Hidden cultural landscapes: survey and digital enhancement of the catacombs of San Giovanni in Syracuse

Elisa BONACINI,1 Graziana D’AGOSTINO2, Mariateresa GALIZIA,2 Cettina SANTAGATI,2 Mariarita SGARLATA1

(1) Department of Humanities, University of Catania, Catania, Italy
elisa.bonacini@unict.it; m.sgarlata@unict.it
(2) Department of Architecture, University of Catania, Catania, Italy
grazianadag@hotmail.it, mgalizia@dau.unict.it; cettina.santagati@dau.unict.it

Abstract

Roman underground cemeteries are an heritage to be safeguarded and enhanced. They constitute the memory of customs, traditions and rituals of a civilization. In Syracuse there are different catacombs complex (San Giovanni, Vigna Cassia and Santa Lucia). They are the most ancient document of Christianity in Sicily. Sometimes, plano-altimetric layout reuses existing hydraulic structures (aqueducts, private channels, cisterns) and earlier burial areas of the city.

The Aim of the research is the knowledge and the enhancement of the San Giovanni’s catacomb complex through digital technologies for 3D data acquisition and virtual models that characterize and document its shape, size, geometry and materials. Moreover, digital enhancement project foresees the creation of a multimedia platform for archaeological complex guided tours and online ones.

That methodological approach required an interdisciplinary team composed by archaeologists, architects, engineers and experts in cultural communication.

Within digitization project our research team had to tackle wide-ranging issues and challenges: the sheer size of the complex, the intricate layout of the rooms and galleries, the surface irregularities, the bad lighting conditions, the significant amount of data to process and manage.

The scientific survey of the archaeological complex is the metric/spatial support that can be used to start innovative methods that allow you to create new scenarios for experimentation finalized to multidisciplinary knowledge and enhancement of not easily accessible sites.

Keywords: Digital Heritage, Laser Scanning, 3D visualization, Catacombs, cultural landscape

1. Introduction

Cettina Santagati

Hypogeous Cultural Heritage represents an enormous and yet systematically and accurately unexplored heritage. The major part of European cities subsoil (for instance Rome, Naples, Prague, Nottingham, Paris) is rich of this kind of hidden cultural heritage. The knowledge and preservation of this heritage affects mainly urban archaeology research as well as the policies aimed at ensuring a safe and suitable use of our soils. The recurrent imprudent human actions and natural events make this heritage a very high risk and vulnerable patrimony. In case of collapse, it could constitute potentially a danger also for citizens’ safety.

Furthermore, the difficulties related to the plano-altimetric complexity of the rooms (narrow and high galleries, irregular rooms) the lighting conditions (often poor) and the environmental conditions (ventilation, floodings, landslips, collapses) make these places difficult to access and document. For all of these reasons this heritage remains largely not well-known, under-studied and poorly preserved.

The aim of this research is the knowledge and the enhancement of the catacomb of San Giovanni in Syracuse, according to a strategy that integrates latest technological developments in 3D data acquisition, analysis and communication of such archaeological landmark.
Effectively, digital technologies allow us to have 3D digital copies of the studied objects, a real clone, full of information where metric, perceptive and visual data can be integrated with interpretative data obtaining a 3D model whose potentialities can be exploited according to different declinations: from scientific documentation to archiving, to museum fruition and educational environment.

This methodological approach required an interdisciplinary team composed by archaeologists, architects, engineers and experts in cultural communication.

After giving an in-depth look into the issues related to 3D documentation and communication of Hypogeous Heritage in Section 2, Section 3 will give an overview of the historical and structural aspects of the Catacombs of San Giovanni. Section 4 will then focus on the digital enhancement and visitor experience. Section 5 will deal with actual surveying and 3D modelling methods used to create digital reproductions of some areas of the Catacombs. Section 6 will focus on texture mapping of the 3D model and Section 7 will examine the results of this study and consider future developments.

Fig. 1-3.: The rotunda of Sarcophagi (1), the decumanus maximus (2) and the rotunda of Adelfia (3).

