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From aerial survey to representation and visualization: the Temple G of Selinunte.

The paper reports the outputs of a research work focused on the segmentation of meshes generated from aerial photogrammetric survey, aiming at the implementation of a database integrated in a web-based Information System developed with 3D-Hop technology, that uses models as the access point to information data.
Segmentation is a relevant topic in cultural heritage documentation, since it is the a pre-requisite for the development of systems that connect information data to 3D models.
The chosen case study is the Doric Temple G of Selinunte, an archaeological site in southern Sicily. Temple G, one of the biggest Doric Temples of Magna Graecia, it is today a huge heap of ruins, probably due to one or more past earthquakes; though centuries have passed, ruined blocks often show their original shape.
The proposed segmentation workflow is based on the identification of the shape and position of the blocks in the original layout of the Temple, via the extraction of section profiles and the NURBS modelling.
The NURBS models have supported the virtual reconstruction of some columns of the southern front of the Temple; the reconstruction model has finally been used for the development of a video that uses motion tracking techniques for the visualization of the columns in the real scene in a footage taken with a drone.

Keywords:
Temple G; Drones; Virtual reconstruction; Motion tracking; Video-compositing.

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INTRODUCTION

The survey of Temple G, performed with a drone, has been illustrated in a previous research work (Agnello, Cannella, 2022) and will not be discussed here. The digital twin of the ruins of Temple G is assumed as the starting point of this research work. The 3D mesh computed with photogrammetric tools documents only the visible parts of the blocks; one of the critical issues in the study of Temple G is that the greatest part of the ruined blocks is partially occluded by the ground or other ruined blocks.

Since the purpose of the research is the identification of the shape and position of ruined blocks, the study aims at reconstructing the entire volume of blocks via the geometric interpretation of the visible parts.

In recent years several researches have focused the automatic segmentation of 3D meshes for the implementations of information systems and of BIM Heritage models; some of these researches use AI algorithms for the identification of elements in point clouds and meshes. The approach seems to be based on the resemblance of parts of the point cloud with digital models or with geometric primitives.

Automatic segmentation is usually on buildings that have preserved their original layout, having their architectural elements (capitals, columns) in place.

The workflow for the interpretation of the shape and position of the surveyed blocks of Temple G has to follow a different path, since the blocks are only partially documented.

The solution that has been tested for the reconstruction of blocks is the extraction of sections, the re-drawing of section profiles, often affected by irregularities due to decay phenomena of surfaces, and to the construction of 3D NURBS model that represent the stone block (drum, cornice, and the like) in its full original dimension and shape.

The 3D modelling process uses archaeological studies and the theory of representation for the identification of the shape and function of the blocks.

In this research work the 3D models of the blocks are used for a double purpose: i) test the efficacy of free web based solutions for the implementation of databases where information data are directly linked to 3D elements; ii) test the use of motion tracking techniques for the visualization of the virtual reconstruction of some architectural elements of the Temple for dissemination purposes.

Temple G is a case study that allows to show the potentials of the combination of digital replicas and digital drawing and modelling tools for the interpretation of architecture. Though thirty years have passed, the illuminating definition of the surveying process due to Riccardo Migliari sounds as a warning for researches on Cultural Heritage: "The purpose of survey is the reconstruction of the design process".

TEMPLE G SURVEYED, REPRESENTED AND RECONSTRUCTED (1764-2021)

Selinunte, located on the Southern coast of Sicily, marked the western edge of the Greek area in Sicily; the town was close to the border of the region dominated by Carthaginians. The construction of Temple G, one of the greatest Doric Temples of Magna Graecia, started in 530 B.C.E. and was interrupted in 409 B.C.E., when the town was destroyed during a war against Carthage; at that time the Temple was yet unfinished, as witnessed by the absence of flutes in the drums of most columns. Temple G is a pseudodipteros, i.e. a peripteros temple whose colonnade is far from the walls of the naos, at a distance that is usual in temples with a double colonnade (dipteroi). The naos was divided into three naves by two rows of columns and its inner area was hypethral, i.e. not covered by a roof. The colonnade was made of 8 columns along the eastern and western fronts and 17 columns on the others. Temple G is one of the three Doric Temples that were built outside the walled acropolis of Selinunte, beyond the river that flew along its eastern side, on a patch of almost flat ground, usually named 'Eastern Hill' (fig. 1).

Fig. 1 - Photo of the Eastern Hill. Temple G is pictured on the right lower corner of the image.

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The Temple is today a huge heap of ruins, probably the effect of one or more undated earthquakes.
The site of Selinunte was first noticed in the second half of the 16th century by Domenico Fazello, a Dominican friar and historian.
In the Grand Tour age, 18-19th century, when the study of ancient architecture was considered a mandatory step in the education of architects, many scholars came to Sicily from northern Europe to study Greek and medieval architecture; Selinunte was one of the privileged sites of the Tour. The Temples were surveyed and represented in their actual arrangement, and then 'restored' to visualize their original supposed layout.
The first drawing that represents the ruins of Temple G, due to the Dutch scholar Jacques Philippe D'Orville, was published in 1764; the plate is made of two drawings: a perspective 'realistic' view of the southern edge of the huge heap of ruins and a schematic plan with an incomplete reconstruction of the supposed original arrangement of the Temple (fig. 2).
Many other surveys and representations, more and more detailed and penetrating, were made in the lapse of time from 1674 to 1920, but the standard fixed by D'Orville will not change: the representation of the ruins is always made by a perspective drawing of one side of the Temple taken from the ground; the plan always shows a reconstructed simplified representation of the original layout.
No plan of the ruins in their real arrangement has been proposed in these centuries: the lack of an elevated spots around the temple made the survey and the representation of the inner area an almost impossible task.
The first orthographic plan projection of the actual arrangement of the ruins came two centuries later the drawing of D'Orville: in 1985 Giorgio Gullini and Furio Fasolo drew a plan of the Temple using red ink to represent the ruined blocks and black ink for the reconstruction of the plan of the Temple (fig. 3). The drawing was referred to a detailed aerial photo (probably an orthophoto) of the Temple, taken few years before.
A later plan with a similar representation of the Temple has been drawn by Mario Luni and his team, during an archaeological study developed by the University of Urbino from 2011.

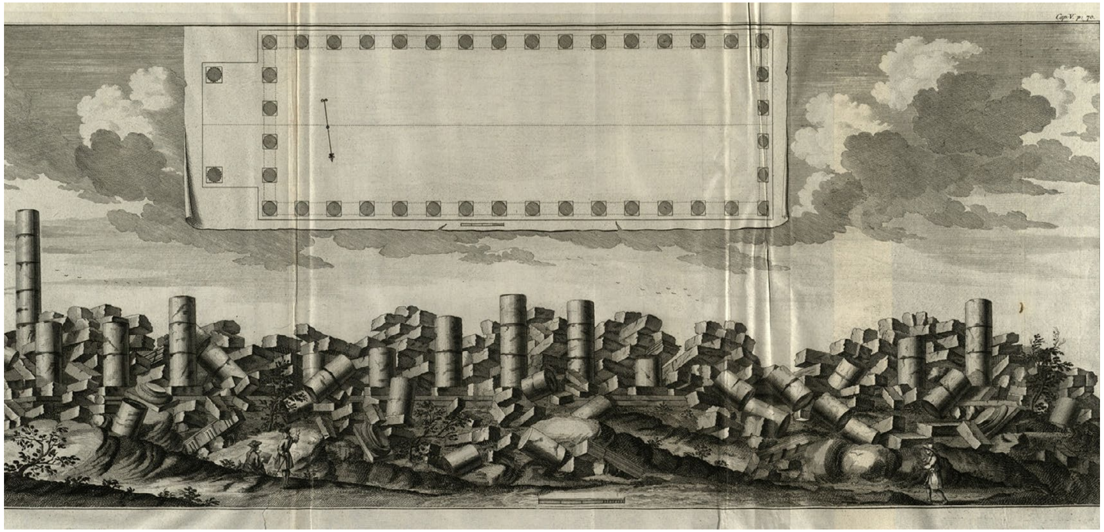

Fig. 2 - Jacques D'Orville, Perspective view and schematic plan of Temple G, from D'Orville, 1764, p. 70.

