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DIGITAL SURVEY IN ARCHEOLOGY

Stefano Bertocci Sandro Parrinello Rebeka Vital

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On cover: General view of the point cloud and three-dimensional processing about Herod's Palace area.
Elaborated by Marco Benedetti.

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Integrated survey methods for the documentation of the Masada plateau

Francesca Picchio

Introduction

The aim of the three-year research programme at the archaeological site of Masada was to document the entire area located on the plateau by testing a data acquisition and processing method that is integrating the best aspects of each of the instruments used on the field.
During the mission, performed in February 2014, an intensive surveying campaign of the Masada plateau was scheduled, that integrated GPS tracking systems with systematic coverage of the entire area covered by laser scanning. At the same time, intensive and systematic data acquisition was scheduled using photographic tools, able to meet a twofold documentary requirement: to produce an image of the state of the building at the time of filming and to be processed, using specific software, three-dimensional models closely corresponding to reality.
The aim of such a documentation project was to produce an image of the site with all its complexities, using a language able to describe them simultaneously on a single print-out.
So, once the complexity of the structure to be analysed and the potential offered by each instrument was established, the task was to organise the work of the research team so as to define a timetable to schedule the individual activities on the field and in the data post-production phase.

Data acquisition by laser scanning

The survey of the ample area on the Masada plateau was performed using some direct surveying methods and testing indirect surveying techniques on a large scale.
The advantages of using indirect instruments such as the Laser Scanner, is that it is able to acquire a very high number of points in a very short time, and that makes it possible to organise work in the field more productively. Indeed, the visible surfaces of a given context or architectural object, even a highly complex one, can be fully surveyed using relatively rapid operations that enable one to postpone the longer phase of processing the data acquired to a later stage of the campaign.[1]
When performing operations in situ, it is the correct positioning of the stations, which determines the quality of the survey product in the form of a high density point cloud. From this information on the spatial con-

firmation of the object or of the surface that is analysed and can be extracted. The characteristics of the laser used significantly affect the programming of the number and position of the stations. The **Leica Geosystems C10 laser scanner** time of flight model used for both missions in 2013 and 2014 permits, at the various settings, the acquisition of a very great number of points at considerable distances from where the instrument is positioned.[2] The scan product is a three-dimensional cloud of what falls within the visual range of the instrument at the time operates. Therefore, to obtain a reconstruction of a complex, three-dimensional space without gaps or points of occlusion, several scans from various points of view are required.

The survey campaign was also conditioned by the need to use a number of homologous or **target** points common to each pair of scans greater than or equal to 3, which block their mutual positions in the three translations and three rotations in space and thus record the scans exactly in relation to each other.[3] To merge

The panoramic view of the vast area of the Masada plateau, object of the research mission 2014.

The laser scanner campaign of the second research mission.

the individual scans in the post-production phase, it was necessary to have the target at the time of the acquisition in situ prepared, namely the mobile elements automatically recognised by the instrument at the time of recording the scans.

The targets available were 3 tilting targets, used as practically fixed references, which were used as reference as homologous points for several stations. A considerable number of adhesive targets were added to these **Scanned 3"x3" Square Target** which increased the number of corresponding points between each pair of scans, considering the possible occlusion of one or more of the tilting targets in some scans. In fact, while the tilting targets were placed high up, as far away as possible from possible problems of occlusion due to the passing by of tourists at the time of the scan, the green ones were placed on the various surfaces of

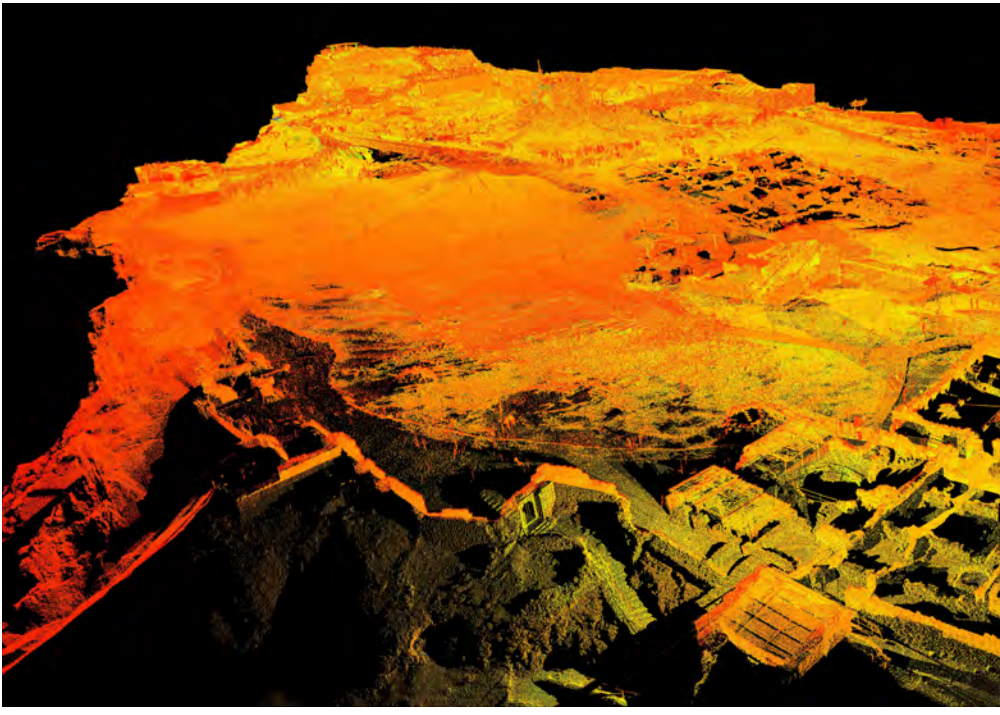
The project of the scans on the general plan.

Point cloud views of the whole area.

