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Surveying hypogeous structures: the case study of Santa Maria in Stelle in Valpantena

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Abstract

The hypogeous complex of Santa Maria in Stelle, known on-site as"Pantheon" and located under the parish church of Quinto in Valpantena, (Verona, Italy), is considered by scholars one of the most interesting paleochristian pictorial monuments in North Italy. Current preservation conditions are poor, affected by temperature and humidity variations which cause percolation, condensation, swelling, and efflorescence occurrences.

Recurrent problematic issues during surveying operations in subterranean structures are:

- *necessity of instrumentation easy to handle and able to make acquisitions with the widest field of view possible, because of confined spaces often difficult to access;*
- *remarkable wall paintings require an appropriate survey methodology through non-contact recording techniques;*
- *the distinctive morphology of structures defined by almost uninterrupted curved surfaces makes it quite impossible to blend the geometric models detecting edges and gaps;*
- *graphic outputs should work as a visual base for highly detailed topic representations of the state of damage.*

This paper reports on the techniques and procedures adopted to survey shape and dimensions of the architectural context (laser scanning), and to record the wall paintings and the floor mosaics (photogrammetry), and also on the line drawings extracted from the three-dimensional model, required as visual aids for documentation and conservation projects.

Categories and Subject Descriptors (according to ACM CCS): I.3.5 [Computer Graphics]: Curve, surface, solid, and object representations, I.3.6 [Computer Graphics]: Methodology and Techniques, I.3.7 [Computer Graphics]: Color, shading, shadowing, and texture, I.3.8 [Computer Graphics]: Applications.

1. Introduction

In research agendas aimed to acquire knowledge about cultural heritage sites, either architectonic or archaeological, an important role is covered by survey work which in recent years, gaining relevance as a non-invasive and non-destructive diagnostic discipline, has been going through a substantial evolution regarding principles and techniques. Because of the irreversible tendency towards automation, survey nowadays is based on the integration of topography and photogrammetry with the more recent three-dimensional scanning techniques. Employment of laser scanners, production of complex models (explorable and measurable) and survey data management procedures currently raise new issues in dealing with a structure that has to be measured, represented, interpreted.

The increasing diffusion of these survey methodologies highlights the more and more fading distinction between measurement and visual representation. The point cloud density used to acquire the object is usually so high that it could seem unnecessary for clear descriptive purposes to provide continuity to point information. But in certain contexts, when the yet evocative point cloud is not accessible, it's still inevitable to deal with the 2D deliverable products, traditionally employed for illustration intentions, and, therefore, to produce vector data, extracted from point image data.

2. Object of investigation and purposes of the survey

The hypogeous cultural site of Santa Maria in Stelle, locally known as "Pantheon" and situated underneath the parish church of Quinto in Valpantena, in the Veronese province, is considered by scholars one of the most fascinating paleochristian pictorial monuments of Northern Italy. It was raised in late Imperial Roman age to be a subterranean devotional space for pagan worship of water divinities, and subsequently became a Christian sanctuary, at the end of the IV century AD.

The documentation project of this monumental complex presents problematic issues recurrent in hypogeous structures. We mean by "hypogeous" any man-made, or transformed by man, underground spaces.

The monumental complex is formed by independent structural components. A small room leads to the ancient entrance, followed by the first corridor 18 m long, covered by a barrel vault, quite narrow and scarcely lit, which takes

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Figure 1: *View of the complex: on the left the parish church's façade, on the right the acquired 3D model, showing the position of the hypogeous "Pantheon" in relation to the church.*

to a quadrangular hall with two side cells (Figure 1 and 2). Floor mosaics and wall paintings are regarded as the most remarkable features of the cells and of the whole complex. Mosaics are partially preserved on the floor of the northern cell and subsist only in fragments in the other one. The barrel vault in the northern cell is painted with a starry sky, while the apse conch harbors decorative patterns lined on four rows. Beneath these, a tall ornamental border, composed of a double greek key drawn in axonometric projection, hangs over the apse wall depicting scenes from the Old and New Testament, spaced out by false pilasters.

