

Article

E-Archeo Project: The 3D Reconstruction of the Roman *Villae* in Sirmione and Desenzano (Brescia, Italy)

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Abstract: The e-Archeo project, commissioned from ALES S.p.A. by the Ministry of Culture (MiC), aims to valorise the multimedia experience of eight Italian archaeological sites. This paper discusses the University of Verona's contribution to this project, which focuses on the virtual reconstruction of two Roman villas located in Sirmione and Desenzano (Lombardy). This paper outlines the 3D survey methodologies and scientific back-end approach using Extended Matrix. The architectural and decorative reconstruction process for each site is elucidated, providing a comprehensive understanding of the process followed. Furthermore, the University developed a narrative to accompany virtual visits. One of the main project outputs was e-Archeo 3d, a virtual reality web app that allows remote and on-site use.

Keywords: e-Archeo; Roman villa; Grotte di Catullo; Villa Romana di Desenzano; virtual archaeology; multimedia enhancement; virtual reconstruction; storytelling; scientific back-end



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1. Introduction

1.1. Aims of This Paper

e-Archeo is an Italian project commissioned by the Italian Ministry of Culture (MiC) and realised thanks to the support of ALES S.p.A., a MiC in-house company. It is a highly innovative project aimed at the multimedia and technological enhancement of eight Italian archaeological sites through different communication formats and, in particular, through digital and virtual reality technologies. The project has been the subject of a recent publication, which puts e-Archeo in the context of other past and present projects, in order to support its novelty and its contribution to the research [1]. Referring to past publications for information related to the project's objectives, the entities involved, and the adopted methods, this paper focuses on the specific role played by the University of Verona, Department of Cultures and Civilisations, on the sites of Sirmione and Desenzano (Lombardy). Among the selected archaeological sites in the e-Archeo project, those of Sirmione and Desenzano constitute a special case for two reasons: they are the only non-urban examples and the only—so to speak—double site, in the sense that they are two Roman villas built at different times and for different purposes, but united by the close relationship that the structures established with Lake Garda (Figure 1). The lake, with its landscape value and rich economy, has thus been the common thread in the story of the two complexes. The first villa, known as the “Grotte di Catullo”, was built on the tip of the Sirmione peninsula in the Augustan age and continued in use until the early 3rd century AD, while the second one underwent a phase of renovation and restructuring involving the creation of a set of formal reception rooms on a monumental scale in the 4th century. The two villas thus embrace a long period of use, ranging from the phase of full Romanization

of the territory to the decline of the Western Empire and the new uses that followed the end of their original functions, offering the possibility of a wide historical narrative of continuity and settlement transformation.

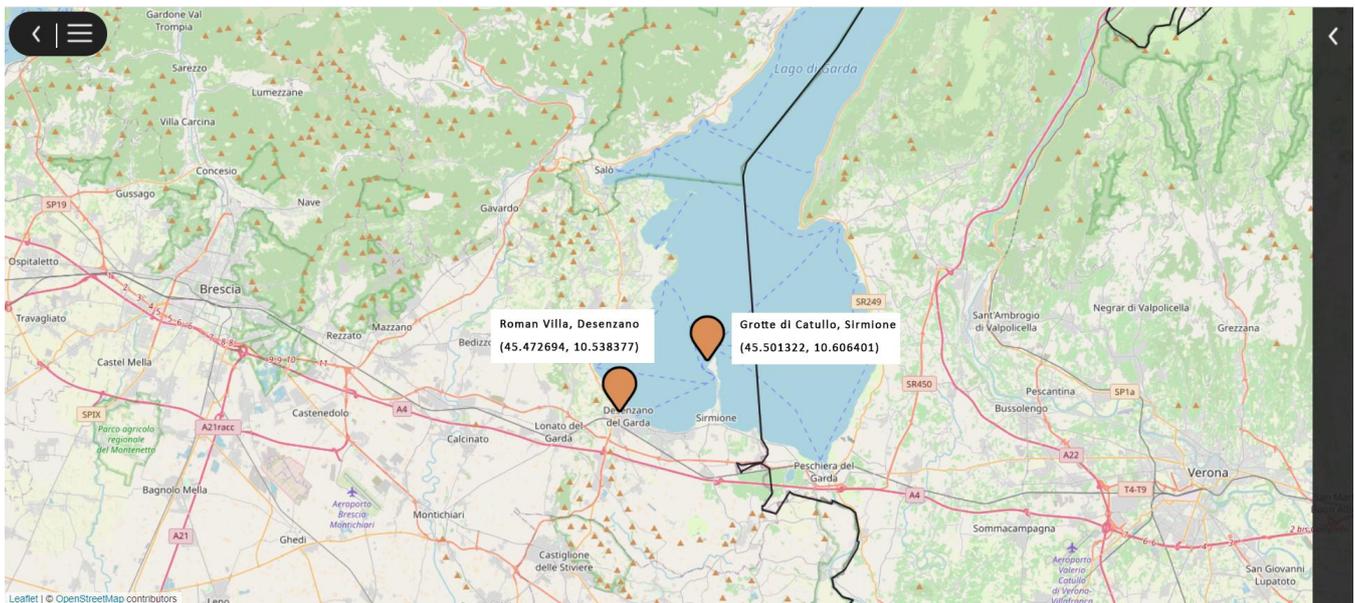


Figure 1. Localisation of the Roman villas of Desenzano del Garda and Sirmione (elaborated from e-Archeo).

In the study and valorisation of the two villas, the University used technical and scientific skills and expertise that usually remain in the narrow circle of research, whereas, in this case, they have been used for a people-oriented project. Plans, reconstructive studies, photogrammetry, and iconographic, historical, and archaeological studies produced by the University have also been shared in an open format on Zenodo [2] and thus have been rendered open and consultable, even before the project was presented to the public.

The following list outlines the specific contributions made by the University of Verona in line with the overall goals of the e-Archeo project:

- (1) The conduct of surveys of both sites using drones and other techniques and the production of phase plans to gather data for virtual reconstructions.
- (2) The study of wall structures, wall paintings, floor coverings, and architectural and statuary elements to compare them with better-preserved examples that could inspire virtual reconstructions.
- (3) The use of virtual reconstructions as a tool for scientific investigation by mapping the scientific back-end of the reconstructive hypothesis.
- (4) The development of a narrative based on scientific and research content to meet the interests of a broader audience. On the one hand, captivating narratives are provided to the curious visitor, focused on daily life in these places and the relationship between the villas and the natural landscape; on the other, information on the levels of reliability of the reconstructions, sources, and interpretative processes are available for scholars.
- (5) The production of texts for a web app developed for the project and used as a basis for content in podcasts, video documentaries, and installations.
- (6) The sharing of plans, reconstructive studies, photogrammetry surveys, and iconographic, historical, and archaeological studies on Zenodo.

All this work was possible in only one and a half years thanks to the fact that the two sites of Sirmione and Desenzano were already well-documented based on solid scientific research and that reconstructive hypotheses for both had already been proposed [3,4].

1.2. Structure of the Paper

This paper develops across five main sections. In Section 1, the introduction and the aims of this paper are presented, and a general overview of the role played by the University of Verona is provided.

Section 2 focuses on the following methodologies used in the preliminary work phases for virtual modelling: the three-dimensional surveys of the archaeological sites and the application of the Extended Matrix for the scientific mapping of the reconstructive hypothesis.

Section 3 presents a historical and structural description of the archaeological context and the different phases of use for both sites not detailed and exhaustive, but sufficient to explain how we proceeded in re-elaborating the 3D reconstructions. We then focus on the selected periods and environments for reconstruction, providing a brief explanation of the reconstruction hypotheses. Regarding the virtual reconstructions, in the case of Sirmione, we focused on the exterior of the villa to highlight the close structural and aesthetic relationship it had with the surrounding lake landscape (Figure 2). For the villa of Desenzano, where the direct connection with the lake has been lost due to the intense urbanization of the town, we instead exclusively focused on the interior views, characterized by rooms that preserve wonderful polychrome mosaics and fragments of wall paintings. In this case, in the 3D views, we also tried to imagine the furnishings of the rooms to populate these spaces where the *dominus* welcomed his guests and celebrated and promoted himself through their splendour (Figure 3).



Figure 2. Virtual reconstruction of “Grotte di Catullo”, Sirmione (e-Archeo).

Section 4 discusses e-Archeo 3D, the web app created based on the previously described work, and describes the narrative choices that characterized the stories of the two sites.

Section 5 is dedicated to general conclusions on the role played by the University in the e-Archeo project and in new future scenarios.



Figure 3. Virtual reconstruction of the interior of the Roman villa of Desenzano del Garda (e-Archeo).

2. Methodologies

The work carried out by the University of Verona was preparatory to the creation of the virtual reconstruction of the two villas in question. The 3D survey work carried out and the scientific back-end methodology used, Extended Matrix, will be illustrated below.

2.1. Survey of Archaeological Areas

The research design developed by the University of Verona for this project had as its main objective an analytic process based on the creation of a reliable database regarding the architectural complexes of the Roman villas of Desenzano and Sirmione. The project's aims include issues directly connected to the management of the sites, both from the point of view of restoration and conservation, and maintenance, organization, and dissemination of results. Specifically, this project tests and analyses the possible interactions that could be established between an information system, such as the Extended Matrix [1], and a remote data and reconstruction system contained in a web app.

Currently, research related to architectural heritage documentation must implicitly reflect the role and value of digital technology. The virtualization of 3D images and the possibility of implementing digital network systems to help deepen our knowledge of the built reality has significantly changed the grammar of architectural representation. The various components of the object of study are treated as fragments that are finally integrated into a single digitised database, a model with a variable form and language whose properties oscillate between the construction of symbols/abstractions and hyper-realism/authenticity. This continuous search for graphic perfection implies that documentation processes must be modified from time to time depending on the object to be measured to correctly manage the obtained data [5].

