

Chapter 11

The Grotta degli Animali in the Garden of Villa di Castello in Firenze



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Abstract The Grotta degli Animali, an artificial grotto located in the garden of Villa di Castello in Firenze, is a significant example of sixteenth-century Mannerist garden design. Commissioned by Cosimo I de' Medici, the grotto was designed by Niccolò Pericoli (Il Tribolo) and later completed by Giorgio Vasari, with contributions from renowned artists such as Jean de Boulogne (Gianbologna) and Ammannati. Featuring marble fountains and animal sculptures symbolizing natural elements, the grotto's hydraulic system once created the dramatic "Scherzo del Diluvio" water effect. Over the centuries, the grotto underwent multiple restorations, and recent work (completed in March 2024) utilized advanced digital documentation and 3D surveying techniques to reactivate the water features and improve its preservation. The project also integrated virtual reconstructions and addressed material degradation by creating a monitoring system for the grotto's microclimate and structural health. Diagnostic surveys and advanced surveying methods, including laser scanning and photogrammetry, revealed key structural challenges and offered insights into the historical evolution of the water system. This work emphasizes the importance of monitoring semi-confined heritage environments like the Grotta degli Animali, where complex microclimatic conditions can lead to localized material deterioration. The CNR-ISPC, in collaboration with other institutions, has developed a methodological approach for diagnosing and monitoring such sites, focusing on assessing conservation states, identifying active decay processes, and

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predicting risks linked to environmental changes. Using non-destructive techniques like infrared thermography and moisture detection, along with the establishment of a digital twin of the grotto, the project aims to ensure long-term preservation. Continuous monitoring and analysis of microclimatic variations will inform conservation strategies, helping mitigate potential decay risks while supporting more sustainable preservation practices.

Keywords Artificial grotto · Historic water supply systems · Diagnostics · Monitoring · 3D model

11.1 Description of the Artifact

The Grotta degli Animali, also known as the Grotta del Diluvio, is located in the garden of Villa di Castello in Firenze, a significant example of an artificial grotto in the mannerist gardens of the sixteenth century (Fig. 11.1). Its construction is closely tied to the project commissioned by Cosimo I de' Medici, who sought to transform the villa, where he spent part of his life, into a sumptuous example of Renaissance architecture and hydraulics. The project was initially overseen by Niccolò Pericoli, known as Il Tribolo, and completed after his death by Giorgio Vasari, with the

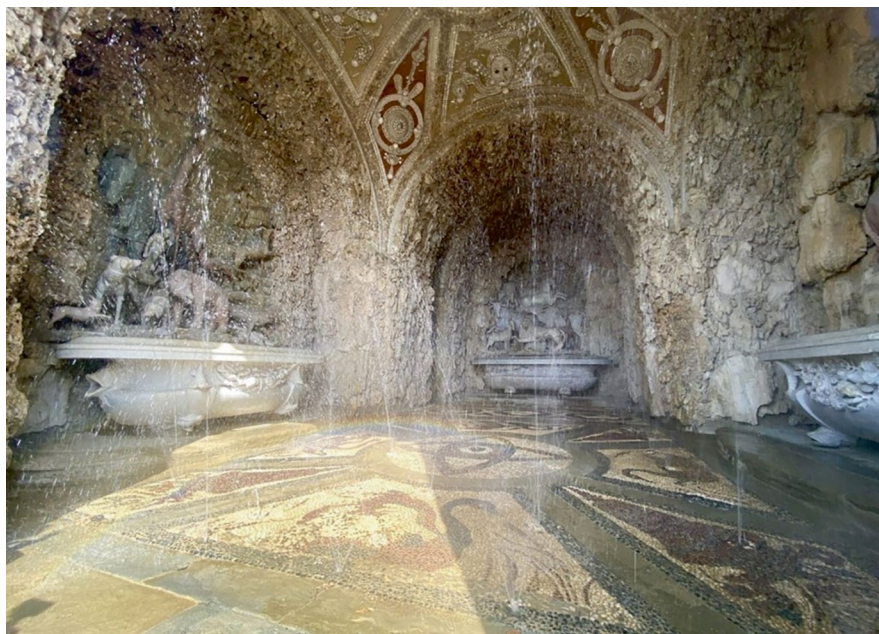


Fig. 11.1 Villa di Castello (Firenze), view of the interior of the Grotta degli Animali after the water supply system reactivation

collaboration of artists such as Jean de Boulogne (Gianbologna) and Ammannati, who were responsible for the sculptural decorations. Table 11.1 reports some general information.