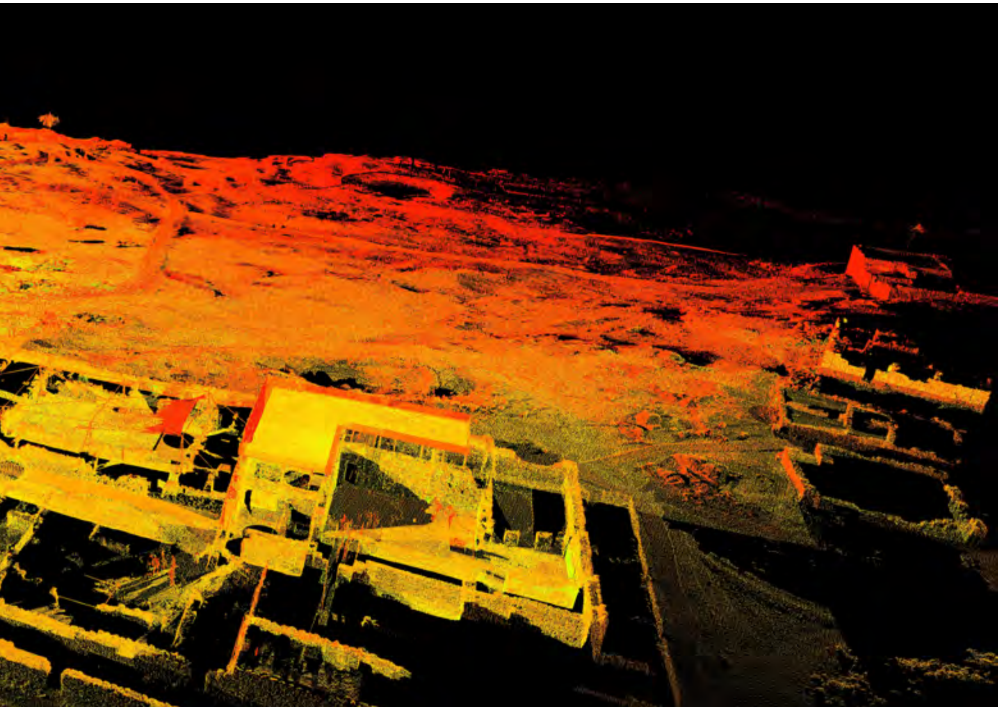
cant surface area, also has the drawback of not having reference elements close enough together. On the first day the spatial conformation of the wall surfaces had permitted linear progress of the mesh of scans, trying to maintain a constant distance of the instrument from the targets placed on the walls.

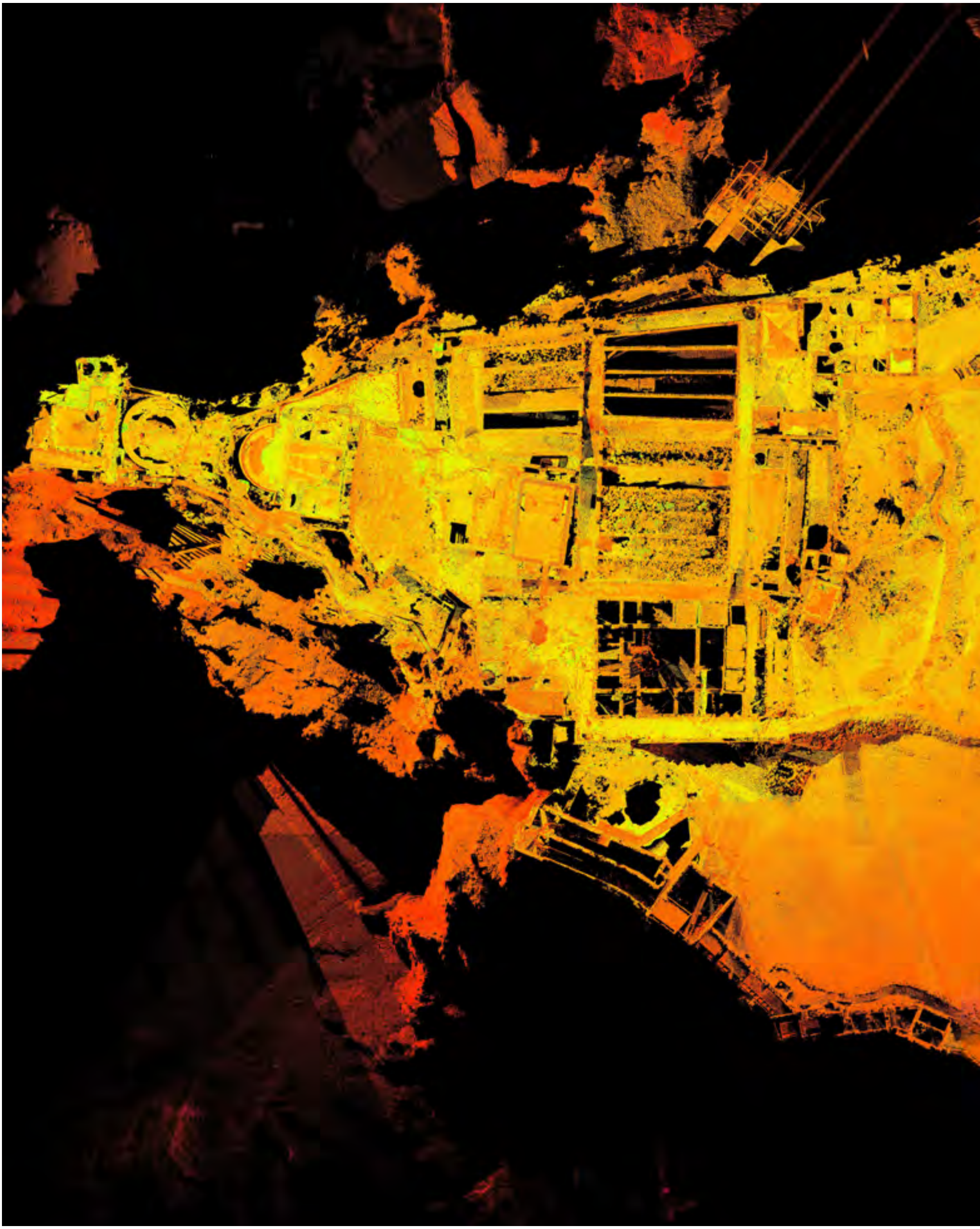
On the second day problems emerged relative to the acquisition of large areas in which the percentage of empty areas was greater than the area filled.

