The 3D recording of the so-called Spreti sarcophagus in the Basilica of San Vitale (Ravenna, Italy)

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The 3D recording of the so-called Spreti sarcophagus in the Basilica of San Vitale (Ravenna, Italy) AQ3

Left running head: G. Ugolotti *et al.*

Short title : 3D recording of 'Spreti' sarcophagus AQ2

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Abstract

This article presents our experience in digitizing a Late Antique sarcophagus using and combining two different recording methods: Structure from Motion (SfM) and Structured Light Scanning. Due to preservation purposes, it was necessary to obtain a reliable 3D digital reproduction of the artifact to perform observations, measurements, and produce graphic layouts for possible forthcoming restorations. The employment of two recording techniques (hardware + software) was necessary to overcome some loss of data that were registered during the acquisition phase. Each method showed some failure in detecting or processing portions of the object surface, mainly due to the mechanical properties of the material (marble) on which the sarcophagus is made. AQ5

1 Preface

The preservation of an artifact often involves technologies that have been developed within other fields of research and for other purposes. For instance, 3D scanning and rapid-prototyping techniques became widely used in restoration practices thanks to the continuous development and improvements of devices and software that drastically reduced costs and enhanced their performances (Bologna *et al.*, 2003; Guidi *et al.*, 2004; Mercante and Speranza, 2017). Nowadays, it is much easier to get a precise and reliable digital reproduction of many different types of objects while keeping a high definition of geometries (polygons) and texture (Abate *et al.*, 2011; Agosto and Bornaz, 2017).

Digitizing cultural heritage has become increasingly popular over the last decade, especially after the dramatic episodes of destruction caused by the terrorist attacks in 2014 and the more recent impossibility to visit sites and museums due to the pandemic. People started to be attracted by the opportunity to keep accessing cultural areas and virtually discover artifacts. This trend automatically increased the need to improve the ways to document and copy heritage. With the newly available tools, it is possible to obtain faithful reproductions with enough quality to enhance a graphic dataset of information; that could be stored and then re-accessed by future generations (Guidi *et al.*, 2004; Remondino, 2011). Building up appropriate conservation projects is essential to offer alternatives and more chances to all those areas that are under threat to survive and that could be accessed (visited) if not in reality, at least in a virtual manner (Bologna *et al.*, 2003; Remondino, 2011; Calin *et al.*, 2015). This is also true, in smaller scales, while digitizing artifacts. When properly executed, considering criteria such as high resolution, metrical control, and scientific awareness, 3D scanning allows the creation of useful repositories of digital copies, usable for educational, promotional, and scientific purposes, including degradation monitoring, quantitative/qualitative analysis, and digital restoration (Abate *et al.*, 2011; Agosto and Bornaz, 2017).

Due to the many variations in the typology of objects, materials, and their collocation, the need of combining different recording techniques to solve a digitization project is not uncommon (Guarnieri *et al.*, 2006; Calin *et al.*, 2015; Nadal-Romero *et al.*, 2015; Agosto and Bornaz, 2017). In this article, for example, we describe our experience in combining two of the most used acquisition methods that are currently employed to document artifacts in 3D: Structured Light Scanning and Structure from Motion (SfM).

AQ6 SfM is a photogrammetry-based technique able to reconstruct the geometry of objects in three dimensions, starting from digital photographs taken (Jones and Church, 2020). Solid and flexible algorithms successfully supported commercial software development becoming very quickly largely used all over the world. Structured light scanning, on the other end, reconstructs objects geometry by projecting patterns of light on to their surface (Furht, 2008; Liu and Wang, 2021). The arrays are partially absorbed by the materials and partially refracted and recorded by the optical sensors installed in the device that translates them into metrical information. Newest generation scanners are manageable and easy to use, without the need to set up stationary scanning hardware. This technique is also known for its recording accuracy that can reach up to one-tenth of a millimeter (Modabber *et al.*, 2016). Flexibility, easy acquisition pipelines, and performing data processing are certainly the attributes in common that motivated us to choose the two techniques that are described in this article.