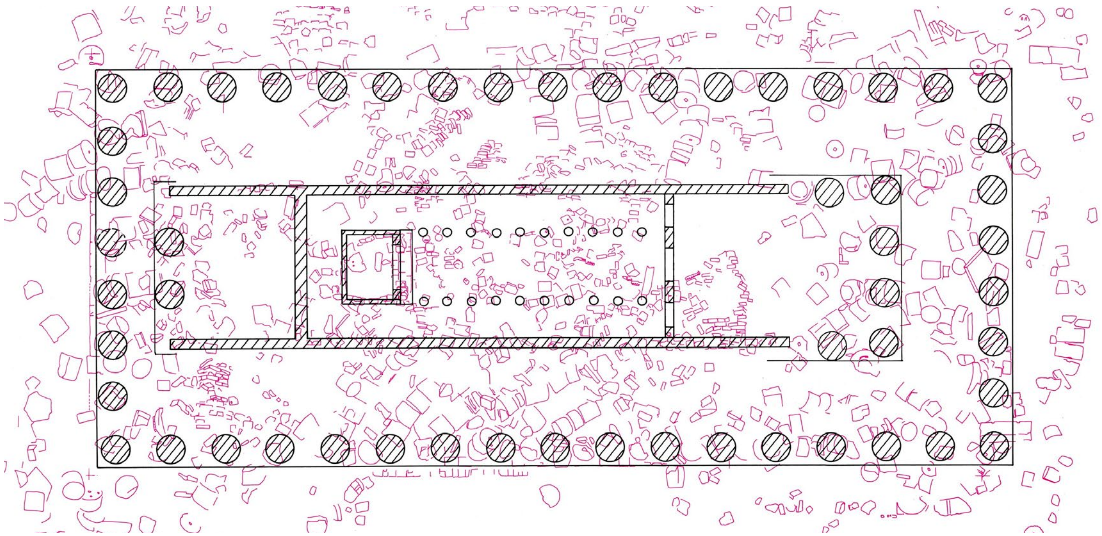

Fig. 3 - Giorgio Gullini and Furio Fasolo, Plan of Temple G and reconstruction of the plan.

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These plans highlight the inability of traditional drawing tools and techniques to represent an unordered heap of architectural elements.

THE DIGITAL SURVEY OF TEMPLE G (2005-2022)

The extremely short and lacking resume reported above, shows that Temple G is a very hard subject for surveying and representation purposes; the main critical issues can be resumed as follows: i) Temple G is a very big monument, wide and long as a soccer stadium, but demands detailed documentation, because the accurate documentation of the shape and size of its constructive elements is mandatory for a correct interpretation of their position and function; ii) the blocks are partially (sometimes fully) covered by other ruined elements; iii) the absence of flutes makes the anastylosis of drums more difficult; iv) vegetation makes roots in the interstices between stone blocks and covers the ruins.

A laser scanning survey was tested, for the first time as we know, during an International workshop promoted by the Universities of Palermo and Barcelona in 2005; scans were taken with a Riegl LMS-Z620 laser scanner. In order to achieve a complete documentation of the whole area of the Temple, the laser scanner was placed on a mobile platform positioned at approximately 18m from the ground. The platform was stabilized with the aid of ropes fixed to posts hammered in ground, in order to limit the movements due to the mechanical features of the elevator and to the wind.

The outputs of this first surveying session, presented in past conferences, evidenced two critical issues: i) the platform's stabilization did not prevent small vibrations and movements, that emerged from the comparison of the topographic and laser scanning coordinates of targets placed on the ground, with errors ranging from 1.5 to 5cm; ii) the resolution of scans was inadequate for the documentation of the geometry and constructive details of the blocks, both for the technical specs of the device and for the low scanning resolution, used to limit the time of acquisition and hence the movements of the platform; iii) the time needed to set up the platform, the spots and the scanner allowed the acquisition of few scans per day; iv) stabilization obliged to place the platform outside the Temple and the resolution of scans decayed in inner areas (fig. 4). The 2005 surveying campaign evidenced that the 3D documentation of Temple G demanded an aerial survey; aerial photogrammetry was well developed at the time, but it was quite difficult to extract a 3D model from a bunch of photos with the photogrammetric tools available at that time, especially if the 3D model had to be accurate and detailed.

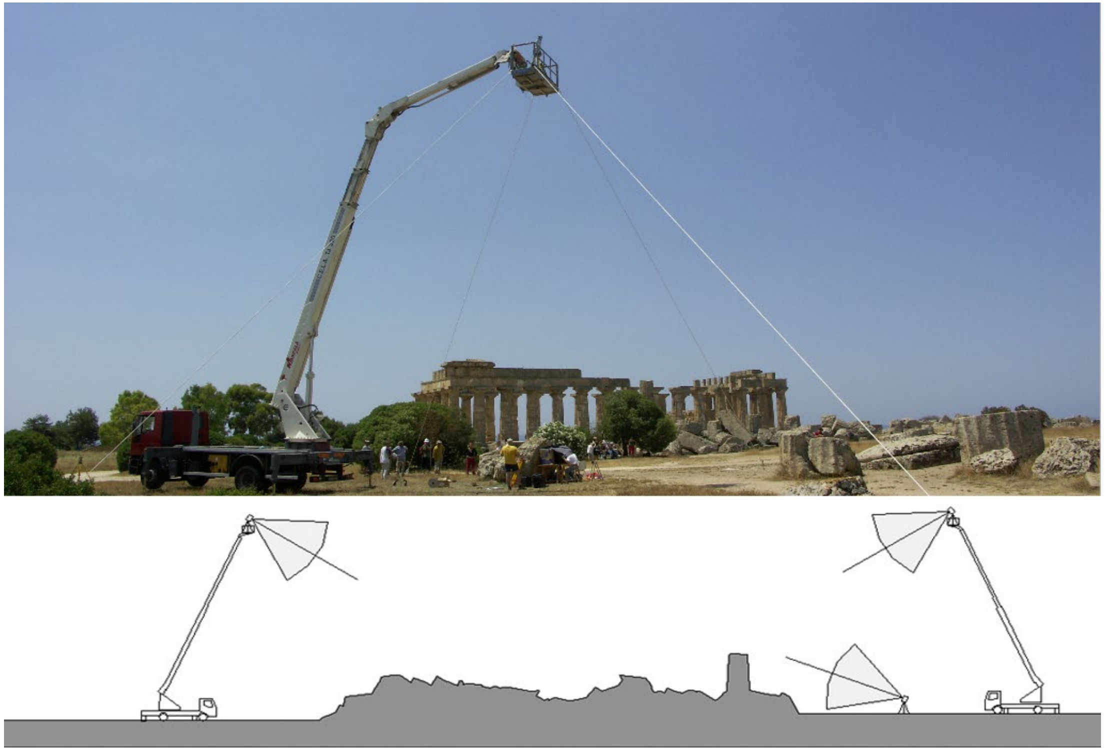

Fig. 4 - The mobile platform, stabilized with ropes, used in 2005 for the acquisition of laser scans.

