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Geomatics for studying historic supply systems: the *Grotta degli Animali* case study

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Abstract. In the past, it was difficult to exhaustively document gardens and artificial grottoes with traditional manual survey techniques and maybe also for this reason the restoration Charters used to pass over the need of an accurate survey. Currently, high resolution sampling allows to obtain 3-D data acquisition and realistic and metrically accurate representations. However, the quality of a digital model is not validated by automatic measures or likelihood but following rigorous acquisition and processing workflows, which must be described in metadata and paradata. The new survey reveals some aspects of the historic water supply system for a better understanding of the construction of this monument and will be extended to the narrow tunnels included in the retaining wall around the grotto.

1. Introduction

In the past, it has been repeatedly pointed out how was difficult to measure and draw the typical organic shapes of fountains, grottoes and nymphaea in Mannerist gardens, if not with simplified, unfulfilling representations. Current three-dimensional digitisation technologies, known as geomatics, sample accurately even the most complex geometries, also under the metric point of view, provided that data acquisition and processing are rigorously carried out.

The new survey of the *Grotta degli Animali* (figure 1), in the park of the Medicean *Villa di Castello* (near Florence), has been performed by GeCo Lab as a part of a research agreement between DICEA-UNIFI and Polo Museale della Toscana.

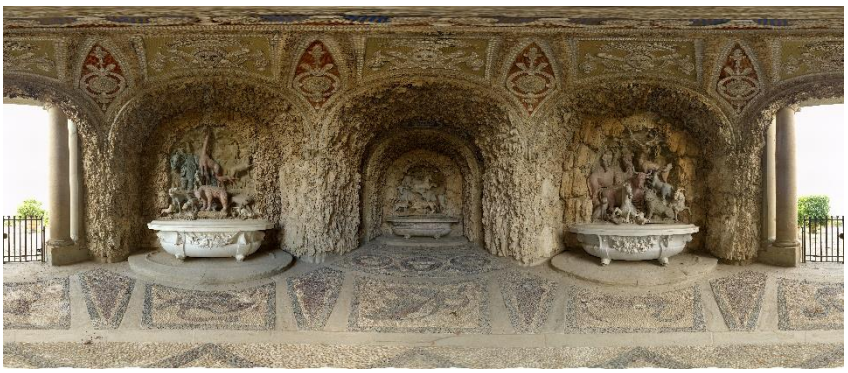

Figure 1. Panoramic view of the interior of the *Grotta degli Animali.*

It represented a new and intriguing challenge, both for overcoming the problem of the geometric shape, which was considered as an epistemological obstacle before the spread of 3D digital technologies, and for understanding the functioning of the historic water supply system in view of its re-activation.

The paper deals, first of all, with the role of the survey in the restoration Charters in general and on historic gardens Charters in particular (section 2); then it examines some critical aspects of the survey of artificial gardens and grottoes and the improvements coming from the current techniques for the automatic spatial data acquisition (section 3), and highlights how to evaluate the quality of the resulting digital models (section 4). The final part is dedicated to some aspects of the *Grotta degli Animali* documented in the new survey (section 5).

2. The survey in restoration and historic gardens Charters

The well-known restoration Charters represent (also with their omissions) a significant evidence of how the documentation provided by a metric survey has been considered in the conservation process. The *Athens Charter* (1931) [1] mentions "accurate records" only before reburying archaeological findings which cannot be preserved. *Venice Charter* (1964) [2] prescribes a "precise documentation in the form of analytical and critical reports, illustrated with drawings and photographs", but does not discriminate between sparse sketches and a complete and systematic metric survey. Only in 1972, the Italian *Carta del Restauro* [3] lists the content of a restoration project, stating that "it must be based on a complete graphic and photographic survey to be interpreted also from a metrological point of view".

It is therefore significant that in the *Florence Charter* (1981) [4] on historic gardens a "thorough prior research to ensure that such work is scientifically executed and which will involve everything from excavation to the assembling of records relating to the garden in question and to similar gardens" is still considered sufficient, without any prescription about the need to verify on the field the actual consistency of the surviving elements for discerning between restoration or reconstruction works.