These survey methods are not universal but require a very acute sensitivity to the sites and their contexts, which typically only archaeologists possess, and imply a deep understanding of the historical context and critical reading of the past, not only in relation to tools and processes but, above all, in relation to the documentation and enhancement/management of heritage. The process used for data management can be tailored to the needs of the analysed context or the specific qualities of the object under examination. The complexity of the three-dimensional display and registration process increases, allowing for a wide range of communication possibilities, making each research project unique.

This process of reflection is an ongoing scientific debate and is closely related to the development of digital survey tools for virtualising 2D and 3D images. The various methods aim, on the one hand, to reproduce the atmosphere of the existing space and to highlight some aspects of landscape modelling (such as in Sirmione); on the other hand, they aim to reproduce as faithfully as possible the architectural and graphic components that characterize a site (such as the mosaics of Desenzano).

Before generating a dynamic 3D mesh and a database that allows users to interact, experiment, and query virtual spaces, a preliminary inspection was conducted at each site to identify specific survey needs. This step made it possible to establish the most appropriate measurement methodology for each reference context, obtaining different datasets for the calculation of point clouds obtained mainly through terrestrial photogrammetry or drones [6]. Without going into detail about individual actions, the survey team was divided to simultaneously operate on the two Roman villas with the aim of completely surveying both archaeological areas. The data was then used as a basis for the generation of a complex and queryable information model.

The survey of the two villas was carried out both on the ground and by drone, but the purposes were completely different. For the villa in Sirmione, due to its large size, more than one type of drone was used to ensure that the entire site could be captured. On the other hand, for the villa in Desenzano, drone imaging allowed for zenithal photographs of the mosaics. Hundreds of high-resolution images were taken at a low altitude of the floor covering of each individual room to create an orthogonal photomosaic of the entire floor plan of the villa.

The scanning of the villa in the Sirmione area was primarily conducted by drones. For example, the so-called Campo delle Noci area (Figure 4) would have been impossible to capture solely from the ground: its tall structures, its position overlooking the lake, and the presence of vegetation made the use of UAVs indispensable. The zone was divided into sectors that were scanned separately and later merged using known reference points. The points were measured with a total station, starting from geodetic points, the details of which were provided by the Archaeological Park. A chart was provided. For the surveying process, the development of an integrated detection system using different instruments was planned. Before the 3D survey, the areas were divided into multiple quadrants for better data management, error control, and a simpler and more effective survey campaign (implementable). Additionally, we also requested the monographs of the geodetic points positioned in the monument areas in order to topographically frame the monument within the territory. These points were used for georeferencing the 3D model, DTM (Digital Terrain Model), rasters, and contour lines. To obtain an overall point cloud with a reduced density for the Grotte di Catullo area, a drone survey at an altitude of approximately 20 m was planned. From the survey using these instruments, a general point cloud with a point spacing of approximately 5 mm (Sirmione) was obtained. This point cloud was also used for creating a low-polygon model. To increase the point cloud's definition, a morphometric survey of the Grotte di Catullo area was conducted, specifically targeting sub-quadrants, arches, tunnels, and areas inaccessible to drones. This three-dimensional photogrammetric survey using the Structure from Motion (SfM) technique also provided a high-quality texture to overlay onto the previously acquired point cloud. This campaign was carried out using specialised image-based instruments such as calibrated professional mirrorless cameras, ensuring uniformity in exposure, tone, and saturation parameters. During the photogrammetric acquisition campaign, suitable targets (reference points) were placed according to both the drone methodology and the SfM, enabling the referencing of the two surveying systems and obtaining a highly reliable photogrammetric 3D model. For better data management, a low-polygon model was exported. The point cloud was decimated, allowing for a model that preserves the apparent morphological complexity of the Grotte di Catullo area while being compatible with management tools and information systems. Subsequently, the processed data was exported in the required formats for further

utilisation. The final processing of these data not only led to the calculation of a mesh with high resolution but was also used for the web application (low-polygon model).

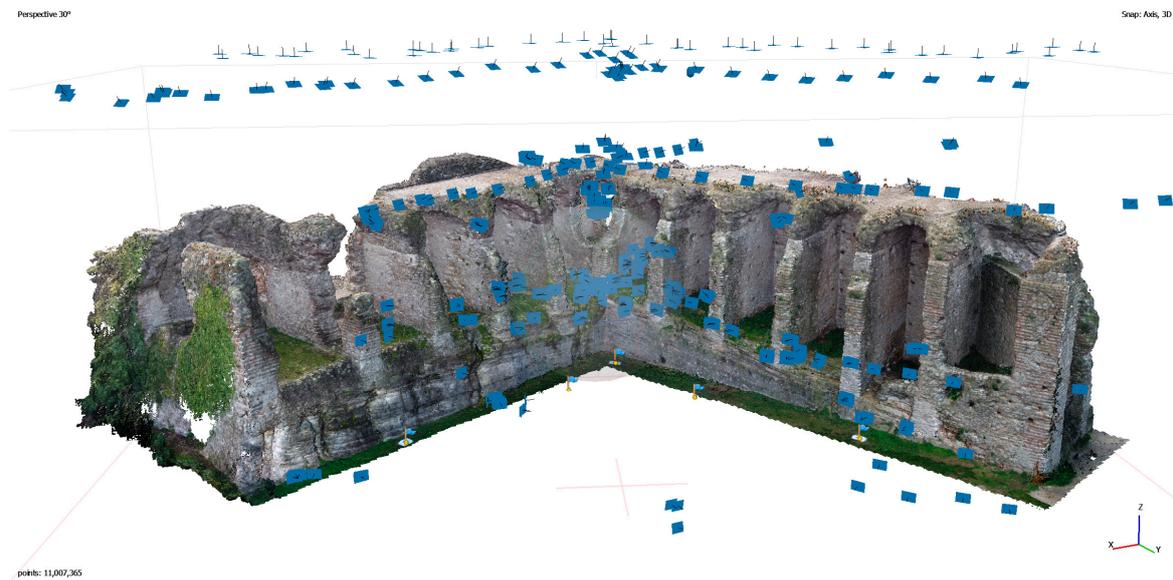


Figure 4. “Campo delle Noci”, Grotte di Catullo, Sirmione. Three-dimensional mesh and positioning of the photographs taken by drone (7emezzo.biz).

2.2. Extended Matrix

One of the main goals of the e-Archeo project was to ensure the transparency, durability, and queryability of virtual reconstructions. To achieve this, a formal language was used that could guarantee the scientific mapping of virtual reconstructions. This methodology, called the Extended Matrix, was devised at CNR-ISPC [7]. This tool allows data to be organised so that the different stages of the reconstruction process are transparent and scientifically complete, offering a standardised workflow and a set of tools for data analysis and visualisation.

The reconstruction hypothesis is based primarily on the study and investigation of the existing data and archaeological research, relying on finding comparative case studies, iconography, and literary sources, when the preserved elements do not provide sufficient information. All the documents used were then organised into a file to be used within the Extended Matrix [8]. Starting from the concept of the Harris matrix, the Extended Matrix proposes an extended version, including information related to the reconstruction. Virtual stratigraphic units are added to the traditional stratigraphic units, to which a specific colour is assigned based on the degree of certainty about their existence as follows [9]:

- red for preserved and/or documented archaeological remains;
- blue to identify virtual restorations derived from physical evidence;
- dark yellow for elements that were not found in situ and have been repositioned and light yellow for the anastylosis of missing parts;
- green to identify elements reconstructed without physical evidence but based on deductive processes.

For each virtual unit inside the matrix created with the yEd software, the documents used to arrive at the hypothesis are directly linked through nodes, specifying for which property (geometry, material, position, etc.) they were consulted (Figure 5). yEd [10] is a free desktop application used to quickly create, import, edit, and automatically arrange diagrams. Each stratigraphic unit is represented here, and a reference is linked to it in media format or in the form of a citation. The diagram created in yEd, using a specific palette [11], regulates the representation and succession of shapes in Blender and is, in fact, the heart of the Extended Matrix system.

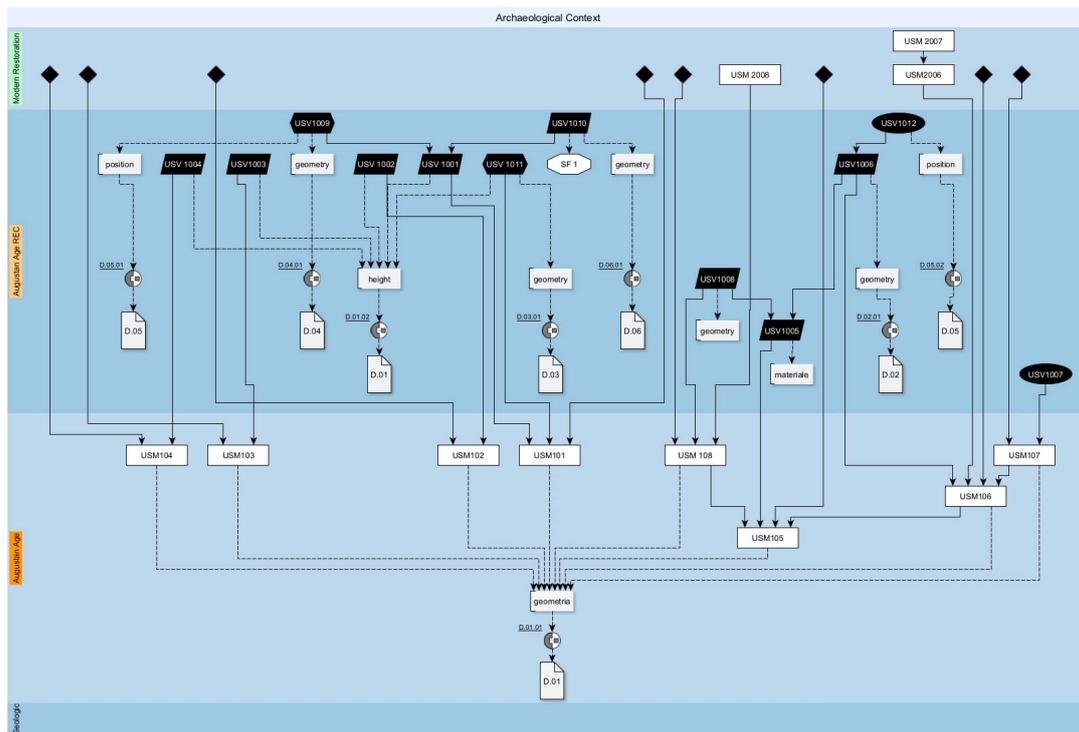


Figure 5. Extended Matrix of Cryptoporticus created in yEd (Grotte di Catullo, Sirmione) (Nicola Delbarba).