Even aerial laser scanning was available at the time, but the cost and the resolution of aerial scanners suggested to discard this opportunity.

In 2009 laser scans, taken with a Leica Scan Station 2 and with a Leica P20 scanner, addressed the documentation of restricted areas of the southern colonnade and of the naiskos at the western end of the naos, for the purpose of study and virtual reconstruction.

In the second decade of this century, SfM photogrammetry and drones have been noticeably developed and have become effective tools for the documentation of architecture. The coeval evolution of low cost hardware and software tools for aerial survey made the overall documentation of the ruins, for the first time, an achievable task.

In 2021 the opportunity for a survey that used drones and SfM photogrammetric techniques was

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provided by the decision of the Archaeological Park Governance to remove the vegetation that, 11 years later the previous removal, had come to cover a great part of the visible surfaces of the ruins.
The first step of the surveying process was dedicated to measure a topographic polygonal that encompasses the area of the Temple.
Photos have been taken with an Autel Evo II Pro drone at a flight altitude ranging from 15 to 20 meters; missions were planned in 'oblique' mode: when flying in this mode, the software draws 5 grids, almost overlapped and overlaid to the rectangle that frames the area to be surveyed. The first grid is made of the flight paths swept by the drone when capturing nadiral images; the remaining grids are covered by the drone for the acquisition of images with a tilted customizable shooting axe; each grid corresponds to a shooting direction on a vertical plane orthogonal to each side of the rectangular surveying area.
The area of temple G was divided into four parts and a mission was planned for each part. The photos taken for the documentation of the four parts amount to 5605.

DIGITAL 'CONTINUOUS' REPRESENTATION (ORTHOPHOTOS, SECTIONS, TEXTURED MESH)

The SfM photogrammetric model allowed the calculation of three outputs: dense point clouds, textured 3D meshes and 2D orthophotos. At a distance of almost 40 years from the publication of the plan of the ruins drawn by Gullini and Fasolo, the orthographic plan projection of the photogrammetric model can be considered the first comprehensive measurable orthographic representation of the Temple. Further Orthophotos have been calculated for the representation of the fronts of the ruins (Fig. 5).
The textured 3D mesh has been used for the representation of sections as well: the section line can be extracted automatically from the mesh, or can be redrawn on a filtered visualization of the point cloud, realized with the aid of cutting planes properly arranged in the 3D virtual environment. In this study the second mode has been chosen

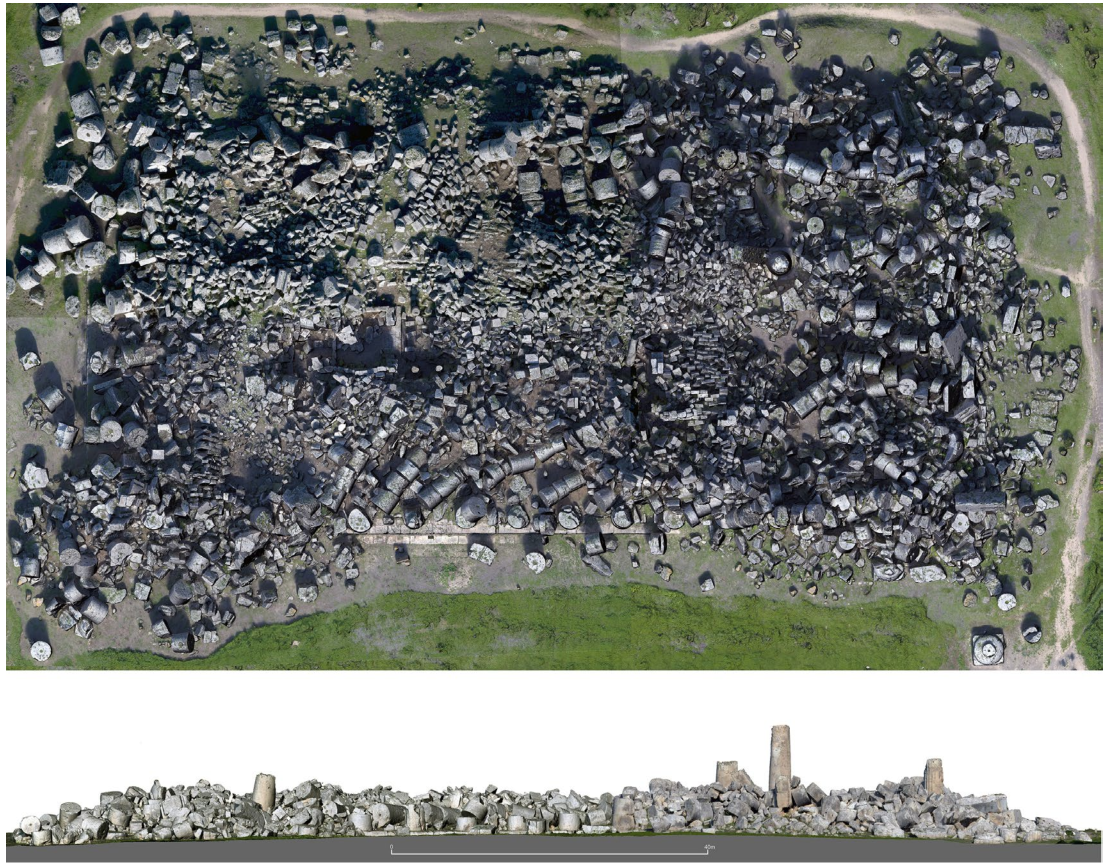
Fig. 5 - Orthophoto of the plan and the southern front of Temple G.

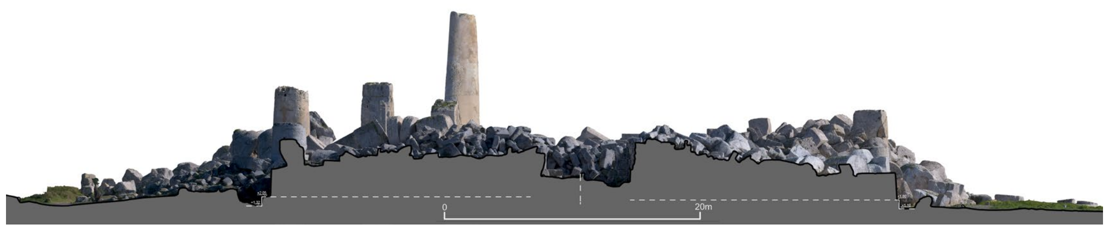

Fig. 6 - Vertical transverse section of Temple G; hidden lines represent the reconstructed section of the peristyle.