2. 3D documentation and communication of hypogeous cultural heritage
Cettina Santagati

Hypogeous sites are negative spaces generated by subtraction of matter where each element is at the same time structure, form, function and it is solidly connected to the surroundings. It is very difficult to understand this heritage in its structure and articulation because underground the visual contact with all the surroundings and with the external context is lost.

3D methodologies provide a visual, metric and spatial description of the studied object and can be considered a powerful and successful tool for knowing, documenting and conveying such complex cultural heritage almost hidden to citizens’ eye.

The advent of ICT has changed the traditional approach to knowledge, documentation and communication of Cultural Heritage, opening the doors to new research scenarios and as of yet not extensively explored synergies and leading to an increasingly high demand for standards and methodologies internationally shared (London Charter, Seville Charter).

At European level, the growing interest in this challenging domain is proved by different EU funded projects aimed at 3D digitization (EPOCH, 3D-COFORM), the creation of databases shared on the network (EUROPEANA, CARARE, 3D Icons, Ariadne), the identification of global shared standard (MINERVA), the creation of network of excellence on issues related to Virtual Museums (VMUST.NET), the identification of best practices and the identification of open and interoperable formats that allow the reuse of 3D models.

Among the research developed in the field of underground heritage, we can highlight the START project concerning the Roman Catacomb of Saint Domitilla [1, 2]. The mainly aim of the research was 3D documentation of the archaeological complex along with its early-Christian funerary paintings by means of laser scanning. They have tested some solutions for the interactive visualization of the site and an out-of-core octree structure for the management and processing of the huge amount of data generated.

The Nottingham Caves Survey [3] is the first part of Caves of Nottingham Regeneration Project (CoNoRP) and is aimed at mapping, 3D documenting and visualizing of the labyrinthine complex of caves under the city of Nottingham. The project intends to encourage the city and its visitors to appreciate the caves for the unique historical resource they are. 3D acquisition is carried out by means of laser scanning, the point cloud can be cut and sliced into plans and sections, ‘flown through’ in short videos, and examined in detail either on the web or on desktop environment.

Among the projects aimed at the enhancement and communication of Hypogeous Heritage stands EtruscanRegolini Galassi in Cerveteri has been reconstructed on the base
of 3D laser scanning data. The funerary furniture that actually is exposed at Etruscan Gregorian Museum (Vatican’s Museum) has been virtually rearranged inside the tomb. The innovative feature of this project is the interaction paradigm based on the use of natural interaction interfaces (MS Kinect).

Always related to the communication of cultural contents of Hypogeous heritage we can highlight Matera città Narrata [5]. This is a project aimed at the creation of a digital platform able to support the public before and during the visit of Matera (World Heritage since 1993), providing cultural contents by multiple communicative formats and access possibilities. The main components of the project are: the multimedia web site, adapted also for smartphone; cultural contents and applications for mobile devices.

![Image](image.jpg)

Fig. 5-6: The three-dimensional model of the cubicles of Eusebius and Paul in false RGB visualization.

As stated in the introduction, the aim of the study concerning the Catacombs of San Giovanni is to comprehensively document and communicate this heritage, according to a strategy that integrates latest technological developments in 3D data acquisition, archiving, analysis and communication. Dealing with a so complex site some question arises and need to be answered:

- How to choose what is relevant for documenting this site? What is the level of accuracy needed? We can document for conservation studies, restoration, architectural analysis, history of art or archaeological research. Each of these fields has different goals and needs a different level of details. How can we integrate them and give an appropriate and scientific answer to all the disciplines involved? May we still use the same equipment that we use above the ground? Most probably the lighting conditions and the presence of narrow, high and irregular tunnels will require the development of new solutions and methodologies. Furthermore, once everything is documented, another question arises: how can we describe the process of documentation and make it transparent? It is necessary to test new ways of exploiting 3D models potentialities. Each kind of data acquired during the surveying phase should be normalized, catalogued and integrated into an articulated digital model.

- How can we organize a 3D repository which will include also legacy data, all bibliographic references and previous works? How can we link data and metadata directly on the 3D model? We need to develop an intelligent repository where all data are organized and linked to metadata and will be available in future.