Separately, the creation of a virtual model was carried out using the open-source software Blender [12]. The digital replicas of the site, as described in the previous paragraph, were imported into the software, and the reconstruction was modelled on top of them, allowing a perfect overlay between the real and virtual [13]. In this phase, the reconstruction model is characterised by a low-poly geometry, where the architectural structures are reconstructed using simplified volumes. Through a specific add-on developed for Blender [11], the graph of the Extended Matrix is connected to the simplified model, which inherits the semantic code and the source information described above (Figure 6).

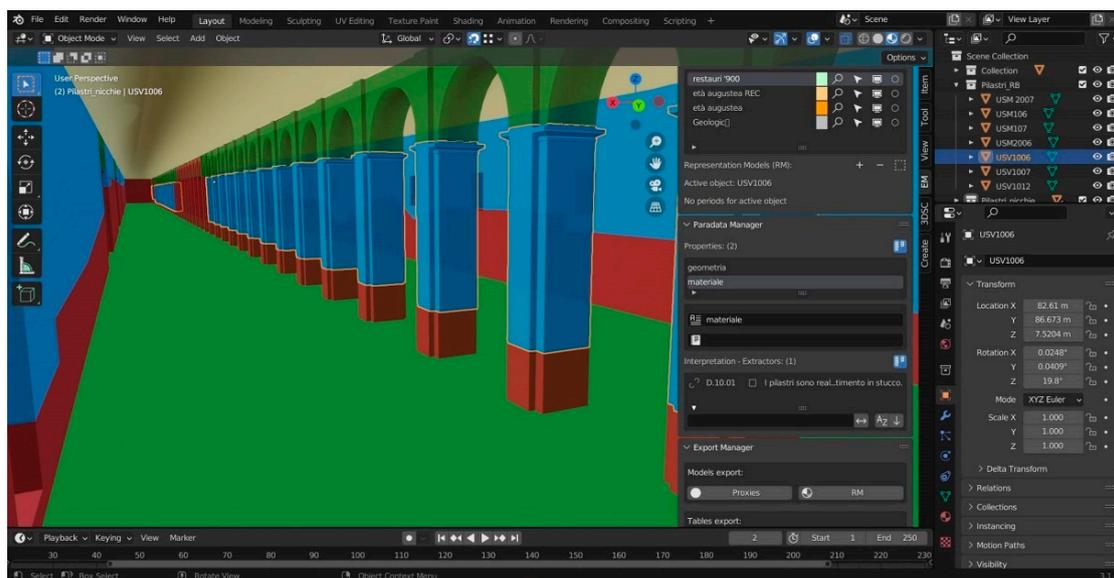


Figure 6. Blender workspace of the cryptoporticus (Grotte di Catullo, Sirmione) (Nicola Delbarba).

In this way, simply by selecting the desired element, specific information on the reconstruction hypothesis made and a direct reference to the sources used to validate the hypothesis itself can be obtained.

3. The Virtual Reconstructions of the Villas

3.1. Sirmione: "Grotte di Catullo"

3.1.1. Presentation of the Site

The villa known as the "Grotte di Catullo" (Figure 7), located on the tip of the Sirmione peninsula, is unique among the Roman villas of northern Italy, particularly for its monumentality and architectural design features [14]. The site underwent various phases of use, which are briefly summarised below. The walls found underneath the southern residential sector of the complex have been attributed to an initial construction phase that predates the 1st century BC. It is not possible to reconstruct the plan of this building. The currently visible complex is dated to the Augustan age, both on the basis of archaeological elements found during recent excavations and for typological and decorative considerations [15].



Figure 7. "Grotte di Catullo", Sirmione (e-Archeo).

In the 2nd century AD, renovation works, perhaps linked to a change of ownership, led to the construction of the bath complex in the western part of the southern residential sector [16]. The villa was destroyed and abandoned in the 3rd century AD, possibly due to an earthquake or a raid. This caused a fire, traces of which are visible on the plaster, and the collapse of the structures [17]. From the middle of the 4th century AD, a necropolis was established in the villa area, probably connected to a military camp of considerable importance, as demonstrated by the finding of a *Keller 6* fibula [18]. In the 4th–5th centuries, the structure was incorporated into a fortification wall, of which long stretches are still preserved [12]. With the arrival of the Lombard people, the villa continued to be used as a necropolis, but with increasingly sporadic evidence of use until the 7th century, in conjunction with the development of the current historic centre of Sirmione [16]. Most of the remains of the villa, especially in the northern sector, always remained visible in later periods.

This study aimed at the virtual reconstruction of the complex focused on the Augustan age, i.e., on the monumental *otium villa*. It is a rectangular complex (167.5 m × 105 m) with projections on the north and south short sides. The rocky slope on which the villa is built

made it necessary to build substructures on the northern, western, and (partially) eastern sides to create a uniform base. What is best preserved of the building are the substructures of the *basis villae* characterised by barrel-vaulted arches, especially in the northern sector where they exceed 15 m in height [3].

The building is arranged on three levels (Figure 8), not uniformly present across the area but following the needs dictated by the different levels of the rock. On the upper level, which must have housed the reception rooms, only some rooms in the southern sector are preserved, including several rooms of a baths complex (from the 2nd century AD) in the western part. The existing walls reach a height of only a few tens of centimetres, and in rare cases, fragments of wall decoration are preserved [3]. There was a large garden in the centre of the upper level. The intermediate level is characterised on the western side by the presence of a cryptoporticus (104a, Figure 8), the best-preserved room of the villa and one of its most imposing structures, with a length of 158.8 m [14]. The southernmost part of the corridor was obtained by excavating into the rock layer, and the central part is on ground level, while the northern part rests on substructural rooms. It served both as a substructure for the erection of the upper loggia and as a closed and covered space for walks and meetings of the *dominus* and his guests.

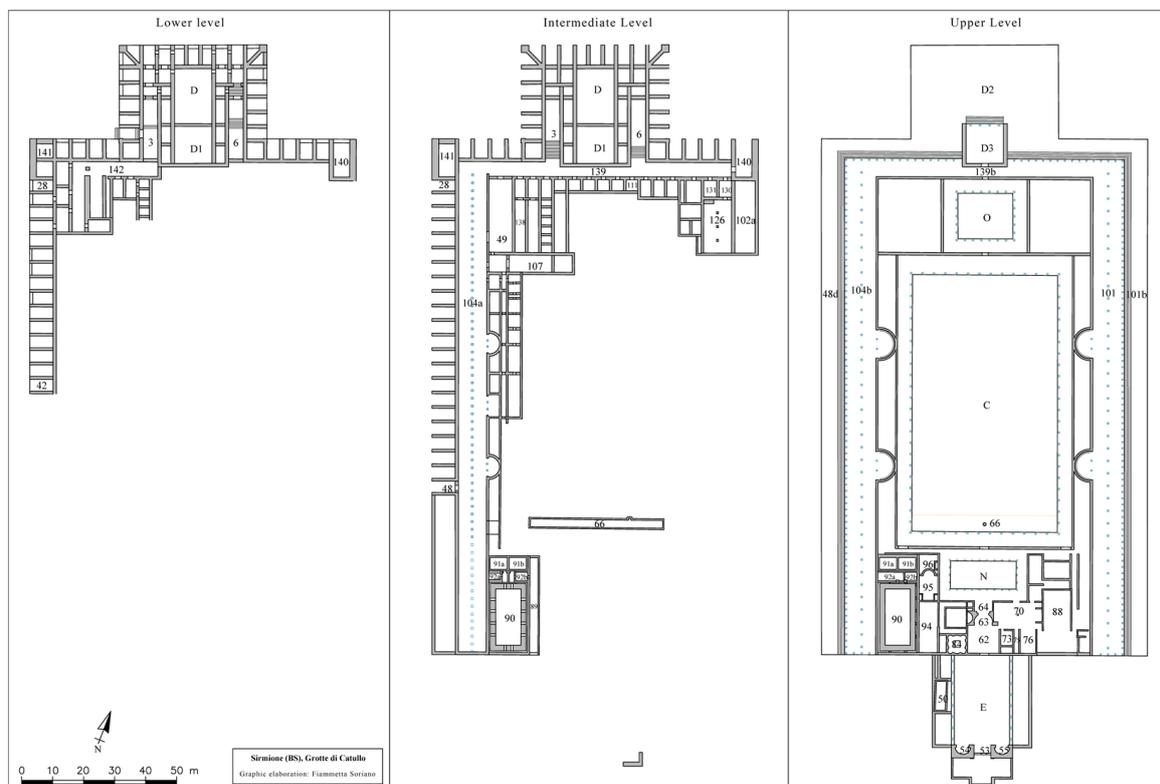


Figure 8. Two-dimensional reconstructive plans of the villa “Grotte di Catullo” in Sirmione (Fiammetta Soriano).

3.1.2. Reconstructive Hypothesis

The villa project was conceived in a unitary and coherent manner, in strict relation to the surrounding lake landscape, as evidenced by the chosen location and the presence of large open spaces, terraces, and panoramic viewpoints. For this reason, and due to the current state of preservation described above, the focus of the reconstruction, which concerned the 1st century AD villa exclusively, was on the exteriors, for which a fundamental reconstruction hypothesis had already been proposed in the past [3]. For this virtual reality project, the interior spaces selected were the cryptoporticus (104a, Figure 8) and

the largest room in the southern sector (room 88, Figure 8), probably a *triclinium*, which presents fragments of well-preserved mosaic flooring.

The exterior of the villa (Figure 2) is characterised by the substructures, reconstructed based on the extensively preserved archaeological evidence in the northern sector. The walls were plastered white, as attested by some preserved fragments in the substructural rooms of the same sector.

