3-D VISUALIZATION AND ANIMATION OF ARCHITECTONIC ELEMENTS FOR PREHISTORIC MEGALITHIC TEMPLES OF THE ISLAND OF GOZO: THE TEMPLE OF GGANTIJA

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ABSTRACT

Laser scanning can now be defined without doubt as the newest frontier in the field of survey technique, and recent technological developments of instruments and processing software have encouraged the introduction of this technique in the world of applications connected to archaeological site and other related disciplines. The temple of Ggantija on the island of Gozo was considered to be representative of the entire series of temple complexes due to their particular architectural characteristics, their stage of evolution and form of deterioration, both material and structural. The survey was conducted by the use of the local geodetic network in the different phases:

- Topographic survey
- 3D laser scanner survey
- Photographic Survey: both traditional and digital pictures will be taken in order to fully documentation internal and

external surfaces of the site. The treatment and analysis of data collections was divided into the following sub-stages: elaboration and compensation of close polygonal, thickening polygonal and direct measurements; elaboration and compensation of altimetric network; linking of the above data with the existing Maltese national networks; elaboration of laser scanner positions and absolute orientations; elaboration of points coordinates for georeferencing and linking the point clouds coming from laser; final data verification end quality control; analysis of laser measured point clouds, for filtering and subsequent elaboration; scanning orientations and subdivision into "islands" (internal rooms and external sides); analysis of laser measured point clouds over the grid determined by the topographic survey.; modelling of the Archaeological site, elimination of noises and metric "pollution" by statistics and verification; accentuation and reduction of triangles on areas interested by complex geometries; triangles transformation into complex surfaces (mesh); model checking by topographic points; mapping of digital photocolors covering all the surfaces of the site. The digital model will be cut by vertical and horizontal section plans at heights requested by customer 2D graphic editing of the plans, sections and elevations. Finishing of vertical sections (sections and views) using the mapped model created by rendering calculated, generating contours lines from the 3D model; of a light model (low density model) of the laser scanner data using the filtering tools of the software package; of an virtual animation of the high density model; of a mapped VRML (Virtual Reality Modelling Language) model for a web interactive and hypertestual navigation, using the low density model. This part of the study was aimed at defining the architectural characteristics and mode of construction of this monument.

1. INTRODUCTION

Malta has a rich archaeological heritage dating back to the prehistoric-megalithic period with numerous architectural sites in a poor state of conservation. The structures are more similar to ruins in a slow process of decay; the original geometry of these complexes is based on curved lines, on the juxtaposition of concave and convex surfaces with complex hollow volumes. These are some fine examples of the highly developed Maltese culture of that period.

The analysis of this type of structure has nothing to do with the classic concepts of a plan with a horizontal and vertical layout. The most appropriate choice involves instruments that allow you to read the constituting elements with their complexity of shape and dimension. Therefore, scanning is a suitable instrument for interpreting, and at the same time it provides the priority result for subsequent inspections and research on the structural character of the building as a whole and of the single parts of it , while providing qualitative information on the materials and the alterations the same have been subject to.

Research is based on applying terrestrial laser scanner techniques to the three-dimensional surveying of monuments, in order to establish a data bank which can be used according to the needs of various specialists.

In the field of studies of safeguarding and preserving Archaeological assets, three dimensional images appear to be a very useful tool in view of their many expected applications. They can be a tool for simulating working hypotheses which could justify technical, aesthetic and historical choices; both in the case of restoration work and in the case of studies by architecture historians and archaeologists.

They can be an immediate way to display information to a public which is not used to graphical representation of a monument. On the other hand, like plastic models, it is a fundamental teaching tool to highlight the quality of a job, to explain the theoretical principles and the construction techniques typical of a building, to teach its history; and more generally, as a support for history of architecture or to present tourist information at a high level.

They can be a "spectacular" tool, often associated with cinema and visual information media in order to show everything which has disappeared: the destroyed or radically restructured parts of a building, the archaeological reconstruction of a site, of a habitat, etc.

Finally, they can be a tool for memory, which can associate the shapes of the "synthesized" objects with immediately accessible and complex information: the materials, the dates, the state of preservation, restoration works.

