A virtual experience across the buried history

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Abstract. The Sant'Angelo cave church is an underground medieval Benedictine complex in the south of Italy, affected by serious structural and chemical degradation. In the context of a documentation campaign promoted by the local Superintendence and supported by the IPERI-ONCH.it project, we carried out an accurate 3D and photographic survey, and reconstructed a detailed 3D model of the site (encoding shape and colour). While the primary purpose of this large amount of collected data was to provide a metric documentation of the site, the completeness and the high detail of the survey suggested also a possible use for dissemination and virtual presentation. Thus, we exploited the 3D digital models to design and build a virtual visit of the church, oriented to scholars, museums and tourists. This paper describes the design and implementation of this educational experience, closely related to the bibliographic sources of the artistic heritage, fully enriched with hyper-textual information, intuitive and easy to use for all users regardless of their level of familiarity with the 3D medium.

Keywords: virtual tour, 3D reconstruction, interactive experience, 3D web

1 Introduction

Located in Casalrotto, Taranto (IT), the Sant'Angelo cave church is a peculiar structure, since it is a completely hypogean complex. The Benedictine church has been carved in the tuffaceous rock between the IX and XV century a.C.; its structure and decoration constitute an exceptional evidence of the Greek and Byzantine influences in the art of southern Italy [7, 5].
The complex is composed by two underground floors, divided by pillars into three absidate naves, following the traditional structure of the Cappadocian, Caucasian and Byzantinium funerary crypts. Some of these naves have Greek altars, others are decorated by various frescoes with multiple style contaminations. The upper floor was mainly intended to liturgical private functions, the lower (accessible by a flight of stairs from the back of the right nave at the first floor), slightly smaller, served for funeral rites, as shown by the presence of

seven tombs carved into the floor. Over the centuries the architectural structure suffered several changes: most probably, it was initially composed by one floor of two aisles and the third one was excavated later; the lower level was a later addition as well. The detachments of some painted portions from the walls revealed chronological stratification of paints.

Fig. 1. Sant'Angelo church. Top row: entrance and upper floor. Bottom row: details of the structure.

Cave churches are an amazingly interesting heritage: the arrangement of spaces and the decorations were related to very strong symbolic meanings, and they can tell a lot about the local culture and the influences from the Greek and Byzantine worlds. Unfortunately, they are only partially known by the wide public. One of the reasons for this is that most of the churches are difficult to reach (see Figure 1), and due to their structure, they often lack the proper safety requirements to allow visitors. Additionally, a massive amount of tourists may impact on the already critical humidity and stability conditions.
The Sant'Angelo church is affected by serious physical and chemical degradation phenomena mainly due to the high level of humidity of the underground that permeates the friable rock of water. In recent years, a number of targeted restoration actions and physical-chemical surveys have been carried out aiming at preserving both the paintings and the rock structure. The latest of these surveys was supported by the IPERIONCh project.
In this framework, the Visual Computing Lab of ISTI-CNR performed a 3D laser

scanning campaign of the Sant'Angelo cave church, coupled with a photographic survey. Then, since the frescoes are the most affected by the degrading effects of moisture, a detailed photographic survey covered a set of six frescoes, among the most historically and artistically relevant. This detailed coverage has been used to generate 3D-from-photos model, then integrated with the laser scanner data to produce models with higher detail.
The main purpose of this survey was the creation of technical metric documentation of the current state of the church structure as a whole, but also of the frescoes. The aim was the mapping on the 3D digital models of the different analysis and observation done by the restorers and curators. The 3D models will then be used as a support for the planning and the mapping of future analysis and restoration actions.
After fulfilling this primary goal, the availability of the 3D digital models suggested a different work direction. Given their completeness and level of detail, it seemed natural to exploit them as a way to create a virtual visit of the church.

