The Grotto of the Animals

A SIXTEENTH CENTURY "*HYDRAULIC MACHINE*"

By GeCo Lab

Set within a celebratory context of the Medici dynasty, the grotto is considered the prototype of artificial caves that, starting in the mid-16th century, spread across Italy and Europe. It was built alongside the garden, designed by Niccolò Pericoli, known as Tribolo. Since 2013, the Villa has been part of the UNESCO World Heritage list. Through the digital twin, it becomes possible to trace the historical path of the water, observe how it has changed over time, and document not only the material heritage, but also the intangible values of this intricate 16th-century hydraulic machine.

The Grotta degli Animali is one of the most remarkable architectural features of the garden at the Medici Villa of Castello, one of the earliest examples of an Italian Renaissance garden.

The space was carved through a complex excavation of the terrain and enclosed by a retaining wall. It was conceived to imitate a natural cavity: dark, humid, animated by tartar encrustations and shells. The ceiling, covered in sponges, and the mosaic floor conceal the outlets of the water features.Inside, three niches house marble basins topped with zoomorphic sculptures—common and exotic animals such as a lion, a giraffe, and a rhinoceros—as well as a fantastical creature, the unicorn. These figures were designed to inspire wonder. The immersive effect was enhanced by bronze birds, works by Ammannati and Giambologna, now preserved at the Bargello Museum.

A complex hydraulic system, still partially intact today, powered the water features. A network of conduits distributed on several levels allowed the water to flow: from the Gennaio basin, it encircles the grotto, runs along the retaining wall, and reaches the nymphaea. Another conduit, made of stone and terracotta, runs above the vault: it branches into lead pipes to create the effect of a "Deluge." A third channel, located beneath the floor of the grotto and the Garden of the Citrus Trees, carries recovered water back into the garden. Today, these narrow and uncomfortable passages are not open to the public and are accessible only to technical staff.

Until recently, many challenges in documenting these extraordinary spaces—especially Mannerist gardens—stemmed from the difficulty of accurately measuring and representing their organic forms. Simplified and often unsatisfactory representations were the norm. The challenges are even greater for the hydraulic tunnels: narrow, unlit, and difficult to access, with small openings that make it hard to understand their spatial layout.

High-resolution 3D surveying technologies, such as laser scanning, have helped overcome

these limitations, allowing for the creation of accurate models that reflect the physical reality.

Since 2012, the Geomatics Laboratory of the University of Florence, in collaboration with the Regional Directorate of Museums, has led the documentation project of the grotto. Numerous surveying campaigns have produced a highly detailed 3D model of the entire complex—including the grotto, retaining wall, nymphaea, and both underground and external hydraulic conduits—to support the restoration project for the reactivation of the water features. In parallel, the CNR-ISPC in Florence has carried out diagnostic investigations to monitor the conservation state of the structure.

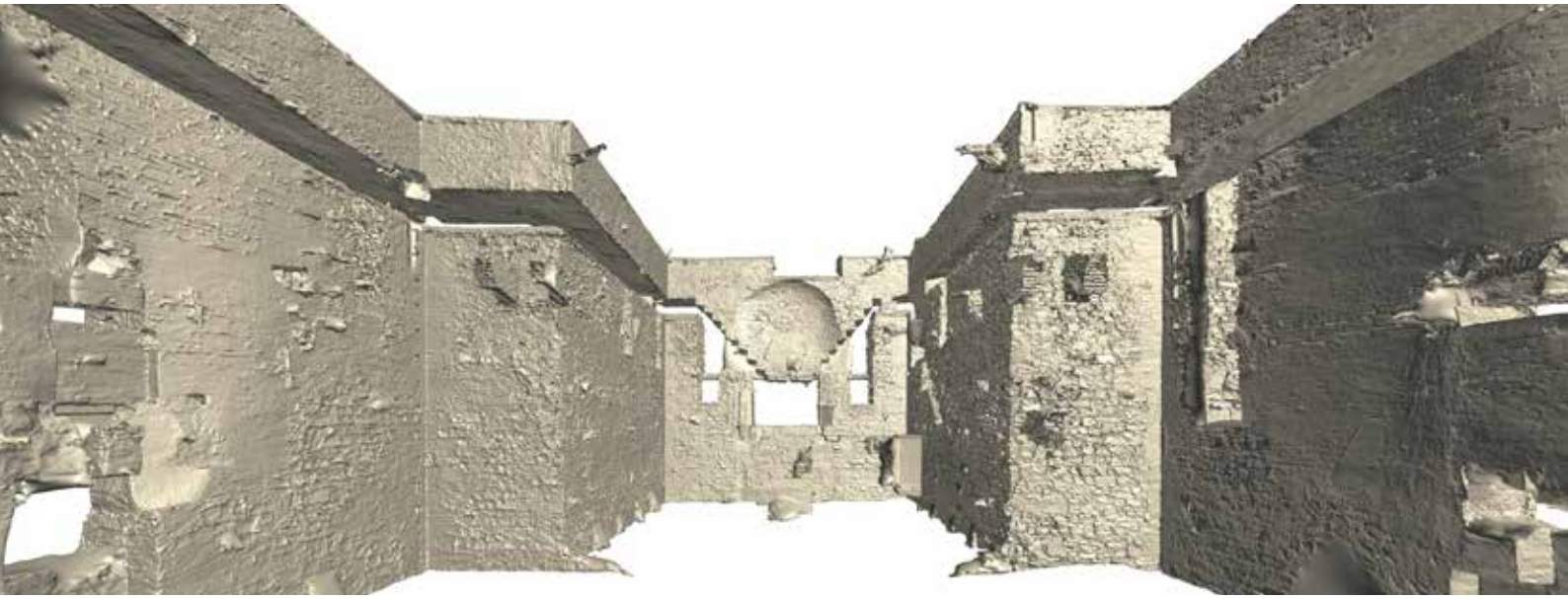
In 2024, environmental sensors were installed to measure temperature and humidity in real time, in order to assess the condition of the grotto following the reactivation of the water system. In the future, extensometers will also be added to monitor the state of the masonry structures. The installation of the sensors and the integration of their data with the geometric model was achieved through collaboration between the University of Florence (UNIFI), the CNR-ISPC (Florence and Lecce branches), and the Regional Directorate of Museums. Thanks to the SENNSE platform (Spatial hEritage sciENce oNline Sensor Environment), developed by the DHILab of the CNR-ISPC, the model is evolving into a Heritage Digital Twin, combining 3D geometry with dynamic sensor data.

This will make it possible to detect critical conditions and plan targeted maintenance interventions, potentially allowing for remote control of the water features. The system also contributes to the enhancement of spaces normally closed to the public, offering a new way to tell the story of the grotto's defining element: water.

Above: resin replica to be used as a model for the realization of the bronze reply of a hawk to reposition on the site.

Below: The cave, internal view.

On the previous page: "The dromedary tank". Ortimmagine of the surface model with Ambient occlusion



Top: Surface model. View of the three-dimensional model of the surface of the animal cave, which highlights its architectural and morphological conformation.

Middle: Tunnels and conduits. Surface model of the tunnels that develop around the structure, inside which the hydraulic ducts used to power the water games flow.

Left: Vault of the cave, detail.