2. THE TEMPLE OF GGANTIJA

The history of man in the Maltese islands dates back to times of old. The first settlers arrived from Sicily roughly 7,000 years ago. In the second Maltese prehistoric era, dating from approximately 4000 to 2500 b.C., extraordinary stone structures called temples were built. There are numerous examples on the island, and these are some of the most characteristic of the period. The form of the temples, since their firs appearance, reproduced on the ground the shape of the lobed underground tombs. The first temples appear to be simple structures, which became more impressive and complicated as time past. The construction of the Temple of Ggantija passes from an internal trefoil layout to a symmetrical plan with five apses. There are two temples in the complex. One with five apses, and the other with four apses and a niche at the back. They have a common external wall, but separate entrances. The structure, of a notable size, is made of irregular blocks of hard coral limestone along the walls, and blocks of globigerina limestone in the passageways with a smoother and well-finished surface (fig.1).

Figure 1. Site description con i rosso il limite dell'area da rilevare e il particolare di una parte del complesso megalitico

3. DATA ACQUISITION

The topographical framework for the complete survey of the Ggantjia megalithic temple was made in order to pursue two specific goals: the generation of a reference topographic polygonal, and the creation of references for future scans. The polygonal shape was made out of a main closed polygon, with eight sides connecting, one after the other, the station vertexes Stn 1,2,3,4,5,6,7,8. Some topographical stations have been joined, according to the geometry of the main polygonal, and placed into the niches of the two temples, in order to survey details Stn 9,10,11 inside the Small Temple, and details Stn 12,13,14,15,16 inside the Big Temple.

The main and detail vertexes of the polynomial have been chosen so that the surveyed object was completely encompassed, and so that they were in the best possible position to measure the markers, set as a reference for connecting the point clouds.

Later on a compensation computation of the main polygonal was made, first computing a free polygonal in the local framework, then adding the constraints set by the coordinates taken from the reference frame, as previously defined by the printouts supplied by the Planning Authority. Polar distances have been measured with an electronic total station, mod. Leica TPS 700. Overall, there were sixteen stations, twenty-four scan markers, and several detail points, that enabled us to get an early planimetry of the surveyed complex alongside the planar-altimetrical trend of the environment (fig.2).

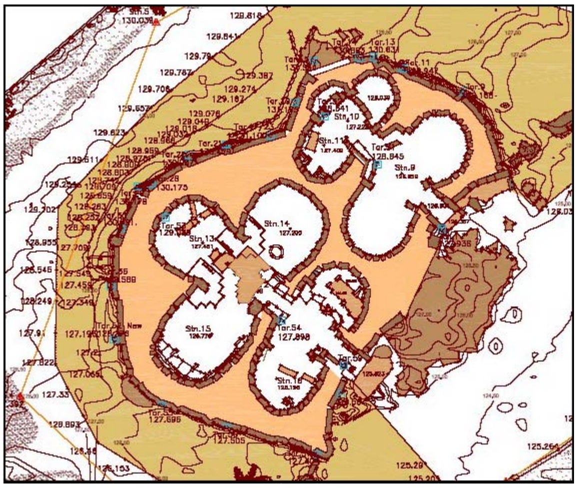

Figure 2. Topographical survey complete layout

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he survey trial on the Ggantija megalithic site has been made using a ToF laser scanner, mod. Leica HDS 2500 (fig. 3)

Figure 3. Leica HDS2500 laser scan

This laser scanner has a maximum reach of 100 m (best between 1 and 50 m), a field of view of 40 degrees both horizontally and vertically, and has quite a high single point accuracy, ± 6 mm at a reach of 1.5-50 m; the spot size is less than 6 mm up to 50 m of distance. The scan speed is one column per second for a 1000 points-column, two columns per seconds for a 200 points-column; the minimum distance between points is 0.25 mm, both horizontally and vertically, while the maximum line and column sizes are 2000 and 1000 points, respectively. Overall, it is a reliable and flexible instrument.

