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From the Museum to the site and backwards

Digital Archaeological reconstructions usually aim at documenting the original position of blocks and architectural elements of the building, both the ones on site and those exhibited in museums. Digital survey and representation provide the opportunity to place the fragments into the reconstruction model of the building, thus making the understanding of their shape and function much easier.
A relevant difference between past and present reconstructions is the representation of the context and the landscape. The context is a relevant feature of watercolor ‘Restorations’ of the Grand Tour; on the other hand, in digital reconstructions the landscape is often neglected or reduced to a ‘background’ neutral image.
The study evaluates the use of equirectangular images as a tool to reconnect the metopes of the Temple E of Selinunte, today in the Archaeological Museum Salinas of Palermo, with the temple itself and with the landscape of Selinunte. The backwards experiment aims at displaying the metopes attached to the ruins of the temple on site. The position of metopes in the 3D model of the temple allowed to reconstruct the position that a camera should have on site, in front of the Temple, to match the point of view of the visitor inside the hall. The alignment of equirectangular images allows, in the museum, the transition between the real view of the hall and the real view of the Temple and the landscape around, combined with the virtual view of the reconstruction with the metopes; on site, symmetrically, the transition between the real image of the temple and the virtual images of the metopes will show their original position.

Keywords:
Virtual contextualization; Archaeological Museums; Selinunte; Temple E; Museum Salinas

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1.INTRODUCTION

The birth of Archaeology is usually dated from the second half of the XVIII century, when the excavation of Pompei arose a new and diffuse interest in antiquities. In literature and arts Romanticism echoed and implemented this interest.
Scholars from England, Germany and France visited many archaeological sites in southern Italy and in Sicily; the purpose of these travels, later named 'Grand Tour', was the documentation of archaeological ruins and the proposal of restorations, i.e. the reconstruction of the original layout of monuments, temples and sites.
Some restoration works focused the representation, in their original location, of architectural fragments discovered during the excavations and exhibited in museums.
Many 'restoration' drawings, e.g. perspective drawings, rendered the site and the landscape on the background of buildings and monuments.
Perspective 'restoration' drawings focused a major feature of ancient Greek towns and temples: the link between architecture and the landscape. It is well known that the choice of the proper site was a crucial step in Greek urban planning and architecture and that the beauty of the landscape of archaeological sites is usually comparable to the beauty of ruins.
After the end of the 'Grand Tour' season, the interest of scholars moved towards a deeper scientific knowledge of ancient buildings and artworks; surveying and drawings aimed therefore at the documentation of the actual layout of ruins, at supporting dating questions and at maintenance and preservation purposes; virtual restorations were almost dismissed and the interest for the natural context of archeological ruins waned.
The diffusion of digital surveying and representation tools in the past 30 years has reignited the interest for virtual reconstructions; the visual simulation of light and materials has offered the opportunity for a 'realistic' reconstruction of ancient buildings. Realistic models have been widely used for education and fruition purposes and by the entertainment industry as well: Greek and Roman monuments and towns and sites have become the background and the location of movies (e.g. Ridley Scott's *Gladiator* in 2000 and Wolfgang Petersen's *Troy* in 2004).
Although the fascination of Grand Tour's watercolor drawings cannot be equaled by digital representation, 3D 'realistic' digital reconstructions have disclosed new forms of fruition that use VR and AR tools for the visualization of virtual scenarios populated by ancient buildings and urban spaces.
Digital survey and representation tools give today the opportunity to virtually place 3D models of architectural fragments exhibited in museums into the reconstruction model of the buildings they were part of, thus facilitating the comprehension of their shape and position.
AR and VR solutions can operate a twofold reconnection between the fragment and the building: in the museum, the building can appear connected to the fragment; on site, the fragment can appear in its original location.
A relevant feature that marks a difference between archaeological virtual restorations from the past centuries and present digital reconstructions is the representation of the context and the landscape. Although the context, as stated before, is a major feature of archaeological sites, digital reconstructions often neglect it or substitute it with a background neutral image.
The experiment discussed in this paper aims at the implementation of a workflow that uses digital surveying and representation tools to set up

Fig. 1 - The metopes of Temple E in the Metope Hall at the archaeological museum A. Salinas of Palermo.

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a twofold connection between: i) architectural fragments exhibited in museums and the building they were part of; ii) the building and the landscape around it.
The workflow aims at enriching the visit experience in archaeological museums through the combination of: i) the pleasure given by the vision of the exhibited artworks; ii) the vision of the artworks in their original location; iii) beauty of archaeological sites and landscape. The expected result of such combination is to stimulate the museum visitor to visit the site as well.

The symmetric experiment aims at the visualization on site of museum's artworks in their original location in the 3D reconstruction of the buildings. The experiment uses equirectangular images for the visualization of virtual reconstructions.

2. CASE STUDY

The experiment focuses the Temple E of Selinunte (Sicily) and a set of three metopes, found amid the ruins of the pronaos during the excavation in 1832.