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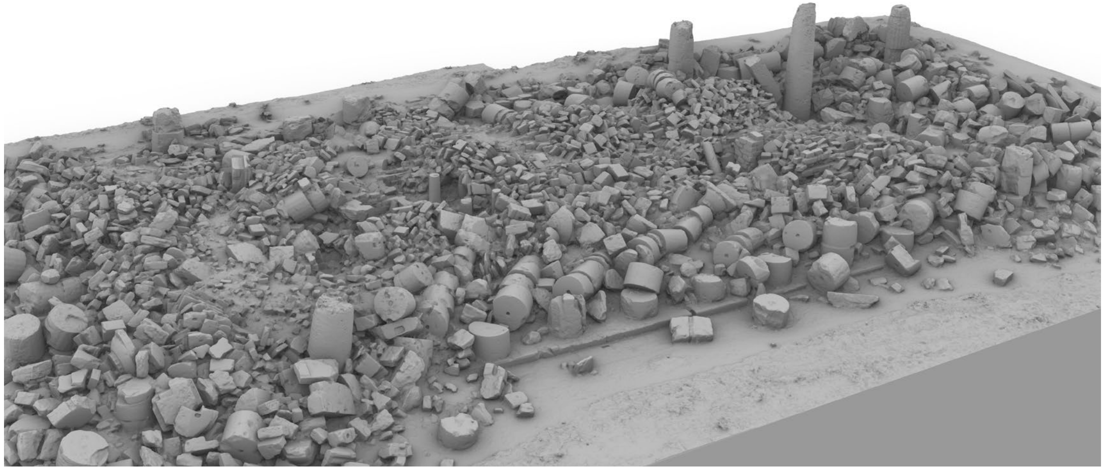

Fig. 7 - Perspective view of the 3D mesh generated with photogrammetric tools.

Fig. 8 - Orthophoto of the plan of Temple G. Continuous lines represent the base drums of columns that can be detected; hidden lines refer to the supposed position of the remaining columns. Transverse and longitudinal distances between the centre lines of the wings of the colonnade are reported. The section line refers to fig. 6.

because it allowed a higher control by the operator. Each section has been integrated with the orthographic projection of the 3D textured model of the ruins onto the vertical section plane (Fig. 6). Orthophotos and 3D meshes (Fig. 7) extracted with photogrammetric semi-automatic surely provide effective representations of the actual arrangement of Temple G, but no information on the design of the Temple and on the position and function of its ruined blocks has yet emerged. Nonetheless, digital twins provide the opportunity to investigate, with drawing and modelling tools, measures and correspondences simply unachievable with a traditional survey.
The only way to enrich the knowledge of the Temple, of its size and proportions, of the shape of its constructive elements, is to go beyond the 'continuous' representations and start the creation of 'discrete' representations, using drawing and modelling tools.

DIGITAL 'DISCRETE' REPRESENTATION: DRAWINGS AND 3D NURBS MODELS

The first step of the study has addressed the identification of the size (length, width) of the Temple; this step is not so easy, because a great part of the upper edge of the stylobate is hidden by ruined blocks. The orthophoto and the 3D analysis of the mesh allowed the identification of the base drums of many columns and the representation of their circular profiles. The straight lines through the centres of the circles, compared to the representation of the visible parts of the edge of the stylobate, allowed to argue that some base drums have moved from their original position, due to the collapse (Fig. 8).
The distance between the lines through the centres of southern and northern colonnades results 45.56m; the transverse size of the stylobate, measured along the section line, from the visible parts of the southern side to an excavated spot on the northern side, is equal to 49.87m; the average distance between the centre of drums and the edge of the stylobate results therefore equal to almost 2.15; this datum is validated by meas-

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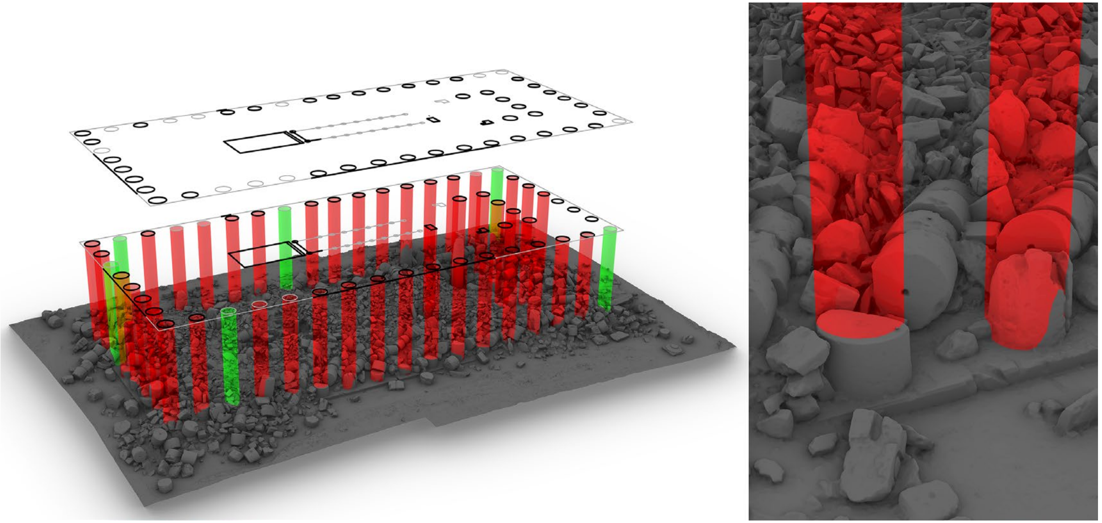

Fig. 9 - 3D verification of the position of base drums. Red cylinders refer to visible drums; green cylinders to columns that have been reconstructed. The close view of the model on the right shows a base drum that moved from its original position.

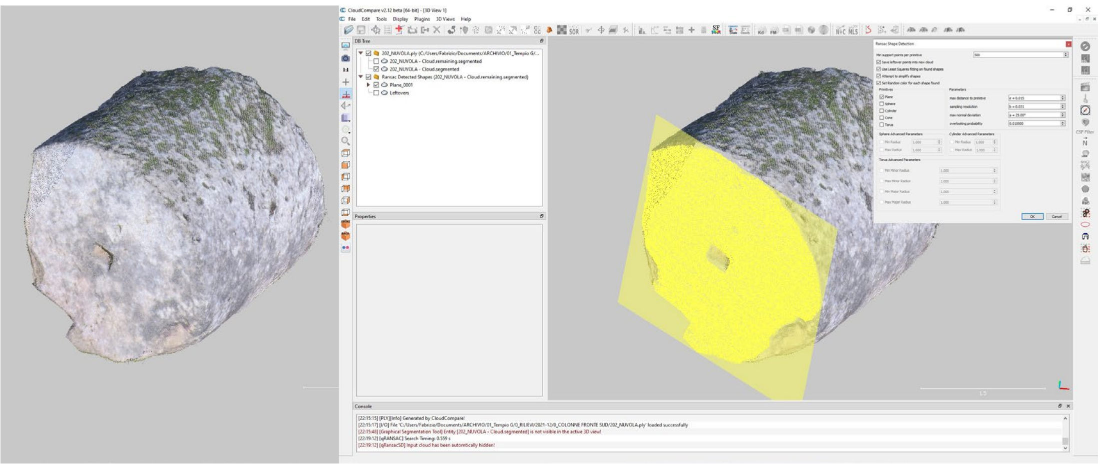

Fig. 10 - Segmentation of the point cloud to isolate the investigated element. Points on the lower base of the drum are selected and the Ransac calculation is launched. The plane mesh surface is imported in the drawing and modelling software Rhinoceros.

ures taken on the four sides of the Temple. The 105.03m distance between the lines through the centres of eastern and western colonnade, lead to fix the longitudinal size of the temple to 109.34m. The careful survey of the Temple, calculated by Koldewey and Puchstein in 1910, restituted a size of 50.10*110.36 meters. No data are available on the measures reconstructed after 2011 by professor Mario Luni and his staff.