The grotto's structure consists of a single chamber measuring 13 m in length, 8 m in width, and 8 m in height, divided into three main niches. Each niche houses large marble fountain, topped by reliefs depicting animal statues made from various stone materials, symbolizing the realms of nature: water, earth, and air. The vault is decorated with porous stones, pebbles, shells, and other natural elements typical of Renaissance artificial grottoes. The grotto's distinctiveness lies particularly in its intricate hidden hydraulic system, which powered water jets placed in the vault and floor, surprising visitors with spectacular water effects.

The complex hydraulic system that powered the grotto was made up of lead pipes and terracotta conduits, hidden within the walls and the vault. This system was connected to a series of channels that allowed water to flow through the decorations, creating fountains and a rain-like effect inside the grotto, known as the "Scherzo del Diluvio" (Flood Trick). These hydraulic and decorative elements were symbolic, representing the control of nature through technology and human ingenuity, a central concept in Renaissance thought.

The grotto's history is marked by numerous maintenance and restoration interventions. Already in the eighteenth century, under the Lorraine dynasty, significant changes were made to the garden and the grotto's structure, which also led to the abandonment of part of the original hydraulic system. In 1745, a report described the grotto's deterioration, with a damaged vault and ruined niches. Further work in 1779 permanently sealed parts of the original hydraulic system when the terrace above the grotto was paved. In the twentieth century, there were additional attempts to restore the grotto, including the restoration work in the 1990s, promoted by the Superintendency. These interventions brought to light part of the original hydraulic system, when essays were carried out on the extrados of the vault that allowed for the removal of a concrete roof, carried out in the 1970s. This period was important for the documentation of the site, especially thanks to the use of more modern surveying and analysis techniques.

More recently, a new phase of restoration work was initiated due to further deterioration of the various interior decorative materials and the collapse of the decorations. This phase saw the use of three-dimensional surveying techniques, including laser scanning, to map the grotto's structure and the hydraulic system conduits. The objective was to support the restoration of the water features by locating the path of the water in the lead pipes from the extrados to the intrados, so that the existing pipes could be used without damaging and altering the structure of the grotto. Investigations revealed that many of the existing pipes were corrupted or obstructed, so these were removed and replaced with a new, more modern hydraulic system that respected the original aesthetic configuration of the grotto. The work was completed in March 2024, with the reactivation of the water features.

In addition to the physical restoration, the project also included a series of digital documentation and conservation initiatives. A three-dimensional model of the grotto was created to accurately document its structure and decorations, allowing

Table 11.1 General information

Object	Artificial grotto
Scale of reference	Architecture/Sculptural Group
Original/Current Destination	Grotto (AAT: grottoes/ID: 300006807/Page Link: http://vocab.getty.edu/page/aat/300006807)
Author	Pericoli Niccolò known as Tribolo (from 1538), Davide Fortini, and Giorgio Vasari (from 1550)
Location	Garden of the Villa di Castello, Via di Castello, 44, 50141 Firenze (FI)
Geographic Coordinates	43°49'14"N 11°13'49"E
Chronology	First half of the sixteenth century
Ownership	Public Property
ICCD Sheet	ICCDI5176713 (https://catalogo.beniculturali.it/detail/HistoricOrArtisticProperty/0900281675-0)
Authority responsible for protection	Superintendency for Archaeology, Fine Arts and Landscape for the Metropolitan City of Firenze and the Provinces of Pistoia and Prato
Keywords	Mannerist gardens, Artificial grottoes, Historic water supply systems
Risk map	ID 923 (Villa di Castello)
Type of risk	Anthropogenic risks: inadequate air conditioning, micro-climate effects Climate change effects: weathering increasing, speeding up erosion processes, increased wetness Natural risks: landslides, ground water, weed vegetation
Research team	This research was conducted following an agreement between the Polo Museale della Toscana and the Department of Civil and Environmental Engineering (DICEA) for the creation of the three-dimensional survey, and with CNR-ISPC (Istituto di Scienze del Patrimonio Culturale) for the identification and characterization of the chemical-physical properties of the constituent materials

restorers to visualize and study the monument's condition in detail. This 3D model not only facilitated the planning of restoration interventions but also paved the way for virtual reconstructions of the grotto and its original appearance. Among the proposals is the idea to virtually reintegrate the bronze bird sculptures, now housed in the Bargello Museum, which once adorned the grotto's walls.

