IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

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To cite this article: M. Bici *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **949** 012117

A preliminary approach on point cloud reconstruction of bronze statues through oriented photogrammetry: the "Principe Ellenistico" case

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Abstract. Close-Range Photogrammetry is a widespread and efficient technique in the 3D acquisition of artefacts, particularly in fields like Cultural Heritage. Despite this wide usage, also due to a convenient quality/cost ratio, it shows some limitations due to light conditions as well as the artefact surface finishing. In this paper, we would like to report the assessment of a photogrammetry approach to 3D capture metal reflective surfaces, such as bronze, which is a widely used material in ancient statues. To this aim, we propose a photogrammetry workflow based on systematic steps capable of overcome some of the main issues of reflective surfaces. To validate this approach, the developed 3D model is compared to a more accurate model of the same artefact, obtained with a 3D scanner. As a case study, we selected the Principe Ellenistico, an ancient bronze statue conserved in the Museo Nazionale Romano (Rome, Italy), of which a photogrammetric model is firstly developed and then compared to the scanned one.

Keywords. Close-Range Photogrammetry, 3D acquisition, Systematic approach, Bronze statue, Principe Ellenistico.

1. Introduction

Close-Range Photogrammetry is a widespread technology in the Cultural Heritage field as well as other 3D capturing techniques. It is generally an easy-to-use technique, thanks to the continuous enhancement of technology as well as the development of user-friendly software and represents a cheaper option with respect to other non-contact methods for acquisition (e.g. laser or structured light scanning) in Reverse Engineering field. Close-Range Photogrammetry is widely used to obtain 3D textured models, useful for restoration, exhibitions, digital archiving, augmented reality applications, digitals reconstructions, inputs for Finite Elements Analysis simulation since providing information about statics and posture of statues and others artefacts, etc. On the other hand, it is generally less accurate than the other techniques. Moreover, similarly to 3D scanners, the photogrammetry results are highly conditioned by light and surface finishing, as in the case of metallic or reflective surfaces. Since many ancient artefacts present these challenges, as in the case of bronze statues, and they need to be 3D captured for documentation of the current state of preservation (comparing the state before, during and after possible restoration phases, for example) or for the creation of digital copies, the literature presents some researches dealing with their photogrammetric reconstruction. In [1,2] the authors presents their experience with a bronze statue (the Neptune statue of Bologna, Italy) using a semi-automated 3D photogrammetry-based solution, with the aim of supporting restorers in the open-air bronze cleaning from corrosion and weathering decay. In [3], the authors employ a close-range photogrammetry for the 3D model reconstruction of bronze cast sculptures, with a focus on the analysis of image processing strategy and its impact on the quality of the final model. Other works deal with the application of photogrammetry to bronze artefacts, such as a bronze door [4] or underwater artworks [5]. Despite some limitations, the low cost, the versatility and the user-friendly approach of photogrammetry make it a promising technique [6,7], even for complex material, such as bronze. Hence, our goal is to define a structured photogrammetry workflow focused on highly complex geometry and/or reflective (metallic in most cases) surfaces finishing capable of generate an accurate 3D model, as a possible alternative to 3D scanning. One of the fundamental characteristics of the developed procedure is the usage of a standard camera, without any filter or action of post-processing onto the photos. To test this approach, we attempted the reconstruction of the 3D digital model of the Principe Ellenistico, a 2 meters tall bronze statue conserved in the Museo Nazionale Romano (Rome, Italy), and then compared the photogrammetric model with the one already obtained by a 3D scanner acquisition.

The paper is structured as follows: Section 2 presents the systematic approach. Section 3 introduces the case study, the development of the photogrammetric 3D model and its comparison with the scan one. Section 4 presents some final remarks, with conclusion and further possible developments.

2. Workflow

The proposed method follows 5 main steps, that, in general, could be followed in the prescribed order, achieving a subgoal for each of them that could be used as the input of the next step.