2 3D data acquisition and processing

The upper floor of the church covers approximately $14m$ by $12m$, while the lower $10m$ by $10m$, the height of walls is approximately $2.3m$ on average. In addition to the two main areas, the architectural complex includes a sloped depression at the ground level, leading to the entrance, and another small external room. Given this considerable size, the device used to acquire its global shape was the phase-shift laser scanner Faro Photon 120, that is a device used for architectural end engineering survey.
To overcome self occlusion problems related to the presence of pillars, niches, altars and loose materials, 29 scan positions have been used. In order to obtain a sufficiently detailed coverage of the church without having an excessively large amount of data, the resolution of the range scans was set to $1 - 2cm$. The resulting pointcloud, after cleaning and alignment, had around 175 million points with a global resolution of less then $1cm$ (due to the overlapping among scans). A triangulated surface 3D model of the entire church was obtained using Poisson reconstruction [8]. The final 3D model id made of 56 million triangles (see Figure 2). All the processing stages were performed using the open source tool MeshLab [4].

As previously mentioned, Sant'Angelo church walls are adorned by frescoes, full of symbolic meanings. The precise color reconstruction is not an aesthetic need, but it helps the historical interpretation. Two sets of images were captured using a Nikon5200 using external diffusive flash or spotlights: 152 pictures for the global coverage and 221 for an higher resolution color mapping for the six most significant frescoes. After the pre-processing stages, the pictures for the global covering were registered and projected onto the 3D geometry using MeshLab (see results in Figure 4). The other set was processed using Photoscan [1]: the image-based reconstruction was used to achieve an higher color resolution (see

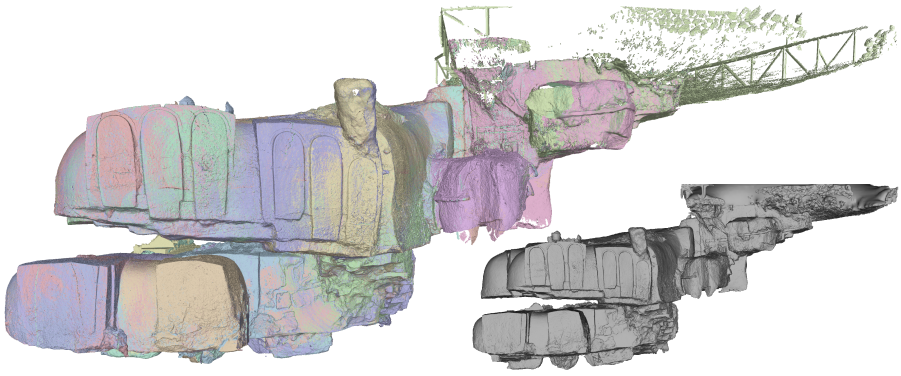

Fig. 2. The processed 3D data, after scans alignment and 3D reconstruction

Figure 3) in the painted regions, and an easier alignment and color mapping on the 3D scanned geometry.

3 Designing an interactive education experience

The increased availability of high quality 3D models is a major breakthrough also for Cultural Heritage, both for the technical use and the dissemination. While their use as a technical tool is slowly becoming a consolidated workflow, the way the 3D model are used when presented to the public still needs specific care, because non-technical users are involved. It is always necessary to explicitly design the interactive experience, the type of information that has to be conveyed, the target audience, the interaction modality.
Before choosing how to display the collected data, we had to better understand which were the storytelling needs related to this particular subject, exploring the bibliographic material, and what type of visualization fit better to its shape. Historical and cultural overview derived from literature sources provided explanations about the church architecture and the meaning of the internal placement of the artworks. These historical interpretation had to be contextualized within the model.

3.1 How the visualization of the 3D metric data might influence perception

When working with an object, may it be a vase or a statue, simply displaying it on the screen, and letting the user spin it around may be enough to effectively convey its shape in a way that mimics the real viewing experience. Buildings,

Fig. 3. First nave's Deésis and San Pietro fresco: 3D models renderings

Fig. 4. A rendering of the 3D model of Sant'Angelo's cave church.