Departing from the quadrangular hall, a narrow tunnel, 85 m long, takes to the water spring. This tunnel traces out the natural trail originally developed by the underground stream, outlining three segments interspersed by wells.

Preservation conditions are the same ones concerning all hypogeous structures: constant exuding humidity (either from pipes conveying water or the ground), cause frequent deterioration activity, with localized variations and seasonal aggravation circumstances. Evident damage on the mural paintings can be spotted in swelling episodes, washouts, color alterations and efflorescences. Air circulation is scarce because old air shafts have been closed and air vents on the church's floor are not effective underground. In such a precarious situation, there were clearly an urgent need for surveying and an unavoidable restriction to use non-contact techniques for measurement acquisition, to prevent further damages in the structure. The objective has been achieved making an integrated use of various survey techniques, as laser scanning and photogrammetry.

3. Operational methodologies

The instrument employed for detail surveying, HDS6000 (Leica Geosystems) phase-based laser scanner, suited well

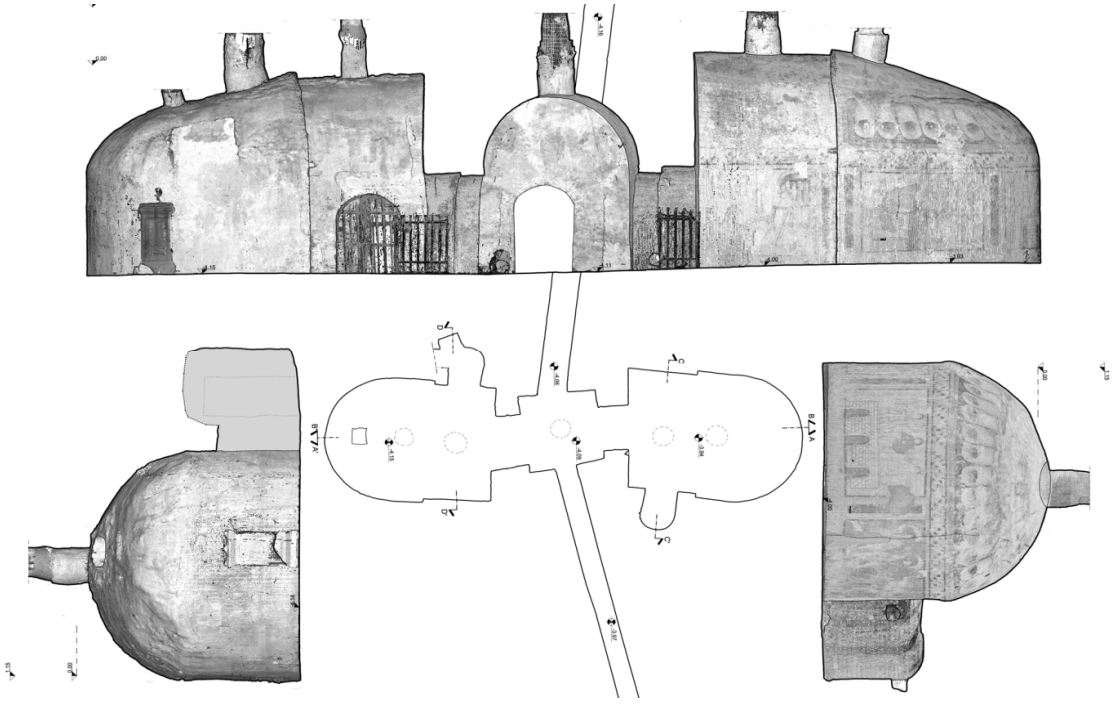

Figure 2: *Plan view and elevations rendered with point cloud image in gray scale.*