11.2 Specific Reachable Goals

OO1: Development of guidelines for the management and maintenance of complex, multi-material garden structures.

OO2: Study for the creation of a prototype 3D information system for the localization of materials that make up the grotto, spot analyses, degradation, and restoration interventions, in collaboration with other research groups and restorers, for the study and monitoring of microclimatic variations in the Grotta degli Animali.

OO3: Evaluation of the durability of replicas made from different materials and finishes exposed to atmospheric and environmental agents.

11.3 Survey, Monitoring and Diagnostic Techniques: Best Practices

11.3.1 *Best Practices for the 3D Surveying of the Hydraulic System*

The multiple transformations that have affected the garden of the Villa Medicea di Castello and the Grotta degli Animali complex over the centuries are extensively documented by significant iconographic evidence and surveys, spanning a long period from the early sixteenth century to the 1990s (Tucci et al., 2018). However, surveying such complex works, characterized by organic and articulated forms like those found in gardens and their architectures, particularly in grottos, has always posed a significant challenge. The surveying technologies used in the past, while contributing to the historical understanding of the site, did not provide the accuracy and completeness needed to fully capture the richness and complexity of the details.

Since 2012, commissioned by Superintendence, the Laboratory of Geomatics for the Environment and the Conservation of Cultural Heritage at the University of Firenze has undertaken a series of surveying operations, organized into several campaigns, the latest of which took place in March 2021 (Table 11.2). During these 12 years, the main objective has not only been to document the current state but also to monitor ongoing work, adapting to the needs of the construction site and supporting diagnostic investigations.

Table 11.2 Summary table of the various survey campaigns carried out over the years

Survey campaigns	Scans	N. of points	Avg. resolution
08-2012: Intrados vault and containing wall	22	370.714.688	0.005 m at 5 m
02-2013: Grotto	8	369.353.135	0.005 m at 5 m
10-2013: Extrados and SLAM test on tunnels	18	713.732.636	0.006 m at 10 m
09-2015: Extrados and ph. acq.	25	864.683.723	0.006 m at 10 m
12-2017: Conduits, upper tunnel	23	354.049.412	0.12 m at 10 m
09/10-2018: Conduits, lower tunnel, tunnel “del Gennaio”, left and right tunnels	83	1.834.724.922	0.006 m at 10 m
03-2021: Excavation in the “Limonaia” plane	19	388.198.231	0.006 m at 10 m
Total	198	4.895.456.747	

11.3.2 *The Survey of the Grotto and the Extrados Area*

The survey of the Grotta degli Animali represented a significant challenge, overcoming the epistemological difficulties related to the measurement and representation of organic forms, a problem that had arisen in the documentation of Mannerist gardens and their associated water architectures. Thanks to the adoption of three-dimensional digitization technologies, it was possible to obtain high-resolution digital models capable of capturing complex details with great accuracy. From the digital model, obtained through the acquisition and processing of spatial data, the materials for documentation and the drafting of the recovery project were extrapolated, derived from a mixed 2D and 3D graphic representation: the high-resolution surface model (triangular mesh) (Fig. 11.2), which effectively represents the organic lines of the sculptures and the sponge cladding, was sectioned to produce orthogonal views that clarify the constructive rationale of the cave.

In parallel, the survey of the extrados and lead pipes was carried out during the excavation campaign, with initial acquisitions in 2013 and further checks in 2015. Thanks to the three-dimensional model, it was possible to conduct analyses that would not have been feasible with only two-dimensional representations, correlating the pipes of the extrados with the internal pockets of the cave, which are essential for activating the “Diluvio” effect. Additionally, a close-range photogrammetry campaign thoroughly documented the pipe system, allowing for the analysis of the various components of the hydraulic system, including water supply and distribution.