In the same year, the *Carta italiana per il restauro dei giardini storici* (as cited by Dezzi Bardeschi [5]) indicates, in a more appropriate way, the need to study the garden "in all its components (architectural, vegetable, water, geological, topographical, environmental, etc.) and through historic and literary documents and sources, and through surveys, topographical and cadastral surveys, as well as any other iconographic source". The spatial information is therefore finally listed among the documentation required, also suggesting topography, in those years the most suitable and available technique for surveying gardens.

3. Traditional vs. digital techniques for surveying Mannerist artificial grottoes

Despite this indication, many studies on gardens have been carried out without the aid of reliable and up-to-date measured and drawn documentation, at least to compare the current consistency with the historic sources.

Scholars who in past years studied organic and complex forms, as gardens, their architectures and artificial grottoes, are legitimated by the use of traditional tools (like the manual survey) before the definition of strict data acquisition and management protocols. The report of the survey of the *Appenino* by Jean de Boulogne, coordinated by Marco Dezzi Bardeschi and Luigi Zangheri and carried out by Emilio Sacchini and Elisa Sambataro [6] is an example of this approach; the surveyors acknowledge that they were "satisfied" with a so-called "organic" result, which allows "checks and comparisons" between parts, but is not totally fulfilling the standard requirements of an architectural survey.

Claudia Conforti argued [7] that the survey of artificial grottoes, carried out by trilateration of the most significant points only, produces a "geometrical model (...) that inevitably tends to highlight the original and artificial matrix of the object, before to the process of *naturalisation*". The surveys she directed reconstruct the continuity between the measured points with freehand curves and uses drawing techniques like shading, smudging and stippling, more used in artistic than in technical design. This was acceptable when all renderings were drawn by hand, but the lack of other information

and paradata is less adequate. The survey of the *Grotta degli Animali* edited by the same scholar [8] is important being the first systematic representation of the monument and because it shows the level of the ground on the roof before the 1994 excavations. However, the elevation and section lines are not visible and all data are missing (except for the name of the surveyors), e.g. the date, the scale of original drawings, if it was carried out by professionals or students, where data are stored and so on.

Considering that a survey can be the only testimony of the condition of an artefact at a certain date, it is evident the importance to strive for the highest degree of objectivity allowed by the available tools and to provide all the information to assess the reliability of all data.

Geomatics, by means of high-resolution sampling, allow to overcome these challenges [9], producing accurate metric drawings, regardless of the complexity of surveyed geometries also dealing with garden architectures [10]. The resulting point model can be used as a *replica* of the real object (or, more correctly, of some of its properties) to support many aspects of the conservation process [11], like for designing a restoration project [12] or for building models for structural analysis [13] and other simulations and researches [14]. So, the digital model is not only as a visual representation, but a flexible, integrable, transmissible, and shareable 3-D database.

4. The quality of digital models

The quality of a digital model is not guaranteed by its realistic appearance or because is the result of automatic measures and processing. On the contrary, this can lead to inappropriate decisions based on unreliable data. All survey procedures, from acquisition to final deliverables and visual representations, must be designed with the aim to contribute to the knowledge and documentation of a cultural asset in the most reliable way. It is the design of the survey that can and must certify the quality of the resulting model, attesting its suitability within the overall conservation process [15].

The survey project should explain how to control and document the acquisition, processing and storage of data and the reliability of the results. Before starting to measure, it is necessary to consider all the criticalities of the object, the available techniques and instruments, what degree of data completeness is required and how it can be achieved. It is also important to design an expandable measurements network, foreseeing possible interpretation and future requests.

The quality of data, and therefore of the model, can be defined through metadata and paradata, which are the information describing the data itself and how they are obtained. Metadata and paradata must therefore be considered an integral and qualifying part of the survey and the models.