The three metopes from the pronaos, together with one metope from the opisthodomos (a small space symmetric to pronaos), are today exhibited in the 'Metope Hall' of the archaeological museum A. Salinas in Palermo; the metopes are mounted in a real scale arrangement that reconstructs a part of the frieze of the pronaos with triglyphs, cornices and guttae (fig. 1).
The metopes, as usual, render characters and events from the mythology. From left to right, the three metopes form the pronaos render *Heracles and the Amazon*, the *Wedding of Hera and Zeus*, *Artemis and Actaeon*; at the right end, the metope from the opisthodomos renders *Athena and Enceladus*.
Temple E, probably dedicated to Hera, is one of the three temples located outside the town of Selinunte, in the so-called Eastern Hill; the columns of the peristyle were found stretched on the ground, probably as a consequence of an earthquake. Extant Temple E is the result of an anastylosis carried out in 1956: the columns of the peristyle were erected and a cornice was built. Ruined walls of the western part of the naos with the opisthodomos are the only elements that document the inner layout of the Temple. The position of the metopes of Temple E was reconstructed for the first time by Domenico Lo Faso Pietrasanta Duke of Serradifalco in his *Antiquities of Sicily*, published in 1834; according to the reconstruction proposed by Serradifalco, confirmed by later studies (Marconi, 1995), the three metopes that decorated the front of the pronaos took the even spots, 2-4-6; fragments of the metopes that decorated the odd spots, 1-3-5, were found irreparably destroyed during the excavation (figg. 2, 3).

3. BACKGROUND

One of the first and most relevant experiment on the use of digital surveying and representation technologies for the recontextualization of archaeological fragments exhibited in museums was developed in 2004 by a multidisciplinary team

Fig. 2 - Ruins of Temple E in Selinunte.

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led by Paul Debevec. The work of Debevec and his team can be considered a high level, unparalleled and pioneering achievement. Even if 17 years have passed and the technology has moved far away, the amazing movie *The Parthenon*, that displays the marbles exhibited in the British Museum of London in their original location on the Acropolis of Athens, is still today a reference for researchers interested in the use of digital tools for the valorization of archaeological heritage.
In the years that followed lots of researchers focused the use of digital tools for the documentation, the reconstruction and the fruition of archaeological heritage; the shortest summary of published papers would fill many pages.
If we strictly refer to the Hall of metopes in the museum A. Salinas of Palermo, it is mandatory to mention a relevant research developed in 2005 by a team led by Angelo Beraldin [1]. The purpose of the project was the high res digitization of the metopes of Temple C, the major temple on the Acropolis of Selinunte, mounted on the left wall of the hall of Metopes, few meters far from the metopes of Temple E.
At a later stage the a virtual reconstruction of temple C was realized by Francesco Gabellone (Gabellone, 2006) after the archaeological studies of Carla Amici and Clemente Marconi; the reconstruction of Temple C was part of the LandLab project, coordinated by the University of Lecce.
Recent researches (Cannella, 2019) have developed an AR solution for the visualization inside the Metope Hall of the metopes of Temple E in their location; the proposed solution allows the visitor to visualize the 3D model of Temple E in real time as moving inside the hall.
AR is an optimal solution as well for the visualization of fragments on site, since 3D models can be visualized as the user moves around the ruins. AR usually displays 3D models; if the focus is the landscape, equirectangular images could be a better choice.
Equirectangular images have become familiar to millions, thanks to Google street view application; the application Google Arts and Culture uses the street view technology to propose virtual visits in many cultural sites and institutions.

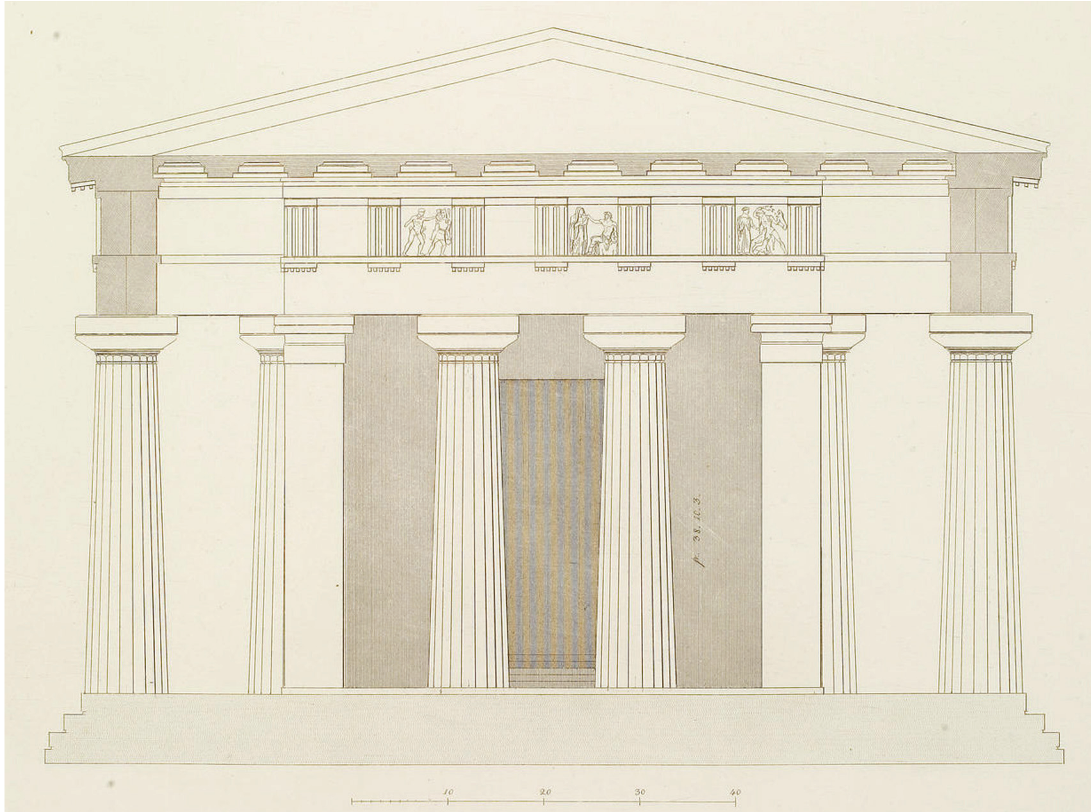

Fig. 3 - Serradifalco's reconstruction of the metopes on the front of the Pronaos of Temple E.