In the northern sector overlooking the lake, the building was characterised on the upper level by a large belvedere terrace that occupied the entire front part. Terraces also ran along the long sides of the complex. The pavement was in *opus spicatum*, partly still preserved above the vaults of the northeast corner of the villa [3]. Collapsed blocks of pavement (Figure 9) have also been found in the western and northern sectors. The discovery of two stone elements (Figure 10), similar to those found in amphitheatres and theatres to support the poles of the *velarium*, has allowed us to hypothesise the presence of a temporary covering as protection from the sun [3,19]. The large terrace was then characterised by a belvedere room [3], the existence of which is hypothesised based on the presence of a substructural room on the lower level, which suggests its dimensions [20]. For the reconstruction of the elevation of this room, the main source was the comparison with pictorial representations of villas [21], which often testify to similar temple-shaped structures, with a facade consisting of four columns supporting a pediment and a double-sloping roof.



Figure 9. Supports of the velarium (Nicola Delbarba).



Figure 10. Blocks of *opus spicatum* (Nicola Delbarba).

Porticoed spaces (Figure 11) were located alongside the terraces, situated at a higher level, defined by the still preserved segment of the vault above the northern corridor of the intermediate level. The northern portico (139b, Figure 8) assumed the dimensions of the corridor below (139, Figure 8), presenting itself as a *porticus simplex*. On the long sides,

the portico (101, 104b Figure 8) had a double width equal to that of the cryptoporticus present at the intermediate level (104a, Figure 8) on the western side, which also performed a structural function. On both sides, semi-circular *exedrae* opened, still preserved on the eastern side. The discovery of capitals, bases, and shafts and the study of the collapse dynamics of the pieces have allowed us to formulate the hypothesis that it was a *porticus duplex* with an external Corinthian colonnade and an internal Ionic one [22]. The core of the columns was made of quarter-circle bricks or soft yellowish limestone blocks covered with stucco. The height was reconstructed by applying Vitruvian modules, as was the intercolumniation, in a ratio of 1:2 between the outer and inner colonnade. The capitals belonging to the portico were directly modelled only in their main components; the more elaborate ornamental elements were applied in stucco, directly painted on the stone, or with a whitewash coating [22].

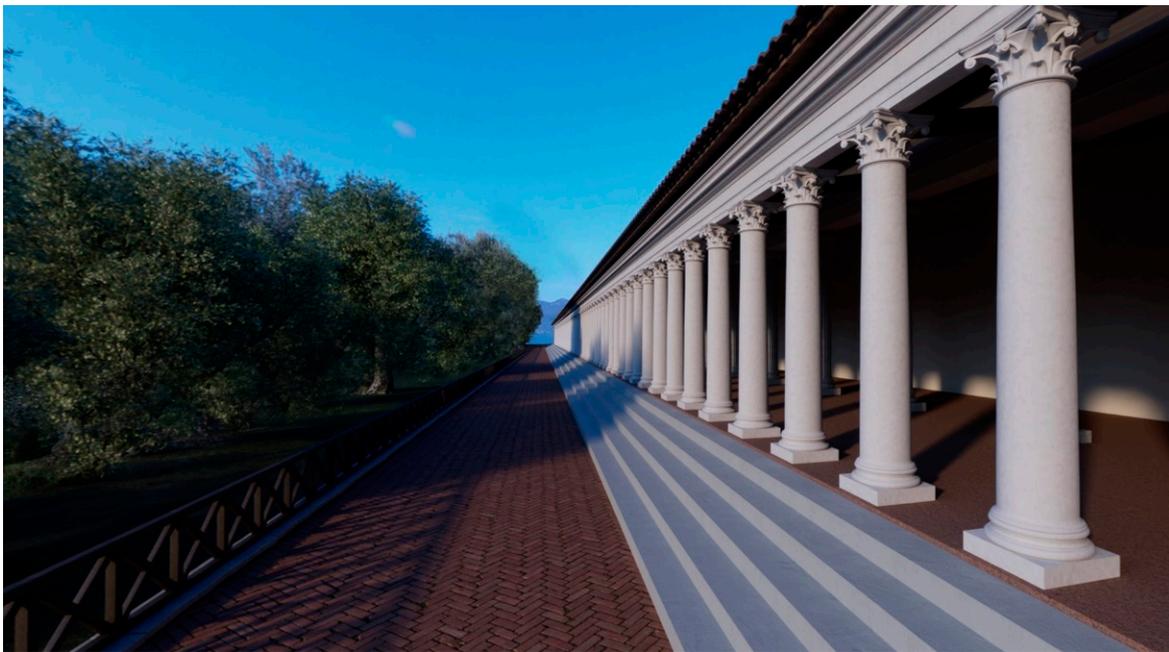


Figure 11. Porticus duplex, Grotte di Catullo, Sirmione (e-Archeo).

The central part of the villa, which did not yield any evidence of wall or floor structures, has been identified as a large courtyard, approximately 4000 square metres in size. It has been hypothesised that it was used as a garden surrounded on all four sides by a portico. At the southern end of the courtyard, the largest and best-preserved cistern in the complex is present. It is over 40 m long, 3 m wide, and covered with *opus spicatum* pavement that is slightly concave to better collect rainwater.

Among the interior spaces that have been reconstructed, the cryptoporticus (Figure 12) is certainly the most imposing and best preserved. It is a corridor approximately 9 m wide, divided into two naves by 64 cruciform-shaped pillars with pilasters applied to all four facades and Tuscan capitals, on which semi-circular arches with a height of 3.50 m are set. The pillars were made of different materials and uniformly with a stucco covering [23]. Three niches, two semi-circular and one rectangular, divide the eastern side. Large portions of the roof, made of blocks of conglomerates of porous and lightweight limestone found in a collapsed state, allow for the reconstruction of semi-circular arches with a height of 6 m [14]. The lighting of the space was characterised by wall openings. At first, wolf-mouth windows were hypothesised based on comparisons with cryptoporticus of other villas and with a room in the “Grotte di Catullo” itself (126, Figure 8), symmetrical to the cryptoporticus but much smaller, which preserves staggered openings. Various factors, including the presence

of the vaults of the external substructures, which would have prevented the entry of light into wolf-mouth openings, led to the proposal of rectangular-shaped windows positioned at a height of about 1.85 m from the floor and centrally located with respect to the external substructures, as suggested by some surveys carried out in the past on bricked-up openings in the northernmost part of the structure.



Figure 12. Cryptoporticus, Grotte di Catullo, Sirmione (e-Archeo).

Finally, a reconstruction of a T-shaped room with an area of 230 square metres located in the southern sector of the building (room 88, Figure 8) has been proposed, for which the function of a *triclinium* has been hypothesised [14]. The floor is made of white mosaic tiles with a black tile border. Considering the close relationship between the villa and the surrounding lake landscape, two large window openings on the southern side, overlooking the Veronese shore of the lake, have been hypothesised for this room.

3.1.3. Reconstructive Plans, Sections and Elevations

On the basis of the stylistic and comparative study of buildings, as well as the analysis of ancient sources [24], which have allowed us to reach the conclusions described above, reconstructive plans, sections, and elevations were created. The previous study made it possible to deduce and establish the norms of the proportion of various architectural and structural elements, translated into reconstructive drawings useful for depicting the building at the time of its construction. For the creation of the 2D reconstructive graphic documents (obtained in a CAD environment), we proceeded with the digitalisation of the surveys and phase plans [25], which were then integrated with the various reconstructive hypotheses.

The floor plans (Figure 8) show the reconstruction of the architectural layout of the building, distributed over three levels. In order to depict the greatest number of architectural and structural elements of the villa, as well as the different changes in elevation, reconstructive elevations and sections were produced.

The elevations (Figure 13) show the reconstruction of the external facades of the villa and highlight the natural rock of the promontory (deduced from the point clouds of the 3D models [26]) with the various reconstructed parts of the villa above.

As for the reconstructive sections (passing through the areas of greatest interest in the villa) (Figure 14), they highlight many structural elements and the organization of the internal spaces and volumes of the villa.

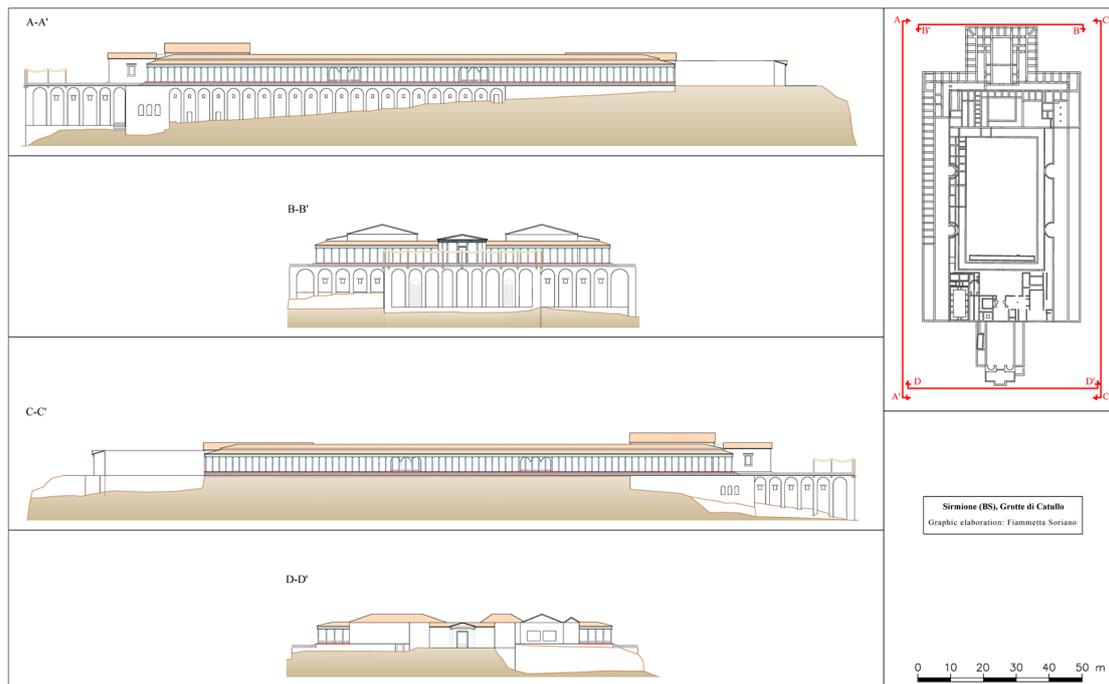


Figure 13. Two-dimensional reconstructive elevations of the villa “Grotte di Catullo” in Sirmione (Fiammetta Soriano).