1) Preliminary analysis of the artefact, its geometry and surface finishing, looking at the possible difficulties that could arise from them. In particular, we focus on complex points and areas (such as undercuts, deep holes, hidden features, etc.) and, at the same time we analyse the artefact surface for possible reflections connected to the local finishing.

2) Background and light setting: In general, direct light onto the artifact should be avoided, especially if we are working with a metallic statue. So, to solve this issue, light shields and diffuser could be used, flashes should be avoided, using natural lights instead of artificial ones. In order to avoid the alteration of the original surface texture, we decided also to avoid the usage of polarizing filters.

3) Taking care of the previous analyses, we can define a framework (also called “virtual cage”), around the artefact in order to shoot photos from different registered positions. As an example, considering a statue representing a standing person, we can imagine to envelope it with a cylinder. Then, we can divide the cylinder in angular and vertical coordinates: for each angular step at the basis, we set vertical distances that correspond to the positions in which taking photographs. A similar approach is applied to 2D artefacts, such as floor mosaics, in [8]: Fazio and Lo Brutto divided the space into a regular squared grid and take a photograph in each node of the grid for photogrammetric reconstruction.

The set-up of this “virtual cage” allows also to work in a detailed manner on complex areas and parts of the artefact (e.g. a protrusion that projects a shadow onto a part of the statue, e.g. an arm), in order to take photos with different orientations, by varying zenith and azimuth of the camera but maintaining its fulcrum in the same point through the usage of a tripod (or just through the operator skills). In each fixed position, firstly a photo at zenith and azimuth both equal to zero is shot, then, maintaining fixed the fulcrum of the tripod, four photos with positive and negative zenith variation (about 10° for the first couple and about 20° for the second) are made. In case of complex areas, also similar azimuth variations can be made. In addition, depending onto the distances from certain details, also the focus of the camera is calibrated in order to achieve a correct resolution in for every feature present in the model. At the end, when every prescribed position and orientation of the camera has been used, if shadowed zones, undercuts, and other criticalities will need additional information, some extra photo zones could be added to the prescribed framework. Obviously, even for these extra zones, the position is registered.

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4) Once photos are collected, they must be aligned, then the point clouds of the virtual model must be generated. This is done through the usage of dedicated software (es. Agisoft Metashape, Autodesk Recap Photo, Meshroom, etc.), that then generate meshes and the correlated texture. Some of them are free and open, depending also on the number of photos allowed to reconstruct. Anyway, even if it is fundamental for the quality of the results, the software choice remains free in order to make the user able to choose according to its needs.

5) Once the model is obtained, it can be evaluated in terms of possible non-reconstructed zones, approximations, holes, etc… After, it can be compared with other models, assumed as references. In our application, the reference model to be compared with is a cloud of points obtained through a 3D scanner. The comparison can be done through inspection software like Geomagic, RapidForm, Polyworks, etc.

The comparison is done through a direct overimposition of the two models, and it outputs a color map with a scale related to the measured distances. In this way, we are able not only to evaluate model accuracy (as the distance between the photogrammetric one and the reference) but also the quality of the reconstructed surfaces, appraising possible local defects connected to the procedure and its settings.

3. Case study

3.1. *Principe Ellenistico* (Museo Nazionale Romano)

The proposed procedure has been developed and applied onto the "Principe Ellenistico" statue. It is a bronze statue, 2,04 m tall, datable around the 2nd Century B.C., found in 1885 on the hillside of Quirinale, Rome, probably in the ancient area of the Costantin's thermae. It represents a naked hero as usually made in case of sovereigns or warlords; its subject still under investigation, but some experts have recognized it as an hellenistic prince, probably brought in Rome as spoils of war. (Figure 1, left).