One of the advantages of equirectangular images is the representation of the site as it appears in photos; a further advantage is the limited computational resource needed for the visualization of images.
The great limit of equirectangular images is the link to a specific position. This is probably why equirectangular images have been rarely used to visualize virtual reconstruction or to propose the virtual reconnection of architectural fragments to the buildings they once belonged to.
The technological progress has led at the diffusion of wide angle cameras capable of capturing a panoramic image in one shot; the diffusion of these cameras arouse the interest for panoramic images, but the great part of the papers focus the use of panoramic images for surveying purposes (Paris, 2017). The use of these images for the fruition of cultural heritage seems minoritarian today, even if this technique has been used with success in the past for the visualization of archaeological reconstructions (Gabellone, 2015).

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4. PROPOSED METHOD

The proposed method uses laser scanning data and SfM photogrammetric tools to calculate, in a specific scene, the coordinates of the focal point of a set of images used to generate an equirectangular image; modeling tools have been used to build a sphere centered on this point and to map its surface with the equirectangular image.
In in order to fix the position of the focal point of photos taken from the ground, the camera, equipped with a wide angle lens, has been mounted onto a mechanical Nodal Ninja bracket; the bracket was positioned on a topographic head that was mounted on a tripod.
A sphere placed inside the museum will be mapped with an equirectangular image made from photos taken on site. The focal point of the panoramic image taken on site should be placed in a position that corresponds to a chosen point of view inside the museum: if, for instance, the metopes are mounted 1.5m high from the hall's floor and they originally stood in the Temple 15m high from the ground, then the image on site should be taken from a fixed point of view 13.5m from the ground.
In order to achieve such correspondence, the 3D model of the museum hall and the 3D reconstruction model of the building the fragments belonged to, are needed; in the modeling scene, the 3D model of the museum room moves until the fragment takes its position in the 3D model of the building.
After the hall has been referred to the building, a point of view inside the hall is positioned; this point should allow the vision of the fragment, the building and the landscape at the same time. The equivalent position of this point on the building on site, becomes the destination for a drone that captures the images needed for the creation of an equirectangular image.
The position of the point created in the 3D models and the position the drone will take on site will obviously not exactly match, but if the distance between these points is limited (10-30cm), the equirectangular image taken on site will nonetheless result effective for fruition purposes in the museum.
The position the visitor should take inside the hall, when watching the panorama taken on site, could be pointed by a removable marker sticked on the floor.
Small deviations on the horizontal plane, between the calculated and the real focal point, are not a problem because the marker on the floor can be shifted, when possible, to match the actual position of the focal point taken by the drone; deviations on the vertical axe, on the contrary, could affect the correspondence between the vision of the museum hall and the panoramic image taken on site.
The take-off spot of the drone on site can be manually positioned on the ground using the distances of the calculated point from the building, measured along x and y axis. The distance of the drone from the ground can be easily controlled by the altimeter.
Obviously, many panoramas can be taken on site from different points of view, and the same could be done inside the museum hall. The realization of many images, anyway, is not the focus of this research; the point of interest is the feasibility of a workflow that uses digital tools to match images taken on site with corresponding points of view inside the museum and overlaid panoramic images to contextualize, on site, the fragments exhibited in museums.
For the contextualization of the exhibited fragments on site, panoramic images that use photos taken from the ground from a fixed focal point should be taken. After the coordinates of the focal point of the equirectangular image have been calculated with SfM photogrammetric tools, a virtual camera, positioned on the corresponding point of view in the virtual space of the 3D reconstruction model, should be used to generate the equirectangular

Fig. 4 - 3D NURBS model of the Metope Hall in the museum A. Salinas with the mesh model of the metopes from Temple E.