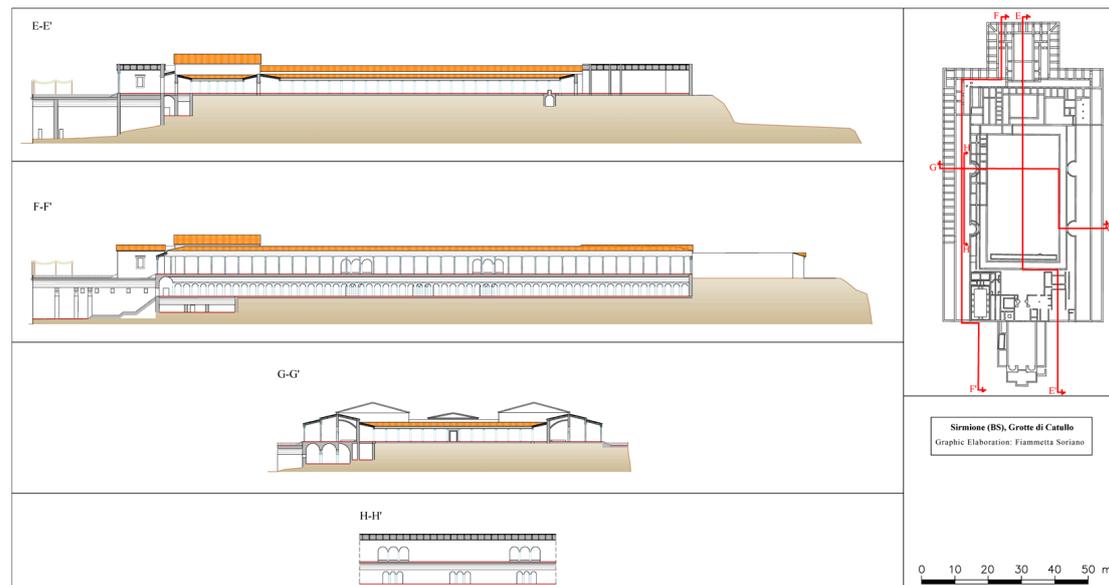


Figure 14. Two-dimensional reconstructive sections of the villa “Grotte di Catullo” in Sirmione (Fiammetta Soriano).

3.1.4. Wall Decoration

The study of the paintings in the villa, which was a precursor to the development of hypotheses regarding the reconstruction of the wall decoration of the rooms, is certainly complex due to the abandonment of the building and the subsequent removal of the plaster covering on-site to recover building materials from the wall structures. Several thousand fragments demonstrate the richness of the painted decoration of the villa, but only a single non-monochrome fragment has been preserved on a wall [27]; it belongs to one of the rooms (room 107) connected to the western cryptoporticus (Figure 15). By comparing the relevant fragmentary material and what is visible on-site, it was possible to enrich our

knowledge of the decoration that originally adorned the room and develop a more complete hypothesis about its layout on the wall, particularly concerning the middle register, which seems to have been organised around a central aedicula in which pink columns and pillars painted in green and yellow colours supported an epistyle composed of a rich sequence of slabs alternately red and yellow, decorated with lotus flowers, and separated by narrow white bands; stylised circular elements painted in black hung along the pillars at the sides (Figure 16). In the central field, slender thyrsi, from which leaves and small four-petaled holes emerged, presumably supported a yellow frieze decorated with a reversed Lesbian kyma, from which garlands decorated with yellow and blue flowers were suspended. The aedicula was flanked on both sides by light architectures consisting of tapered columns with fanciful “water-leaf” capitals from which garlands of flowers were hung; the frieze was enriched with acroterial elements and delimited by palm leaves from which small squares hung. The composition was closed on the sides by candelabra columns, one of which is still visible on the wall, with two other aerial architectures, one on each side, in which a low pillar base was connected, via slender thyrsi, to a polychrome band as an epistyle crowned by a pediment (Figure 17). Almost certainly, the decoration of the middle register was crowned throughout its length by an applied stucco moulding; another stucco moulding was also horizontally arranged to close the upper decorative register, perhaps at the level of the vault impost. This pictorial context, unusual for its exceptional possibility of re-contextualisation, offers us a new, albeit partial, image of what the decoration of the III Style in the rooms at the level of the cryptoporticus could have been [20]. In the absence of archaeological evidence of the cryptoporticus’ wall coatings, in the virtual reconstruction of the paintings of the room, the decorative scheme of an adjacent room was used. The lower register—not documented in this limited section of plaster—was integrated with a decorative motif well attested in contemporary paintings [28] (Figure 18).



Figure 15. Photoplan of the in situ painted decoration in room 107 (G. Laidelli).

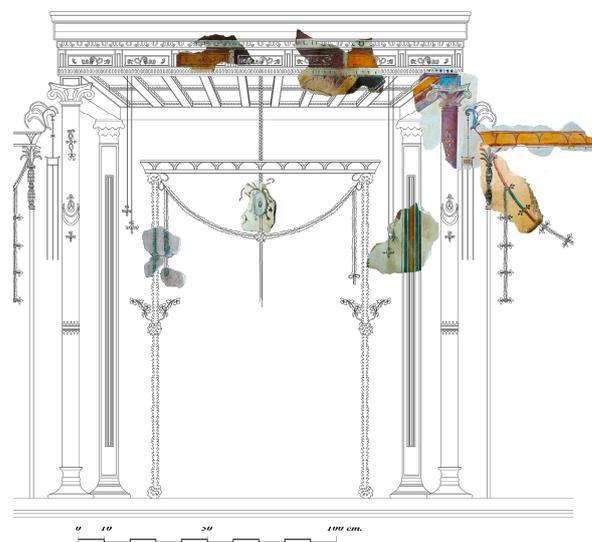


Figure 16. Graphic hypothesis for the restoration of the painted decoration in room 107: perspective view of a niche (G. Laidelli).



Figure 17. Hypothetical restoration of the painted decoration in room 107: candelabrum column and architecture with pediment-crowned entablature (G. Laidelli).

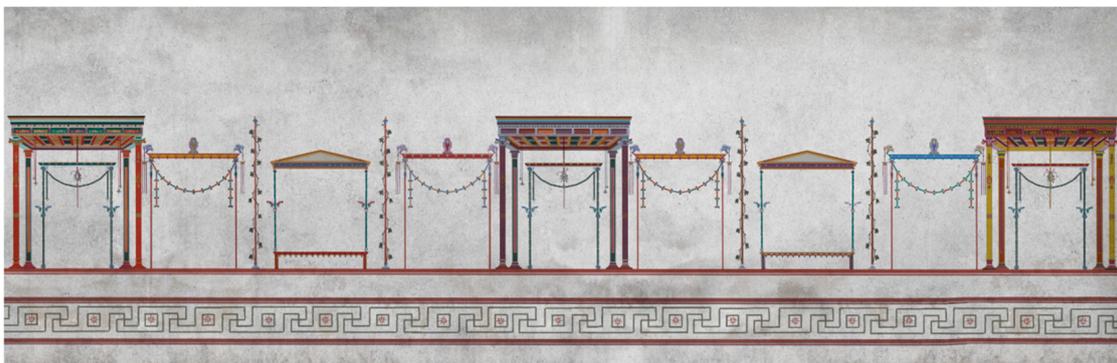


Figure 18. Virtual restoration of the development of the painted decoration in the cryptoporticus (CarraroLab).

For the virtual reconstruction of the painted decoration in room 88, possibly a *triclinium* of the villa, the excavation data relating to the fragments of painted plaster relevant to the lower register of the room decoration were first taken into account. These mostly consist of portions of the black-coloured base found on the wall during the excavation as well as a pertinent fragmentary material. Secondly, to develop the decorative scheme in its elevation, a fragment preserved at the Museum of the Grotte di Catullo was utilised, which is the result of a past restoration intervention on the pictorial material from the villa [29]. This fragment represents a significant portion of a decorative scheme in which the architectural motif passes through two registers: an *edicola*, flanked on either side by overlapping and separated black and red areas, topped by an *epistilium* composed of a rich sequence of slabs ornamented with vegetal motifs, and crowned by a pediment adorned with acroterial elements, particularly female figures with veiled heads lying on top; in the upper register, the “structural” motif rises in slender architectural forms adorned with acroterial elements, with friezes of palmettes supporting oscillating ribbons (Figure 19).



Figure 19. Sirmione “Grotte di Catullo”. Panel with recomposition of a decorative section: middle and upper registers. Niche with pediment (G. Laidelli).

The painting documents the “architectural type” of the central *edicola* that interrupts and focuses the horizontal flow of the decoration in the middle zone of the wall and extends upward into the upper register. This hypothetical type of wall decoration, organised around a centre (*edicola*), usually reserved for spaces intended for longer stays, is well suited for the decoration of a *triclinium* (Figure 20).



Figure 20. Virtual restoration of the development of the painted decoration in room 88 (CarraroLab).

3.2. Desenzano: Roman Villa

3.2.1. Presentation of the Site

Starting from Sirmione and moving along the coast towards the southwest, one reaches the Roman villa of Desenzano. It occupied an area of about one hectare and was bordered to the east by the waters of the lake. The splendid view that would have been enjoyed in ancient times, looking out from the rooms of the villa, is now difficult to perceive as the lake's shore has retreated by 70 m, and the archaeological remains are hidden among the modern dwellings of the city's historic centre.

Over time, the area of the villa experienced a series of (re)constructions from the end of the 1st century BC to the middle of the 5th century AD (Figure 21).