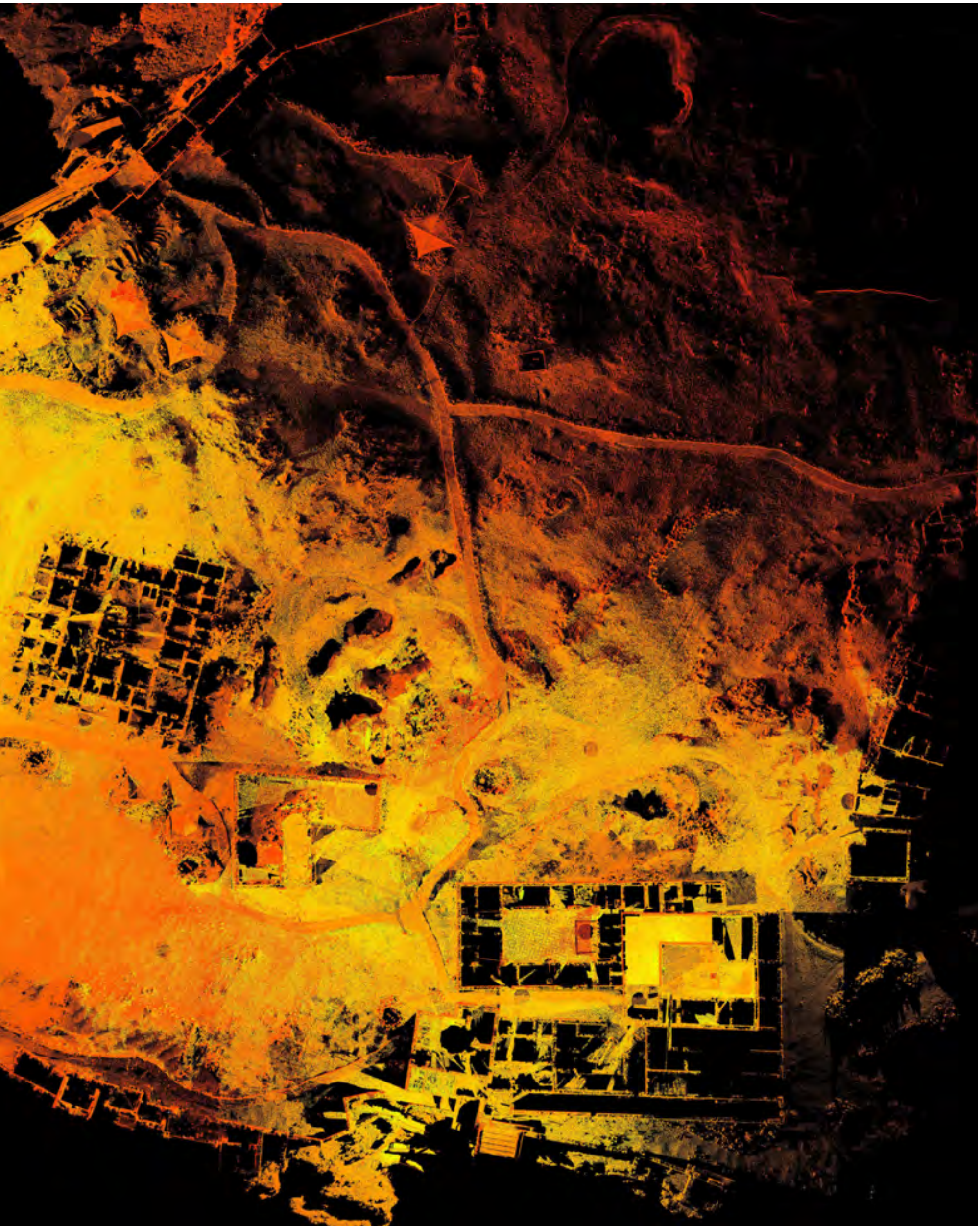
The rooms situated inside this area of investigation were at too large a distance from each other to be able to establish in advance the choice of the wall surfaces on which to place the reference targets, needed to register the individual scans.[4] As a result, an initial reconnaissance of the site was necessarily followed by a care-