and especially complex decorated environments, are not so simple to manage. Ideally, in those cases, one would like to show both the building as a whole *and* its detail in a more focused way. This is not an easy task, as each level of navigation would require a different interaction paradigm. At the same time, there is the problem of accessibility: an interface that offers a completely free navigation makes possible a complete exploration of the artwork, but may prove to be too complex to use for the generic user; conversely, a constrained navigation is easier to use, but may be too limited and boring. Leveraging all these aspects (generality versus specificity, freedom versus guidance) in a single navigation scheme is difficult.
Instead of trying to create a multi-purpose visualization with a complex interface that tries to show all the available data (an approach that, in our experience, is never really working), we decided to implement different viewers, each one tailored to a specific aspect of the church that we wanted to convey. In this way, it was possible to choose, for each kind of data, the best possible interface. Offering multiple way to explore the environment also makes the experience more approachable for the user, that may choose its own path to explore the church. We then applied the Hypertext principle, interconnecting the different visualizations, letting the user go jump between the different layer of information and presentation paradigms. In this way, the user can experience each facet of the building using the most suitable interaction method, but at the same time he is able to create its own exploration path across the data.

3.2 From global to details

The Sant'Angelo church has interesting aspects at several "levels": from the global structure to the single painted surfaces. For this reason, the interactive experience was structured to covey these multiple perspectives of the church, by using a *multiscale* integrated presentation.
This idea was developed in the context of a website, where interactive three-dimensional components were obtained using *3D Heritage Online Presenter* (3DHop [11]), an open-source software package for the creation of interactive Web content, oriented to the Cultural Heritage field. 3DHOP is fully customizable, and is basically a toolkit to create interactive 3D presentation; this feature was really important, as we wanted each visualization to use a specific interface and interaction. Another important feature of 3DHop is the use of multi-resolution algorithms [10], that makes possible the visualization of very high resolution 3D models on the web, by streaming the model during the navigation, adapting the experience to the device and available band.
The general structure, visible also in the main page of the website, is shown in Figure 7. The *global* navigation layer provides two modalities: one to visualize the structure "from the outside", and one to navigate the interior of the church. The *relationship* layer, where analogous portions of the church can be compared, and the *detail* layer, where each one of the frescoes may be examined individually.

A global perspective In the global perspective, the overall structure is displayable both from the outside and from the inside. Again, trying to show the environment from these two perspectives using a single interface would result in a limited experience not able to effectively convey the ide a of a "walkable" space, nor the idea of a complex building structure. Thus, we designed two visualization pages, following two different paradigms, each tailored to the specific perspective (inner space / outher space).

A navigation designed for the audience Sant'Angelo church is normally closed to the public for safety and conservation reasons; only a limited number of visitors is allowed in the church, and only by appointment. For this reason, we decided to create, as our first exploration method, a virtual visit that mimics the way the church is explored by foot. At the same time, we exploited the possibilities of the interactive media: linkong the 3D geometry to the church's artistic contents, and fully enriching it using hypertextual information. This feature uses the 3DHOP hotspots: Figure 9(a) shows red areas indicated on the 3D model; by clicking on the red area, the user can obtain additional information about the details in the church. Other hotspots are used to connect this visualization to each separate frescoes (see Section 3.4).
The cave is pervaded by an intimate and liturgical atmosphere, concordant with the functions of gathering the believers and taking care of the deads. This feeling could be well experienced much more easily by a virtual environment visit than the by mere two-dimensional image observations. A number of recesses and the entire lower floor are almost totally immersed in darkness, so that the real physical experience is limited by the poor visibility (and frescoes are hardly discernible). Virtual visitors have the possibility to adjust the light direction both to have a better visibility and to obtain a suffused lighting.
One issue was related to the navigation of the three-dimensional space. Given the wide range of potential users, the exploration should have been intuitive and easy to use for all, regardless of the level of familiarity with the 3D medium. When dealing with complex architectural environment, free navigation in a videogame-like style can be devised, but this usually needs a massive amount of work to prepare the model, possibly leading to lower geometric detail. Alternative solutions [2] try to provide free navigation where the user can easily control movements. A different strand of research removes the plain 3D rendering, using alternative solution like panoramas [6].
In this case, we opted for a constrained path navigation, where the user can move inside the environment following an invisible pre-defined track. As in a guided tour, starting from the outside square the user enters through the gate to the left along the first nave, comes in front of three apses to get down to the subterranean burial and finally return to the starting point. The user may move along the path on its own, using the mouse wheel, or follow it with an "autopilot". At any time, (both in manual or automatic mode) the user may change the facing direction, to look around. In the automatic mode, when the

user reaches an interesting point (marked by a hotspot), the path stops, and the view direction is rotated automatically to face the point of interest.
Methods for automatic determination or improvement of constrained navigation have been investigated [9, 3]. In this case, we decided to set the track in a manual way, given the type of information we wanted to convey, and the structure of the church (see next sections).