Figure 21. Plans of the villa in Desenzano (in red, the survey from orthophoto conducted by Fiammetta Soriano, Andrea Zemignani, Elaboration from the plan. Table IV [28]).

The oldest period (late 1st century BC) is represented by two buildings: to the south, the so-called sector A, visible below the current Antiquarium, belongs to the *pars urbana*, composed of a group of seven rooms of a bath complex, of which the *suspensurae* and the floors with black and white mosaics are recognisable. To the north, instead, in sector D, the *pars rustica* should have been located, of which traces of hearths arranged around an *atrium* remain. In the mid-1st century AD, the area was occupied by a house with a marked productive character, as the territory was perfectly suited for the cultivation of vines and olive trees, as well as fishing. A trace of a productive installation is indeed recognisable in a room where a circular imprint, probably left by a wine press, is visible on the floor [30] (Figure 22).



Figure 22. Room with circular trace of the press (Alessandra Marinello).

In the first half of the 2nd century AD, the villa was renovated, especially in terms of decorative elements. Many rooms were repurposed for residential and reception functions, with direct access to the lake. The terracotta floors were replaced with precious mosaic floors, and the walls were decorated with refined frescoes [31]. The rooms were also enriched with a significant number of statues, some of them life-sized, whose subjects, quite common in domestic contexts, alluded to the grandeur of the *dominus* and the richness of the place [32].

The architectural and decorative layout that can be admired in the archaeological area today, however, dates back to the mid-4th century AD, more precisely between 336 and 348 AD, as evidenced by some coins found during the archaeological excavations [33].

The villa was organised into pavilions connected by internal paths. The so-called sector A mainly served the function of receiving guests, as well as being the residence of the owner. Sector B was entirely dedicated to residential functions, while Sector C was occupied by a large bath complex with direct access to the lake [34].

The villa retained its function as a great *otium* residence until the mid-5th century AD when it was abandoned following a fire. The last interventions before abandonment concerned the insertion, in sector B, of a large apsidal hall, almost 10 m in diameter, with a magnificent *opus sectile* floor in black, pink, and white diamonds that formed a perspective cube pattern. The villa also became enriched with objects with clear Christian references, including a cup with a Christological scene and lamps with the Chi-Rho symbol [34].

Sector A, in the 4th century phase, represents the best-preserved and most well-understood area, both stratigraphically and functionally. Thanks to its particular planimetric development and the richness of its artistic and architectural decorations, sector A is considered the focal point of the entire complex. For these reasons, some of its specific rooms have been selected for virtual 3D reconstructions. Finally, these were employed as part of a virtual reality model where the user has the opportunity, through the web app, to immerse himself in the reconstructions.

3.2.2. Reconstructive Hypothesis

Sector A is composed of a series of spaces dedicated to the reception of visitors and the projection of status, arranged along a single main axis; the levels of architectural and decorative complexity increase as one moves along this axis from east to west. In sequence, we find (Figure 23) an entrance with an octagonal plan (room 1), a courtyard with a portico (peristyle, room 2), an *atrium* with two apses (“forcipe”, room 3), and a magnificent three-apsed hall, called a *trichora*, intended for convivium (room 4). The axis ends with a *viridarium*, a garden closed to the west by a *nymphaeum*, where water flowed from niches forming a splendid architectural backdrop (room 5). The latter environment, not directly accessible from the preceding reception rooms, had a predominantly private character reserved for the master and selected guests. On the south side of the garden, there were rooms that constituted the summer apartment of the *dominus*, characterised by two *cubicula* with octagonal and hexagonal plans and an apsidal vestibule (rooms 6–8). From the peristyle, other rooms could be accessed; it is possible to recognise, in the rooms opening along the south side, the winter apartment of the *dominus* (rooms 10–12) with a private *balneum* (rooms 13–14), while on the north side were various service rooms.

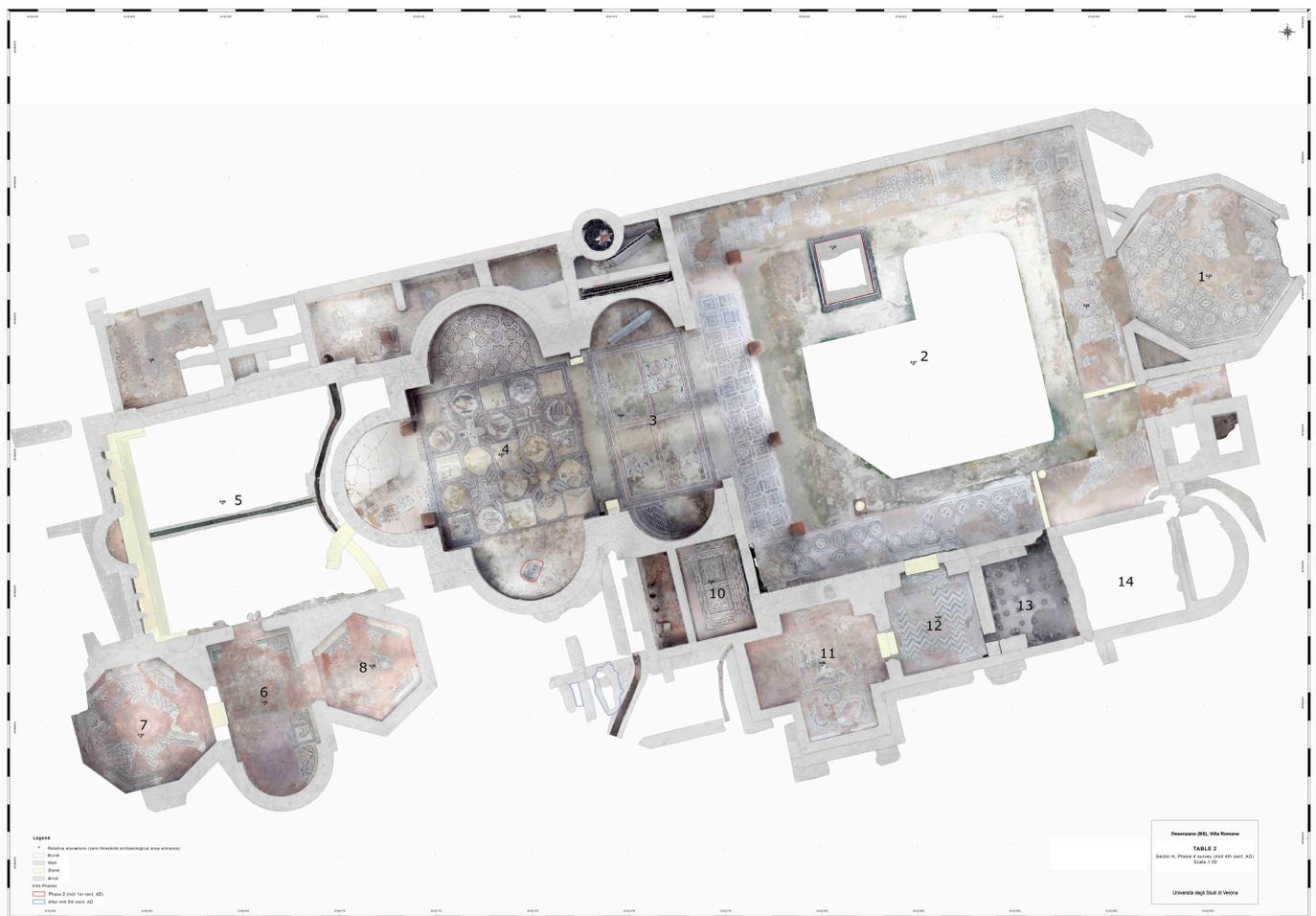


Figure 23. Orthophoto of Sector A (Fiammetta Soriano, Andrea Zemignani).

All rooms were richly decorated with mosaic floors featuring geometric patterns or scenes evoking daily life activities or allegorical figures; for example, we find scenes of cherubs fishing (room 3), scenes alluding to the themes of banquet and Dionysian revelry (room 4), scenes evoking the seasons (room 10), and, finally, a panel depicting a male

figure accompanied by a dog and a sheep (room 11), probably referring to the image of the *dominus*. Naturally, the walls were also adorned with lively frescoes, and although the walls do not survive beyond one metre in height, it is still possible to glimpse fragments of the socles [4].

Virtual reconstruction has involved the five representational environments along the main axis, from the entrance to the *viridarium* (Figure 24). Taking into account the archaeological data and published documentation, including comparative data with nearby contexts for chronology and function, it was possible to obtain a reconstruction of the elevations and interiors that is as philologically faithful as possible. The succession of environments characterised by complex and different floor plans, as in this case, provides an insight into the development of the elevation; from the outside, the complex must have appeared as a juxtaposition of volumes whose different shapes and heights allowed the functional and hierarchical articulation of the environments to be recognised at first glance.



Figure 24. Virtual reconstruction of the villa in Desenzano (e-Archeo).

The first environment, hypothetically the entrance, had an octagonal plan that must have appeared on the outside as a tall turret, emerging on the lakeside landscape to emphasize the prestige of the building [35]. From there, one entered the peristyle, where it was possible to walk on mosaic floors with geometric motifs along the four sides of the portico. In line with the entrance, on the opposite side of the peristyle, there were formal reception spaces. The first was an *atrium*, a room for welcoming guests, characterised by two lateral apses, decorated with a mosaic with a coloured scale motif, while the central part was marked by four panels representing scenes of cupids fishing from boats and rocks. Two of these panels face the peristyle, while the others look into the next room, to accommodate both the entrance and exit paths. Guests were then invited to participate in the banquet. The convivial moment was characterised by greater luxury and splendour and represented one of the main methods of self-presentation of the *dominus*. The room is characterised by three large apses, inside which the tables were placed, called “sigma” for

their characteristic semi-circular shape, surrounded by couches (*stibadium*), while in the central space of the room, performances and entertainment were held to accompany the banquet [36]. The central mosaic is composed of a complex geometric pattern of octagons and squares as follows: scenes of cupids harvesting grapes (alluding to the seasons) and on a chariot pulled by felines (alluding to circus games), satyrs and maenads, beasts chasing deer (with a reference to the theme of hunting), *kàntaroi* with vegetable branches within crosses (in harmony with the Dionysian celebration of the cycle of nature), and in the central panel, now missing, perhaps the figure of Dionysus. Additionally, in this environment, the panels are oriented towards the four outer walls so that the images can be seen when entering the room or standing near the three apses. The floors of the apses were instead decorated with simpler mosaic patterns, as the furniture would have hindered the visibility of the decorations. Drapes, furniture, and candelabra completed the room's decoration, while large windows probably illuminated the room from above; it has also been imagined that there might have been a window in the central apse from which one could admire the splendid *nymphaeum* of the *viridarium*.