Fig. 11.2 Mesh model, view of the front tank

11.3.3 *The Survey of the Underground Ducts*

The project continued with the survey and analysis of the complex water conduit system that supplies the grotto and the other fountains in the park. This task was particularly significant, as these conduits, dating back to the construction of the Grotta degli Animali in the early sixteenth century, had never been thoroughly analyzed. Their intricate layout, combined with the difficulties of accessing narrow spaces, had made it challenging to create a detailed map of the underground hydraulic system that powers the monumental works in the garden of the Villa Medicea di Castello. Given the morphological complexity of the tunnels, some of the most advanced surveying techniques available at the time were tested, particularly those based on automated mobile scanning, supported by Simultaneous Localization and Mapping (SLAM) technology. To document the grotto's tunnels, the Zeb1 device by GeoSLAM was used, equipped with a Hokuyo UTM-30LX profiler mounted on a rotating handle, allowing the operator to maneuver it easily. The point cloud model generated, which was acquired quickly, accurately described the geometry of the spaces. However, the point cloud's resolution was significantly lower than that obtained through static scans, proving insufficient for precisely detailing the surfaces of the tunnel structures or generating a sufficiently detailed continuous mesh model. The surveys conducted over several campaigns between 2017 and 2021 revealed important factors useful for understanding the function of the water features and the changes they underwent over time. Initially, the lower tunnels running along the three sides of the grotto were examined, with two branches leading to niches behind the side nymphaea, and a third branch leading to the chamber below the "Gennaio" basin, accessible via a stone spiral staircase that exits directly at the base of the statue. The survey then proceeded to cover the tunnel running beneath the grotto's entrance floor, followed by laser scanning acquisitions of the perimeter tunnels on the upper level, accessible through two openings on the extrados. The

point cloud model (Fig. 11.3) facilitated an understanding of the relationship between the internal and external spaces of the entire architectural complex. Further investigations revealed additional conduits and currently inaccessible spaces, which are believed to correspond to a second level of tunnels above the two side branches leading to the lateral nymphaea of the grotto. The survey of the trees also allowed for an analysis of how the roots impact the ground and, in turn, the conduits, which in some cases are directly affected by the root system, compromising their structural integrity.

11.3.4 Best Practices for Diagnostic and Monitoring for a Semi-confined Environment

Cultural heritage located in semi-confined environments represents a unique and underexplored area of study, distinct from the more extensively researched indoor and outdoor environments. Semi-confined environments are characterized by spaces that are partially exposed to external conditions, resulting in specific microclimatic variations within the structure (Becherini et al., 2010). These variations can result in differential deterioration, such as localized high humidity levels, which can accelerate the deterioration of materials in certain parts of a monument. For example, areas with poor ventilation may trap moisture and promote biodeterioration, while other areas may remain dry (Cuzman et al., 2023). Similarly, differential exposure to sunlight can lead to uneven discolouration or fading of surface materials. These effects are particularly pronounced in environments such as cloisters, caves, or partially enclosed galleries where external weather patterns still influence the

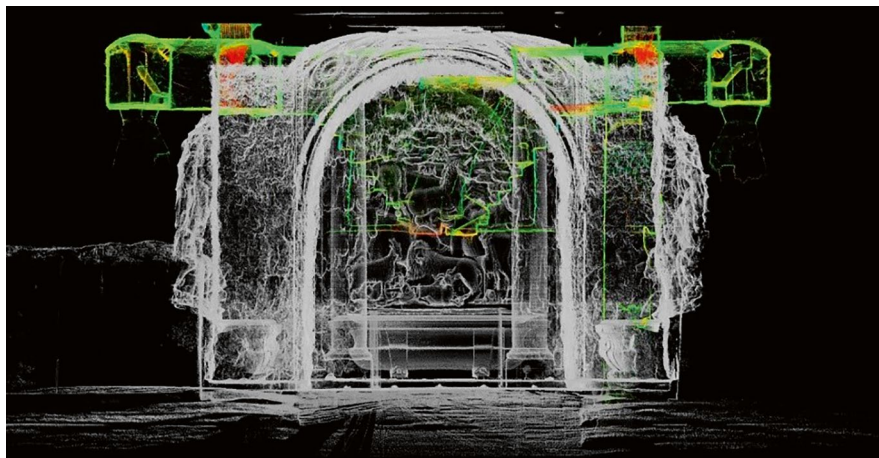


Fig. 11.3 Image of the point cloud model as of September 2018, showing the grotto and the perimeter conduits of the second level