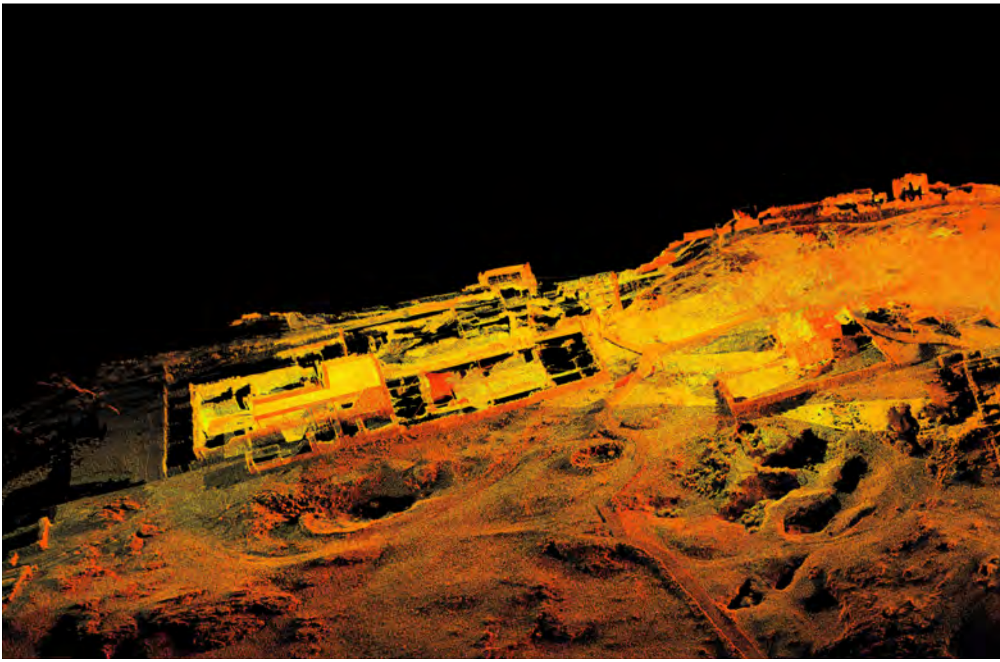
ful planning of the **positioning** of the stations, evaluating both the difference in level of the floor, and the visibility of the surfaces to be scanned by each station. The positions and the number of stations needed to cover the entire area were marked on a map. This operation led both to the structuring of a network which, starting from the survey of the previous mission, expanded the perimeter bordered on the east-west by the walls, and included the larger buildings within, and to a clearer division of the time of the acquisition work, depending on the complexity of the portions to be scanned on each day of the campaign.
The first three days involved surveying the portion of the plateau immediately south of the **storehouses** and of the rooms previously acquired. A perimetral



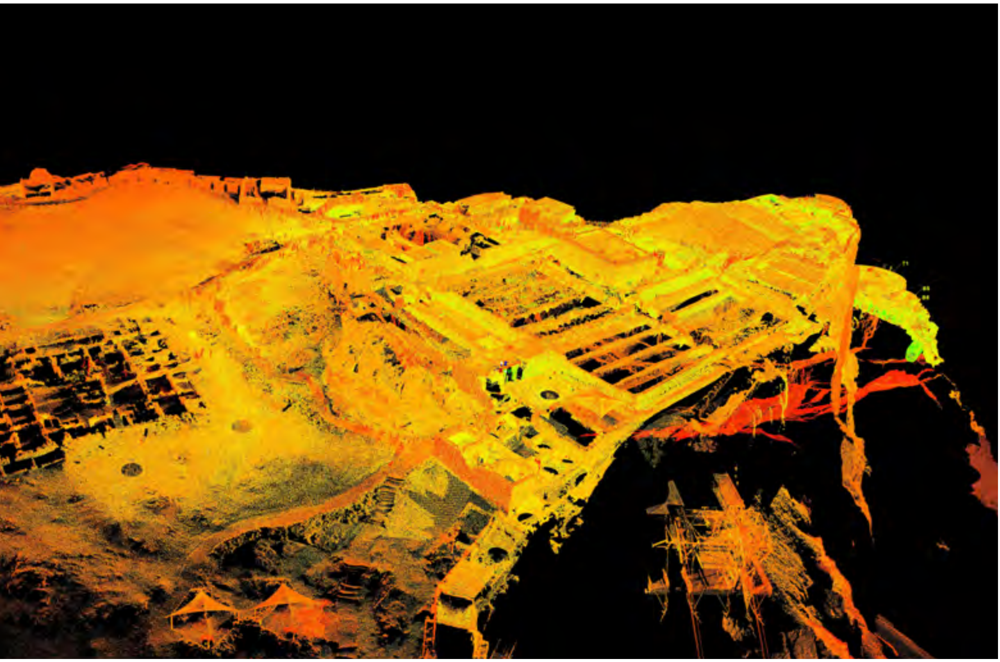




approach was thus adopted which from the west involved the entire portion of the plateau as far as the east side, where the Building No. 8[5],and the grottoes immediately opposite it are located.
The idea was to proceed then in transversal bands and later return to the central position of the area examined and, in a westerly direction, to acquire the structures situated on the plateau from outside.
When the scanner was in a central position, the instrument settings were evaluated: the calibration of the instrument for which, in many of the central stations the maximum range of instrumental resolution (Ultra High) was used, made it possible to acquire a large number of points at a considerable distance, and reduce the number of some scans, thereby optimising survey times.
The **High Res** setting of the scans performed in a cen-



tral position of the plateau, and therefore at a considerable distance from the surfaces of the architectural structures on which the targets were placed, made it possible to acquire them at a resolution sufficient to identify them on the point cloud. The central scans were thus crucial to understanding the environmental extension of the complex, and provided the basis for setting up the survey projects of the individual buildings.
The planning of the scans for documenting the interior of what would have been the Building No. 8, the remains of the Building No. 9 - Residential Building[6] and the Byzantine church, took longer on account of the large number of scans performed. In particular, for the Building No. 8, ***25*** scans were made both of the interior and the exterior of the structure.

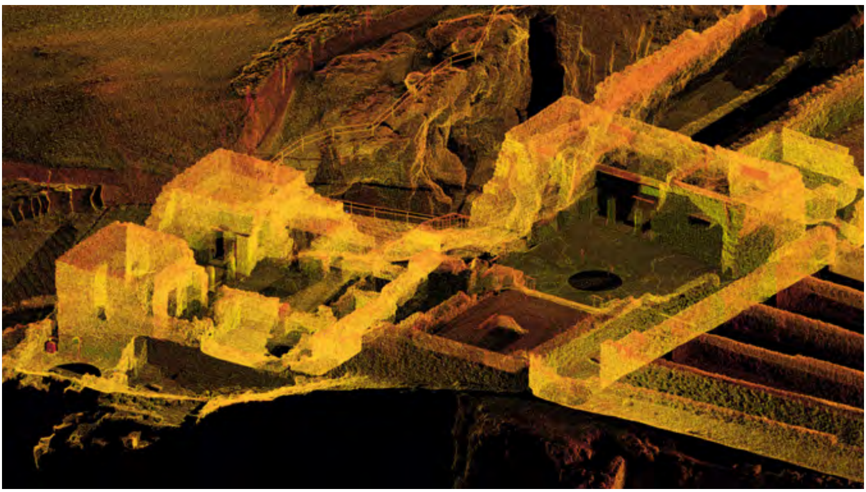


Point cloud view of the Northern Palace.