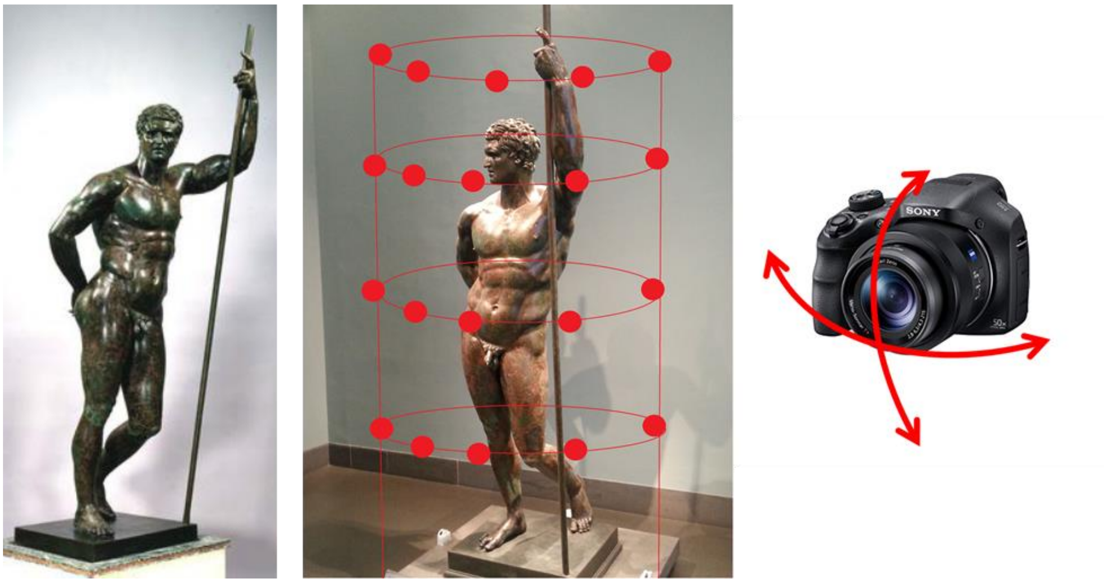

Figure 1: The statue; an example of "virtual cage"; zenith and azimuth variation.

The statue, found in fragments (body, left arm and right leg, the spear is not original), has been restored two times since the finding, and nowadays, it is conserved in Museo Nazionale Romano.

The first restoration has been done just after the finding, in order to recompose fragments, guaranteeing, at the same time, the structural support through an ad-hoc frame.

The reconstruction of fragments concerned front part of the right foot, right leg at the thigh (found separated), left leg at the knee, left arm (found separated, with lacuna). Plates of brass have been used for conjunctions joining them to the statue, transversally to cracks and edges, through brass screws (Ø

6mm). Bronze has been used for rebuilding and filling missing parts and holes. A non-original spear in the left arm has been added according to the final posture and iconographic studies.

The second restoration, in the last century, was focused not only to general operations but also on the internal support and the renewal of the support of the left arm. Due to the repositioning of the arm in this phase, the statue has encountered an unharmonious posture, increasing the feeling of a possible "fall" in the front of the statue. With studies of compared photogrammetry between photos taken before and after this restoration, in previous work, it has been demonstrated errors in repositioning, mainly concentrated onto the left arm, during the restoration. [9,10].

So that, major investigations about possible reconstruction of the original asset of the statue seem to be necessary. With this research, in fact, additional information to the already obtained models can be achieved in order to continuing the facing of posture problems, a kind of issues approached also by other authors in other case studies [11,12]. Only the most recent interventions, have been focused on the concept of "preserving", also applying experimental and numerical investigations. Restoration and maintenance of bronze statues obviously concerns with surface investigation and material integrity, so that, once achieved a model through 3D scanner, a preliminary assessment via CAE methods has been already done to investigate stress-strain distribution, allowing the evaluation of critical-strength areas, the effect of the support and constraint system on the stability [10].

3.2. Preliminary analysis of the statue (step 1)

As explained in Section 2, the procedure starts with a preliminary analysis of the artifact, its peculiarities and possible critical zones for acquisition. In the case of the "Principe Ellenistico", it has to be noted that the statue presents a various set of difficulties and characteristics that should be taken in mind:

- Reflective surface finishing (bronze).
- Due to the bronze ageing and the statue's history, the surface results to be marbled and not uniform.
- The presence of the spear could mean difficulties during the acquisition of parts, near to it, that result partially covered by the spear itself.
- Some zones result to be with reduced accessibility like the inner part of the legs, the bottom part of the right arm (between right arm and hand and the lower back of the statue), the left foot lifted off the ground but close to the basement.