The reconstruction of the position of base drums has been validated in 3D space: cylinders generated by the extrusion of the circles have been built and visually compared to the corresponding parts of the 3D mesh. 3D observations allowed to more precisely detect the drums that slightly moved from their original position (Fig. 9). The following step of the 'drawing' process addressed the measure of the height of columns.

In the southern and northern area of the ruins it is possible to detect the drums that once belonged to some columns; in the southern front, in particular, the drums of four columns and their capitals are visible.

The measure of the height of the columns can therefore be achieved through the anastylosis of these elements.

The anastylosis process addressed the fourth column of the southern front; its drums are on site and integer, but the base drum is rotated and partially covered by other blocks. Nonetheless, it is the only column whose elements appear almost integer and visible; the remaining columns do not provide all the data needed for their reconstruction, because one or more drums are not visible or severely fractured.

The workflow followed for the blocks' shape detection and anastylosis process will be illustrated with reference to one drum. In the first step the part of the 3D point cloud corresponding to the drum has been isolated with manual segmentations performed with Cloud Compare; the points measured on the lower flat surface of the drum have been selected and the calculation of the plane that best interpolates these points has been executed with the Ransac Shape Detection algorithm integrated in Cloud Compare (Fig. 10).

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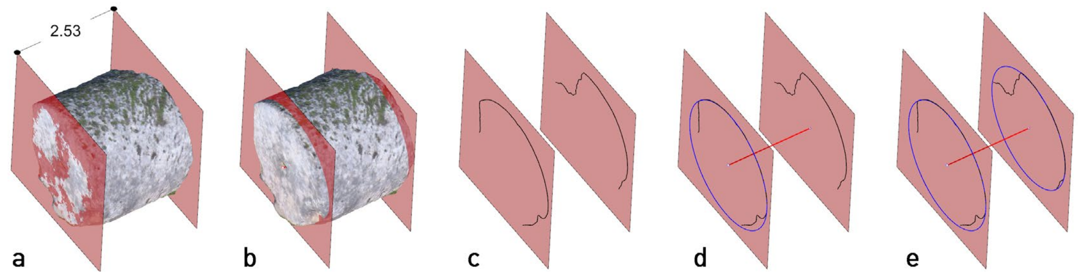

Fig. 11 - Steps of the NURBS modelling process: section profile extraction and drawing.

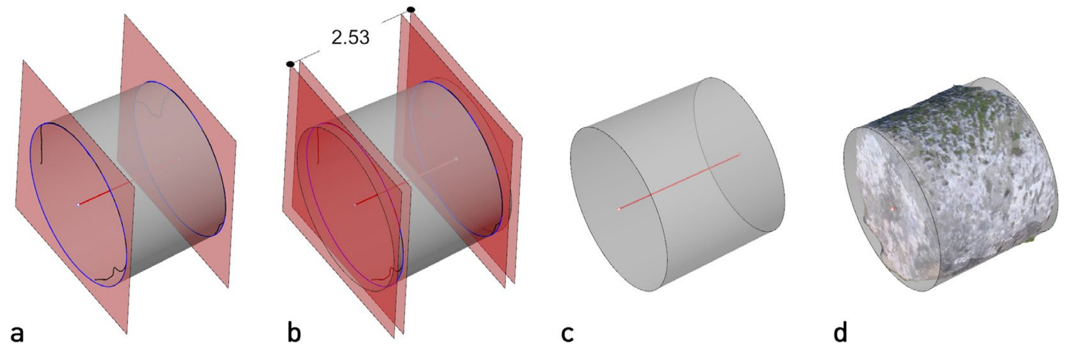

Fig. 12 - Steps of the NURBS modeling process: creation of the frustum surface and visual verification of the correspondence with the segmented 3D textured mesh.

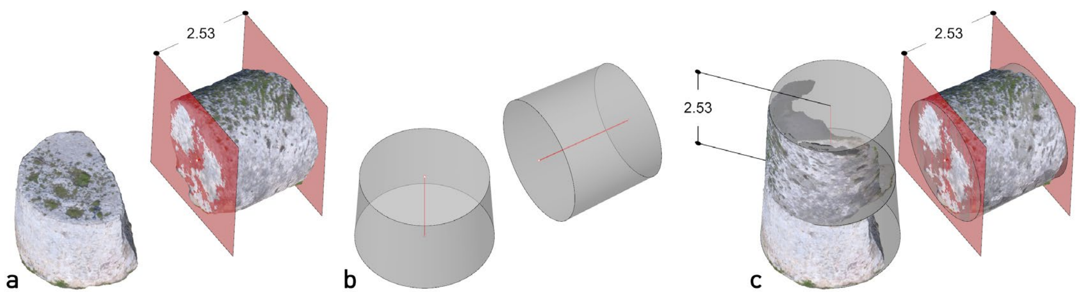

Fig. 13 - Steps of the NURBS modeling process: the 3D mesh model and the corresponding mesh are rotated and the continuity of the vertical axe of the column is virtually reconstructed.

This reference plane, imported in the drawing and modelling software Rhinoceros, has been duplicated and moved to match the upper end of the 3D mesh model of the drum (Fig. 11a).
The vertical axis of the drum has been considered orthogonal to these planes; in order to fix its position, one horizontal section of the drum is needed. For this purpose, a copy of lower and upper planes has been created at a distance ranging from 10 to 20 cm; these planes allow the extraction of the horizontal section of the drum; the offset distance has been adjusted keeping into account the need to cut the mesh in a coherent part of the drum. The circular upper and lower sections of the drum, due to decay phenomena (smoothing) and to fractures and breaks caused by the collapse, appears today deeply altered and cannot be used as a reference (Fig. 11b). The horizontal upper and lower sections' profiles of the drum have been extracted from the 3D mesh; the profiles are not complete, because only the visible part of the drum can be surveyed; the profile results furthermore discontinuous, due to the presence of fractures (Fig. 11c); one circle interpolating the lower section profile has been finally drawn and its centre points has been detected.
A straight vertical line, i.e. orthogonal to the lower plan, has been drawn through the centre of the circle and the intersection with the opposite section plane has been extracted (Fig. 11d); one circle centred on this point has been drawn and the correspondence with the extracted upper profile has been checked. When this circle does not match the section profile, the entire reconstruction process is discarded (Fig. 11e). The following step addressed the creation of a frustum surface through the interpolation of the two circles (Fig. 12a); the surface has been then extended to reach the upper and lower limits of the drum (Fig. 12b-c). The match between the NURBS surface and the 3D textured mesh of the drum has been visually checked (Fig. 12d). At the end of this process the coherence between the lower diameter of one drum and the upper diameter of the drum placed below has been verified. The 3D surface models of the drums and the corresponding parts of the 3D

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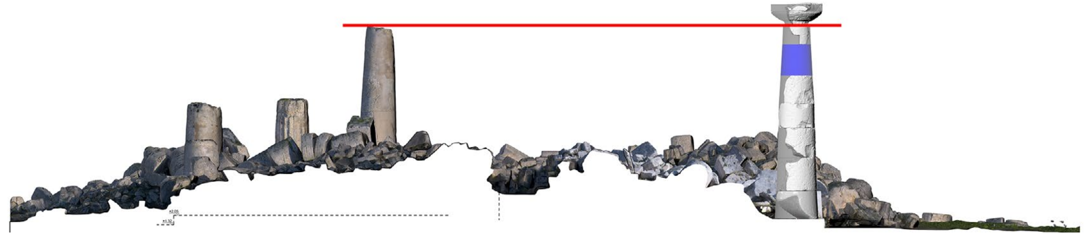

Fig. 14 - The section view supports the comparison between the height of the reconstructed column and the height of the 'Fuso della Vecchia'.