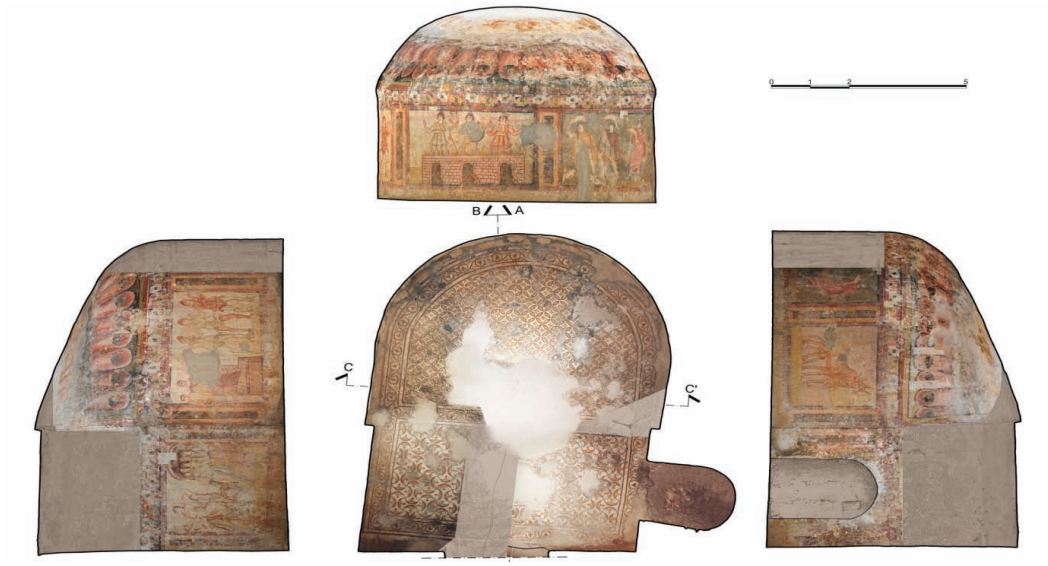

Figure 3: *Plan view and elevations rendered with floor's photoplan and wall's orthophoto.*

for the on-site investigation of confined spaces: easy to carry and not too big, it allowed to acquire all the interior structural information, in the accessible parts of the complex and also in the more inconvenient ones, as the long and narrow tunnels which connect the quadrangular room to the peripheral spaces.

In order to reduce holes in the set of collected data and to relate surface and underground architectural units, 18 scans have been performed, inside and outside the hypogeous structure. Scans have been registered in a common co-ordinate system based on a topographic grid and their alignment has been optimized through ICP (Iterated Closed Point) algorithm procedures.

The resolution of measurement has been modified according to the morphological features of each structural unit. Higher levels of detail were required in the northern cell (Figure 3) the only one to maintain the noteworthy set of mural paintings and floor mosaics. Also, given this peculiarity of the cell, it's been essential to integrate laser scanner's 3D data with textural information obtained through photogrammetric processes.

Considering purposes of survey, level of detail, scale of the planned graphic output and expected accuracy, it was decided that the direct extraction of control points co-ordinates from the shape model of the object would be sufficient for the photogrammetric images orientation. With regards to this, it's important to underline that such an operation, if it allows to streamline the on-site acquisition process, on the other side it implies a lower accuracy of measurement than the one which can be obtained with topographic instruments. This approximation is not caused by the fact that the two systems are distinguished by a difference in measurement uncertainty, but is attributable to a higher difficulty in spotting the appropriate control points on the model – which is the result of a sampling action – rather than on the object, as these should be related to geometric irregularities or color variations. In this specific matter, according to the set goals, a preference has been made for a complete but less precise photographic overlay of a more rigorous shape model, providing the textural data through a quick photogrammetric survey. Photographic images were taken with a reflex Nikon D700 digital camera.