preservation conditions but are mitigated by architectural features. The lack of focused research on semi-confined environments has left significant gaps in understanding of how best to preserve heritage in these sites, which exhibit a complex interaction between natural factors and built materials. Addressing these challenges requires interdisciplinary approaches that consider not only the material conservation and structural integrity of the monuments, but also the microclimatic and environmental dynamics at play. Changes of the microclimate condition due to restoration works or maintenance can also affect the equilibrium conditions for the conservation between materials and environment. In this way, the case study of the Grotta degli Animali in the garden of the Villa di Castello presents some significant aspects, since the hydraulic system supporting water features has been recently reactivated after at least two centuries of dismissal (Tesi, 2018).

The activity of CNR-ISPC in collaboration with UNIFI, OPD and ICR aims to establish a reliable methodological approach for controlling the state of conservation of heritage assets located in a semi-confined environment such as the artificial grotto of Villa di Castello. In particular, the proposed approach must consider the following steps:

- to determine the state of conservation of the surfaces and structures.
- to evaluate the presence of active alteration/decay processes and their correlation with the changing of the micro-environment
- to assess the potential risks for the conservation related with changing of the environmental condition due to Climate Change or man-made changes such as the reactivation of water features.
- to monitor the risks for the conservation finalized preventive conservation planning (see Chap. 14).

When it considered heritage materials exposed to water action, different decay mechanisms can be activated also consider the strength of sorption due to free water (as water sprayed from the grotto's ceiling), capillary water, and hygroscopic water (due to the environmental condition: relative humidity and temperature).

In the case-study, the main sources of the decay can be categorized as direct and indirect. In the first group of sources are included falling water that impacts directly on the stone surfaces of the sculptures, on the spongy stone cladding and on the multi-material floor. This can affect the stone materials in different ways, among which:

- mechanical damage promoted by the strength of the sprayed water resulting in loss of cohesion and potential detachments.
- the water retention can promote microbial colonization and biodeterioration (algae, fungi, biofilm, etc.) (Li & Gu, 2022; Lamenti et al., 2000; Peraza Zurita et al., 2005).

The combination of the previous mechanisms puts a strain on the effectiveness of the protective treatment eventually applied on the surfaces for their conservation (Hansen et al., 2003; Sacchi et al., 2020).

As indirect source, for example, the water supply is responsible in the changing of the micro-climate inside the grotto, since the increased humidity level could promote the dissolution process, salts migration, and, combined to the temperature and wet-dry cycles, the biodeterioration and bioactivity.

Starting from an exhaustive diagnostic survey, here described in terms of methodological strategy complete with the description of the measurement equipment which can be used, the alteration/decay mechanisms potentially induced by the water games reactivation are described, so an effective monitoring strategy is proposed. To this aim, two main research aspects are addressed:

- the identification of the materials' key parameters to be accounted in the monitoring as result of the diagnostic survey.
- the design criteria to develop a monitoring sensors system for providing a clear description of the microclimatic changes inside the grotto and particularly in the areas where the three fountains are located.

As a final purpose, the acquired multidisciplinary data will be entirely managed using a digital platform (see Chap. 14) for the storage, processing and analysis of acquired data. The platform will host the digital twin of the grotto, where the 3D model will be completed with the sensors network for a real-time description of the parameters of interest. This perspective will allow the data visualization and interrogation through the geomatic digital twin of the grotto (Tucci et al., 2020). The tool will provide a remote-control system for the state of conservation against the risks of environmental damage, supporting the decision-making process for the definition of a preventive conservation strategy. The tool can contribute to a more sustainable planning the onsite survey and diagnostic campaigns, limiting them only when necessary.