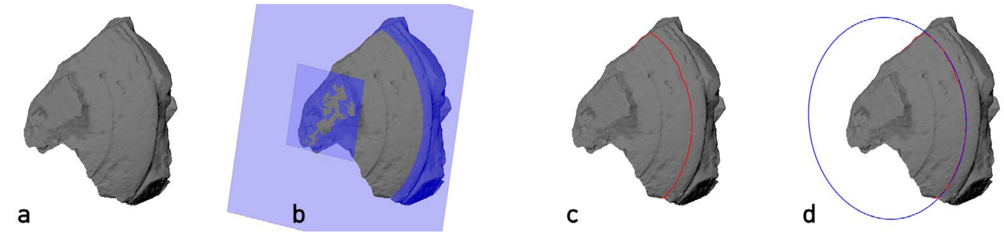

Fig. 15 - The capital's 3D reconstruction: the horizontal section profile of the echinus is extracted and redrawn.

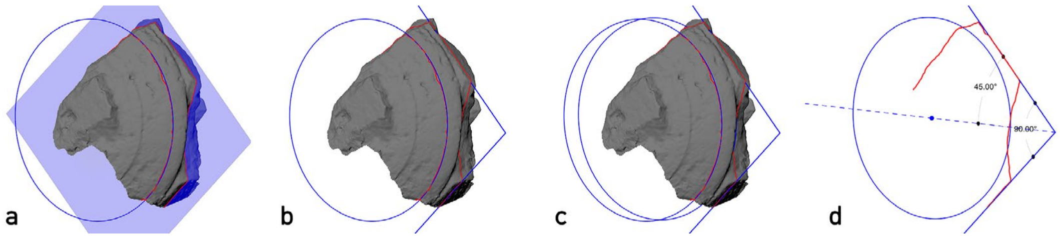

Fig. 16 - The circular section of the echinus is projected at a higher level to match the section of the abacus to evaluate their correspondence.

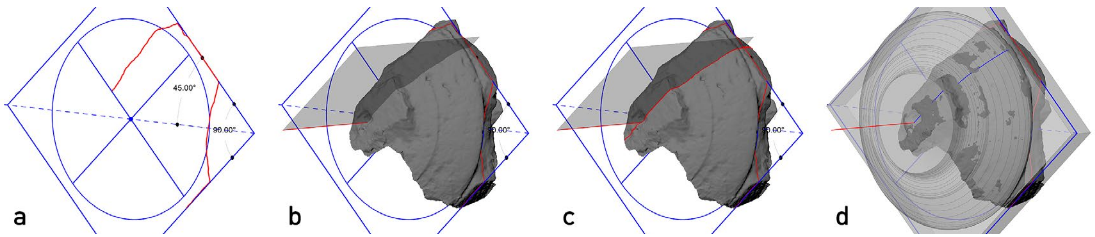

Fig. 17 - The vertical axe of the capital through the center of the circle, allows the creation of a radial section plane; the vertical profile of the echinus is extracted and redrawn; finally, the 3D reconstruction model of the capital is created.

textured mesh are rotated to set their axes in the vertical direction and to align all axes on one single vertical line drawn through the upper centre of the base drum (Fig. 13a-b-c).
The workflow resumed above has been applied to the drums of the four columns of the southern front; the 3D modelling and anastylosis process revealed that the height of drums changed from one column to another.
The reconstructed height of the column, except the capital, has been compared to the height of one column of the pronaos restored in 1832, the only standing column of Temple G, commonly named 'Fuso della Vecchia'; the comparison revealed a good correspondence between the extant and the reconstructed column (Fig. 14).
One remark is mandatory: the anastylosis of drums cannot be 'perfect', because the absence of flutes does not support the calculation of the rotation around the vertical axe, made by the collapsing drums ; the reconstruction has been therefore executed via the replica of the mutual ruined position of the drums.
A relevant information about the rotation of the column due to the collapse comes from the capitals; these are the only elements of columns that were finished before they were positioned, and their lower parts show the flutes that had to act as a reference to carve the drums. The upper part of the capitals, namely the abaci, are delimited by vertical planes; two planes were parallel, and the remaining were orthogonal, to the edge line of the peristyle.
The direction of the collapse suggests that the vertical surfaces of abaci today facing upwards, probably faced west and were therefore orthogonal to the line of the peristyle. This datum guided the anastylosis of the columns of the southern front and the proposed rotation of their drums around the vertical axe. The 3D reconstruction of the capitals uses the horizontal lower face and, when available, the vertical faces of the abacus. In the proposed example (Fig. 15a), a capital affected by many breaks and incomplete, the lower face and small parts of the vertical faces of the abacus are detected onto the 3D mesh. The base plane,

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detected with the Ransac tool, has been copied and moved upwards (Fig. 15b) to extract the section profile of the echinus (Fig. 15c). A circle interpolating the profile is then drawn (Fig. 15d).
The plan is copied once more upwards to extract the section of the abacus (Fig. 16a-b) and the circle is projected onto this plane (Fig. 16c). On this plane the straight lines corresponding to the section profiles of the abacus are drawn at right angle and the bisector line 45° oriented is drawn through the centre of the circle. This line matches the reconstructed corner of the abacus, thus validating the proposed reconstruction (Fig. 16d).
The centre of the circle and the lines of the abacus allow the reconstruction of the geometry of the capital (Fig. 17a); at this stage the vertical axe through the centre of the circle is drawn and a vertical plane is modelled (Fig. 17b); this plane provides the extraction of the radial section profile of the echinus (Fig. 17c); the 3D model of the capital completes the reconstruction process.
The capital has been finally positioned at the top of the column, whose height resulted equal to 16.36 meters (Fig. 14).
The workflow that has been resumed is an evidence of the potentials of digital representation and modelling; the availability of a digital twin of the blocks allows an analysis of their geometric features simply impossible with the aid of traditional surveying and drawing tools.
The most effective representation of Temple G appears to be the 3D reconstruction of its blocks and their virtual anastylosis in the supposed original position.