4. Two-dimensional representations

One of the fundamental tasks of the surveying activity is primarily to provide full and reliable documentation on configuration and spatial extension of the analyzed spaces. In a research program focused on gaining knowledge about an architectural or archaeological structure, the production of maps referring to different topics (materials, state of preservation, stratigraphic reports) is traditionally performed on two-dimensional layouts. Since it's possible to link all deliverable datasets to the main survey reference system, the relation between the three-dimensional database and the classical line outputs can be constantly maintained, and the integrated recording of new collected spatial data can always be carried out.

Various vertical and horizontal cross-sections needed to document the hypogeous structures have been obtained:

- cutting thin portions through the scan data and vectorizing the geometric profiles;
- mapping the surfaces with textural information extracted from the point clouds or from the projection of oriented digital photographic images, when required by level of detail and highly decorated areas.

Particularly, two outputs were generated: the rectified photography of the floor decorated with mosaics and the orthophoto of the frescoed walls of the northern cell's apse.

The photoplan, produced with 6 photograms, has been calculated analytically (Archis, Siscam) on the basis of the control points co-ordinates extracted from the 3D model. In order to achieve an ortho-image, intended as the differential correction of the captured image, photogrammetric shots and a DEM, in our case created from 3D scans, are

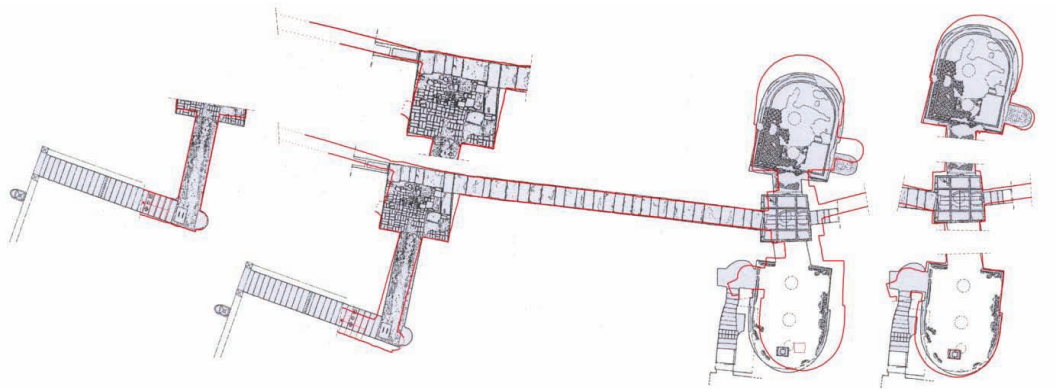

Figure 4: *Comparison between the survey described in this paper and a previous work, carried out through hand survey.*

required.

The orthophoto of the painted walls has been calculated through the independent orientation of each photogrammetric image with space resection procedures (Micromap, Microgeo). This method allows to project the photographic image on the DEM and to tie every pixel to its corresponding elevation value.

Because illumination was scarce, each digital image has been preemptively edited to uniform RGB value of single shots. At last, all ortho-projected photogrammetric images have been assembled together to generate global perspective views.

4. Conclusions

The resulting digital archive, constituted by 3D co-ordinates and high resolution photographic images, turned out to be an essential recording source for a better understanding of the subterranean structure and its location in relation to the church above.

Reminding that level of accuracy is determined by measurement features of the employed instruments and its uniformity by the surveying methodologies which have been adopted, the hypogeous structure plan drawn out from the 3D model was compared to a previous hand survey, executed only with length measurements. If very limited areas are compared, a good degree of concurrence can be found, but overlapping the plans of the whole complex the overall mismatch is significantly increased (depending on the "fixed zone", until about 1 m). Single length measurements are reliable, but considerable deformations are determined by the propagation of however small measuring errors. This inevitably occurs when one single point is chosen as origin of all measurements and the entire survey activity proceeds from it: the consequence is a perceptible loss of uniformity in terms of geometric accuracy.

Our new survey enhances the high resolution 3D data coming from laser scanning with digital images, but highlights too the fundamental role of topographic measurements , that worked as the reference frame for all measuring operations ensuring appropriate and steady accuracy.

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