Advantages of a three dimensional representation The virtual visit outlined in the previous section mimics something that can be done in reality; however, 3D models may be used to show aspects that cannot be fully appreciated on-site. In this case, something related to the underground nature of the site. The overall structure, hidden underground, is hardly intelligible from standing on the ground level, but also from the inside in a simple visit; conversely, by looking at the 3D model from the "outside", we perceive much more better the spaces and the relationships between them. We can for example notice that the two levels (Figure 6) are slightly misaligned, and have an idea of the thickness of the floor (see Figure 5). So, we decided to create a viewer using the digital model of the church as a "maquette", with the 3D geometry viewed from the outside.
However, looking a the 3D model in this way is not enough to convey the relationship between its structure and the inside space: for this reason, still following the "maquette" paradigm, we subdivided the church in slices, and the **external navigation** (Figure 8) allows to "switch on and off" the visualization of each slice of the church (using the interface on the right side). Clicking on a layer makes that slice transparent, while all the ones above it are made invisible, and all the ones below it are made visible and solid. In this way, the user may *peel away* the structure slice by slice, exploring it from top to bottom. Several important aspects of the church can be seen with this visualization: among them, the carving of the higher ceiling the first floor plant, the mutual positioning of the columns, the arched entrances, the altars and the opening to the floor below. This solution represents an added value compared to the direct experience or to other forms of documentation. It allows the user to overcome the problem of non-visible offering in the same time the perception of the shapes and occupied spaces, difficult to reach by a simple site visit.

3.3 A comparative perspective

A different level of exploration of the church is focused towards the comparison of recurring elements of the church. The underground environment is full of recurring elements: altars, frescoes, apses. In many cases, there are several variations of the same elements, and exploring them side-by side could help understanding the analogies and the differences between them.

Among the different recurring elements in the church, we chose to work on the two Deésis frescoes on the upper floor. A third one, on the lower floor, is

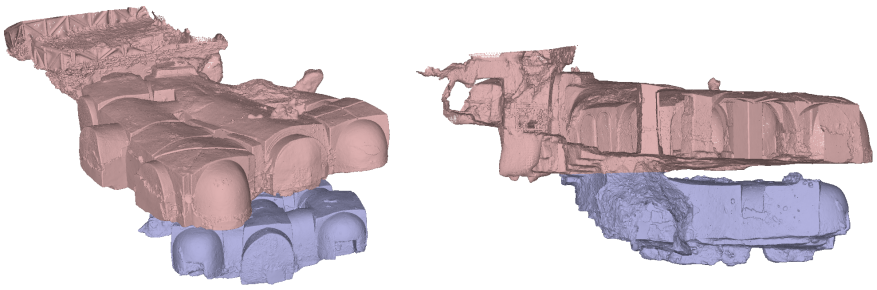

Fig. 5. Left: the misalignment between the two floors. Right: an image showing the floor thickness

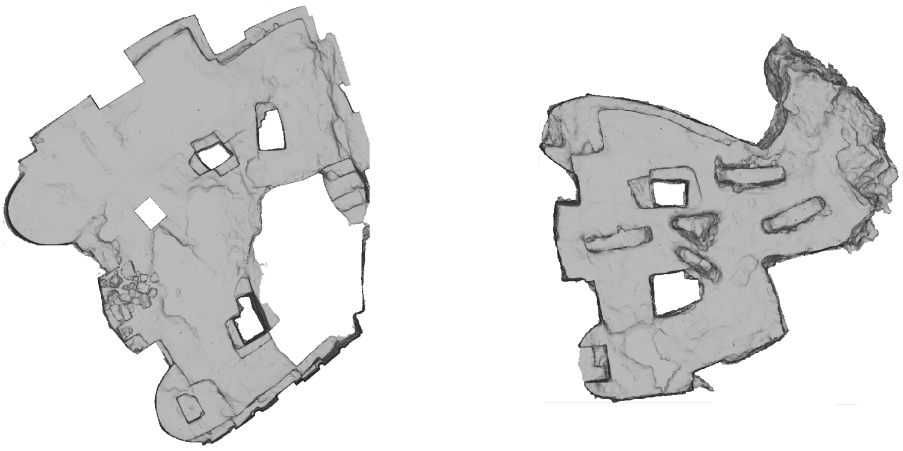

Fig. 6. Plants of the first and the second floor, extracted from the 3D model.