11.4 Results and Discussion

11.4.1 *Simplifying Complexity: The Grotto and Hydraulic System Model*

Based on the data collected during the various survey campaigns of the grotto and the surrounding conduit system, a simplified model was developed using NURBS surfaces, which was subsequently divided into a hierarchy of elements identified within the conduits (Fig. 11.4). The 3D surface model was initially broken down into macro-elements, starting with the broader context, which includes the surrounding terrain and the retaining walls of the Grotta degli Animali, before moving on to the various conduits that encircle it. A further breakdown was then carried out, focusing on the main masonry structures, secondary conduits, vertical conduits communicating with the exterior, supporting walls for the open-air conduits,

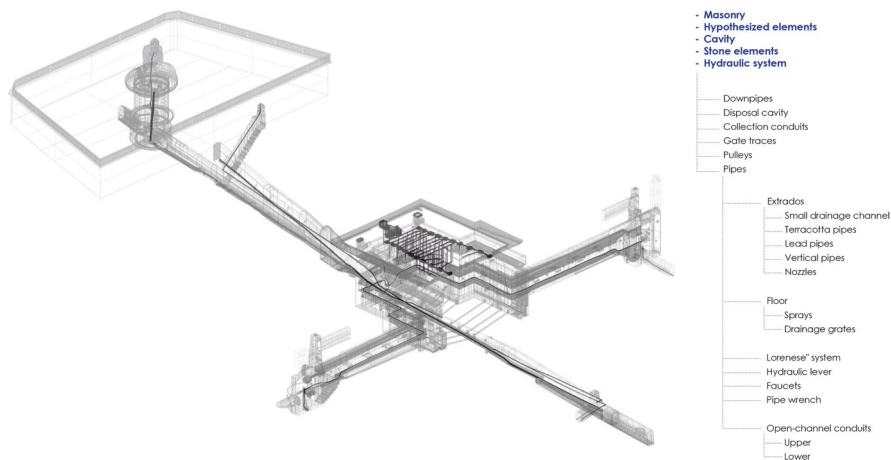


Fig. 11.4 Overview of the surface model highlighting the decomposition of the hydraulic system layers

buttresses, staircases, and more. In future work, the terminology within the model’s semantic structure will be selected from a controlled vocabulary.

The simplification of the modeling process has made it easier to understand the complex hydraulic system, which would otherwise be difficult to interpret due to fragmented historical sources and hard-to-access survey data. This model helps restorers plan interventions with precision, reducing the risk of unnecessary or excessive actions that could compromise the site. Additionally, the model holds great communicative value, allowing visitors to visualize and understand the hidden conduits and how water was channeled to create spectacular visual effects. Beyond serving as an educational and engaging tool, it could also serve as the foundation for a digital twin of the hydraulic system, useful not only for monitoring its conservation against environmental risks but also for gathering and preserving the historical and technical data accumulated over time.

11.4.2 Diagnostic Results by the Planned Multi-disciplinary Approach: State of Conservation and Risk for the Conservation

The characterization and the correct knowledge of the state of conservation of the materials inside the grotto are therefore important and necessary to estimate the process of decay in terms of entity and rate. In fact, the characterization of the state of conservation at the initial stage of monitoring (time 0, T0) is mandatory for the prediction of the incoming problems of conservation and as a first step of the

monitoring plan for risk assessment. The state of conservation has been investigated by a proper diagnostic campaign based on a multi-technique and multi-scale approach.

Sampling and non-destructive analysis for the characterization of the stone materials of sculptures and fountains were performed. On the 31 samples collected from the surface of the sculptures and from the stone apparatus, the analytic investigation was performed by Fourier-Transform Infrared Spectroscopy (FTIR), X-ray Diffraction (XRD), Raman Spectroscopy, Scanning Electronic Microscopy (SEM) combined with Energy Dispersive X-ray Spectroscopy (EDS), and Optical Microscopy (OM). Pigments, white-washings, decay-processes were identified, revealing some deposits resulting from the old activations of the water features. In particular, the analysis of fragments sampled from the stone slabs under the right-hand marble fountain pointed out some interesting evidence. In fact, in Fig. 11.5, the cross-section of the sample reveals a stratification of multiple layers. The outer layers appear as alterations due to the successive re-precipitations of calcium-carbonate, probably due to the wet-dry cycles that occurred at the early stage of the hydraulic system activation. While the presence of Lead, recognized by SEM-EDS mapping, is probably associated with the water supply system on and off. The inner layers, although still carbonate, appear to be plastering layers, due to their morphology.