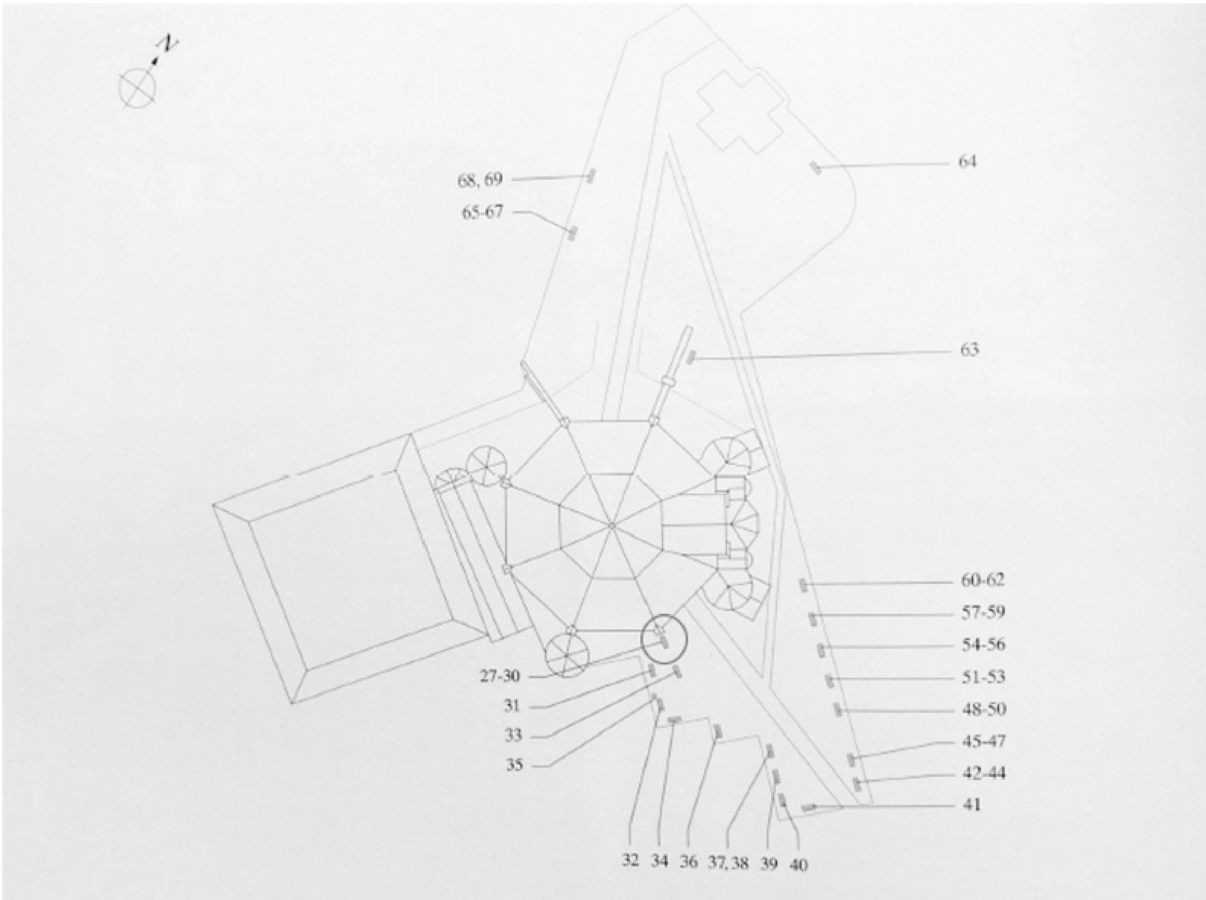
Results from this digitization project will demonstrate how well the data obtained from each recording system can be integrated to overcome scanning issues that were found after each session (Guarnieri *et al.*, 2006; Calin *et al.*, 2015; Nadal-Romero *et al.*, 2015).