- How to transform scientific data and convey it for public information/knowledge? How to simplify and optimize the 3D model in order to reuse it in different communication outputs (web, on line/desktop application, real time) and reach financial sustainability? The Virtual Reality (VR) becomes the best way to access, visualize and interact with this hidden cultural heritage. We should think in terms of Virtual Museums (VM). Which is the best way to communicate a hypogeous site? We need to investigate new creative scenarios that technology can open up; the outputs generated by the use of innovative advanced VR systems, hybridization and combination of media, artistic approaches [6, 7, 8]; think in terms of sustainability, durability and reusability of formats.

3. Historical and Structural aspects of the catacomb of San Giovanni in Syracuse

Mariarita Sgarlata

Suburban cemeteries, fanned out from the area of Fusco, in the quarter of Neapolis, to the Santa Lucia area, in the southern part of Acradina, this indicates unequivocally what the perimeter of the city must have already been in the early and mid-Roman Empire. The History of the area, which was going to hold the catacombs (San Giovanni, Vigna Cassia and Santa Lucia), spanned the centuries between the classical Greek and late antique ages, gradually giving evidence of quarries (Latomie), water supply systems to the city, characterized by cisterns and aqueducts [9: 682], handcraft workshops from the beginning of the 4th/3rd century BCE and burials datable to the early and mid-Roman Empire.
The quarter of Acradina therefore had a different designation and held in part a proper Ceramic with workshops. It is no accident that if hydraulic systems and furnaces have been found inside the three biggest catacombs. The funerary evidences prior to the creation of monumental community cemeteries – and among these San Giovanni holds a very special position – are columbaria, hypogea of different sizes inserted into the catacombs or isolated from them and sub divo burials, all datable to the first three centuries of the Roman Empire, if not beyond, and commissioned by pagans.

Several interest will be given to structural aspect of the catacomb of S. Giovanni, practice of funeral rituals, ethnic and cultural fruition’s characters, transformation in the use, transformation in the way of using spaces for graves, to complete a general point of view about the phenomena of continuity and innovation as to previous sepulchral arrangements and, in the analyzed periods, the facies belonging to the different settling, variegated in the committees’ ideological and religious themes, in choosing monumental types (like rotundas) and decorations, in self-representative aspects, in burial uses. In this perspective we will give particular importance to the study of executing techniques, of material employed, of working funerary organization. Just as in Roman catacombs, but with a bigger monumentality, the project of the catacomb of S. Giovanni involves realizing a regular urban plan for the subterranean city of the dead. In the catacombs, indeed, the exploitation of pre-existent hydraulic structures is not unusual: aqueducts, private channels, circular section well and conical or bell-shaped cisterns [10,11].

The same happens in the catacomb of San Giovanni, with the diversity due to a well-defined project; in several cases the fossores (gravediggers) were forced to demolish or amputate the cisterns that, because of their position, influenced the construction of the regular structure according to the project. It is feasible to see numerous cases of hydraulic installations reuse, which facilitated the realization of galleries, lucernaria (skylights) and private chambers (rotundas of Marina, Adelfia and Sarcophagi). It only remains to make a choice between two possible explanations: 1) it is a case of a pantheon constructed ex novo on the pattern of the mausolea above ground, as the rotunda of Antiochia in the northern region, to suit both the local and passing members of the élite, without any influence imposed by preexistent hydraulic structures [12: 764]; 2) the rotundas reuse hydraulic preexistences and adapt them to a private vision of the space. In this case the presence of previous structures (cisterns of large dimensions), probably increased even further and whose undeniable traces remain (openings for drawing water and inspection pit with platforms) and have been the input for creating subterranean mausolea [13: 81-83].

Fig. 4. The ground plane of the catacombs where the areas of interest are highlighted.