A measurement campaign by non-destructive techniques was also performed to detect differences in heat emitting and possible areas of moisture retention (Fig. 11.6a), to localize the metal supports of the animals' sculptures and the walls of the grotto, and to assess the rate of biological growth. For the above targets the InfraRed Thermography (IRT), Pacometric Surveys and bioluminometer (for the Adenosine Triphosphate detection) were employed. In particular, the thermal survey was also performed for monitoring by thermal images the different surfaces' drying time after water spraying. Due to the water run-off on the stone sculptures' surface, the occurrence of corrosion phenomena had to be considered since the

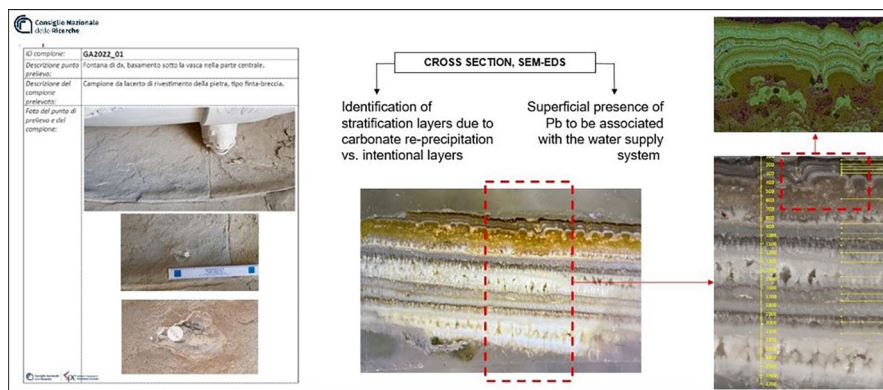


Fig. 11.5 Results of the diagnostic analysis performed on a sample of the stone slabs under one of the marble fountains



Fig. 11.6 (a) Thermal survey performed on the sculptures; (b) internal reinforcement elements detected by the pacometric measurements

presence of internal reinforcement consisting of iron pins and iron brackets. To achieve this aim, a pacometric survey was performed exploiting the principle of the magnetic field absorption measurement to locate the metal elements and their state of conservation (the diameter of the pin can be estimated). On Fig. 11.6b, the map of the detected pins (\varnothing 8–16 mm) and brackets, is shown. Their presence is mainly due to the previous interventions for the consolidation, strengthening, and replacement of damaged parts (more fragile parts, such as the animals' paws, the animals' ears). Moreover, the grouts and mortars used for filling the fractures and junctions among different parts will be monitored to prevent water infiltrations and corrosion risk.

11.5 Prospective for New Research

11.5.1 *From History to Virtuality: From the Replicas of the Birds to the Digital Future of the Grotta*

Among the upcoming developments is the planned creation of replicas of some bird statues that adorned the Grotta. Many of the bronze sculptures, attributed to Ammannati, Giambologna, and Giovan Battista Ferrucci Del Tadda, are currently housed in the Museo del Bargello. This is following the theft of the bronze pigeon figure, which was taken from the grotto on August 1919. For this reason, measures were taken to secure the other five figures still present inside the grotto at that time (Frommel, 2018; Mozzo, 2018). The creation of faithful copies of the birds, to be installed on the ceiling to reconstruct the original iconographic and figurative integrity of the grotto, represents a complex methodological challenge. Although the replacement with replicas may raise debates about the authenticity and aesthetic experience of the artwork, it is increasingly regarded as a necessary measure to protect cultural heritage for future generations. While there are no explicit rules

regarding the use of copies to safeguard the originals, decisions regarding their use depend on a combination of international regulations, professional guidelines, and national regulations. To date, some of the statues preserved at the Museo del Bargello have been acquired through SFM photogrammetry, particularly the owl and falcon attributed to Ammannati. A print is planned that will serve as a counter-mold for subsequent bronze casting. The “digital cast,” resulting from the three-dimensional survey, will meet various needs in both the conservation of the original and its enjoyment and dissemination.

Furthermore, with regard to the knowledge, conservation, and maintenance of the original assets, the possibility to create a digital copy completed with the scientific results organized in “layers”, allows to simulate the “state of conservation” based on the environmental parameters. 3D modeling enables georeferentiation of all the performed analyses, thereby facilitating tailored thematic mapping.