These issues will influence the strategy of acquisition, needing attention and particular treatments in order to get solved.

3.3. Development of the Photogrammetric model (step 2-4)

A cylindrical "virtual cage", (Figure 1, middle) as described in step 2 of the workflow, was designed around the statue, with a radius of 2.50m and a height of 2.40m (Figure 2). Then, we set an angular step of 22.5° and a vertical step of 0.40m, and 96 positions were determined. In each position, we took one frontal picture and 4 additional photos with a zenith variation of ±10° and ±20°. In this way, we obtained 480 photos, and then, we add some pictures for complex areas, varying the azimuth, in a range of ±20°,with steps of 10°, and the focus, arriving to a total number of 606 photos. We used a digital single-lens reflex camera Canon EOS 1100D, 12.2MP, CMOS sensor, sensor size: APS-C 22.2x14.7mm, with a maximum image resolution of 4272 × 2848.

The acquisition was made in the museum room where the statue is habitually exposed, during extraordinary cleaning and maintenance operations. This allowed us to work freely around the statue, using natural light, turning the artificial lighting off. Due to the position and the weather conditions, we had to use also light diffuser in order to increase the quality of the pictures to be obtained. This, sometimes, has revealed also the difficulties connected with the relative position of the camera, the statue and the light diffuser. In fact, some photos have been discharged due to a huge light reflection or due to a high similarity of the statue part and the dark background.

Then, the photogrammetric model was developed using Agisoft Metashape software (step 4), which performed the image-based reconstruction, following the photogrammetry workflow based on:

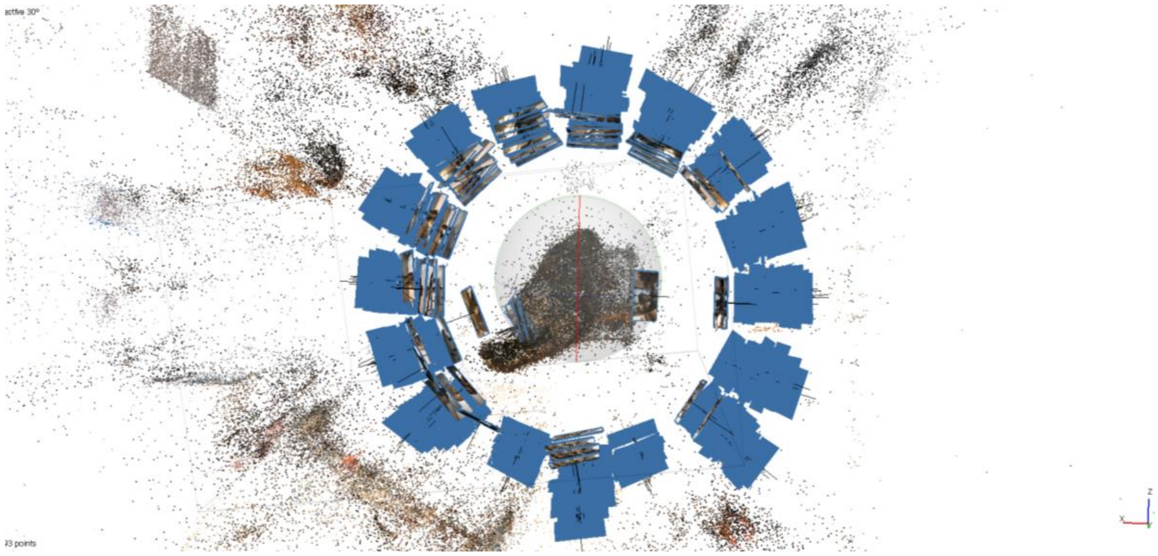

Figure 2. The identification of camera positions within the Agisoft Metashape software.