This article aims to present and discuss the points aforementioned through the digitization experience of our case study, an important medieval sarcophagus (the so-called Spreti sarcophagus) located in the courtyard of the Basilica of San Vitale in Ravenna (Italy). The technical goal consisted in producing a reliable 3D model of the artifact to produce graphic documentation to be used over time for restoration and degradation screening purposes. The history of the sarcophagus and its preservation was the key point of our research question and brought us to evaluate the available recording methods. The following paragraphs will describe our project progress, highlighting the technical aspects that play a crucial role between the two techniques and their potential in terms of expected results. The conclusion will summarize the advantages and problems found during this work and perspectives of our experience, considering how complementary the two techniques are despite the limits presented in each case.

2 The Sarcophagus

The so-called Spreti sarcophagus is an early Christian byzantine artifact in proconnesian marble, located outside the UNESCO site of the Basilica of San Vitale in Ravenna (Italy), and dated roughly to the end of the 6th century A.D. (Kollwitz and Herdejurgen, 1979) (Fig. 1). The 'Spreti' attribute comes from its funerary reuse by the ancient ravennate Spreti family. In particular, Bonifacio Spreti ordered the changes in the iconography of the (currently east) side of the coffin in 1590. He wanted to replace the crosses with a coat of arms with dedicatory epigraphs (De Francovich, 1959; Farioli, 1983; Angiolini Martinelli, 1997).

Fig. 1 Current location of the Spreti sarcophagus (circled), in the courtyard of the Basilica of San Vitale (Angiolini Martinelli, 1997)



The coffin measures 215 cm wide, 98 cm deep, and 98 cm height, while the lid is slightly larger in length and depth (227 × 105) but only 59 cm high. The decorations and structure of the sarcophagus are characterized by the presence of smooth angular columns, culminating in capitals with lanceolate leaves and bearing a flat trabeation. The western long sides of the coffin are characterized by the presence of a monogrammatic cross with an eschatological connotation: an *alpha* and an *omega* hanging from its arms through chains. The short sides (the northern and southern ones) are decorated with two large Latin pattée crosses (Fig. 2).