The latter closed the main axis of the building. It was a small garden enclosed by high walls and accessible through two small entrances, one for service from the north and one from the south. It was used as a private living space and, thanks to the *nymphaeum* on the west wall, provided a pleasant setting. Low shrubs likely enriched the central space, while a fresco garden was reproduced on the walls. The *nymphaeum* was marked by nine niches: seven frontals, of which the central one was larger than the others, and two laterals, ending in arches. From each niche on the front wall, a jet of water flowed into an adjacent basin. The space inside the niches was probably occupied by statues whose subjects were related to *otium* and *convivium*. In fact, the villa was equipped with an important sculptural apparatus unearthed during the excavations of 1963-69. The depicted subjects refer to common repertoires in the private residences of the Roman elite: we find subjects belonging to the Dionysian theme, statues of Hercules, *Apollo* and *Fortuna*, and a portrait head of an adolescent [31].

3.2.3. Wall Decoration

In formulating a hypothesis for the reconstruction of the wall painting decoration, consideration was given first and foremost to the paintings that were preserved on the walls. The frescoes in situ inform the original decoration of the lower register and, in certain cases, partially that of the middle register. The completion of the elevation of the decorative elements was therefore hypothesised on the basis of comparisons. These are pictorial contexts that serve as references from an iconographic point of view but are only partly consistent with that of the Garda region due to geographical distance, as well as—in some cases—chronological distance; however, they are all united by the same figurative code. This is the case, for example, with the “garden” decoration of the *viridarium*, which has illustrious antecedents, such as the hypogeum of the Villa of Livia in Prima Porta [37], the enclosed garden of the Villa Farnesina [28,38], and that depicted in the niches on the long sides of the so-called *Auditorium* of Maecenas [39], but it features a stylised pictorial rendering and a simplified vocabulary that refers to contexts that are chronologically later, such as those of Ephesus, Pergamum, Balaka, and Bulla Regia [40].

The virtual reconstruction of the painting decoration of the peristyle courtyard follows the paintings still on the wall, i.e., the decoration of the plinth with the motif of a red Greek key that frames stylised eight-petal flowers on a white background [34] and the beginning of the middle register, marked by a red band, painted with a sequence of panels according to a paratactic scheme that is well-suited to passage areas (Figure 25). There are multiple comparisons for this type of decorative scheme, including the motif and the chromatic choice, and they are attested from the 3rd century AD onwards [41].

The virtual elaboration of the painted decoration of the *trichora* took into account first and foremost a painted plaster fragment preserved at the level of the lower register in the western apse of the chamber; this is a portion of the plinth—with a black background—on which a sequence of panels is set: the best-preserved one has a white background with a red border. The development of the decoration vertically in two registers was hypothesised by adopting a decorative scheme based on the combination of panels and painted bands imitating marble (Figure 26), thanks to a comparison with pictorial contexts that are chronologically coeval and belonging to the same territorial area: the villa of Via Antiche Mura in Sirmione [42] and that of Toscolano Maderno on the western shore of the lake [43]. The link between these decorative contexts is exemplified well, for example, via the use of the same geometric scheme both in the mosaic carpet of the trilobate room of the Villa of Desenzano and in the painted ceiling of the Villa of Sirmione, which can be added the close similarity of some decorative motifs. In the villa of Toscolano Maderno, a lakeside context dating back to the first half of the 4th century AD, a large portion of the painted decoration with large panels imitating *sectilia* is still preserved on the wall (Figure 27). Such local testimonies, therefore, once again confirm, in the late Roman-era pictorial tradition, the use of imitation geometric marble inlays in wall paintings. The tendency to employ a common decorative repertoire becomes prominent in the late period when the repertoire of patterns and motifs is shared by not only private but also public buildings.



Figure 25. Desenzano. Fragment of painted plaster partially preserved on the west side of the peristyle (University of Verona).



Figure 26. Virtual reconstruction of the development of the pictorial decoration in the three-lobed triclinium of the villa in Desenzano (CarraroLab).



Figure 27. Hypothetical restorative sketch of the decoration in room 28 of the villa in Toscolano Maderno (G. Laidelli).

4. E-Archeo 3D

4.1. The Web App

4.1.1. Structure of the App

The virtual 3D reconstructions, the associated scientific metadata, and the narrative content converged in various multimedia applications with the aim of enhancing the eight archaeological areas to reach the public in different ways, both on site and online.

The interactive application that deals with the visualisation of 3D data is called e-Archeo 3D [44] and is a web app that allows the visualisation of eight archaeological areas through interactive 360° images. e-Archeo 3D was created on the basis of an existing Open-Source platform developed by CNR called Aton [45]. This software, unlike its commercial and Open-Source competitors, meets a series of requirements that focus on human interaction, making its accessibility and sustainability over time its strengths. Among these requirements, there is compliance with usability standards (ISO 9241-11:1998, subsequently updated by ISO/2014) that allow users to save cognitive effort, access data quickly, and provide interactions that are easy to memorise and use.

Moreover, being an Open-Source product, it benefits from a community that very actively participates in its development and maintenance. Its information architecture has been made compatible with all web browsers for both desktop and mobile devices. It allows professionals to easily manage videos through HTML5 players, view 3D models in real-time, listen to the audio content in the scene, and above all, visualise and query semantic mappings applied to 3D models, automatically loading data from previously generated Extended Matrix projects [46].

Within this web app, exploration is designed to be carried out on site by a user without a particular device or archaeological skills, making the interactive site visit engaging and attractive not only for adults but also for schools. By accessing the web app, within each archaeological site, there is a map with the geolocation of the reconstructed monuments

in 3D that shows their current state of preservation and their hypothetical reconstruction in each historical period. These hypotheses are based on the scientific studies of various research teams and possess a degree of reconstructive reliability described by the Extended Matrix, whereby the 3D reconstruction of each architectural element present in the scene is linked to a note, bibliographic description, image, etc., that allows the user to understand the motivation behind some interpretive choices. By accessing the level of visualisation of the current site at a certain point in the archaeological site as it is now, it is possible to move to multiple viewpoints within the visitable area, even while navigating the reconstructed space. It is also possible to integrate both descriptive and scientific information at the same time, in both Italian and English, with access modes for the visually impaired and with automatic audio reproduction to engage a wider audience.

4.1.2. Storytelling

In the cultural field, storytelling has become a fundamental element for engagingly transmitting the history and value of cultural heritage, making it accessible to all users. Understanding the context and using simple language that is not too technical or descriptive is the first step in creating an interesting and captivating narrative. Additionally, it is important to consider the target audience, their expectations, and needs and to use appropriate tools to reach them. Thanks to technology and new forms of communication, stories can become even more immersive, creating memorable experiences for the audience.

Taking these aspects into consideration, a personalised storytelling approach has been created for each level of information and reconstructed environment, with the goal of offering visitors the opportunity to approach a reality other than their own. The texts are more narrative compared to traditional academic/archaeological articles, and the narration is compelling and stimulating, devoid of superfluous adjectives or descriptive content. The objective is to convey to the reader a clear image of daily life in ancient times, social relationships, and technological capabilities.

For both villas, the focus of the narrative is on the characteristics of the villas as, for the wealthy, places of *otium*, the relationship of the two buildings with the surrounding environment, and the lifestyle that was enjoyed there [47,48]. The first two levels of the web app, “what it was like” and “what it is like now”, provide information about the foundation of the villas, the architectural evolution they underwent over time, and their discovery in contemporary times. Other annotations relate to the people who lived there, special construction techniques, or the appearance of the ancient landscape. For each reconstructed environment or view, there are in-depth explanations that relate interesting things about the activities carried out inside, decorations, or objects used for specific activities. In the last level, “sources”, bibliographic sources on which the architectural reconstruction was based on are linked to the Extended Matrix to give greater value to the reconstruction itself.

4.2. “Grotte di Catullo”, Sirmione

The proposed virtual reality tour of the “Grotte di Catullo” is an ideal route that could have been taken by both the ancient guest of the *dominus* of the residence and the current visitor. It begins with two views of the complex, one frontal and one lateral, which allow for a better understanding of the architecture of the building as a whole while also evoking the impact that the monumentality of the villa must have had on visitors arriving from the lake. It continues into the so-called “Campo delle noci”, a large garden at the lake level in the northeast corner of the villa. The ideal landing place for guests arriving from the lake is presented, where the remains are preserved at their maximum height. After a stop in the large central courtyard, the visit continues into the cryptoporticus, observed from both the inside and outside. The user is then virtually transported to the *porticus duplex* that ran above the previously covered corridor, which is no longer preserved today. The visit concludes in one of the few partially preserved representative rooms on the upper level, probably used as a *triclinium* (room 88), evoking a banquet.

For each stop, images of the current state of the villa and its virtual reconstruction are complementary, creating a narrative continuum between the modern and contemporary history of the site and the daily life that took place in those environments in Roman times. The scientific back-end, on the other hand, is disconnected from this narrative thread and is instead dedicated to specialists.

Through the use of hotspots, the narration has tried to broaden its thematic scope, addressing issues that rarely emerge, such as the presence of women inside the villa, the conditions of slaves and servants, the role played by the lake, water supply, and construction techniques.