Overall, we have made one hundred and twenty-eight scans from several station points, twenty-two from the outer area of the site and thirty-nine between the Small and Big Temple, for a total of roughly 67 million points taken. Additional fourteen scans have been taken from three raised points on an elevating platform. The aerial scans covered the top part of the site, which couldn't be reached easily in any other way. Another element that made the survey operations problematic, was guaranteeing an effective coverage of all the zones to analyse. For this reason a printed file was attached to each scan, to record the data and provide a preliminary survey of the scanned zone (fig.4). The scans were run with a variable step of between 0.8 and 1 cm. Numerous targets were positioned on the external surfaces of the site to join the scans automatically, while inside we chose to join the scans through the acknowledgment of corresponding points, positioning a sufficient number of targets for the dimensional control.

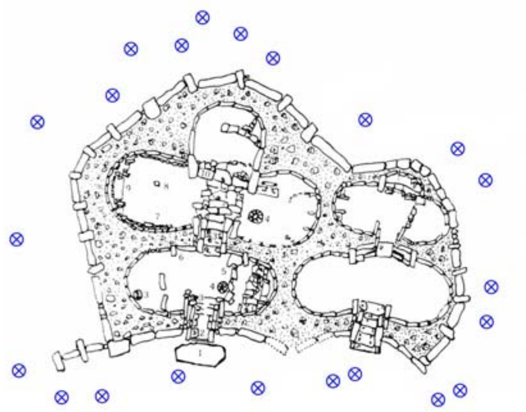

Figure 4. Station points in the outer area of the site

4. POST PROCESSING

Data acquisition is only one earlier stage of the survey with a laser scanner; a second, quite complicated, stage is the so-called post processing of data, where most of uncertainties and problems connected with surveying technique do accumulate.
This operation sums up all those computer-aided processes, both automated and manual, that lead from the “raw” point cloud – output of the instrument – to the final desired graphical result.
The point clouds were merged with Cyclone 5 without having to reduce the data, thus keeping all the surveyed points, regardless the fact that the survey file was about 4 Gb; for the 3D modelling stage, on the other hand, we had to reduce the generated polygons.
Uniform, or intelligent discretization is just one of the operations that we must perform in the post processing stage. The raw cloud, as fed from the scanner into the processing environment, needs most of the time to be “cleaned”.
Laser scans quite often include the survey of unwanted objects, such as trees, cars, people placing themselves between the sensor and the surveyed object, elements on the background; therefore we must limit the cloud to the surveyed object, for a better display and in order to avoid the processing of useless points by the PC.
We have seen before that we should take more scans for a better description of the object: after noise subtraction, these scans usually are merged into one.
There are two main methods to make this merge, that is also called registration. The first method, manually performed by the user, allows to recognize in two adjacent scans some homologous points and then constraint these points to get the same coordinates.

Figure 5. Clouds of points during the post processing phase

If these scans have been made with the aid of an auxiliary topographical survey, then we can merge and georeference the entire survey with this method through the successive adding of scans.
As for the second method, we need to place on the object some suitable flat or spherical targets, that the scanner can recognize and scan. Later, the post processing program can compute the centre of mass of these targets as weighted average of the point cloud of a given set, thus minimizing the error. This method allows to merge automatically all scans.
Again, in such cases, it is clear the advantage of having a topographical survey that can be used as a dimensional reference for the merging processes of scans.
The registration and merge of the numerous scans taken at the Ggantija site was undoubtedly one of the most complicated stages of the whole survey campaign, both since the high number of scans and the unique morphological complexity of the site.
Both registration methods (homologous points and targets) have been employed, and the whole operation was completed without reducing the number of surveyed points.
Other possible post processing operations are the smoothing and model mapping with digital pictures.
Meshes made from scans are, usually, quite edgy; each surveyed point is shown as a vertex in the model, hence the visual perception is not always pleasant.
The model can be made more agreeable with a mesh smoothing, that leads to an edge cutting and softening of the overall shape, hence to a visual perception that sometimes is more pleasant than the one given by the original mesh model.
Before smoothing, it is common to reduce the triangles (see fig. 6), thus diminishing definition but in the mean time making the mesh easier to work with by the PC.
For the reduction of surfaces we can apply uniform or intelligent reduction methods, as we did before for point clouds.