The alignment of the three rotundas would be, in this sense, related to their original utilization from above (for the system of the lined cisterns in Syracuse see [9: fig 3], more than the alignment of the roads and neighboring hypogea [12: 763]. The former explanation for the genesis of this sector does not convince, mostly because of the idea of an adjustment of the alignment of the three rotundas with a nearby road, 350 m away from the catacomb, identifiable with a late mending of the supposed via lata perpetua, which served the theater area. A comparison with the alignment of neighboring hypogea, accessible through their own direct staircases and, as such, in necessary relation to the road network, is not proposable for the mausolea of the catacomb, since they are not in immediate relation with the above ground. The same central thread seems to link the three rotundas – of Marina, Adelfia
and Sarcophagi – to the solution adopted in the catacomb called “Grotta di Fragapane” in Agrigento [14: 205,215, fig 7], where preexistent granaries develop into circular chambers. The analysis of the funerary system certifies one hand the dependence on the Roman model, and other the debt in respect of local traditions.

4. Digital enhancement and management of the Catacombs of San Giovanni

Elisa Bonacini

Cultural tourism has become faster and demands quality in culture; museum’s audience wants more information during the visit especially with reference to the context [15: 132]. Many new technologies are available, or are currently being developed in the field of cultural management. Thanks to these ongoing technological changes, museum visitors and tourists are given more freedom to move past the limits of architecture and traditional tour guides. In today’s world of wireless personal devices, visitors can become mobile or even wireless visitors, who can access high-quality multimedia contents from anywhere. This evolution is based on new buzzwords such as connectedness, freedom, mobility, accessibility, walking tour [16: 67-222].

Use of ICT in fields of cultural management and tourism fosters the development of better cultural and touristic policies and strategies, which in turn create new value, in terms of creation of cultural value (providing new cultural experiences for consumers, whose expectations regarding consumer culture are clearly on the rise) and economic value (direct effect on cultural institution and indirect effect on the local community) [17; 18:112-114]. Therefore, cultural institutions must embrace a new philosophy of cultural tourism, which will use technology to allow visitors to engage freely with their surroundings and see past the surface and the visual space using tools, as multimedia guides, that allow contents that are not easily accessible in real life, or not visible otherwise, to be “accessible digitally” and to tell them “stories” that lie beneath great works of art and historical landmarks, enhancing the emotional side of an already highly evocative cultural journey. Fostering the use of digital technology in CH management is also crucial to bringing local museums and cultural sites up to the standards of national and international institutions.

Answering these issues, Catacombs’ digital enhancement and management project will see the integrated use of three systems: online and on-site communication systems and monitoring, attendance, feedback and interest systems.

The museum’s website will promote the Catacombs that are currently open to the public (through the creation of an itinerary of the Catacombs) and offer “virtual access” to the areas that cannot be visited. It will also give visibility to other local cultural landmarks by introducing combined offers and touristic routes. The website will be available in various languages and featuring extensive descriptions and a comprehensive collection of multimedia resources (photo galleries, videos, 360° visits, 3D reproductions). The aim is to attract young visitors and schools to the museum by creating interactive games related to the Catacombs and building an online community through various forms of interaction and content-sharing.

To enhance the visitor experience on-site the museum will use innovative communication methods:
- multi-touch [19] multimedia tables featuring multiplayer interactive games that will make the visit more entertaining and fun, especially for young visitors and school excursions [16: 169-178];
- holographic projection [16: 161-169;19] of a 3D virtual reproduction in situ of Adelfia’s sarcophagus (the original is currently on display at the Paolo Orsi Museum) at the centre of the eponymous Rotunda; Adelfia herself tells her story, according to the most recent emotionally approaches in digital storytelling [19: 106-110; 20: 27-47];
- WiFiGuide® [21] providing multilingual information and multimedia contents about different key items spread across the Catacombs and the Crypt, using a specific App that drives you through Point of Interest (PoI); the information will be accessible on the visitor’s own mobile device or on rented devices (iPod Touch) via an underground WiFi network.

Two different platforms will be used to collect real-time statistical data that will help to define appropriate strategies: eFlowAccess® to monitor visitors’ access at the entrance and eFlowFeedback® to monitor their feedback at the exit [22]. Both applications use highly customizable templates to generate multilingual feedback forms and multiple-choice questionnaires.