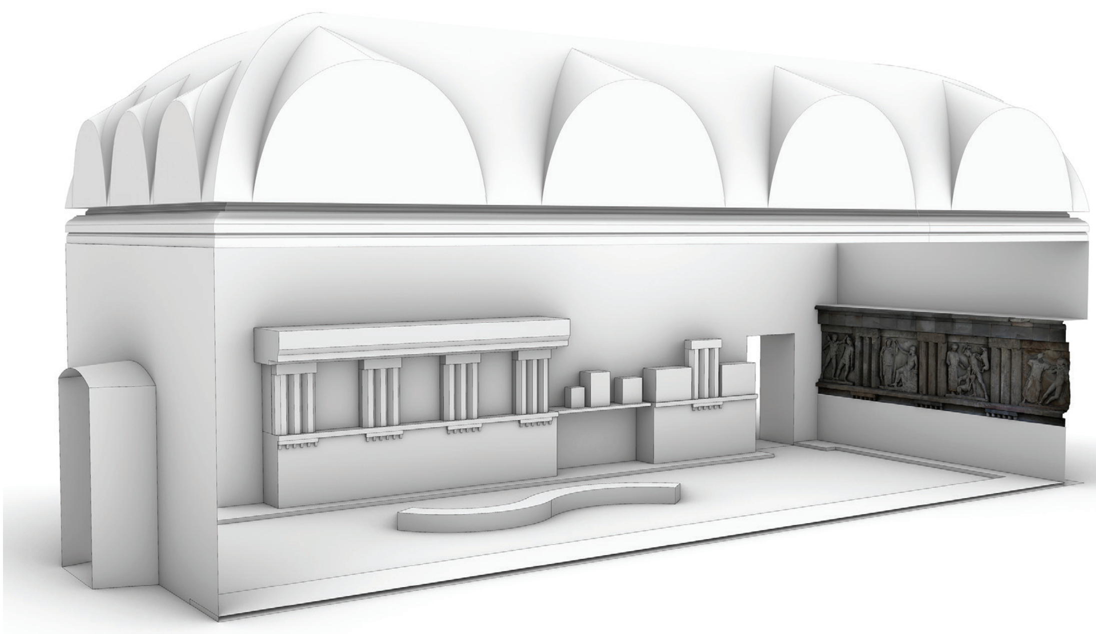

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image of the reconstruction model of the building with the exhibited artwork. The visitor, when on the place corresponding to the focal point of the equirectangular image, could watch the artwork from the museum in their place, inside the reconstructed model of the building. The position for the proper visualization of panoramas could be marked, on site, by small tiles fixed on the ground. The twofold reconnection between the artworks exhibited in museum and the building would be achieved at the end of the workflow; furthermore, the landscape and the site would become part of the visual experience of the visitor at the museum.

5. EXPERIMENT AND ANALYSIS

The first step of the experiment addressed the survey of the Metope Hall at the museum A. Salinas; a couple of laser scans and many photos of the metopes were taken; the laser scanning point cloud was rotated around the z axe to make the bottom wall with the frieze parallel to *XZ* reference plane. The point cloud has been used to build the 3D NURBS model of the Hall and to scale and orient the SfM photogrammetric model. The mesh of the frieze with the metopes was finally generated with SfM tools and was combined with the 3D NURBS model of the Hall (fig. 4).

In order to test the photogrammetric calculation of an equirectangular image's focal point, a second set of photos was taken from a fixed point inside the hall, almost 16m far from the wall with the frieze, 1.60 high from the floor. Further photos of the hall with the camera hold in hand have been taken to improve the orientation of the SfM photogrammetric model [2].

The photos have been uploaded in the same chunk (the sub project unit used by Metashape); the images taken with the Nodal Ninja bracket have been grouped in a folder and this folder has been classified as 'Station Folder', meaning that all photos in this folder have been taken from the same point of view. The images have been aligned and the photogrammetric model has been scaled and oriented to match the laser scanning point cloud, according to a well-known workflow that uses markers whose coordinates are taken from the laser scanning point cloud (fig. 5).

The Panorama and the coordinates of the focal points of photos have been exported; in the 3D model of the Hall a sphere has been centered on the focal point of the images used to calculate the panorama; the normal of the sphere has been directed inwards; the equirectangular image has been mirrored around its vertical symmetry axe with a photo editing tools. Finally, the sphere has been mapped with the equirectangular image. In order to check the correspondence between the panorama and the 3D model of the hall, a vertical plane through the center of the sphere and a specific point on the *Heracles and the Amazon* metope has been generated; the meridian at the intersection of the plane and the sphere has been generated (fig. 6).

A virtual camera placed on the center of the sphere revealed that a 90° CCW rotation of the sphere around its vertical axe would provide a perfect match between the equirectangular image and the 3D model of the hall. The transparency factor of the texture mapped on the sphere has been adjusted to allow the simultaneous view of the equirectangular image and the 3D model of the hall (fig. 7).

The experiment proved the efficacy of the SfM photogrammetric workflow for the creation and the orientation of equirectangular images in a specific scene.

Fig. 5 - Images of the Hall oriented.

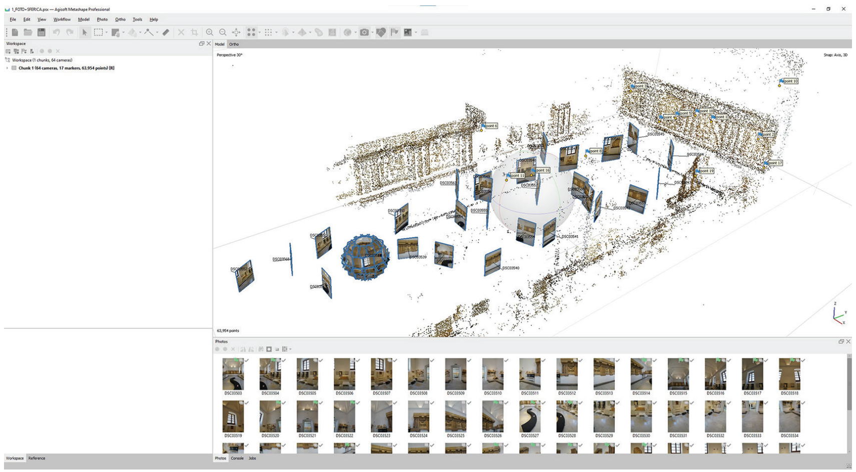

Fig. 6 - The sphere mapped with the equirectangular image generated by Metashape.