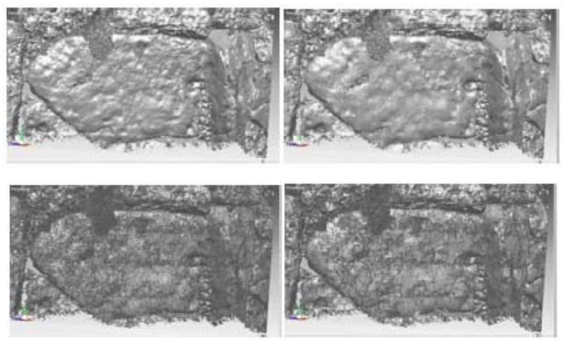

Figure 6. Example of mesh reduction: model becomes less wearisome for the PC, but loses geometrical accuracy

During our trial on the Ggantija site we chose to make a reduction in the management stage of the mesh models, that allowed us to handle even large files, applying some reduction features integrated into Cyclone and Rapidform.
The mesh models of each scan were generated with Cyclone 5, then exported as .dxf.
Given the amount of scans done on the site, and in order to produce .dxf files manageable by the PCs, we had to reduce down to 20% the number of polygons – generated by the point model surveyed on site – applying an uniform reduction tool included in Cyclone. Even after such operation, we still had quite large .dxf files, on average 50-60 Mb each.
The next step was the mapping of the mesh model, made with the Rapidform 2004 program, that operates a recognition, within the pictures and the scans, of the homologous points – in the same way we did for the registration of scans – and then applies the constraint that the picture adapts to the surface model. In the mapping stage we applied upon the model some pictures at 1024 px, and the output .mdl files (the proprietary format of Rapidform) were still quite large.
For instance, in the case of the Big Temple we made five subdivisions, separately processed, obtaining some files (01p.mdl - 36Mb; 02p.mdl - 99Mb; 03p.mdl - 71Mb; 04p.mdl - 61Mb; 05p.mdl – 66Mb).
Given these figures, the goal of merging the split files to get the complete Big Temple seemed to be difficult to fulfil, if we wished to have a file that could be handled by a medium-erforming PC. Even more so, the goal of completing a model of the whole site seemed to be unreachable.
Therefore we had to make a reduction, this time on the mapped files in Rapidform, by using a feature that allows to cut the number of polygons on the less complicated surfaces and keep those on the more complicated ones.
Overall, there was a reduction of 70% of the polygons, and the map pictures were resampled from 1024px to 512 px, so that the files were reduced to the following sizes: 01p.mdl - 16Mb; 02p.mdl - 41Mb; 03p.mdl - 22Mb; 04p.mdl - 22Mb; 05p.mdl – 27Mb.
Although such reduction seems significant, nevertheless once these files are merged together into the complete model of the Big Temple, the resulting file has a size of 130 Mb. Moreover, reduction and resampling led of course to a loss of quality, both in the definition of geometry, and in the picture display, since it's made of a lower number of pixels, as can be see from the two following images showing the same area before and after the reduction (fig. 7).

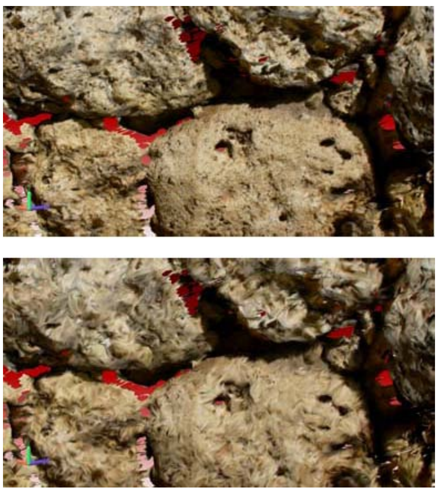

Figure 7. The same area, before and after mesh reduction, and image resample

In view of the above, we chose to make a mapped model that keeps the division between the various elements of the site (for instance niches, outer walls, etc.), and to avoid the reduction operation. We used reduction only to generate models that include, always separately, the Big and Small Temple, and the outer site, not forgetting that the resulting files have huge sizes.