Particularly, these two platforms will be integrated on the same server of multimedia guide in order to monitoring internal usage data to give direct insights into quantitative and qualitative secondary data. The data thus obtained are processed to get statistics and reports (graphs, bar charts, pie charts) for each individual item. The guide allows users to send direct feedback, but it also provides valuable information about visitors’ experience, both quantitatively (number of visitors, language, visitor flow by date and hour) and in terms of quality. The guide can also show the degree of interest towards different exhibits, but it also provides performance indicators such as the attraction rate (how many visitors were “attracted” to a specific exhibit) or the sweep rate (how much time they spent in front of
each item). With all this information at hand, the museum has a powerful tool to monitor visitors’ behaviour based on primary quantitative and qualitative data.

Focusing its cultural product strategy on this guide as visit support, Catacombs of San Giovanni could provide added cultural and economic values and could greatly differentiate its quality of cultural supply compared to other local cultural and touristic institutions. This qualitative differentiation could contribute, on the one hand, to improve Catacombs’ attractiveness both for tourists and for Syracuse’s citizens; on the other hand, it could improve new economic conditions and management strategies [23:103-144]. Monitoring data (both quantitative and qualitative) via access and feedback platforms, as well as multimedia guide, the Catacombs will have a powerful tool to monitor visitors’ behaviour based on primary quantitative and qualitative data. This should be considered the first step in building a coherent Marketing Information System (MIS), which is essential to the implementation of new strategies and cultural policies and to the segmentation of the consumer base into specific target groups in order to identify those who may require different types of services (customer care) and to increase overall customer satisfaction.

This system is in line with the latest standards in terms of integration of tourism development and cultural heritage management, which are easier to implement in areas that are not very extended [15: 136].

5. From data acquisition to geometric interpretation of the complexity of the site
Mariateresa Galizia

The considerable historical stratification of the catacomb of San Giovanni [24,25] as well as the high plano-altimetric and geometric-spatial complexity required a three-dimensional methodological approach for the survey, the representation, and the 3D visualisation. Indeed, considering the execution time and the precision and amount of data obtained, laser scanning was the best way to obtain a 3D model that reveals different historical spaces through virtual reality images [26,27,28,29, 30].

The archaeological site features an intricate network of communicating galleries and large rooms where there are innumerable burial niches and arcosolia cut perpendicularly into the rock walls and laid out side by side.

Fig. 7-8: In situ survey

During the first stage of the project, we surveyed two rotundas (Adelfia and Sarcofagi), and two quadrangular cubicles (Eusebio and Paolo) and analysed all metric data obtained, to find empirical evidence showing that pre-existing hydraulic structure such as water tanks, aqueducts or private canals had been re-used.

We used the Leica HDS 3000 ToF Laser Scanner, whose technical specifications are as follows: accuracy of single measurement position 6 mm, distance 4 mm; scan rate up to 4,000 points/sec; field of view 300°x270°.

The data acquisition project took into account:

• the complex grid system that is composed of a variety of galleries and large rooms connected together;
• the characteristics of the environments that contain multiple niches and arcosolia cut perpendicularly into the rock walls and laid out side by side.

The surveying protocol involved 6 scans: 4 for each space to be surveyed (in barycentric position, aligned with the skylights) and 2 “transition” scans. These last two were captured from the galleries so as to survey the numerous arcosolia in as much detail as possible, while also reducing the black areas inherent to the irregular morphology of the site’s layout.
To ensure proper alignment of the different scans in a common reference system, 29 reflecting targets were scattered across the walls' surface and they were automatically detected and registered by the scanner (minimum of 4 targeted control points for each point cloud). Once all field survey data had been recorded, point clouds were post-processed using specific software, such as Leica's Cyclone, Gexcel's JRC Reconstructor or CloudWorx. Optimising the calculation parameters (sub-sampling percentage, maximum number of iterations), the average initial maximum error of the alignment of about 10mm was reduced to 4mm. The comprehensive model thus obtained consists in 6 scans and a total of 46,940,251 points. Thorough graphic investigation of the point clouds was needed in order to document the geometry of the archaeological complex in plans and elevations without overlooking the site's spatiality and the complexities of its different areas. To draw the site plan we used two horizontal planes taken at different levels of the archaeological site, so as to be able to document its most outstanding features as accurately as possible.