Fig. 2 The so-called Spreti sarcophagus

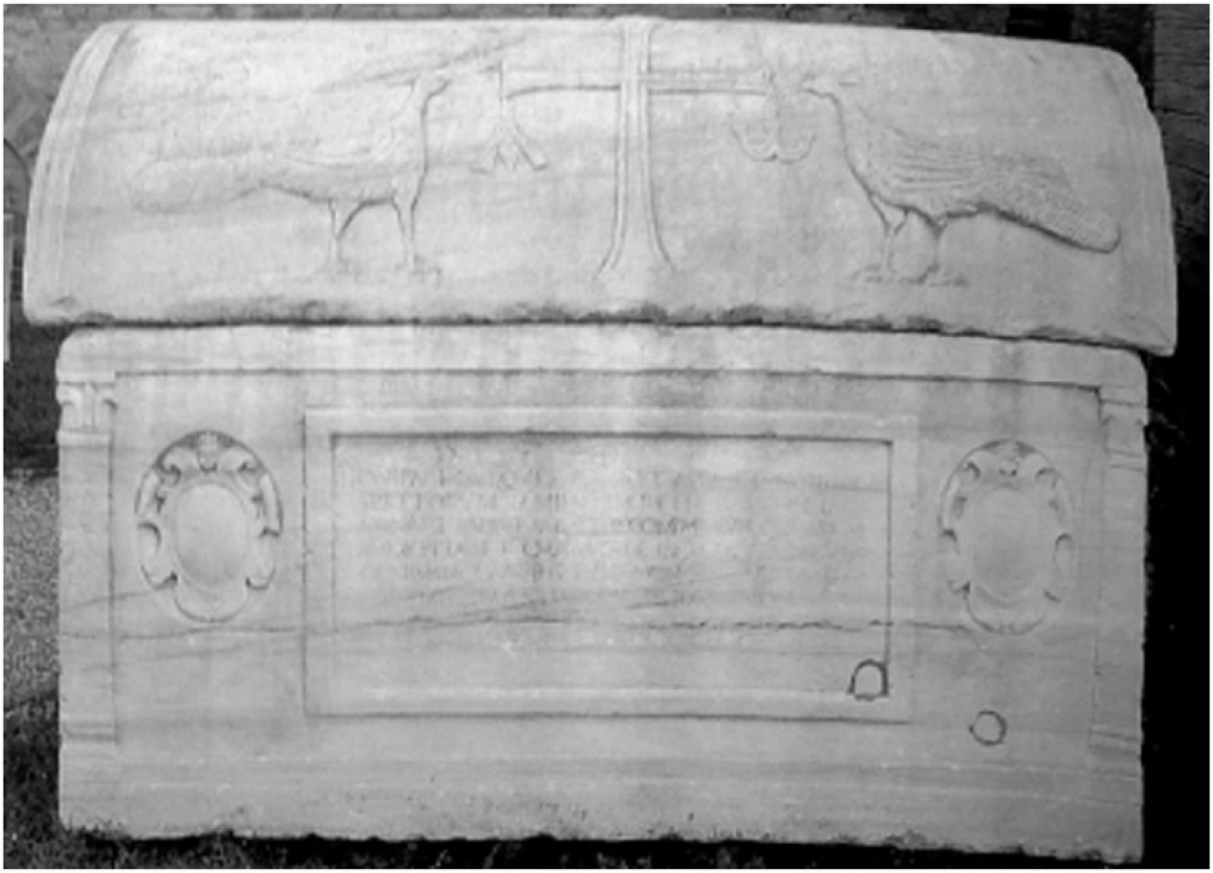
The sarcophagus has changed its location through the centuries. In the 16th century, it was probably located near the church of San Giovanni Battista, while during the early 18th century its presence is attested near the Neonian baptistery (Fig. 3). It was eventually moved to the city's monumental cemetery in 1879 and finally relocated at the National Museum in 1953 (Deichmann, 1974).

Fig. 3 Collocation of the Spreti sarcophagus near the baptistery of Neon in 1860 (Savini *et al.*, 1996)

2.1 Current preservation status

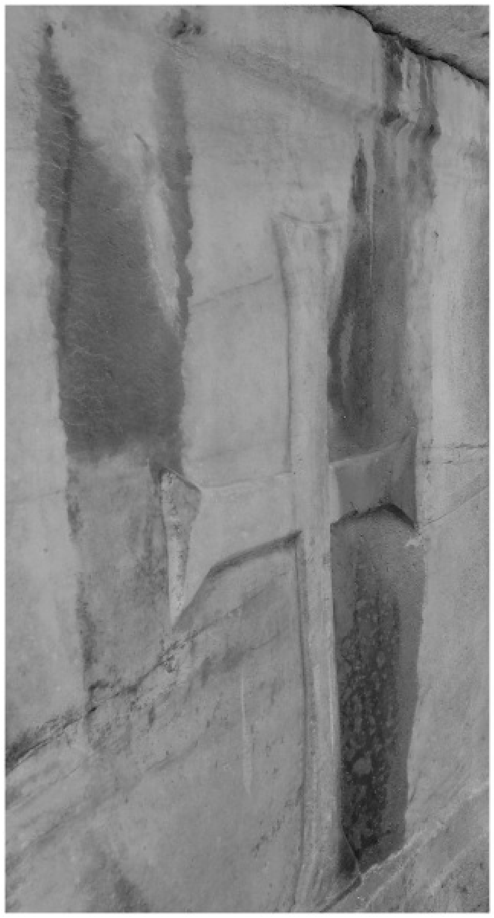
At the beginning of 2019, several traces of decay were found despite the several cleaning interventions made during the 20th century (probably through biocide, as shown in Fig. 4). Thanks to a new superficial survey of the artifact, it was possible to record the presence of degrading materials such as dust, guano, and dirt. Those created sediments that were partially obscuring the decorations. Strangely the lid was less affected by these pollutants, but the rain and other weathering patterns increased the dissolution of the superficial calcite. Sarcophagus and its cover were characterized by widespread desegregation, worsened by thermic changes, growth of microorganisms, and other atmospheric agents, which led to the formation of intergranular fractures, loss of grains, and a not regular decay long the veins.