About metric accuracy, the first steps are the measurement of a topographic network with permanently defined vertices and the setting a common reference system for all the elements (even located at great distances), for referencing data acquired with different techniques and for monitoring transformations occurred over time. In the survey of the *Grotta degli Animali*, it has been possible in this way to reference data acquired during different excavation and work phases or to extend the survey in the underground corridors for the acquisition of the water supply and disposal systems.

About laser scans, each one is initially independent, being made in a local reference system, so they must be aligned in a common reference system. The result is biased both by systematic and random errors (typical of each laser scanner) and by the alignment error, which can be expressed using statistical methods; these values make it possible to value its metric accuracy.

Further parameters for assessing the quality of a model concern the completeness of the surveyed surfaces. They can be assessed by analysing the gaps in the model or the extent of so-called *noise*, i.e. the measure error due to both the intrinsic characteristics of the instruments and the physical properties of the surfaces.

The transition from a discrete point model to a surface (or mesh) model, which has been used for visualising the background elements in vertical and horizontal sections of the grotto (figure 2), must balance the opposite requirements of resolution and file dimension. In this case, quality control can be performed by checking that the distance between the point cloud and the mesh model is under the requested tolerance.

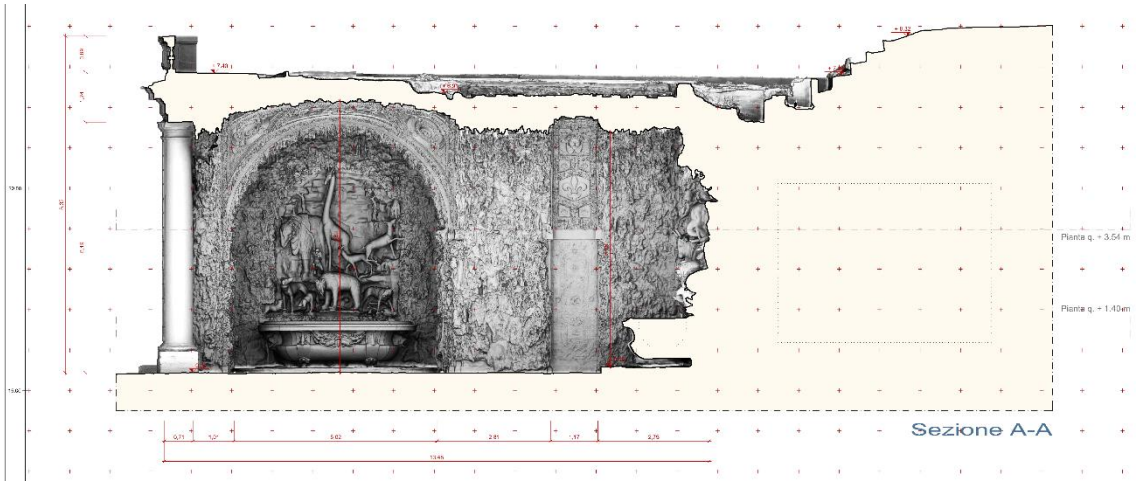

Figure 2. Detail of a cross section, with a view of the mesh model used as background.

Dealing with objects with complex geometries, it is necessary to know the exact position of the section planes for structure monitoring or for a comparison between surveys carried out in different times. In such cases, section lines on drawings may be not sufficient. Their position should therefore also be digitally recorded, for example including in metadata the roto-translation parameters with respect to a local or cartographic reference system.

Moreover, considering that a survey witnesses the geometry of an object at a certain date, it is essential that deliverables are always entirely published including title blocks, legends, metric scales, etc.

5. A digital model for knowledge and restoration

A comparison between the new survey with the drawing *A 1640 v.* of *Gabinetto dei Disegni e delle Stampe della Galleria degli Uffizi* (attributed to Giovan Battista [8] or Francesco da Sangallo [16]), helps to understand the *Grotta degli Animali* (figure 3).