Finally, the digital relocation of the copies of the birds within a complete digital twin of the Grotta degli Animali represents not only an opportunity for visual restoration, but also a powerful tool for communication and cultural sharing. Although the realization of faithful copies to reconstruct the original iconographic and figurative integrity remains a complex challenge, the fascinating suggestion of this project becomes tangible today thanks to virtual reality.

11.5.2 From the Diagnostic Survey to the Monitoring Strategy: A Methodological Approach

The results of the diagnostic survey at time 0 (T0) suggested the relevant materials’ parameter to be considered during the monitoring activities: colorimetric alterations, biological growth, drying rate of the surfaces. Those indicators will be correlated with data collected by the environmental monitoring, showing that whether microclimate changes can resume the previous decay processes or rise additional ones. To this aim, a monitoring setup will be established measuring the main descriptive environmental parameters from a microclimatic point of view: temperature and relative humidity. Other parameters will be useful for monitoring:

- The level of water stagnation, in the sandstone slabs under the marble fountains, after the closing of the water features.
- The surface temperature of some animal sculptures checks the presence of condensation phenomena.
- The solar radiation on exposed surface (in particular, darker stone), since it affects the drying time through the increase of temperature. Moreover, solar radiation can contribute to the growth of autotrophy organisms (algae, moss, etc.) in the area subjected to water retention.

As a result, the differences in microclimate within the grotto among the niches of the fountains—in particular, close to the three fountains—will be deeply understand and related to decay processes of the heritage materials.

The above results will be completed with radiometric data captured on the wetted surface by IR thermography camera. The spot temperature measure is useful to calibrate the radiometric image to obtain information on the drying dynamics of the surface. Continuous thermal monitoring will be provided by the integration of the thermal sensors within the environmental monitoring system (see Chap. 14). This will allow to better investigate the critical aspects, such as areas subjected to water stagnation or subjected to mechanical damage for the impact of falling water (Fig. 11.7).

In conclusion, the monitoring strategy focuses on the correlation of selected parameters, investigated before the water games are switched on, during and after their switch-off, to determine the cyclic variation of the micro-climate conditions inside the grotto; moreover, different drying rates of the stone surfaces will be considered, to detect vulnerabilities and preventive conservation interventions.

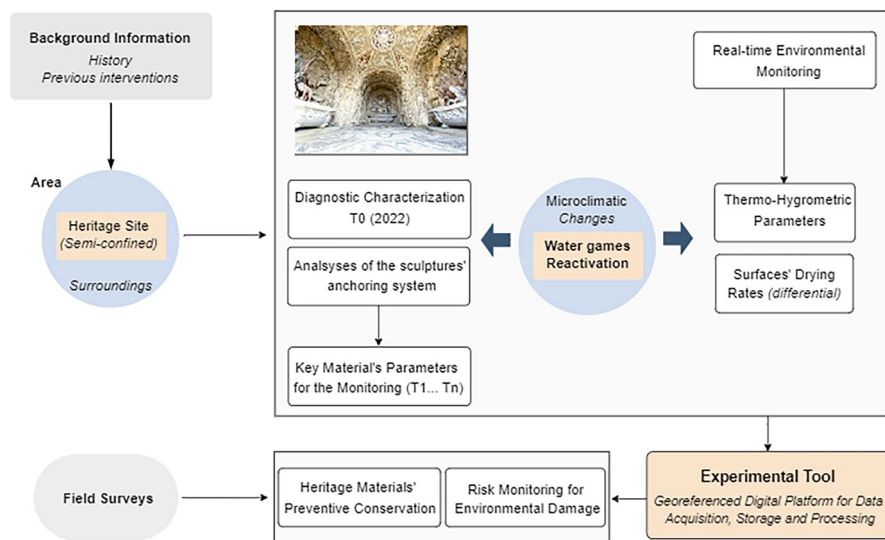


Fig. 11.7 Overview of the methodological approach leading to the development of the Risk Monitoring Tool for Cultural Heritage in semi-confined environments exposed to microclimate changes

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Fabiana Di Ciaccio • Lidia Fiorini • Grazia Tucci
Editors

Methodologies and Strategies
for Cultural Heritage
Protection and Conservation
Against Climate Changes,
Natural and Anthropic Risks

 Springer

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