Fig. 4 The 1997 cleansing of the Spreti sarcophagus (Angiolini Martinelli, 1997)



Both northern and southern sides showed limestone incrustations due to inorganic agents, the so-called Black crusting, created by the iteration between environmental pollutants and the substrate (Fig. 5).

Fig. 5 Detail of a ‘black crusting’ on the northern side of the sarcophagus



3 Acquisition

3.1 Photogrammetric recording using structure from motion

Photographs have been shooted with a Nikon D750 camera with the highest available resolution (6.016 × 4.016 pixels per frame). To control the white balance, we used a mid-gray color control scale bar, to be able to calibrate the textures accordingly and improve the chromatic quality. ISO value was set on the lowest level (200) to reduce the sensor sensitivity and prevent micro-interferences.

The opening was set on 9.0 to get a sufficient depth of field since we had enough light to ensure a good shutter speed response. The images have been shot in RAW format to maintain a high control on the quality and enable major flexibility in the post-editing. The acquisition needed to plan a recording schema for the whole object to help the software in the alignment step throughout the detection of *tie* and *key* points. The total of photos amounts to 117. The images were processed using the third-party software

AGISOFT METASHAPE STANDARD 1.6.3 (www.agisoft.com).

After the alignment of the photos was done, by following the METASHAPE workflow we ran the Dense Cloud step to refine the object shape. After the Dense Cloud creation, the mesh has been built with a high resolution to keep good geometry accuracy. The previous step was enhanced using the 'close gaps' and 'optimize geometries' algorithms. Even if the artifact got recorded with good photographic coverage, the software could not reconstruct part of the surface, resulting in a large hole in the mesh.

Possible reasons for this failure are the changes in the surface illumination caused by the varying weather conditions. Despite further photographic acquisitions, the software was not able to elaborate a complete 3D model (Fig. 6). Considering the situation, we decided to re-record the sarcophagus using a different technology based on structured light scanning. In the meantime, the 3D model obtained through Structure from Motion was exported and saved as an .OBJ file.

Fig. 6 3D model created through SfM, with evident gaps on the western side and on part of the cover

3.2 Structured light scanning acquisition

The acquisition was performed using the Eva Scanner (www.artec3d.com), a hand portable device that demonstrated great performances in speed, manageability, and precision (Modabber *et al.*, 2016). We did not attempt the acquisition using laser scanning to be consistent with typology and dimension of our object, which does not perfectly match what is suggested by the literature[1] (Jecić and Drvar, 2003). The scan rate was set to eight frames per second. The acquisition led to several problems with the scanner that required several attempts to solve them, such as changing the scanner's angle and performing the scanning at different daytime to check for better lighting conditions.

The total of scans was thirty. Several recording sessions have been performed with at least 50% of overlapping area between each acquisition to ensure better detection of homologous points on the surface, necessary for a correct alignment. For data processing, we used ARTEC STUDIO 14 (www.artec3d.com); twenty-one scans were selected while the remaining redundant, erroneous, and poorly recorded ones have been eliminated. Through the Autopilot function, it was possible to determine the most effective settings to elaborate the 3D model. The first step gives the user the possibility to set different parameters to help the software understand how to behave: to improve the 3D model processing, the software needs information such as the quality of the mesh and texture if the object was difficult to acquire, as well as the object size. Therefore, the automatic 'close holes' function was disabled[2] to keep a higher control on each step and avoid misinterpretations of the surface's patterns. The resolution of the texture was set to 512 × 512 pixels, good enough to appreciate details and differences on the sarcophagus surface after its restoration. Textures of larger resolution weigh excessively the model during its elaboration and post-processing phases.