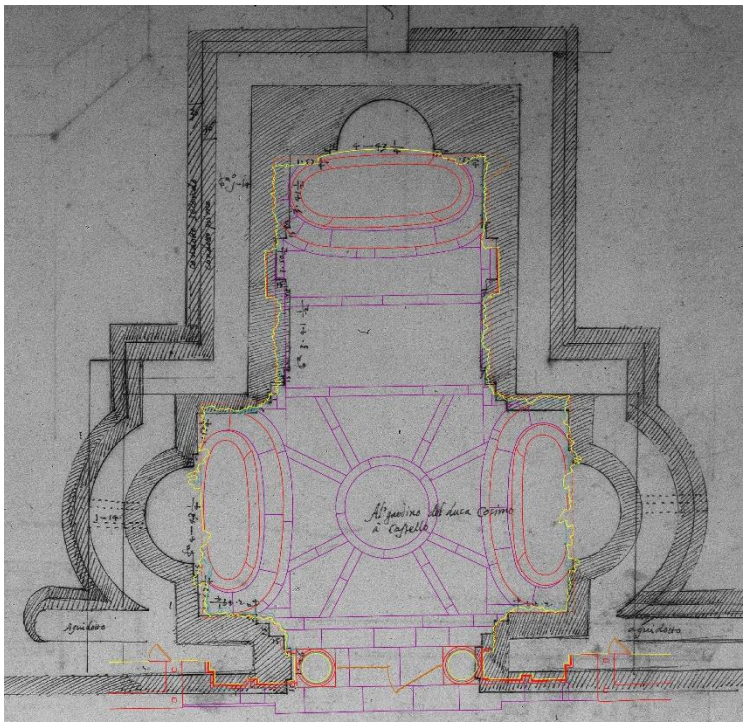

Figure 3. Comparison between the drawing A 1640 v and the survey.

Interpreting some differences in the thickness of the masonry on the interior perimeter as pilasters, in the past it has been hypothesized that the inner space was initially designed with architectural partitions instead of the current rustic cladding.

This assumption, however, does not consider that the baseboard along the perimeter of the room corresponds with the drawing, albeit if some segments are actually shorter. So, the drawing could represent the rough construction prior to the laying of the spongy stone cladding. This does not explain why the three arms were drawn with apses instead of flat endings (as actually are), for this aspect it may be useful the survey of the corridors surrounding the main space.

The new survey is not a mere documentation of the geometry of the *Grotta degli Animali* and its multi-material surfaces, but has been continuously updated throughout the project in order to provide data useful for the works, like the thickness of the vaults or to document the historic water supply network as they have been excavated (figure 4) [17].