The difficulties, in addition to the large numbers of tourists throughout the day, were related to the position of the building: one of the three sides is located on the outer edge of the plateau that juts out to the east just below the **snake path.** The positioning of the laser on the narrow outer corridor was needed however to survey the contour of the plateau outside the walls at the sector analysed.

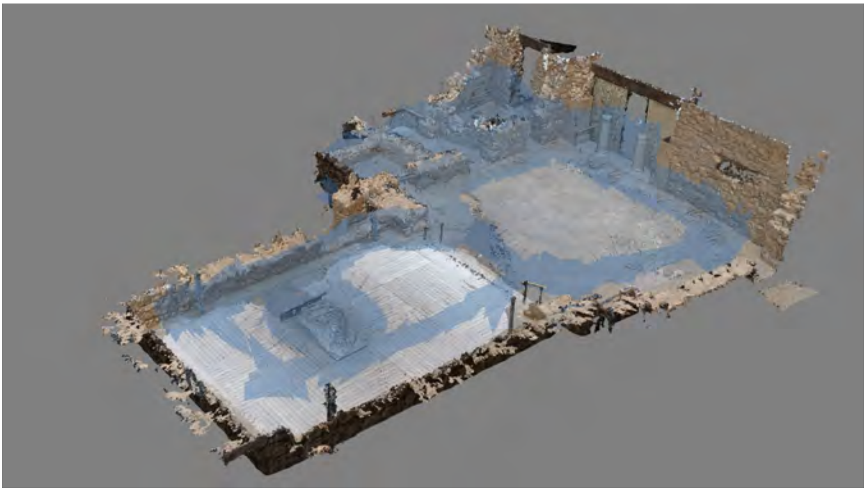
The accuracy of the instrumental survey of this building was aimed at testing the integration of laser scanner surveying and three-dimensional photogrammetry carried out on this complex. Any gaps in the point cloud produced thus needed to be avoided to enable a perfect match and to test the result of the photomodelling in each point.

Testing of the integration of laser scanner - photographic instrument data already carried out during the first mission, when surveying **Northern Palace**, was extended to include aerial photogrammetry carried out by a drone. To perform a match of the two models, targets on the ground (of the black & white type) had



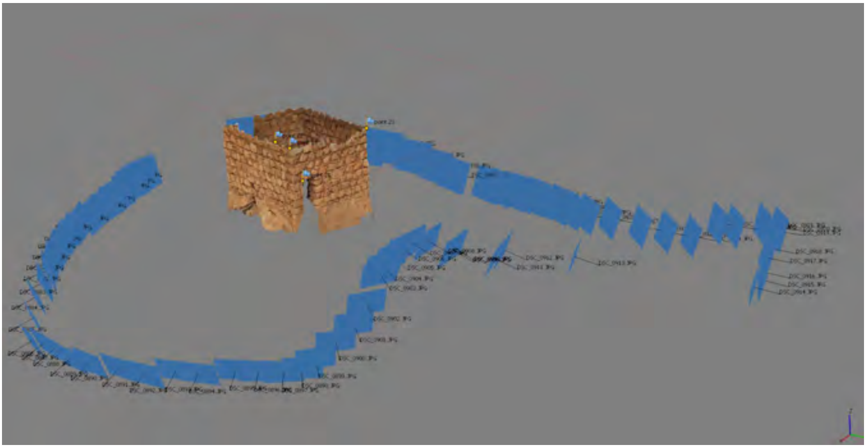
to be provided which could be seen simultaneously by the laser scans and the drone at high altitude. Thanks to these targets, during the data post-production it was possible to combine the products of the two data acquisition tools to obtain a single product characterised by the specific technical features of both solutions.
It is crucial in this type of approach to architectural surveying to get a good basic picture of the state of the object at the time of acquisition. Compared to the previous year, the survey method of the 2014 mission provided for a greater presence of the photomodelling product over that of the laser scan, used to monitor and check the three-dimensional models made from the photographs.
The jump forward in the research between the two missions lies precisely in the awareness of the possibility of performing the entire survey with photographic tools, using the laser scanner merely for verification and control on a large scale, where it should prove necessary to ensure the correct combination of the individual models with each other.

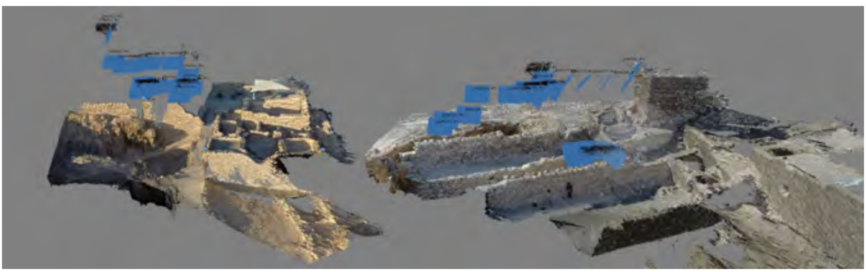
Data acquisition project for the Northern Palace. In some parts it has been possible to acquire the data with camera from above the walls.



The method of acquisition using photographic to-ols for the costruction of models.