Taking the cryptoporticus as an example (Figure 28), in the “Now” view, the environment is introduced from a typological and functional point of view, and then, the construction process and excavations are described. Observing, instead, the environment’s appearance in Roman times, the narration shifts to the *otium* activities that would have been conducted inside the villa, specifically focusing on walks accompanied by a learned conversation. The hotspots cover details of different themes to meet the diverse interests that the public may bring, such as the pictorial decoration, construction techniques, and a particular fragment of a fresco found in an unknown environment, thus probably not coming from the cryptoporticus, which is believed to represent the poet Catullus (Figure 29). This is one of the most emblematic finds of the site, which seems to find its ideal narrative placement in this context, linking to the cultural and intellectual themes that characterised walks in these environments.

4.3. Roman Villa, Desenzano

Virtual reality in the Desenzano villa, on the other hand, follows a tour inside the building, tracing the route that guests followed as they were invited in.

The theme of conviviality and the daily activities that took place in the villa was chosen as the guiding thread of the narrative [47]. Guests, welcomed inside the villa, were immediately fascinated by the richness of the place, a symbol of the prestige of the owning family. The activity that framed the conversations between the host and his guests was the banquet. Many expressed curiosity associated with this theme, such as the arrangement of guests on the *triclinia* during the banquet, the dishes served, the techniques of lighting the rooms, and the meaning of the mosaics.

The time that the *dominus* dedicated to study and reflection was equally important. Taking the *viridarium* as an example, the current state of conservation is described, and the importance that this environment had in great residences in Late Antiquity is discussed. In the reconstructed view, the narration concerns the particular privacy of this place, enclosed by high walls, while the *nymphaeum* created a splendid scenic backdrop.

Finally, the in-depth analysis contributes to providing information on the decorative choices and habits of the owner; for example, the particular fresco that, through an illusionistic game, dilated space; the statues, already belonging to the villa of the previous phase and which were reused here to decorate the niches of the *nymphaeum*; and the summer apartment directly attached to the garden, in which the owner could take refuge, seeking tranquillity and dedicating himself to study, lulled by the flow of water.

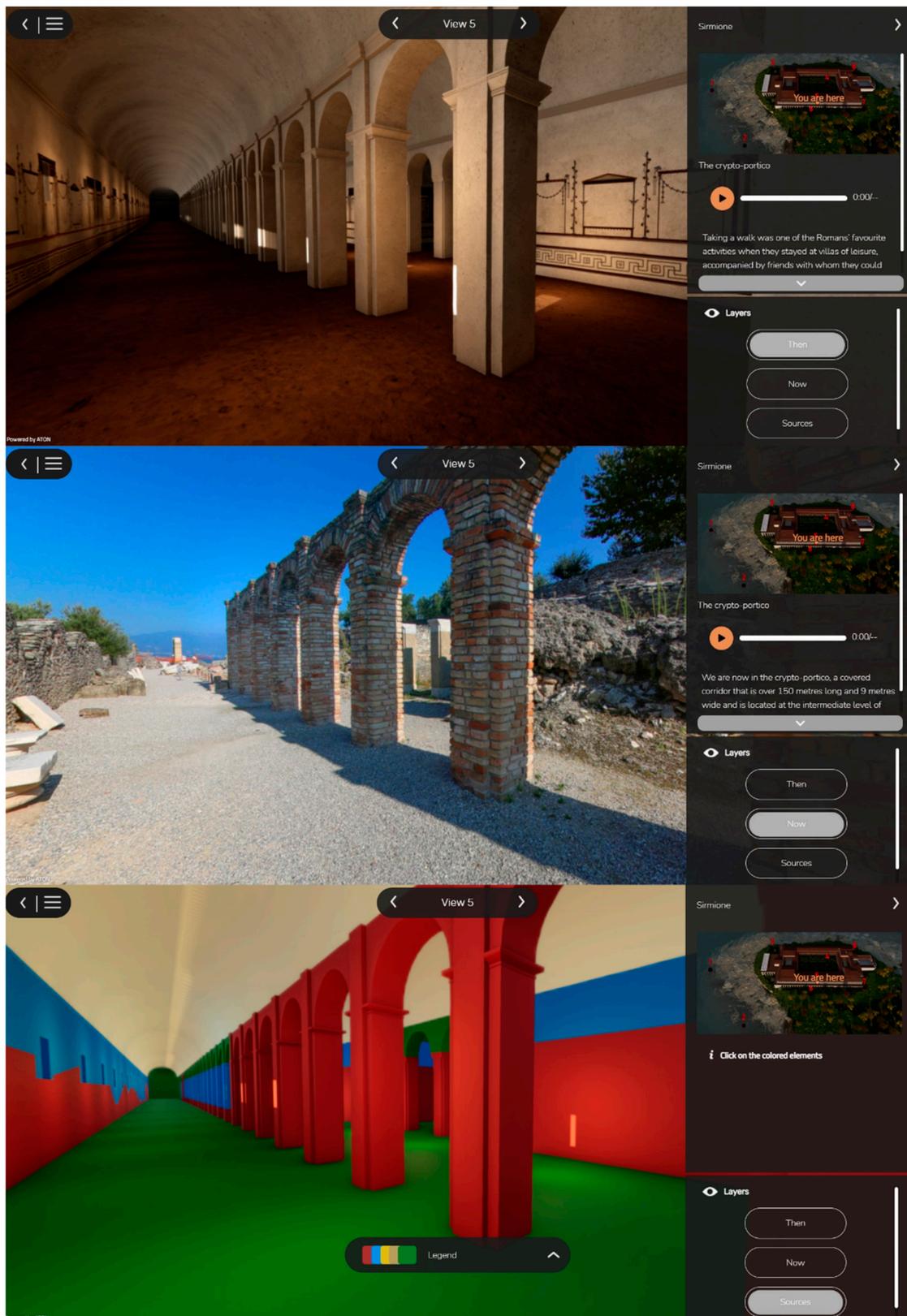


Figure 28. “Then”, “Now”, and “Sources” views of the cryptoporticus of the “Grotte di Catullo” villa (e-Archeo).

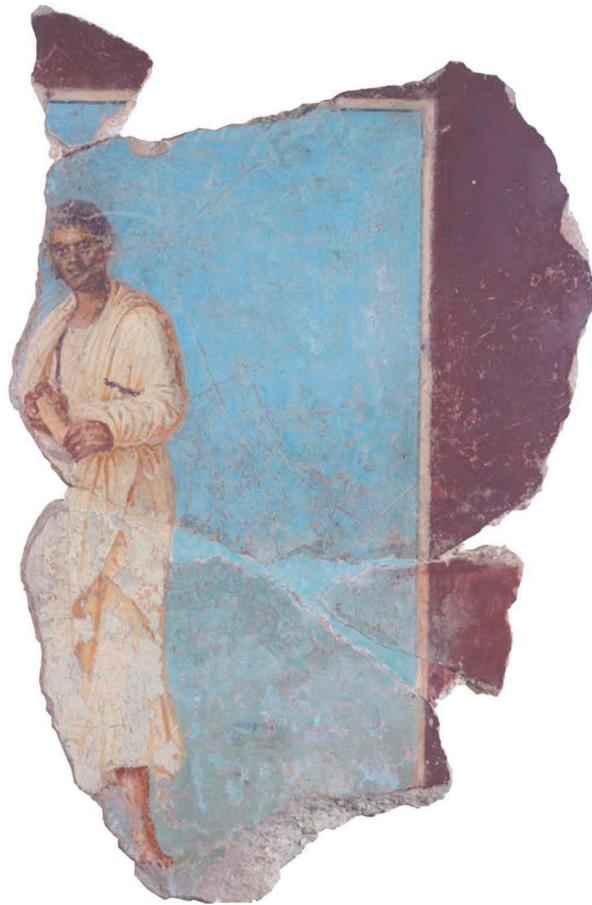


Figure 29. Wall decoration from the “Grotte di Catullo” villa (Catullus?) (Nicola Delbarba).

5. Conclusions

As outlined in this paper, following the methodological guidelines and procedures applied throughout the broader project but obviously adapting them to the two realities in which we worked, e-Archeo has realised the following end-products for the two villas of Sirmione and Desenzano, in addition to the website and the video produced by RAI and E.V.O.C.A. that tell the story of all eight archaeological sites:

- The web app discussed in this article (e-Archeo 3D), where great attention was paid to the relationship of the sites with nature;
- One of the eight podcasts developed from the historical–archaeological narratives of the site (e-Archeo—Voices);
- An application developed for Sirmione (and Cerveteri), where a character—Catullus, in the case of Sirmione—played by an actor in costume, interacts with the user, telling the archaeological area’s story (e-Archeo HI—Human Interface).

Although the intellectual ‘ownership’ of the e-Archeo project’s technical–methodological innovations is by Ales and CNR, in this study and valorisation of the two villas, the University’s contribution was central. The results were significant to the use of digital technologies in a conscious enhancement and promotion of the two sites; to promote the usability of the applications produced by paying attention both to a broad and general public and to a more expert audience thanks to the integration of several levels of content and representation; to also develop a use for scientific purposes of the virtual reconstructions to deepen some specific aspects of the study of the sites; and to use the outputs produced for educational programmes and cultural growth initiatives for visitors.

Regarding this last aspect, it should be noted that the managers of the Sirmione and Desenzano sites were introduced to the use of the e-Archeo project’s narrative in civic

education projects addressed to schools. On 5 April of this year, the University of Verona participated in a meeting with school teachers on the subject of digital education, bringing the experience of the e-Archeo project to Sirmione and Desenzano. The meeting was very successful, and the project was much appreciated.

These collaborations open new scenarios for an active role of the University itself also in the future study of public feedback, to monitor the e-Archeo's impact and the level of satisfaction expressed by visitors regarding the applications, and to understand whether the project has truly achieved its communicative objectives. Finally, of great interest are the future uses of the skills acquired during the project within other projects we have conducted, such as the one in the area of the late antique market and walls of Aquileia [49–51]. At the moment, in addition to the study and excavation of this site, we are starting to plan the valorisation of the structures. For instance, we intend to employ in the 3D reconstruction the methods used in the e-Archeo project, particularly the Extended matrix. In this way, e-Archeo is presented as a long-lasting methodology that will also be of great value in the future for the multimedia and technological enhancement of archaeological sites.

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