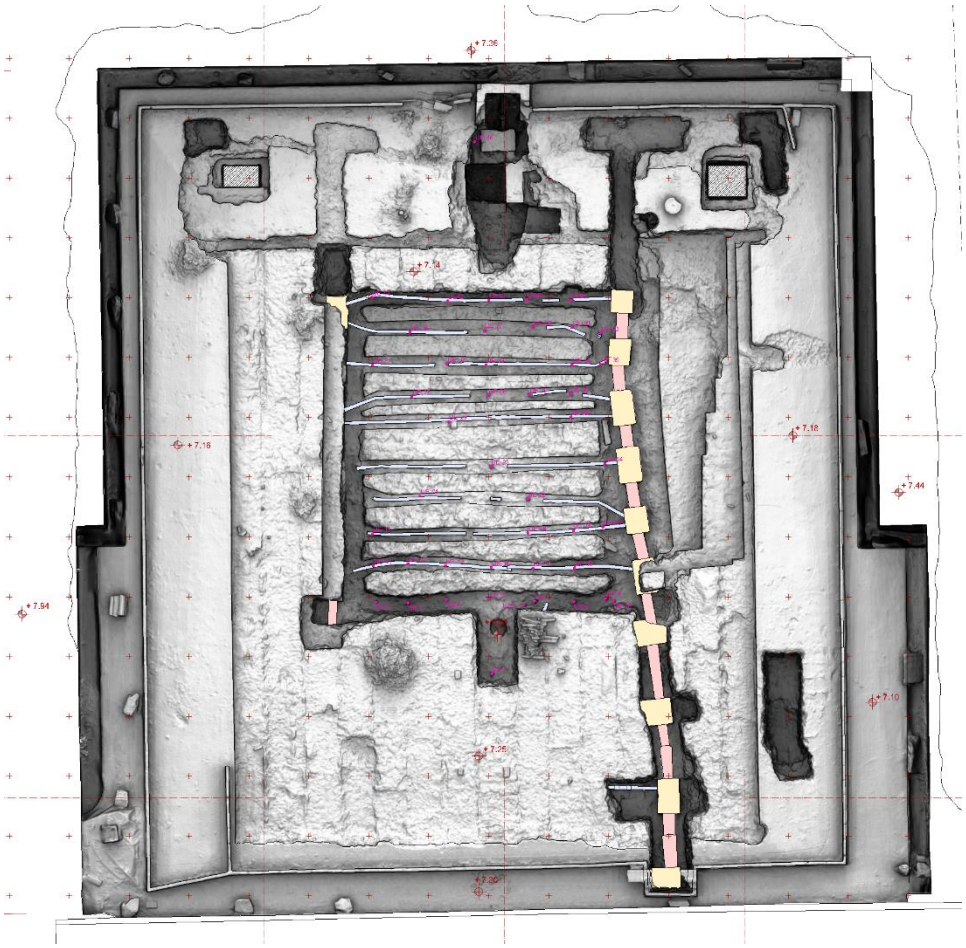

Figure 4. Detail of the survey on the ancient piping in the excavated area above the grotto.

In some cases, the visibility of the water network components has been a challenge; the main terracotta or lead pipes are easily recognizable in the scans, but it is quite difficult to understand where secondary pipes branch off and enter in the vault in vertical direction. Also, the nozzles that sprayed water from the vault and the floor are barely visible, because they were intentionally hidden between the spongy stones and pebbles and are concealed now by oxidation and limescale deposits.

For this reason, laser scanning has been preferred to other techniques, like topography, that measure discrete points and but request to know from the beginning the points to be detected.

Point clouds are currently largely diffused because it is easy to recognize the represented objects; scans are instinctively used as a visual memory, like measurable 3-D photographs. Other abilities of point clouds are more rarely exploited, i.e. to make hardly visible objects and events more discernible. Overcoming these issues is the most significant part of the design of the survey of the *Grotta degli Animali* [18].

A high number of scans (compared to the strict minimum amount in spaces of equal size) has been performed. In this way, the vault has been acquired from more points of view, minimizing the data-less areas (so-called *shadows*) between the rocks of the cladding. Benefiting also from a complete scaffolding prepared for the vault maintenance, all the ends of the pipes on the ceiling and on the floor of the grotto have been preliminarily identified and highlighted with polystyrene spheres and pieces of paper, to make them more recognizable in the scans (figure 5).

Figure 5. Pipes and nozzles highlighted with spheres and paper cuts on the vault and the floor.

Polystyrene spheres have been put at the branches of the tubing at the extrados also. Identifying the two ends of the pipes on both sides of the vault, it has been possible to understand the path of the water supply system.

The pipes through the vault are almost vertical and parallel, but have different lengths, as they start from the same height at the upper level and end according to the shape of the vault inside the grotto. Even if the cladding of the vault seems randomly arranged, the stones are regularly placed to fill the empty spaces between the pipes with a regular pattern. The cross-vault area is different; the decoration at the intrados is totally inconsistent with the sunburst pattern of the pipes at the extrados and none of them go through the vault. These pipes are also in counter slope and probably never really worked.

A photogrammetric survey of the most significant elements has been carried out for a more detailed study and characterisation of the ancient lead pipes (figure 6). There are holes in the upper part of all horizontal pipes at tee-joints with the vertical tubes, probably for discharging potential air bubbles. Therefore, it is likely that the flooring enabled some air flow and maybe the maintenance of the water supply system.