After the first parametrization, Autopilot helped to clean the scans from extraneous elements (i.e. the background and floor) that were involuntarily detected by the software and added to the cloud point. In this case, the alignment was manual. Finally, the Autopilot merged the aligned scans to create the 3D model. The 3D sarcophagus showed a gap in the upper part of the lid, caused by the light refraction on the marble that gave visual noises such as aloes and burned areas (Fig. 7).

Fig. 7 3D model created through scanning, with evident gaps on the cover

Considering the similar issues (gaps on the mesh) that each recording technique created on to the related 3D models (fortunately, respectively, visible on different areas of the sarcophagus), the only chance to get a complete digital copy without any problem was merging them using specific software.

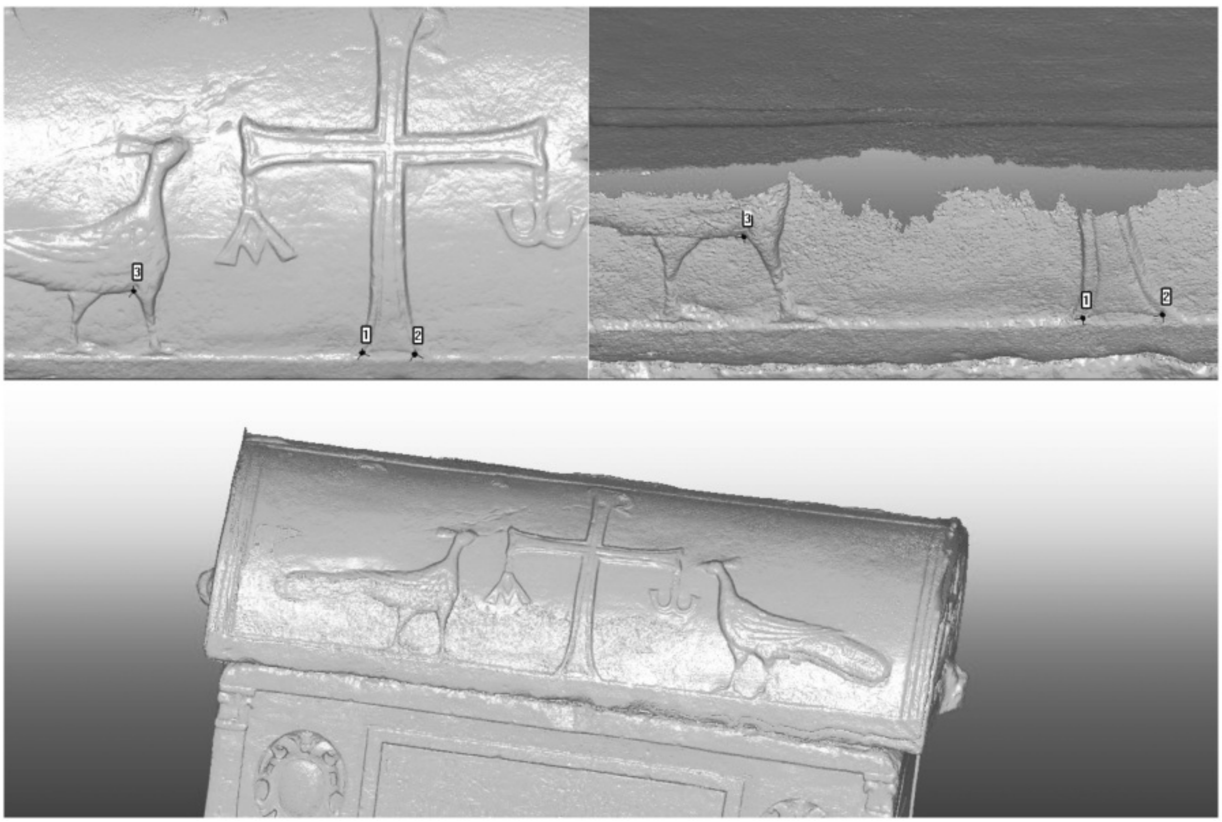
Before getting into the next phase, the 3D model coming from Structured Light Scanning was saved and exported as an .OBJ file.