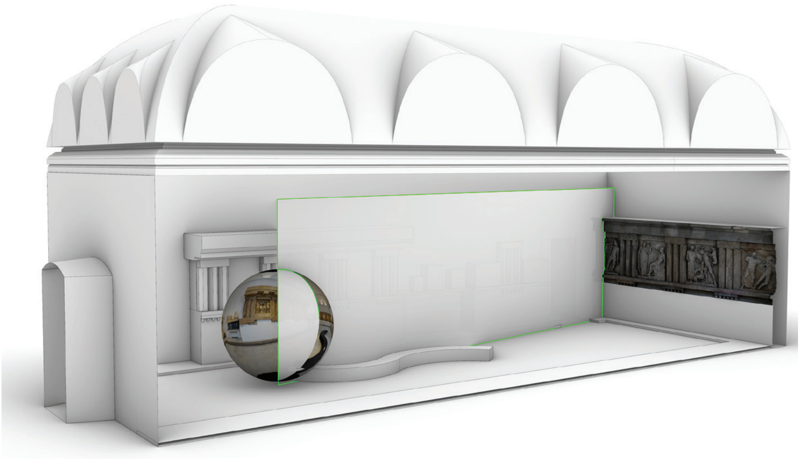

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Fig. 7 - The equirectangular image and the 3D model of the Hall of Metopes viewed from the center of the sphere.

The 3D reconstruction model of Temple E was built according to the drawings published by Lo Faso Pietrasanta; the laser scanning survey of the eastern part of the Temple allowed to check, scale and adjust the 19th century drawings. The laser scanning point cloud has been rotated to make the vertical plane of the eastern front parallel to *XZ* reference plane, i.e. parallel to the wall with the frieze in the Metope Hall.
The following step addressed the calculation of the translation vector that moves the first metope on the left of the frieze, rendering *Heracles and the Amazon*, to the second metope from the left on the front of the pronaos (fig. 8).

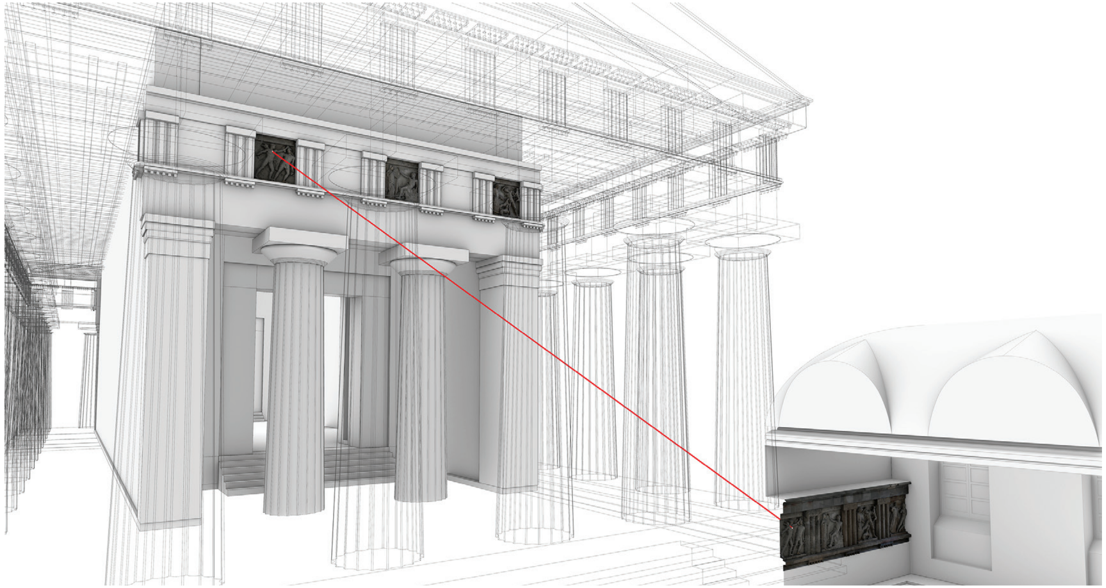

Fig. 8 - The vector that moves the metope Heracles and the Amazon to its original location.

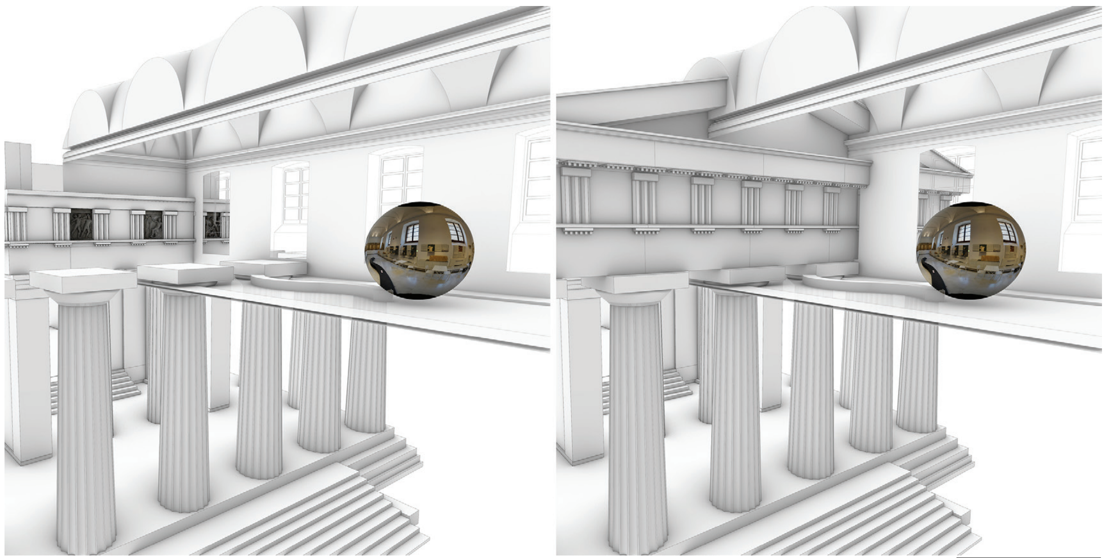

Fig. 9 - The hall moved to match the position of Heracles and the Amazon in the 3D model of the Temple.