So, as discussed for the survey of the **Northern Palace** in the course of the 2013 mission, in the 2014 mission the laser scanner survey campaign was combined with the *structure from motion* data acquisition method, namely a surveying system in which a photographic sequence is used to directly generate a 3D model with information on the building materials provided by the photographs. The methods used to acquire the architectural buildings varied according to the contextual conditions (weather and accessibility to the object), and the morphology of the object itself. [7]





Unlike the first mission, where the object, despite being in various parts, was still all concentrated in a system morphologically enclosed by the shape of the plateau, the area of the site analysed the second year, on account of its vast extent, did not permit the acquisition of the entire surface in a single photographic sequence project. In this phase the complexes which could be considered nuclei in their own right were acquired by using 3D photogrammetry from the ground (such as the Byzantine church and the Building No. 8), while aerial 3D photogrammetry was used to acquire the extensive area of the plateau, where such buildings are located.

The **acquisition** of the interiors and exteriors of the buildings on the site aimed to complete the photographic coverage of all the surfaces of the buildings, from the city walls to the general picture (which includes in a single shot various wall surfaces). Including a number of surfaces in the same photographic sequence makes it possible in data post production to obtain a more general model of the complex and have greater control over the relative rotations from one wall to another. This way the photomodelling programme was facilitated in recognising the homologous points of general models and more detailed portions of the same, and consequently the post-production phase will not require special expedients such as having to manually recognise the corresponding points on the models, such as targets or the very geometries of the architecture.

For the Building No. 8, used to test a method using photography alone as the main surveying instrument to produce the 3D models,[8] the acquisition phase followed a specific time schedule. The entire photographic acquisition took place over 5 days: the work was divided into macro-areas which, from a more general level of the early days to the more detailed level of the final phase, were able to obtain the necessary quantity and quality of data for making the models. The division of the portions of the buildings for the correct management of the archive did not present particular problems: the Palace is a regular shape, the rooms are well-defined, and the possibility of taking photographic sequences from the outer perimeter at a level raised above ground made it easier to produce complete and exhaustive models.

The problems encountered were due to the large number of tourists who during the day crowded the archaeological site, jeopardising the quality of the filming product. Another factor was the lighting conditions: this parameter should be carefully analysed in situ and, after daytime exploration, the best time of day to shoot each portion of wall is the time that it is not exposed to direct sunlight.[9]

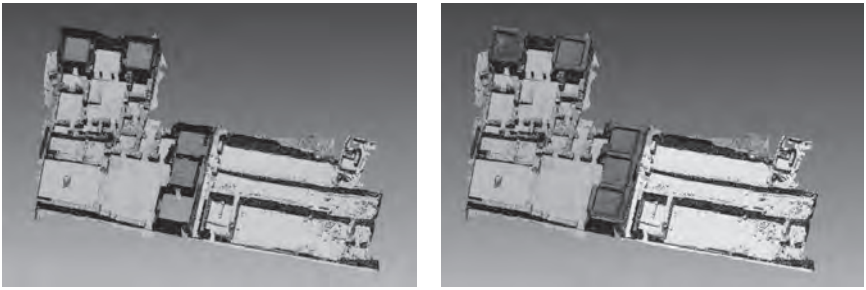
Good and homogeneous light conditions in the photographic sequences taken to generate models ensure a result in which the building material component is optimal, and in which a number of considerations regarding the reliability of the state of the object may be made.

At the end of the day of the acquisition campaign, the data was verified by uploading the photographs taken during the day on the data processing software (Agisoft Photoscan) to check the correct alignment of the model. The merging of the individual models was then performed a posteriori, given the long data processing times.

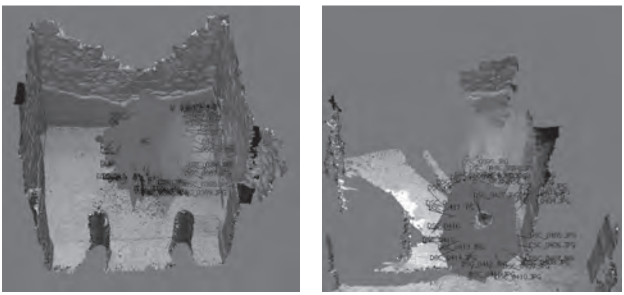
The processing times and the size of the files are unfortunately a drawback of this survey method. It is important to establish in advance what the final output of the model will be, i.e. the purpose of the reconstruction of the building. This is essential for optimising the processing time and targeting the data management to a specific objective.

It is also important to emphasise how, despite using the same survey method for the acquisition phase in both missions, the experiments performed using specific software capable of processing the data coming from scans or photographic models led to very different data management methods given the different purposes.

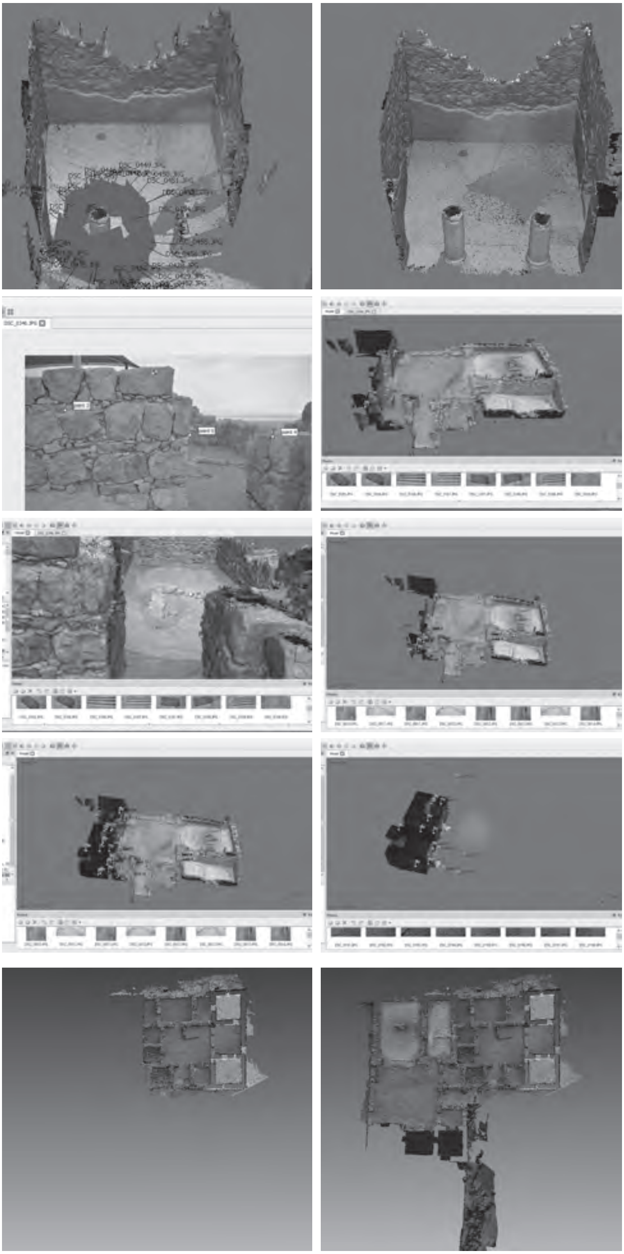
Shape from motion from drone merged with product data acquisition from the ground.