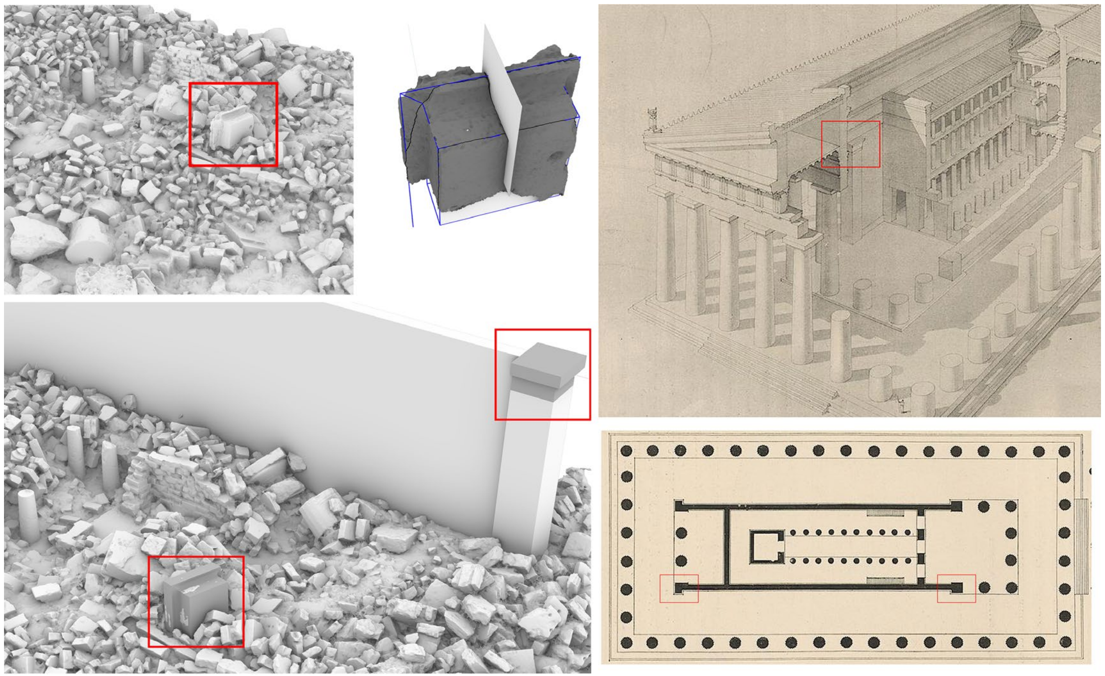

Fig. 18 - The capital at the end of the wall of the naos; 3D NURBS model and virtual reconstruction; the same element in the drawings of Hulot.

Any other representation, useful for maintenance or documentation, does not provide any useful information on the temple and its constructive elements.
The workflow proposed for the columns has been tested on a different element: the rectangular block placed at the upper end of the walls of the naos, that features a peculiar cornice usually named 'owl's beak'.
The description of the reconstruction process can be discarded, since it uses the same tools of 3D modelling and descriptive geometry that led to the reconstruction of the drums and the capitals.
The reconstruction of this element shows an impressive analogy with the reconstruction proposed in 1910 by the French scholars Hulot and Fougères in an astonishing perspective drawing dedicated to the restoration of the Temple (Fig. 18).

3D WEB BASED DATABASE

The 3D models of blocks have been used for an experiment on the development of a database whose data can be retrieved with by simply clicking on 3D entities.
The experiment aims at making the achievements on the interpretation of the function and position of the ruined blocks accessible to a wide range of users and hence support the dissemination of the studies on Temple G.
The open source framework 3DHOP, developed by the CNR of Pisa (Italy) has been used for the development of this part of the research work.
3DHOP, based on the WebGL technology, uses multi-res algorithms that support the visualization of detailed 3D mesh models by the continuous upgrade of the resolution when zooming is performed.
3DHOP can be accessed through common web browsers with any mobile or desktop device connected to internet.
Furthermore, the framework allows the upload, management and access to information data directly linked to 3D geometries.
Visualization tools allow to orbit, pan and zoom the model during the navigation, or change its shad-

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ing mode (textured, monochrome and the like); inspection tools allow the extraction of sections, of the coordinates and distances of vertexes of the mesh.
The operator can add further tools; some of these are integrated to the platform; further tools can be created by more expert users via the compilation of computer codes.
The four 3D textured meshes of Temple G have been joined into a single mesh model, optimized to 20mln triangles; the mesh model has been converted into the Nexus Multi resolution format (*.nxs) for the storage on local servers and into the compressed format (*.nxz) for the cloud storage on the web.
The following step of the experiment addressed the creation of interactive hotspots corresponding to specific constructive elements visible in the 3D mesh and the association between hotspots and information data.
The 3D NURBS models of drums, capitals and cornice provided the reference for the creation of hotspots; NURBS models have been converted into mesh models and uploaded into 3DHOP. These models must be visible during the navigation and highlight the elements linked to information data; this is why NURBS models have been slightly magnified before the conversion into mesh models. Magnification makes these models easily detectable during the navigation.
The last step addressed the creation of panels were multimedia (text, images) information data are presented. In the experiment the panels are dedicated to illustrate the function and the original position of some ruined blocks, with the aid of texts, 3D models views and historic images (Fig. 19). A dedicated command allows to turn hotspots on or off at any time.

BEYOND DRAWING AND 3D MODELLING: MOTION TRACKING TECHNIQUES FOR THE REPRESENTATION OF VIRTUAL RECONSTRUCTIONS.

3D NURBS models and their anastylosis offered the opportunity to experiment another form of representation of architecture, particularly ef-