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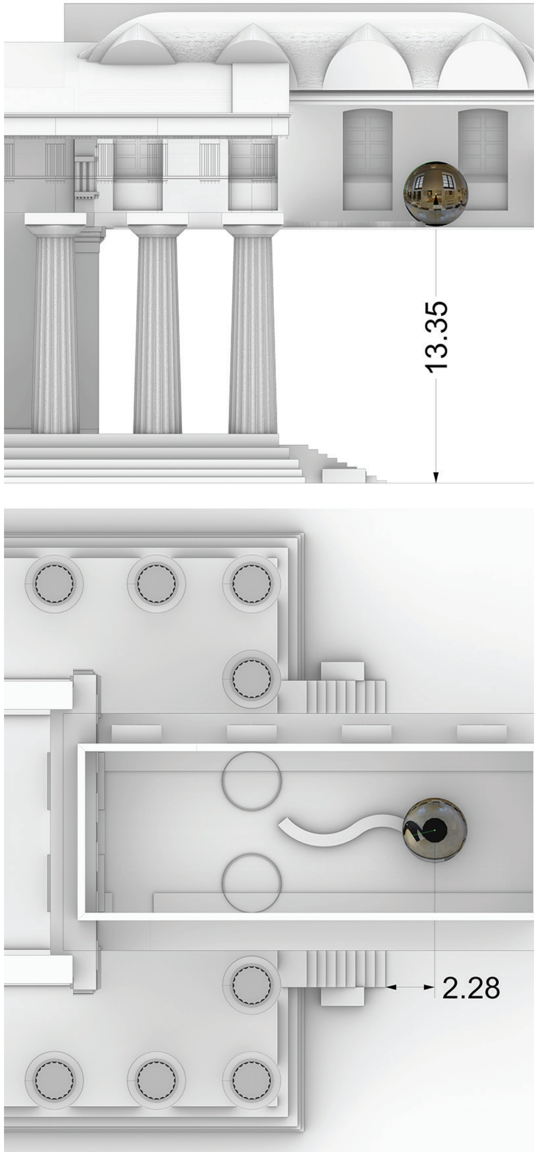

Fig. 10 -The focal point of the Hall's equirectangular image referred to the Temple.

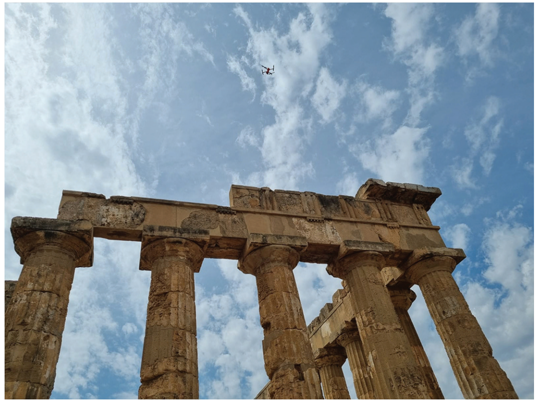

Fig. 11 -The drone flying at 13.30m from the ground.

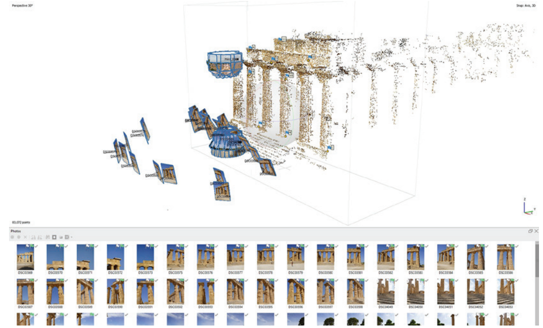

Fig. 12 -The SfM photogrammetric project with the panoramic images taken by the drone and from the ground, plus further sparse images; the image shows the markers used to scale the photogrammetric model and refer its position to the reference coordinate system of the laser scans of the Temple.

The remaining metopes of the front of the pronaos were detached from the frieze to take their supposed original location: the *Wedding of Hera and Zeus*, took the fourth spot and *Artemis and Actaeon* took the sixth and final spot of the frieze of the pronaos (fig. 9).
The second phase of the experiment addressed the realization of the equirectangular image of the Temple and the landscape. The reference of the Metope Hall to the Temple supports the choice a point of view that would allow, at the same time, the vision of the metopes on the pronaos and of the landscape around the Temple. The position of the focal point of the equirectangular image of the hall resulted compatible with this purpose. The following step addressed the calculation of the equivalent position of the chosen focal point in front of the temple, on site. On *XY* reference plane, the center of the sphere resulted almost aligned to the longitudinal axe of the temple, at a distance of 2.28m from the lower step of the access stair; this point, detected on the ground, will be the take-off point for the drone operations. The elevation of the focal point, referred to the take-off point, measures 13.35m (fig. 10).