The *shape from motion method* was extended to the entire area of the plateau to be surveyed, including the buildings and paved area for a good portion of the surface. The opportunity to evaluate the results of the first 2013 campaign enabled the team to develop an extremely rapid survey method based only on use of the photographic image, improving it in the course of the 2014 mission.

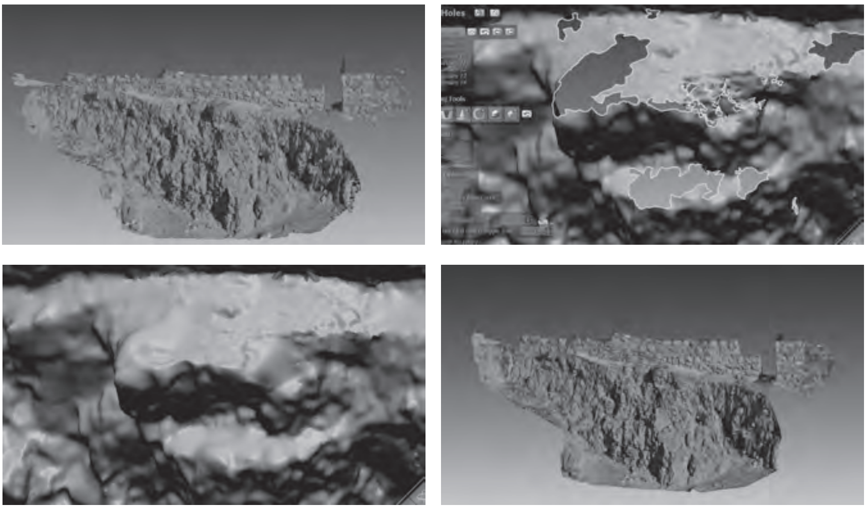


Models combined into a single project to understand the metric reliability metric on a large scale, in comparison with the point cloud system.

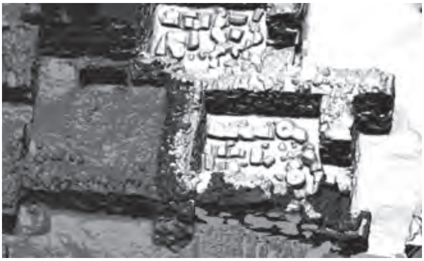


Comments on the acquisition method and management of the three-dimensional model

While in the first mission, the survey was managed so that the photogrammetry could integrate the descriptive material component of the point cloud, in the second case it was the point cloud which provided a support-verification of the photogrammetric models, which at this point became the basis for making a number of considerations on the architectural building.
The management of the 3D model includes a procedure for integrating the products from the two data acquisition systems.
The problems of these models are mainly the size of the output file of the tools which, before being managed, need to be substantially reduced in regard to the number of points or surfaces.
The mesh model generated by the cloud is then reduced into the number of polygons, so as to make the management of the software rendering or real-time visualisation easier.



Optimization of mesh: the integration process of the gaps and the reconstruction of the missing portions of the photogrammetric model. The process has been carried out on individual three-dimensional models, subsequently combined.




The quality of the model is however guaranteed by the excellent resolution of the texture component generated by the photographic sequences around the axis of the object. The texture of the individual photographic models required for mapping the general 3D model of the cloud, is exported in jpg format previously transformed into a surface area of polygons. The experiments on the subject showed the level of detail achieved by models with the same texture, in which the polygonal mesh was more or less reduced, and therefore the level of morphological detail proves more approximated in geometry but not in the graphic rendering.

The results obtained and processed to date for some of the buildings in this area, such as Building No. 8, made it possible to test the effective reliability in the alignment of the individual models, the relative and absolute rototranslations on the basis of the reference laser scan.

The advantage of obtaining three-dimensional models from the photos immediately is that of being able to test the perfect match between the polygonal mesh and the reference texture that it is generated on.

However, the processing and management of the mesh of polygons is not always easy and immediate. A number of problems arise with the mesh generated by photomodelling related to gaps and discrepancies in the polygonal mesh.