(a) Global layer: external navigation, internal navigation

(b) Partial layer: Deésis comparison

(c) Detail layer: exploration of the most important frescoes

Fig. 7. The *three perspectives* visualization criterion: from the global to the detail.

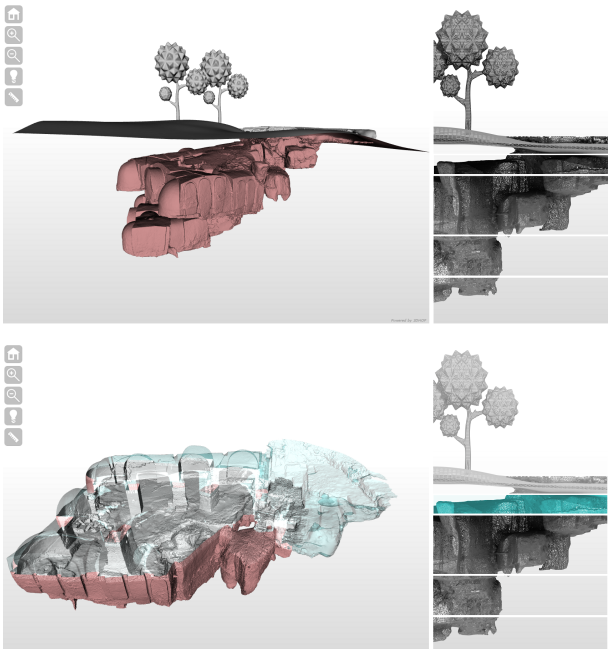

Fig. 8. The external navigation. Top: the whole 3D model. Bottom: the ceiling of the first floor is made transparent to show the structure of the church.

(a) Visible hotspots

(b) Clicked hotspot

Fig. 9. The internal navigation

severely damaged. The Deésis (from the greek $\delta\acute{\epsilon}\eta\sigma\iota\varsigma$, "supplication") is an iconographic Byzantine theme, closely linked to the funerary functions, representing the intercession of the Virgin and the Baptist, in the presence of Christ, for the humankind during the Final Judgment. The two reviewed Deésis (one located in the right apse and the other in the central one) show a number of differences and similarities, that are source of debate for the scholars. For example in the right aisle the figure of St. John the Baptist was replaced by St. James probably for the devotion of the client to the saint and the benedictory Christ, central in both cases, assumes a whole different attitude. Colours for themselves are drastically different.
The *partial* layer gives the possibility to visualize them at the same time (Figure 10), from corresponding viewpoints. Each difference and similarity is highlighted and discussed in the partial display mode through a simultaneous comparison on two juxtaposed panels.
This visualization is peculiar because it gives the possibility to compare two portions that cannot be seen at the same time in the church. Again, the 3D model offers a visualization that overcomes the limits of the physical space.
At the moment, this type of comparison only involves two of the Deésis, but ideally should also be extended to some other architectural and decorative elements that are present in multiple variants in the church. For example, it would be useful to create a similar side-by-side comparison for the different altars (which are of two types: Greek and Latin), but also for the different kind of ceilings geometries.