The photos on site were taken with a drone [3]; the take-off point was positioned manually on the ground with the aid of a distance meter; the elevation from the take-off point was controlled by the altimeter; the photo acquisition process started when the drone reached the desired position (fig. 11).
Further photos were taken from the ground according to the workflow experimented at the Metope Hall: some photos with the camera in hand, and a set of specific photos with the camera mounted onto the Nodal Ninja arm, to be used for the realization of an equirectangular 'ground level' image.
All the photos taken on site were uploaded into a SfM photogrammetric project; the photos used for the computation of the aerial and of the ground level equirectangular images have been grouped in two folders; the photos were aligned and the photogrammetric model was scaled and oriented with reference to the laser scanning point cloud of the Temple (fig. 12).
The coordinates of the images were exported and the deviation between the focal point of the equirectangular image taken by the drone and the corresponding point in the Metope Hall could be evaluated: the focal point of the image taken on site matched almost exactly

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Fig. 13 -The spheres mapped with the equirectangular image of the Hall (left) and with the equirectangular image taken on site (right). The image shows that the deviation is absolutely acceptable for the purpose of the research.

the height of point inside the Hall, reporting a deviation of 5.6cm; on *XY* plane the distance between the two focal points resulted equal to 22.6cm (dx=9.2cm, dy=19.9cm) (fig. 13).
The resulting deviations are surely acceptable for the purposes of fruition and, if desired, the point suggested for the vision of the panoramic image of the site could be exactly positioned on the floor of the Hall, due to the proximity to the calculated point and to the absence of obstacles (furniture, exhibition supports, etc.) around.
If the error had affected the height of the point of view (i.e. 50 cm upwards or downwards), the correction would have been impossible and a new set of photos from the drone had to be taken on site.
Nonetheless, the 20 cm horizontal deviation is so small that the match between the hall

Fig. 14 -The equirectangular image of the Hall and the corresponding image taken on site with the drone.

Fig. 15 -The sphere in the Hall mapped with the aerial equirectangular image taken on site.

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and the equirectangular image of the site would be satisfactory even if the visitor stood in the focal point of the equirectangular image of the Hall (figg. 14-15).

When in position, the visitor at the museum could view the Temple E reconstructed, the metopes in their original location and the astonishing landscape with the Mediterranean sea and the olive and grapes fields in the hinterland (figg. 16-17).

The second goal of the experiment aimed at establishing a connection between the site and the museum; such connection is simpler than the previous one; the equirectangular image realized with the photos taken from a fixed point of view in front of the Temple, 1.60m high from the ground, was mapped onto a sphere whose center matches the position of the focal point of the equirectangular image, calculated, once again, with SfM photogrammetric tools.

The 3D reconstruction model of the Temple has been exported in fbx file format and uploaded in Blender; here, an equirectangular image of the 3D reconstruction model of the Temple has been generated.

The two equirectangular images have finally been combined to make the metopes of the Salinas appear behind the columns of the temple on site.

In both places (museum, site) the points of view for the vision of equirectangular images could be highlighted by small markers fixed on the ground (fig. 18).

6. RESULTS

The research proved the possibility to enrich the visual experience of the visit in an archaeological museum through the use of equirectangular images; such images can effectively operate the connection of exhibited architectural fragments with the reconstruction model of the building they once belonged to, and, at the same time, the connection of the building and the landscape around it.

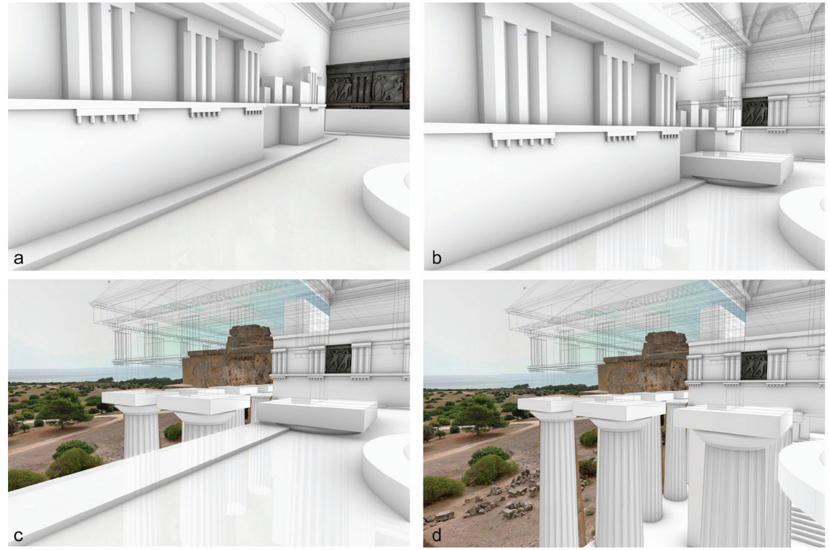

Fig. 16 -Transition from the view towards the left corner of the Hall, the view of the metopes on the front of the Pronaos and the sea southwards