Moreover, we also carefully selected several offset vertical cross-sections, each of them showing specific views of the complex: axis between the entrances to the galleries, in the skylights' axis, in the centre of the rotundas and the quadrangular cubicles. We also obtained section planes of the surface of the ceiling's intrados, as well as the amplitude and depth of the skylights. The arching of the intrados that covers the rotunda has the shape of a somewhat irregular, wrinkled inverted cone. This confirms the previous use of these spaces as water tanks, as can be noticed in comparison with other roman water tanks [31].
6. Problematics related to texture mapping

Graziana D’Agostino

The 3D digital “calque” of the investigated catacombs, thus obtained, provides the basis from which starting different research paths. One of the goal of this study is to give back the “visual appearance” of such complex heritage by means of realistic texture mapping [32,33] in addition to the quantitative and geometric aspects (shape, dimensions, proportions).

In this paragraph the problematic related to the 3D photographic reconstruction are highlighted. In this first phase of the study the cubicle of Eusebius was chosen. It consists of a small rectangular cistern that temporarily hosted the relics of Pope Eusebius before they were transferred into the catacombs of Callixtus in Rome.

The pipeline forecasts the passage from the numerical model (point cloud) to the polygonal one (mesh), the calibration of the images on the cloud point and the texture mapping on the point cloud.

The texture mapping phase was made using the software Cyclone by Leica Geosystem, instead the passage from the numerical model to the polygon model was made using the software JRC 3D Reconstructor by Gexcel.

Spatial information \((x, y, z)\) relating to a single point is generally enhanced with the color component which is acquired according to three methods: a sensor inside the instrument; an external camera axial to the instrumentation; an external camera (for high-resolution acquisitions). Since the digital sensor inside the used instrument has a low resolution (equal to 1 megapixel), and the resulting effect doesn’t fully reflects the real colorimetry of surface, then we proceed by applying to the point cloud high resolution pictures taken by the operator. The photographic acquisition project took into consideration the small size and the poor lighting conditions of the cubicle.

After several attempts to identify the optimal acquisition conditions (with or without the spotlight, with or without a flash, with or without a wide angle, mediating exposure and ISO sensibility), it was used a tripod and remote control distance acquisition, operating in a semiautomatic way and using a focal distance equal to 14mm, an ISO sensitivity of 800 and depth of field equal to f/18 by varying the exposure time between one acquisition and the other. Specifically, we used a Canon EOS-1Ds Mark III digital camera with 14mm objectives and a maximum resolution of 21 Mpixel. Barrel distortion of photographic images has been corrected by the software PTlens. The application process of the images is done through the manual selection of homologous points between the cloud and the image (at least 11). Particular attention has been paid to overlap two consecutive different textures, making them fit perfectly. The average deviation of re-projection was equal to 1.6 pixels (fig. 11).

Then the meshing phase was undertaken. Two different types of mesh were created. The first one was a tight mesh, in order not to lose important surface information, useful for two-dimensional representations, as orthophotos, the other one was a simplified mesh in order to obtain a lower amount of polygons for a better management and visualisation of the files in interactive virtual environment, also even on the Web (fig. 12).

Depth studies conducted highlight how the restitution of superficial and volumetric characters is particularly accurate and less subject to the operator interpretation, by using current 3D acquisition methodologies, especially in post-processing phase. The use of innovative technologies for 3D survey and representations as well as three-dimensional and colorimetric real data, is going to redefine the concept of representation and to test and to find out the extension of their use in the archaeological domain, as surplus of knowledge and information.

Fig. 11-12: Texture mapping(left) and mesh model (right) of the cubicle of Eusebio
7. Conclusions

Through this study, the hidden cultural landscape of the catacombs of San Giovanni is coming to light. Both the material and immaterial features (memory of customs, traditions and rituals of a civilization) have been analyzed and will be structured in a 3D information system [34] and disseminated. To this day only a small portion has been surveyed and analysed. To complete the project large amounts of data will have to be acquired, modelled and processed, using specific procedures and advanced data processing technologies. The challenge of this research is to develop a new methodology in the study of Hypogeous Cultural Heritage. Thus it is necessary to review the entire pipeline from data acquisition to communication: an efficient communication is based on data and information scientifically acquired and converted into engaging formats and languages.

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