- Photographs alignment, using the high accuracy option in the Metashape software. All the photographs were aligned without relevant issues.
- Depth maps and dense point cloud building, using high quality and aggressive filtering mode options. During this step, due to high noise (a huge number of outliers and no-real points caused by the light reflection have been taken (Figure 3), despite the aggressive filtering mode), we were required to filter the point cloud (or dense cloud, as called in Metashape). The most of reflections have been "reconstructed" as offset points from the model, in particular in five main positions: around the left hand holding the spear, around the spear, around the head and shoulders, around the right arm, on the square basement. The initial dense cloud presents around 20'200'000 points.

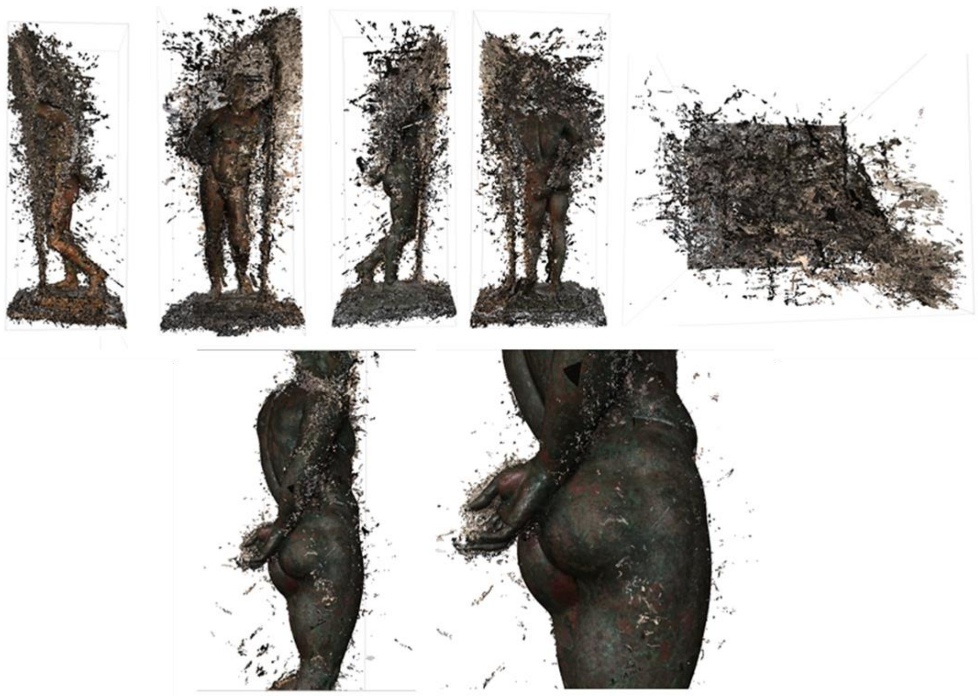

Figure 3. The noise points before and after the automatic filtering of points

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To this aim, three types of filtering operation have been performed:

1) Masking, by cutting all the scene around the statue. However, since we could not move the statue from its position, nor we could surround it with a homogeneous white background (using a panel). Unfortunately, white panels was usable only as a background in the frontal pictures, with the zenith at a zero level. In all the other cases, the panels were not present due to the impossibility of being fixtured.

2) Filtering by colours. The most of reflections have colours from grey-silver (RGB 199,200,196) to light golden (RGB 255,236,195), from light brown (RGB 155,134,110) to beige (RGB 199,176,152), so using a sequence of colour filter operations, we were able to cut more than 2 million noise points.

3) Manual removal/cutting, cleaning the remaining surface, especially noise points between the legs, under the right armpit, around the right hand.

The final dense cloud presents 17’400’000 points.

- Mesh and texture building, using the depth maps for the reconstruction, and during this process, a mesh decimation is performed to automatically delete the outliers or isolated points. The final model counts more than 1’400’000 triangular mesh elements.

Finally, additional post-processing operations may be performed: in particular, the 3D model (Figure 4) is scaled to its natural dimensions using one of the sides of the support as a reference, whose dimension is known. The final model consists of a detailed 1:1 scaled textured 3D model of the statue.