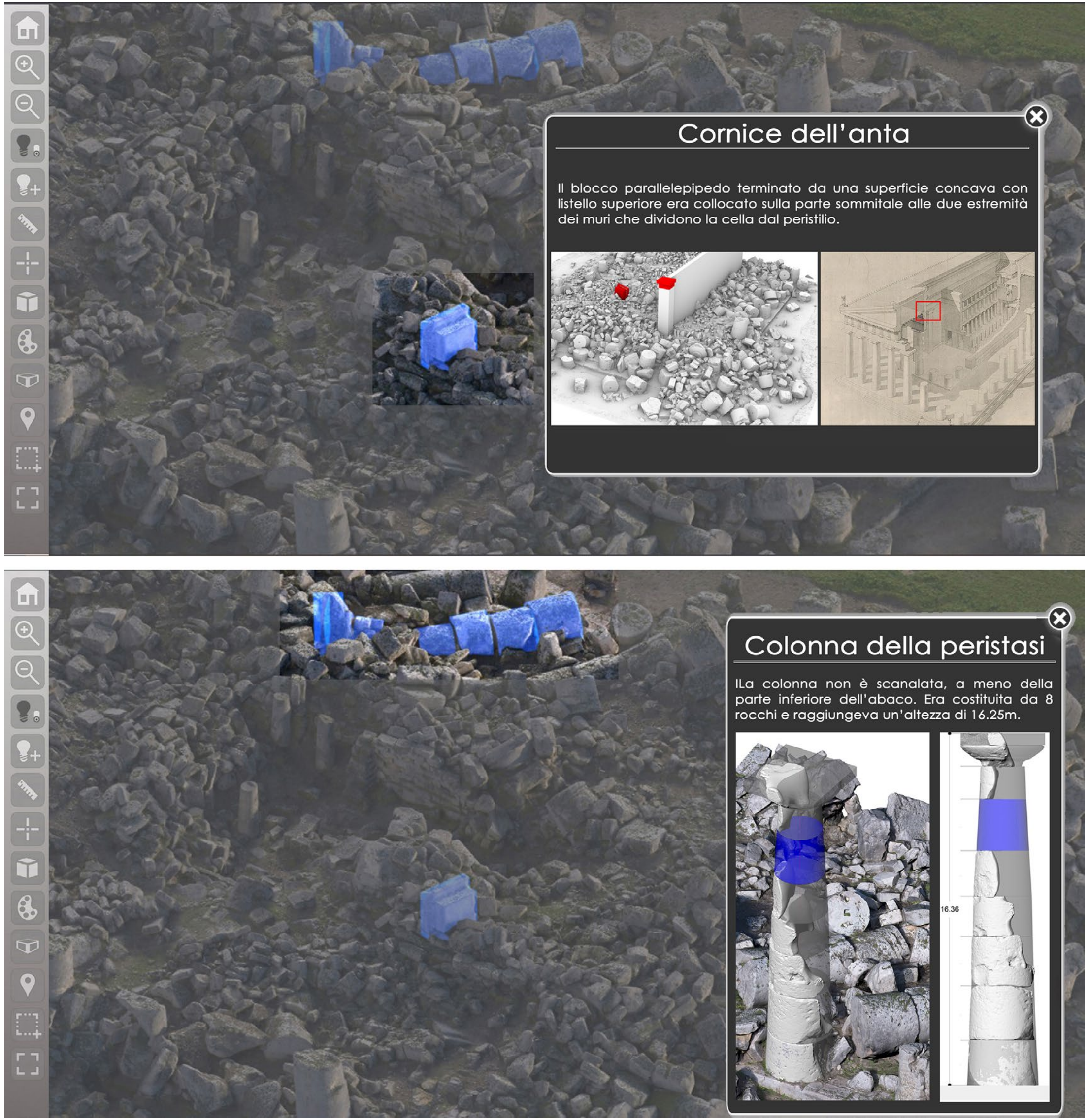

Fig. 19 - 3D HOP allows the inspection of the 3D textured mesh and the access to information data linked to hotspots that are integrated into the 3D mesh model.

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fective for dissemination purposes. This form of representation, uses motion tracking techniques to create videos where reality and 3D models are mixed.
In this experiment a video footage, captured with a drone, has been used to visualize the reconstruction of the four columns of the southern side of the Temple. Motion tracking tools analyse video footages and calculate the 3D camera tracking; different software packages are dedicated to motion tracking: Syntheyes and Nuke are commercial solutions. In this experiment the 3D camera tracking has been calculated with the free package Blender.
The software 'analyses' the video stream and detects features that recur in a sequence of frames; these features, named 'trackers', allow, with the use of SfM algorithms, to calculate the 3D mutual position of the corresponding points and hence the path of the camera in the virtual scene populated by the points. This phase is named 'camera solving'. As any other SfM photogrammetric model, the 3D camera path and the points corresponding to trackers are placed in an environment that is proportionally correct but has no orientation and is not referred to a measure unit.
For this purpose Blender allows to create new trackers or use extant trackers to set up a reference system: three trackers detect a vertical or a horizontal reference plane, its origin, and the direction of one axe. Finally, one reference length allows to properly set the correct scale of the photogrammetric model. This step, named 'scene solving', has been used in this study to refer the camera tracking scene to the 3D mesh model of the ruins. The 3D model of the reconstructed columns has been uploaded into Blender and an animation that used the calculated camera path has been rendered; the video of the animation and the footage have finally been mixed with compositing techniques available in Blender (Fig. 20).
In order to support the integration between the virtual animation and the real footage, lights have been created and positioned in the virtual space to illuminate the virtual objects as if they were located in the real environment.

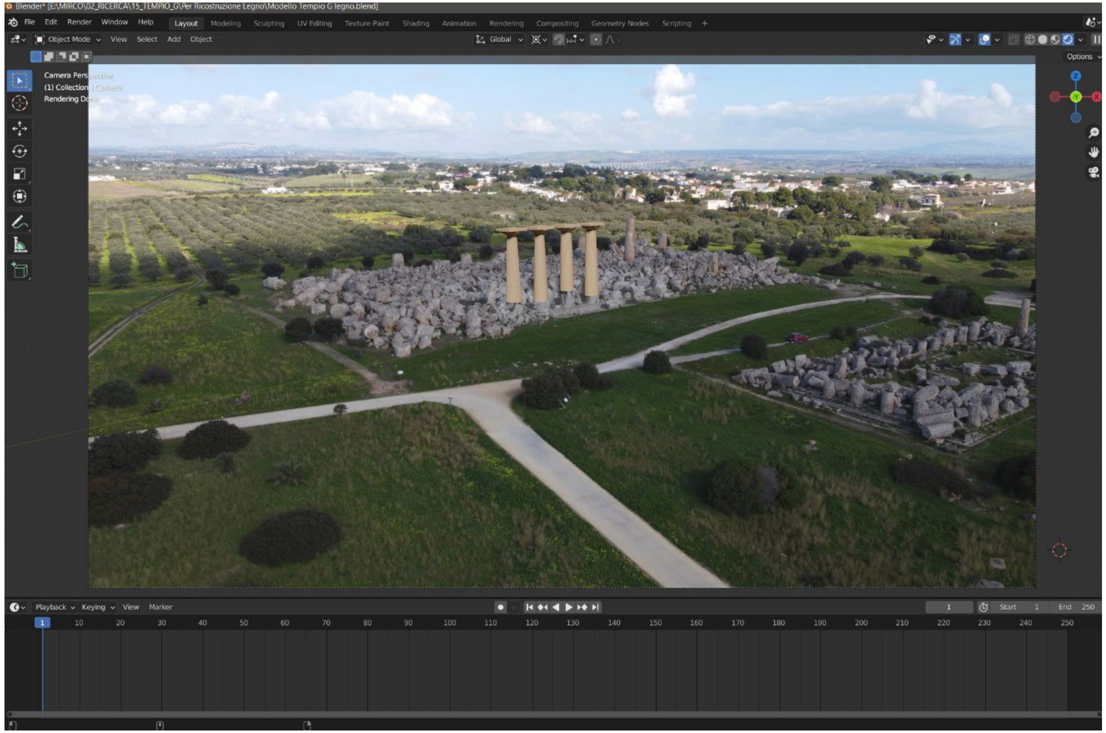

Fig. 20 - Motion tracking solution for the contextualization of the reconstruction of four columns in the footage taken by a drone.

CONCLUSIONS

Temple G is a case study that effectively puts into evidence the potentials of drones and photogrammetric techniques for the documentation of architecture and archaeology. The combination of digital twins and of digital drawing and modelling techniques offers new powerful tools for the study of the geometric and constructive features of monuments. The proposed workflow used semi-automatic shape detection algorithms only as the starting point for the interpretation of the shape of constructive elements, that has been manually developed with the aid of modelling techniques and representation science. The creation of NURBS models supports and validates the reconstruction of the position and function of each element in the original layout of the Temple. These information data have been finally used for the development of two solutions addressed to dissemination: a web based database accessible during the navigation of the 3D model of the ruins and a video that uses motion tracking techniques to visualize the virtual reconstruction of specific elements of the Temple in the present scene. Once again, drones provided an useful support to capture an aerial footage that well pictures the extant arrangement of the ruins and the astonishing landscape around the site of Selinunte.

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