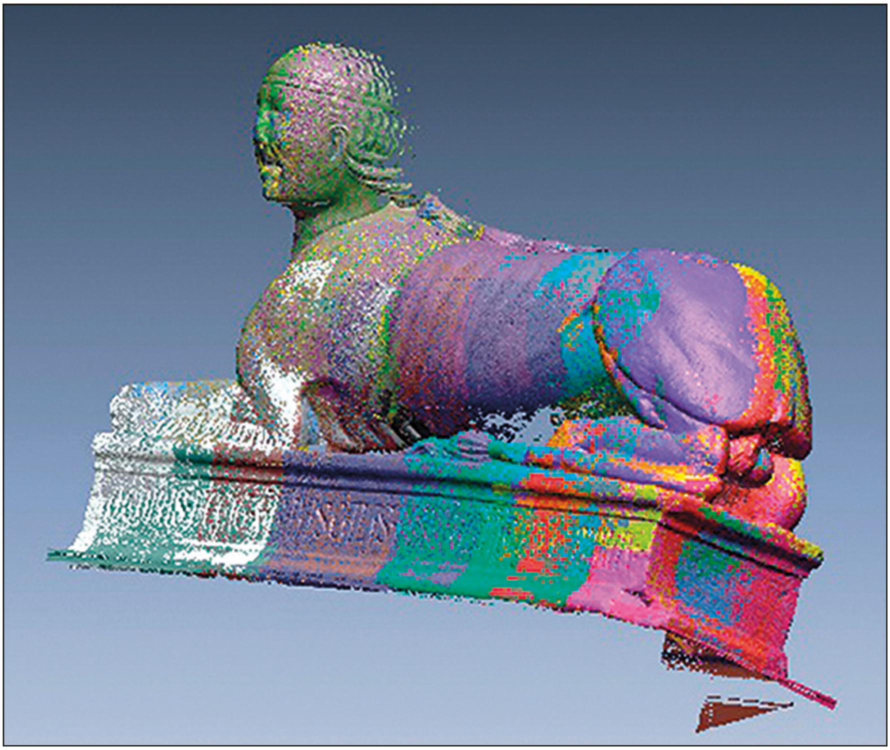

Fig. 3 – The series of scanned areas of the Sphinx aligned (colors are used to denote different areas).

would have enormously increased the file size making its management in the post-processing slow and complicated, including the preparation of the .STL file for the printing. Involving different resolution clouds instead turned out to be a good compromise to acquire a reliable and faithful model.

Generally low light worked better than a bright environment, which became apparent when we compared the quality of the dense point clouds produced by keeping the windows closed, which showed less gaps and noise. Another issue that we had to consider was the reflection of the marble since the polished-like finishing could create flickers and depth errors caused by erroneous behavior of the laser array. In addition to the laser scanning we also photographed the sphinx with a digital camera in order to help the artist of the Peabody Museum to recreate the marble color and texture in the finishing stage (see *infra* § 4). Our experience with the Paschalis Romanus sphinx suggests that the use of flexible scan-settings and strategy may help to optimize the workflow, positively influencing time and efforts/costs.

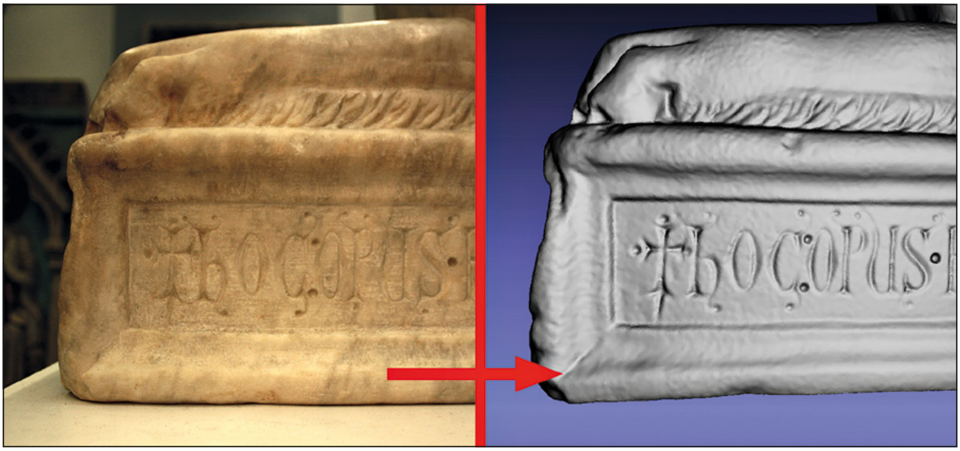

Fig. 4 – Detail showing part of the inscription on the front side and the related 3D geometry (mesh) created by scanning in Macro Mode.