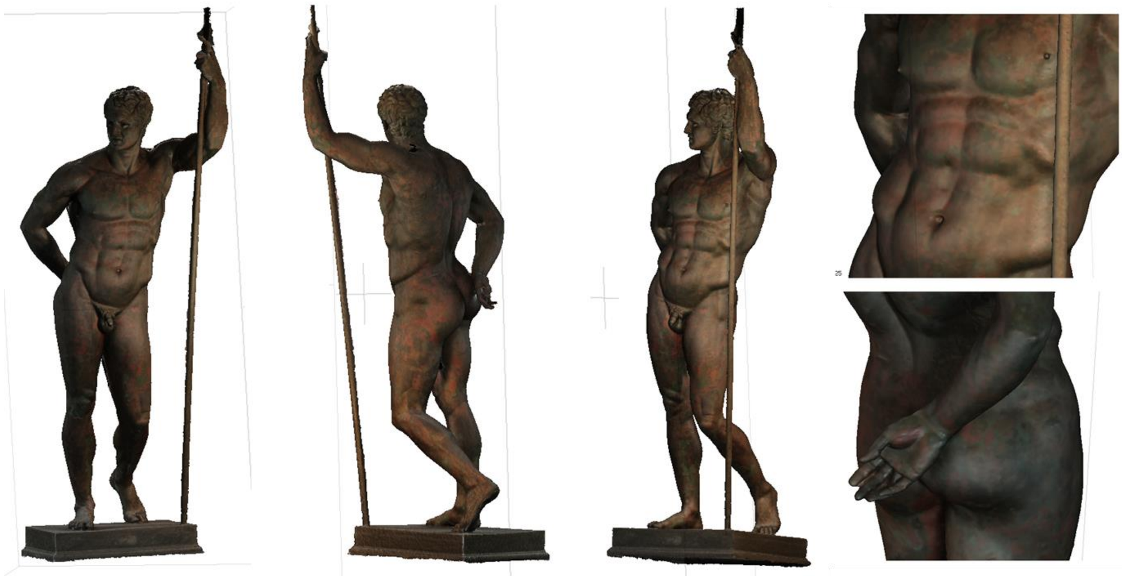

Figure 4. Entire views and some details of the 3D textured model

3.4. Comparison between photogrammetry and scanner

Using Geomagic Control, we obtained a graphical comparison (step 5 of the workflow described in section 2) between the scanned model of the statue (set as the digital reference model) and the photogrammetric model (set as the test model to be compared and evaluated). The scanned model has been obtained with an Artec Eva portable 3D scanner (3D point accuracy up to 0.1 mm, 3D resolution up to 0.5 mm). It is a high resolution model counting 4’750’000 mesh elements (.stl file).

The software allows to overimpose the photogrammetric model on the scanned one, and using a best fit alignment we can create a full colour deviation map comparing the reference to the photogrammetric model and highlighting displacements (e.g. due to surface reflection), holes (e.g. lack of captured data). The colour maps, reported in Figure 5, show some deviations and some critical areas. However, the deviation range of most of the model is limited between -0.7 and 0.7mm. Some areas, as reported in Figure 5, present more deviated results. For what concerns the top of the head, issues are connected with bad conditions of lighting and accessibility. Problems of shadowing and inaccessibility are present in the portion of the left arm, close to the spear, right armpit and in the inner part of the legs. Corners of the basement present high deviations due to reflection and an unfavourable background condition.