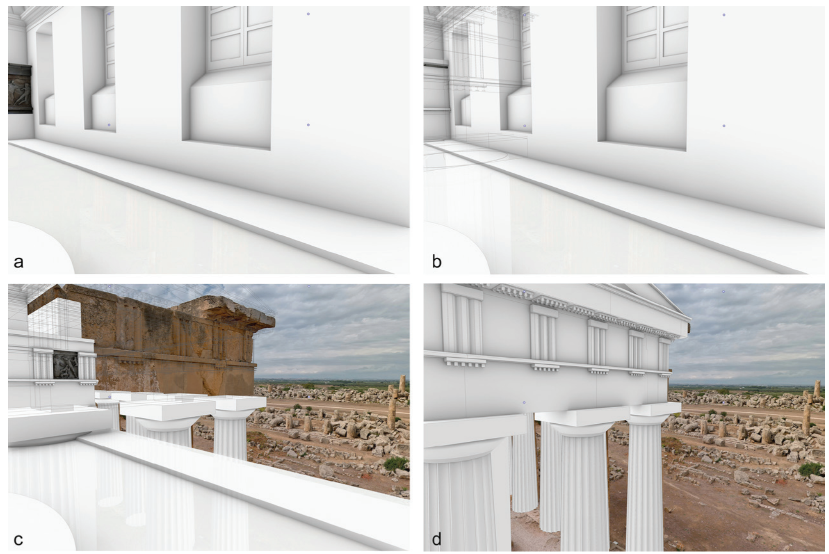

Fig. 17 -Transition from the view towards the right corner of the Hall, the view of the sixth metope on the front of the Pronaos and the hinterland northwards.

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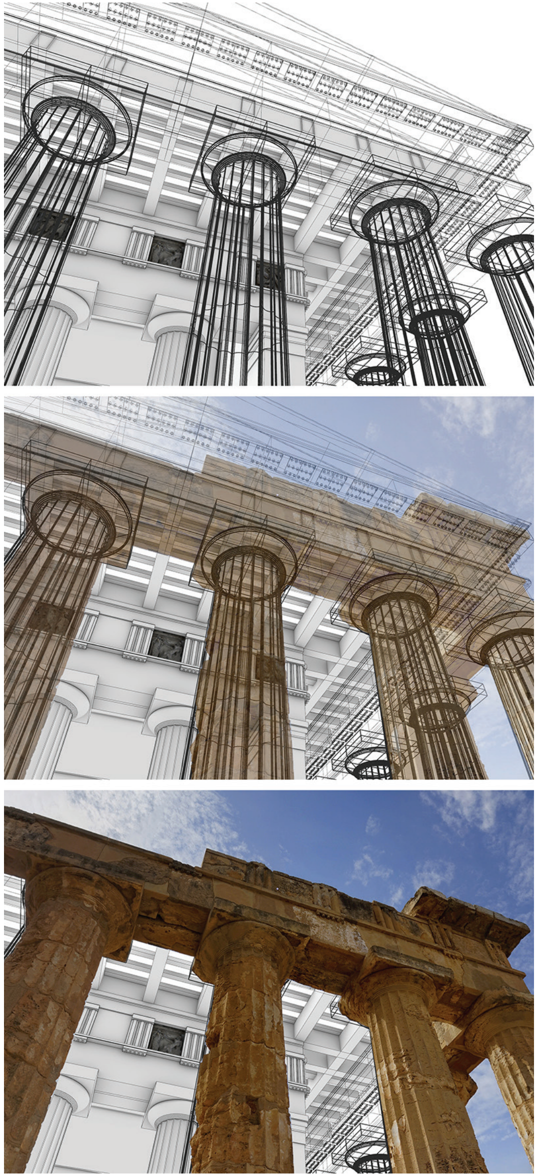

Fig. 18 -Transition from the view of the 3D model of the Temple and the combination with the equirectangular image taken on site.

Virtual reality provides a virtuous connection between the museum and the site, promoting the beauty of the archaeological landscape and inviting museum's visitors to visit archaeological sites as well.
The proposed method integrates laser scanning and SfM photogrammetric surveying tools, plus digital modeling tools, to operate a satisfactory calculation of the position of the point of view on site that matches the equivalent position of a point of view inside the museum's hall.
The symmetric experiment successfully proved the possibility to use equirectangular images to display, on site, the architectural fragments in their original location.

7. CONCLUSION AND OUTLOOKS

The proposed workflow should be tested on similar architectural fragments in archaeological museums. Further experiments should address the combined use of VR equirectangular images and AR solutions to enrich the visual experience of visitors in museums and in archaeological sites. The results of this research suggest that VR equirectangular images should be preferred in museums, whereas AR solutions could be a better solution on site, but the combination of the two could change according to the specific features of each case study.

8. ACKNOWLEDGEMENTS

The author thanks Dott. Caterina Greco, Director of the Archaeological Museum A. Salinas of Palermo, and Arch. Bernardo Agrò, Director of the Archaeological Park of Selinunte, for having encouraged this research and having allowed and facilitated the acquisition of scans and photos.

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NOTE

[1] The project, named *The metopes of Selinunte,* involved the SIBA of the University of Lecce and the Institute for Information Technology of the Canadian National research Council

[2] The photos used for the creation of equirectangular images have been taken with a Sony ILCE 7R mirrorless camera equipped with a 24mm; generic photos with the camera hold in hand have been taken with a 35mm lens; laser scans of the hall and the temple have been taken with a phase-based scanner Leica HDS 7000; SfM photogrammetric processing has been developed with Agisoft Metashape; 3D models have been built with Rhinoceros 6.0.

[3] The drone used in this research is an Autel Evo II Pro; the software that controls the flight operations is implemented with a specific tool for the automatic acquisition of images to be used for the computation of equirectangular images.

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