5. THE CREATION OF THE FINAL OUTCOME

Of course, most surveys aim to draw several kinds of graphical results, on paper or digital, as suited for each field of use.
During this survey made with a laser scanner, the main outcome of the operation was an high definition, three-dimensional database, acquired during the on site campaign. From this database we can at any time gather the needed geometrical information. The features and kind of graphical results (plans, elevations, sections, etc.) will be set by the purposes of the survey.
In this case we provided with some drawings with elevations, sections and contour lines of the surface elements of the monument. These drawings will be an irreplaceable support for any future intervention plan on the object.
Upon the numerical model made from mesh surfaces mapped with their corresponding photos, we fixed the sections and elevations in order to avoid any partial view projection, and, whenever permitted by the object, we made a division into more planes (fig. 8).

Figure 8. Sections and elevations of the mapped 3d model

If we project a numerically georeferenced model orthogonally onto an appropriate representation plane, the result is a drawing that, once mapped with pictures of the surfaces, is a scale and measurable rendering of the surveyed monument.
This so-called ortophoto is not the definite outcome from the post processing stage of the survey, rather the solid foundation upon which understand and discretize all the needed information for the operations on the site (state of decay, materials, state of damages, etc.).
We made seven representations of the outer walls and eight of the inner, at a 1:50 scale, plus one at a 1:20 scale, and all with their elevation (fig. 9).

Figure 9. The digital ortophoto map

Digital ortophoto maps can supply important information regarding the surveyed object, but they do not show the three-dimensionality of the object as contour lines do. Contour lines, especially when they are numerous enough, are amongst the best graphical marks to represent this feature of a monument.
Contour lines were automatically drawn on the georeferenced numerical model, through the definition of the projection and

representation plane, of the desired range, and of the depth of the surveyed region.
We made two representations with contour lines of the outer walls, and four of the inner, at a 1:50 scale, with a gap of 15 mm, thus suitable to highlight even the slightest variation in the morphology.
The kind of results described here are just a small fraction of all the information stored in the geometrical database, nevertheless they show how it is possible, once a precise intervention area is defined, to make extremely detailed qualitative and quantitative surveys (fig. 10).

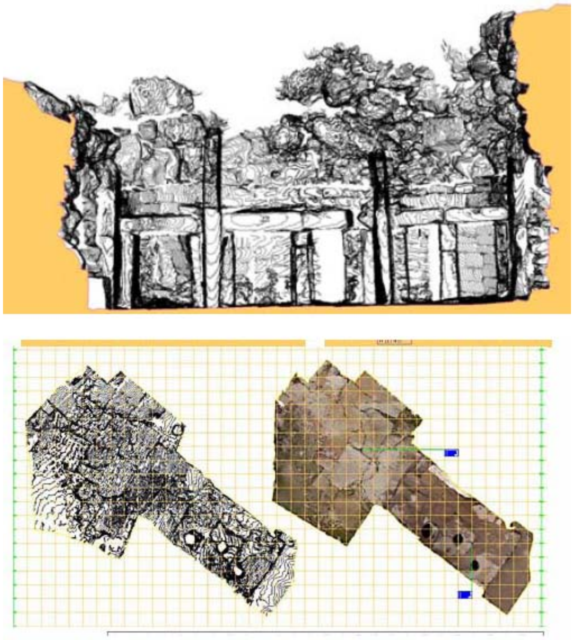

Figure 10. How to show contour lines

The mapped model of the site has been animated, to produce a video of five minutes in .mpeg format. This is an excellent instrument of analysis, which can be used every time the need arises to meet specific displaying requirements (fig. 11).

Figure 11. Walk through virtual animation

6. CONCLUSIONS

Buildings of this size and with these characteristics cause some problems when using laser scanning techniques, related to the scanning methods, the processing of data, and the final results. Furthermore, the three-dimensional survey and its forms of representation, can supply additional elements for the surveys such as open information systems, in particular in the field of conservation, protection and exploitation of the cultural heritage.

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