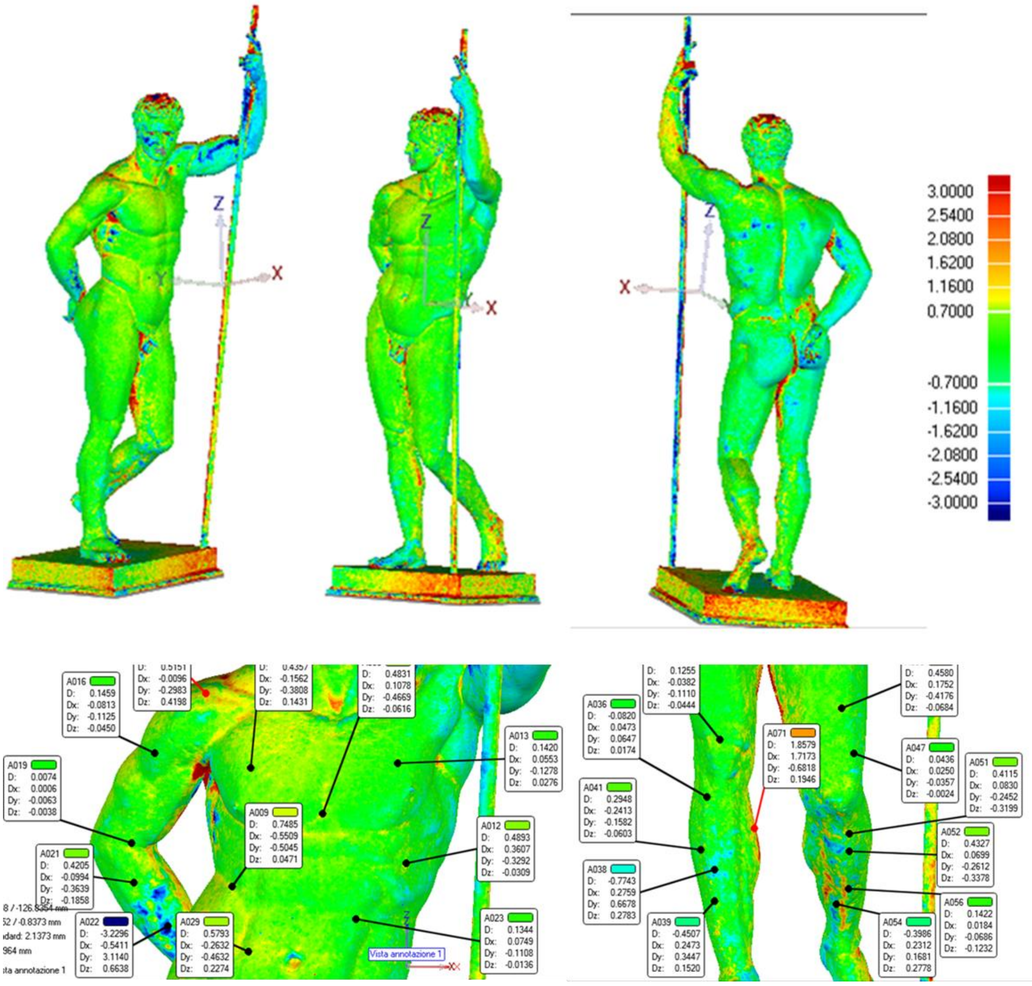

Figure 5. Colour maps showing the comparison between photogrammetric and scanned models.

4. Discussion and conclusions

The paper proposes a photogrammetry workflow focused on reflective surface artefacts, such as bronze statue. Even if suggestions and tips come from the literature analysis, we attempt to stress the traditional approach to close-range photogrammetry technique and assess the use standard cameras and commercial software. To this aim, we defined a workflow that starts from the analysis of the artefact and led to the definition of a virtual cage, obtaining a set of photos regularly taken around the artefact. We achieved a photogrammetric 3D model using commercial software, which has been compared to a reference model obtained by the Artec EVA 3D scanner. The models showed an acceptable level of overlapping, leading to an average accuracy of ± 0.7 mm. These results have been obtained with a standard camera, a simple system of light diffusion and without any filtering operation, so that, it represents a really simple and cheap system. The application of this workflow onto a high-reflecting surface, like bronze, showed criticalities usually not present in models with opaque finishing. Anyway, the results achieved in terms of accuracy and its relation to the cost of the system, can demonstrate its utility.