3.2 *Post processing*

Once the acquisition was complete and all of the scans were verified, it was possible to leave the museum. Later on, back at the lab, we post-processed the data to produce the specific file for the Yale School of Architecture to be printed. First of all, we loaded the pre-aligned file into Rapidform XOR_2 to create the geometries (mesh) from the point cloud. Initially we performed a manual cleaning of non-relevant points recorded erroneously by the laser, to avoid mismatches during the calculation of the mesh. In addition to this, we lightened the file by running a specific algorithm that deleted redundant points without affecting the quality of the model. In this way it was possible to calculate the mesh operating in manual mode (without automatic filters) to avoid any loss of information.

Afterward, another specific process was necessary to prepare the model to be accepted by the 3D printer operational software, according to the specifications previously communicated by the School of Architecture. A careful screening was performed to find and correct any possible error such as gaps or misinterpretations of the geometry. Using the Fill Holes tool we closed all small holes and restored other missing features along the surface so that none of the triangles of the mesh were left empty. It was also necessary to remove carefully all the non-manifold edges corresponding to those edges that were not adjoining with any triangle (Fig. 5). Holes being closed and absence of non-manifold edges are the two main conditions that must work to consider a 3D model as “printable”.

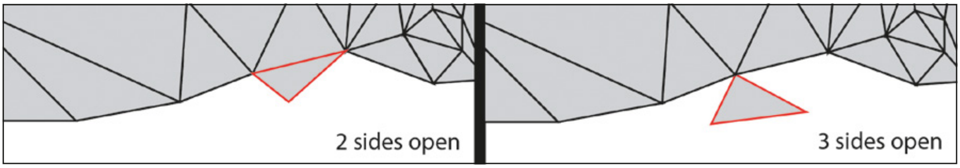

Fig. 5 – Part of the mesh during the non-manifold edges cleaning showing two types of non-adjoining edges.

Working mainly in a manual mode, it was possible to heavily reduce the manipulation of the surface in order to keep the mesh as faithful as possible to the original sphinx.

3.3 *The 3D printing*

When ready, the model was exported in .STL (stereolithographic) that is a common sharing file format widely used for those objects that do not need colors or texture information to be printed. Alternatively, .OBJ and .PLY formats are the most used to reproduce colors and textures by 3D color printers. The printing process was entirely operated by the Yale School of Architecture[12]. We first discussed the best material to create a consistent and detailed project that was within our budget. Neutral white colored plaster was a useful compromise, since it could offer high-control on small details together with moderate costs. Using linear distances measured between several points on the original statue in Viterbo, the file was carefully scaled in order to get an accurate 1:1 real-size 3D print. Due to the bed size of the printer[13], which can build max volumes of 8×8×12 inches, it was necessary to section the sphinx file in 20 pieces that all interlocked and print them separately (for a similar approach see Zhou *et al.* 2016, 65). To execute this properly, all of the parts were designed to seat together with registration tabs to assist the subsequent assembly carried out by an artist at the Peabody Museum (see below).

To make the plaster more resistant we decided to apply a high-strength finishing, impregnating the finished model with a liquid epoxy. The liquid could set up inside of the printed layer without dissolving the unfinished plaster, and once the epoxy finished curing it changed the surface color to a pale yellow, masking the artificial shiny white of the plaster.

[12] We acknowledge Trevor William (System Administrator at the Yale School of Architecture) for his assistance.

[13] http://digitalmedia.architecture.yale.edu/printingplotting/schools-3d-printers.

Fig. 6 – The twenty 3D printed areas of the Sphinx joined together during the assembling stage made by the Peabody artist Michael Anderson.