4 Reconstruction

The merging of the two 3D models was complete using another third-party software called **AQ6**LEIOS 2 (www.egsolutions.com). LEIOS turned out to be very effective in managing heavy files,[3] giving the possibility to keep the original resolution of the meshes without decimating them in this phase.

The first problem to be solved was the slightly different scale of each model after being exported (Mesh 1 from the scanner; Mesh 2 from the SfM). LEIOS has a specific function that resized both models obtaining a perfect match. The following step was the alignment of the models using a method based on homologous couples of points. To do so, we placed several markers on to both surfaces very carefully, overlaying those spots recognizable as ‘equals’ on both models and labeling them in the same way (Fig. 8). Using the ‘Mesh Hole Filling’ option, we first closed all the minor gaps.

Fig. 8 3D models alignment through homologous points



The ‘in curvature’ option was used for curved areas holes, while the ‘in borders continuity’ has performed for edges and corners. Second, it was possible to merge Mesh 1 and Mesh 2. The result was a new single mesh completed of those missing parts caused by the errors in the acquisition phase.

Due to the position of the sarcophagus, it was not possible to record the part underneath the base. In this case, the ‘Close Holes’ option did not succeed, probably for the dimensions and shape of the hole. Specifically, it showed jagged and irregular edges caused by the narrow space between the bottom of the object and the ground. The lack of space prevented the array of light thrown by the scanned to reach the surface therein. To solve this missing geometry, we decided to use the software ARTEC STUDIO 14. After saving the final mesh as .OBJ file on LEIOS 2, the digital model has been imported on ARTEC, where it was possible to reconstruct the missing bottom of the object using specific tools (Fig. 9).

Fig. 9 Final 3D model free from gaps, created by fusing the two original models

Through this method, it was finally possible to display and navigate the 3D reproduction of the sarcophagus without any problem in its geometry. The file was then saved as an .OBJ file to be shared and used by the restorers to perform observation and graphic layouts on their work.

5 Conclusions

One of the goals of this article was to demonstrate how combining two different recording techniques (structured light scanning and Structure from Motion) can overcome scanning issues. The historical-relevant medieval sarcophagus described in this article (the so-called Spreti sarcophagus) can testify at least the advantages obtained for our primary purpose, mostly related to conservation and restoration.

Granite and basalt, if polished, may cause the same reflection issue as the one encountered in marble, while more porous materials like limestone and lime mortars may give some limitations for the color acquisition due to their whiteness. These marble-like materials and so, most sculptural artifacts, could potentially encounter similar acquisition problems if recorded using just a single method. Nevertheless, the marble of the Spreti sarcophagus, even if scanned/photographed in the best lighting conditions, is a clear example of these technical limits.

The work done for this project demonstrates how helpful could be a flexible recording approach and the combination of different techniques to produce graphic documentation to use for restoration and degradation screening purposes. It is worth underlining that this workflow can be easily replicated and applied to any object of similar size and materials thanks to the many different software and devices that are increasingly available on the marketplace.

It would be interesting, in future scanning projects, testing how polished marble will behave if scanned through systems that do not involve light sources, such as X-rays or magnetometry. Unfortunately, the current available technologies allow the investigation of smaller objects but, the potential of these methods is rapidly growing as well as into the world of 3D graphic and the study of cultural heritage.

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We would like to thank the National Museum of Ravenna for granting us access to the sarcophagus. We are also grateful to the Department of Cultural Heritage, in particular to Professor Mariangela Vandini for managing the legal responsibility of the project and Professor Michele Pagani for his support in supervising the restoration project. A final thanks goes to FrameLAB Multimedia & Digital Storytelling for providing the equipment used to develop the entire project.

Conflicts of Interest

None declared

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Endnotes

1 https://www.polyga.com/3d-scanning-101

2 Function 'Watertight': it automatically produces a mesh wishful holes.

3 Some tests have been made with MESHLAB 2016.12, RAPIDFORM XOR, and ARTEC STUDIO 14.

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