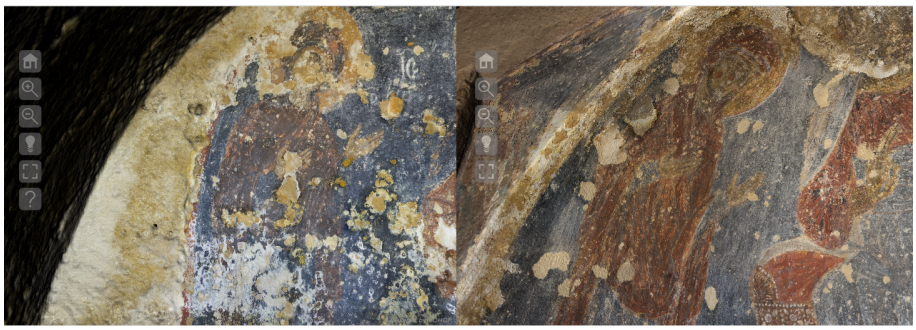

Fig. 10. Deésis comparison: the analysis of the same portion of the two Deésis to show similarities and differences.

3.4 A particular perspective

Finally, it is possible to use the 3D models of the single frescoes to explore the church following its details. In this last navigation mode, it is possible to separately examine the multi-resolution models of the most important frescoes. As they are not just flat images, we used the detail 3D model to also show the relationship between the icon and the shape of the wall. Each of the artworks is presented on its own, in a simple visualization page, that enables the user to pan across the 3D, change light direction, look at the surface from any angle, get close to the picture. The view panel is accompanied by a general description and a number of hotspots with additional information.
Figure 11 shows the visualization of the Pope Silvester fresco. In this case, the navigation mimics the on-site experience (moving in front of the fresco, looking at the wall from different directions, getting close to the surface), with the additional possibilities to visualize the smallest details and to be guided by the hotspots.

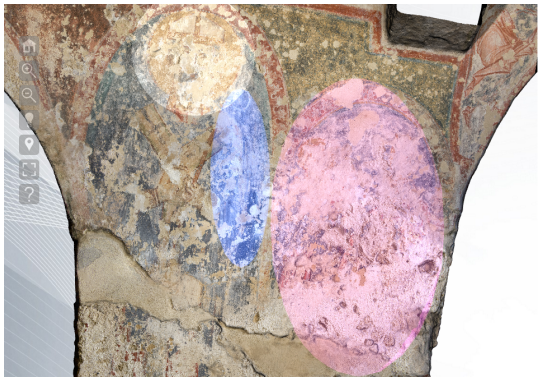

Fig. 11. Visualization Pope Silvester's fresco, with two hotspots.

3.5 A *spatial* navigation through visualizations

One of the interesting mechanisms implemented in the viewers is the interconnection of the various visualizations using a "spatial" navigation. Since all the layers are referenced to a common three-dimensional space (the church), the user can pass from one layer to the other following different paths.
For example, the user can select the visualization of a detail, and from the detail 3D fresco page there's the possibility to switch back to the website structure, as one would expect, but also to jump in the global internal navigation, in the

place where the detail is located, just in front of the fresco. The user can move inside the 3D model, find another detail, and jump to the dedicated detail page. The global external viewer is similarly connected to the details, and the details of the Deésis are connected to the comparison visualization.
In this way, the analysis of the information can follow different paths, and the website and the 3d space are perfectly integrated. We believe that this has a big potential as a way to really integrate three-dimensional data in the context of websites, museum kiosks, mobile applications.

4 Conclusions and future perspectives

This paper presented the results of the uses of 3D data acquired in the context of a 3D scanning campaign for the monitoring and preservation of an ancient cave church. The main effort was focused on the discussion about a possible reuse of the data, in order to construct a virtual experience through an ancient and buried world only conceived for didactic purposes.
The available metric data collected by Visual Computing Lab were easily integrated with other types of data from all the investigations conducted on the site. The navigation of the site was structured in a multi-level fashion, trying to provide information at different *granularity* (a global, comparative and detail layer). While the application was mainly intended for the wide public, it might be interesting to combine this application with one addressed to an audience of researchers and restorers, useful for the purpose of monitoring the church and to constitute a comprehensive documentation of all the previous surveys.

The website (http://vcg.isti.cnr.it/activities/mottola) could be a very good starting point for further integration of other types of information: for example, the evolution of the structure of the church, or the separation of the different layers on the frescoes. In order to obtain this additional information, further study of the historical data, and processing of data would be needed.

5 Acknowledgements

The research leading to these results has received funding from Iperion CH-It Italian initiative. The authors would like to thank Marco Potenziani for the collaboration in data acquisition.

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