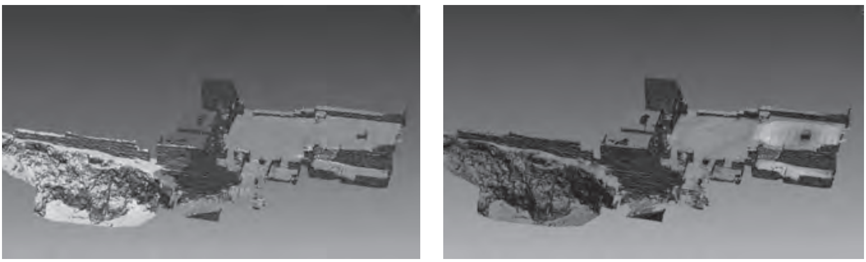
Cleaning the surface of the model involves a much longer procedure than any of the stages and processes referred to above. The elimination of all the polygons with abnormal connections, such as degenerate triangles, inconsistent edges and gaps must be carefully performed on the object, both on a large scale and for the smallest detail. Closing is performed in the case in point by a new triangulation of the missing part using the information of the triangular edges of the gap.[10]

While on the one hand it is the extreme reliability of the measurements, which dictates the survey methods and instruments chosen for the preservation of architectural buildings, the application of three-dimensional models increasingly characterised by the logic of entertainment, advances the language of representation toward multimedia systems that can exploit the best characteristics of each area.

The aim is to develop a platform, a multimedia framework, which, by codifying the complexity of the real object, sums up its formal and qualitative features in a new virtual object, corresponding to reality, reliable and utilisable, applicable in the Cultural Heritage sphere. [11]

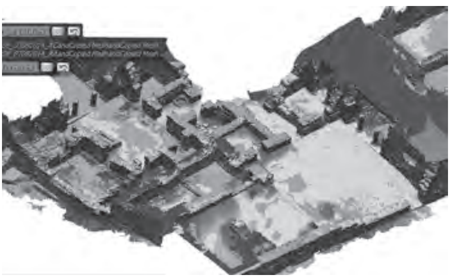
The approach used in the first reconstruction was to develop the general figure of the point cloud, create a polygonal surface with a very high density of vertices to then characterise it with all the information related to the colours and state of preservation from the photo.

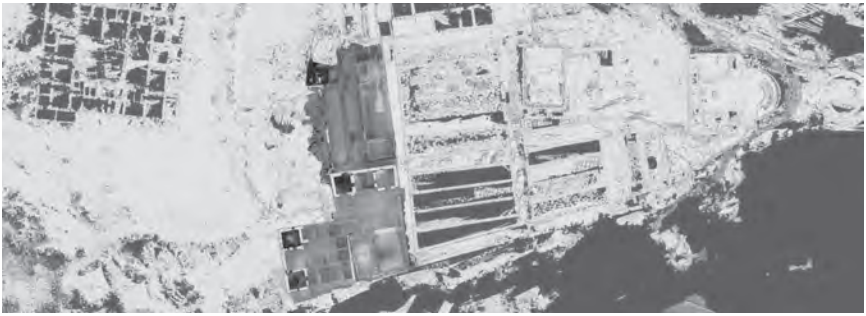
Texturing of the model: the optimized model, finally completed and decreased in the number of meshes in order to make it more easily usable, was imported on PhotoScan software for texturing and make it photorealistic.



The model thus generated is a good basis for a number of considerations, combining the geometric reliability obtained by laser instruments, useful when considering the morphological-geometric nature, with a material quality obtained from instrumentation based on photographic images, needed for considerations on the state of conservation of the building.
The aim of this type of testing is to see how at the end of each year, through the processing of data coming from the research missions to the archaeological site of Masada, one can test not only the potential of the instruments and dedicated software, but above all see how new data management systems radically change the planning of the survey in situ, the times and skills of the work team. Understanding the dynamics of how methods such as photomodelling will develop in the future applied on a large scale to architectural surveying helps us to understand which approach is most appropriate in each case, assessing the impact in terms of cost, time and data management.

Comparison between the mesh of the point cloud and the mesh created by PhotoScan software.





Notes

1. See *Data acquisition activity* in *The integrated survey and laser scanner methodology,* Sandro Parrinello, Masada Notebooks, Report of the Research Project 2013, Vol 1. Edifir Edizioni Firenze, Pisa, 2013.

2. The benefits of using a laser survey method are significantly reducing the time of data acquisition compared to a direct or topographical survey of the site, as relating to the possibility of surveying complex geometries, such as mouldings and decorative elements with a very high degree of precision and morphological accuracy. For a more in-depth discussion of the subject see *The scanning projec* in *The integrated laser scanner and survey methodology,* Sandro Parrinello, Masada Notebooks, Report of the Research Project, 2013, Vol 1. Edifir Edizioni Firenze, Pisa, 2013.

3. See *The scanning project* in *The integrated laser scanner and survey methodology,* Sandro Parrinello, Masada Notebooks, Report of the Research Project, 2013, Vol 1. Edifir Edizioni Firenze, Pisa, 2013.

4. Ibid.

5. E. Netzer, Masada III. The yigael yadin excavations 1963-1965, final reports the buildings stratigraphy and architecture. Israel exploration society the hebrew university of Jerusalem, Jerusalem 1991, pag. 189.

6. Ivi. Pag. 201.

7. See. *Data acquisition and automatic processing by 123DCatch,* Francesca Picchio, Masada Notebooks, Report of the Research Project 2013, Vol 1. Edifir Edizioni Firenze, Pisa, 2013.

8. The testing of the method was in this specific case analysed by the undergraduate student in architecture Monica Bercigli who participated in the second research mission, handling the surveying and data management specifically of the buildings of the Building No. 8.
The images presented here are parts of the elaboration of her project research.

9. For a more detailed discussion of this topic see *Data acquisition and automatic processing by 123DCatch,* Francesca Picchio, Masada Notebooks, Report of the Research Project 2013, Vol 1. Edifir Edizioni Firenze, Pisa, 2013.

10. The results of the experiments performed on the field during the first year were presented during the discussion of Marco Benedetti's thesis, who took part in the first research mission in 2013.

11. *The use of reality based models for the interpretation of ancient architecture: experiences of reverse modelling at Masada,* Filippo Fantini, Masada Notebooks, Report of the Research Project 2013, Vol 1. Edifir Edizioni Firenze, Pisa, 2013.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Masada 2014