Figure 6. 3-D model (obtained by a photogrammetric survey) of an element of the ancient lead pipes.

In the floor of the grotto, the nozzles are arranged in parallel longitudinal rows; this suggests a probable path of the pipes, but they are embedded in the floor structure and non-inspectable. In some cases, they are irregularly spaced, to avoid that they are on the stone frames the mosaic, with a totally different design.

Some documents in different years mention automata, sculptures or fountains situated in the *Grotta degli Animali*. Nevertheless, it must be observed that a nozzle is located right at the centre of the mosaic design, in the most likely position for a prominent artwork. Near the entrance, a section of the mosaic has been clearly repaired and also the nozzles are unevenly placed, showing that the renovation concerned also the underlying piping.

Surveys of the multi-level utility corridors around and below the *Grotta degli Animali* are currently being carried out and will be possible to obtain more detailed information on the structure, plumbing systems and water features (figure 7). First results are giving new information on the drainage network and revealing some of the underground structures below the entrance. They are possibly connected with the automatic mechanism for closing the gate, described by Agostino del Riccio and dismantled during the Lorraine interventions.

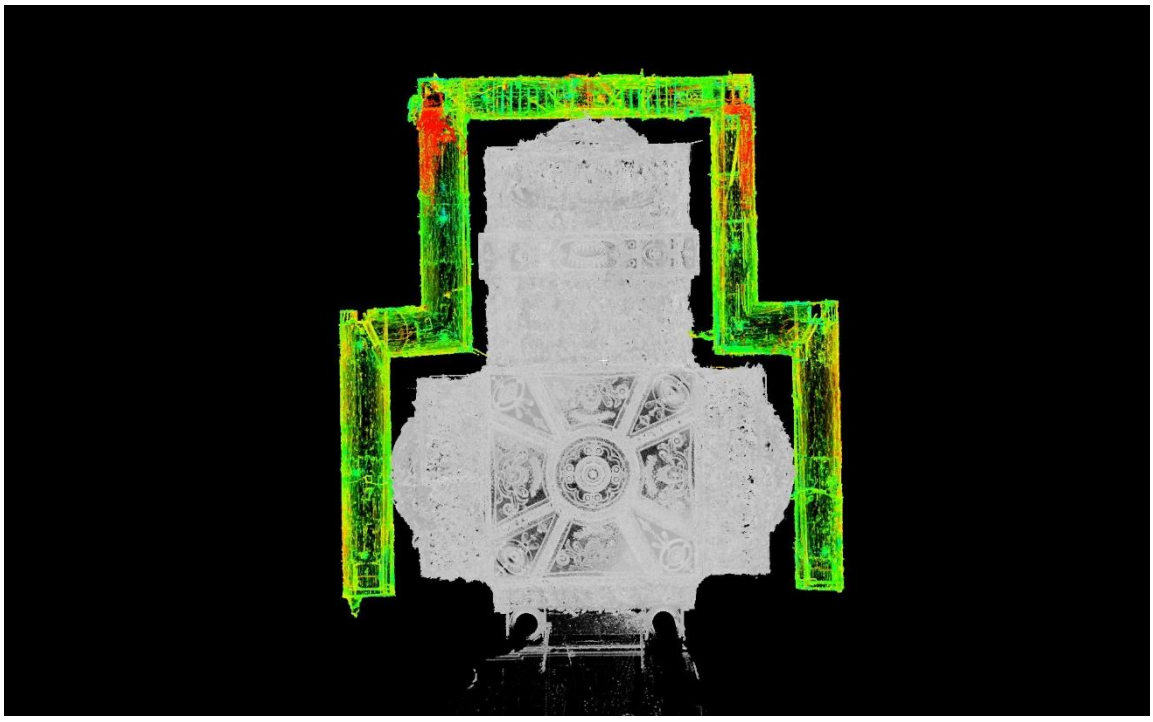

Figure 7. Point cloud model of the grotto (in b/w) and a part of the surrounding corridors (in false colours).

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