Further investigations and developments, even in what concerns the workflow itself, will be conducted, to solve issues connected with the critical areas. These zones and their low accurate results, even if limited, are connected with the light conditions and diffusion, with the absence of filtering operation and also to shadows and undercuts. We are going to work for applying the proposed workflow onto other statues, made by several materials, reflecting or not. Other efforts will be made to improve the workflow for what concerns photos and the photogrammetric reconstruction. Firstly, we are planning to apply artificial intelligence and deep learning to achieve algorithms able to cut out automatically the background from the single picture, leaving only the area of interest. Other investigations will be conducted onto the possibility of using also photos taken randomly and not only for this specific purpose.

Aknowledgements
Authors are pleased to thank “Museo Nazionale Romano”, all its restorers, for the possibility of collecting photo and information about the “Principe”. Authors want to especially thank Dr. Olimpia Colacicchi Alessandri, Dr. Ida Anna Rapinesi and Dr. Marina Angelini for their collaboration.

References
[1] Apollonio F I, Ballabeni M, Bertacchi S, Fallavollita F, Foschi R and Gaiani M 2018 Digital documentation and restoration tools reusing existing imagery: a multipurpose model of the Neptune’s Fountain in Bologna *Applied Geomatics* 10(4) 295-316 doi: 10.1007/s12518-018-0210-x
[2] Apollonio F I, Gaiani M, Basilissi W and Rivaroli L 2017 Photogrammetry driven tools to support the restoration of open-air bronze surfaces of sculptures: An integrated solution starting from the experience of the neptune fountain in Bologna International *ISPRS Archives* 42(2W3) 47-54 doi: 10.5194/isprs-archives-XLII-2-W3-47-2017
[3] Santoši Ž, Šokac M, Korolija-Crkvenjakov D, Kosec B, Soković M and Budak I 2015 Reconstruction of 3d models of cast sculptures using close-range photogrammetry Metalurgija 54(4) 695-698
[4] Pukanská K, Bartoš K, Weiss G and Rákay Š 2014 The application of close-range photogrammetry for a documentation of metallurgical art-historical objects International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM 3(2) 327-334
[5] Barrile V, Fotia A and Bernardo E 2019 The submerged heritage: a virtual journey in our seabed 2019 ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences 42(2/W10) 17-24 doi: 10.5194/isprs-archives-XLII-2-W10-17-2019
[6] Gherardini F, Santachiara M and Leali F 2019 Enhancing heritage fruition through 3D virtual models and augmented reality: An application to Roman artefacts Virtual Archaeology Review 10(21) 67-79 doi: 10.4995/var.2019.11918
[7] Santachiara M, Gherardini F and Leali F 2018 An Augmented Reality Application for the Visualization and the Pattern Analysis of a Roman Mosaic IOP Conference Series: Materials Science and Engineering 364(1) 012094 doi: 10.1088/1757-899X/364/1/012094
[8] Fazio L and Lo Brutto, M. 2020 3D survey for the archaeological study and virtual reconstruction of the sanctuary of ISIS in the ancient lilybaeum (Italy) Virtual Archaeology Review 11(22) 1-14 doi: 10.4995/var.2020.11928
[9] Bici M, Guachi R, Colacicchi O, D’Ercoli G and Campana F 2019 Posture evaluation for fragment re-alignment of ancient bronze statues: The case study of the principe ellenistico. Lecture Notes in Mechanical Engineering 323-335 doi: 10.1007/978-3-030-12346-8_32
[10] Bici M, Campana F, Colacicchi O and D'Ercoli G 2018 CAD-CAE methods to support restoration and museum exhibition of bronze statues: The "principe Ellenistico" IOP Conference Series: Materials Science and Engineering 364(1) 012014 doi: 10.1088/1757-899X/364/1/012014
[11] Fatuzzo G, Musumeci G, Oliveri S M and Sequenzia G 2011 The "Guerriero di Castiglione": Reconstructing missing elements with integrated non-destructive 3D modelling techniques. Journal of Archaeological Science, 38(12) 3533-3540 doi: 10.1016/j.jas.2011.08.016
[12] Sá A M, Rodriguez-Echavarria K, Griffin M, Covill D, Kaminski J and Arnold D B 2012 Parametric 3D-fitted Frames for Packaging Heritage Artefacts. VAST, 105-112