4. Technology and art

When the School of Architecture completed the finishing stage, all the pieces of the sphinx were transferred to the Peabody Museum to be assembled. The artist Michael Anderson (among the authors) started gluing each element together, which proved to be a challenging operation. Since the statue was divided into so many pieces, even a very small shift could create visible discontinuities on the surface. Tiny errors during the slicing and printing stages created small gaps that prevented a perfect match between two parts, further complicating the process. Using various sculpting techniques, these small imperfections were corrected, thus recreating the entire statue in a single block in its original size (Fig. 6).

At this point, small artistic corrections were applied to the replica, sharpening a few details that appeared too smooth, i.e. along the fur, hair, and some of the deepest spots in the lettering. Last but not least was the color finishing, aimed to simulate the original marble surface. To do so, the artist used washes of acrylic paint with an acrylic medium. Applying multiple layers of this treatment could build up an acrylic layer over the surface of the sphinx, which recreated in a realistic way the original marble patterns. Finally, the replica of Paschalis Romanus sphinx was ready to be placed into the showcase and appreciated as an artefact at the entrance of the exhibit (Fig. 7).

Fig. 7 – The Paschalis Romanus sphinx replica finished and displayed into the Echoes of Egypt showcase at the entry of the temporary exhibition area (photo courtesy by William Guth).

5. Conclusions

In our opinion 3D printing is already part of a new and expanding tool for the future of Cultural Heritage. If we consider our medieval statue as part of a broader group of examples, partially described in this paper, it is possible to say that we are not only talking about the matter of "how to create a faithful reproduction of a sphinx", but rather how to create an archive of knowledge that can be shared and reproduced worldwide. Having a 3D digital model of an object, is equal to having a dataset of information that describes the object in the moment it was recorded with the advantage that this can be modified by adding or subtracting information according to the goals of each project (Di Pietra *et al.* 2017). High-resolution models are at the same time a dense repository of knowledge that can be spread and retrieved online, that is a much easier and quick way than traditional methods, allowing researchers to overcome many of the issues that are obviously involved in the management and access to the original objects.

If we consider the two goals that in 2011 the research team from ISTI-CNR hoped for the future of these technologies, the first one oriented in fundraising purposes and the second one in the development of a "multidisciplinary background" for who is involved in this fields, we can say that both, in our opinion, have been quite well achieved (Scopigno *et al.* 2011, 53-54). The first one is demonstrated by the increasing number of private and public founders that are investing in this field, starting from a smaller reality as in the case of our Sphinx but especially since the violence against monuments in the Middle East (we can mention again the case of the Triumphal Arc of Palmyra and remind the many other artefacts involved, partially presented in Al-Baghdadi 2017. For an overview of the problem see also Fisher 2017). The second one, as well, can be demonstrated by looking at our project as minor example, where three of the authors of this paper have a background in archaeology and anthropology and not in technology. As for the three of us, many other professional figures that are operating in the field of Cultural Heritage have nowadays similar backgrounds. This certainly helped the achievement of all the results described herein and of the many that are frequently appearing in the news.

While 3D printing and scanning have been and continue to be applied to Cultural Heritage projects, certain advantages of the technology have not been explored completely yet, i.e. the possibility to standardize into a more univocal system all these new datasets of three-dimensional information, including high resolution data, that are still not so easy to retrieve and fully investigate among the multitude available online. Beside technical matters, the value of digital technologies has been clearly recognized by international and European funding programs (i.e. the Horizon 2020)[14] that, as with the example of the Paschalis Romanus sphinx, will play a very important role in producing new ideas and projects. This will help to reduce risks and find new solutions to familiarize the public with the multitude of pieces that are still stored in museum basements or magazines, or those artefacts that are not any longer available because they have been destroyed or are located in dangerous areas.

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ABSTRACT

This paper aims to highlight the importance of 3D printing to support Cultural Heritage and related activities. We will demonstrate the advantages that a conscious employment of techniques and methods, together with the right expertise, could offer to an exhibition. We will detail the steps we took to produce a 1:1 copy of a medieval sphinx for the exhibition *Echoes of Egypt: Conjuring the Land of the Pharaohs* which took place at the Yale Peabody Museum of Natural History (USA). This paper highlights the project's workflow, from the digital 3D scan, data processing, 3D printing, to the artistic finishing to prepare the object for display.