

# INTEGRATION OF NON-INVASIVE TECHNIQUES FOR DOCUMENTATION AND PRESERVATION OF COMPLEX ARCHITECTURES AND ARTWORKS

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## ABSTRACT

The digital documentation of cultural heritage is receiving much attention in the last few years and 3D modeling of objects or sites is one of the main research topics in this field. Many improvements have been done in the generation of digital models of cultural heritage, concerning range sensors and image based modeling. But there are still a lot of open questions and problems in deciding which technique should be employed in which situation. While in the past years, when high level of detail was required, range sensors were usually preferred to image data, nowadays, due to the considerable algorithm improvements and increase of automation in the image-based modeling process, the digitization of cultural heritage based on close-range photogrammetry covers a more and more important role. Furthermore, new sensors, working outside the visible spectrum, are nowadays available for cultural heritage documentation and preservation. Therefore the integration of all these digital information would leave to much more detailed, interesting and valuable results.

In this article we present the most common techniques for heritage surveying and 3D modeling and we report examples related to the frescoed Romanino's Loggia located in the Buonconsiglio Castle (Trento, Italy).

## 1. INTRODUCTION

Three-dimensional modeling from images is a great topic of investigation in the research community, even if range sensors are becoming more and more a common source and a good alternative for generating 3D information quickly and precisely. 3D modeling of a scene should be meant as the complete process that starts with the data acquisition and ends with a virtual model in three dimensions visible interactively on a computer. The interest in 3D modeling is motivated by a wide spectrum of applications, such as animation, navigation of autonomous vehicles, object recognition, surveillance, visualization and recently also digital documentation and preservation of cultural heritages in digital form.

In the last years, the employment of computer technology to create digital archives of cultural heritage and artistic objects with different characteristics and dimensions (monuments, archeological sites or finds, architectural features, etc.) has received a considerable interest. This is due from one side to the availability of new technologies for digitalization and investigation purposes and, from the other side, to the interesting of archaeologists and restorers to instruments able to provide innovative investigations. We also consider that the international heritage is continuously under threat and danger and the needs for precise, fast, detailed and digital documentation are increasing day by day. The importance of a correct (digital) documentation and conservation is furthermore well recognized by different communities and the pressure of international organizations towards protection and conservation ended up in guidelines reporting standards for documentation [Venice charter, 1964] or the use of 3D visualization in the

research and communication of cultural heritage [London charter, 2006].

Although the increasing interest for virtual restoration, diagnostic and non-invasive documentation at multiple scales, it is important to remark that: (i) many 3D surveys performed with active sensors require high costs, a lot of time for data processing and dedicated software and hardware; (ii) the surveys executed with digital camera requires experience in the acquisition step, dedicated software and often manual interaction; (iii) new sensors able to acquire data in a particular range of the electromagnetic spectrum (IR, UV, etc.) can provide specific information on the conservation status or detect details not visible by the human eye.

Considering this, the selection of the right approach and technique requires great experience and the consideration of different project parameters. In this contribution we report the available digital techniques for the documentation of cultural heritage. Furthermore we present how infrared images could be really useful for further and deeper documentation and studies of monuments or artworks. The innovative aspects of the contribution are the integration of the different techniques, in particular as far as the infrared information concerns.

## 2. CH DOCUMENTATION TECHNIQUES

The realization of an accurate and photo-realistic 3D model of a heritage is one of the most complete, adequate and flexible way to show it all over the world, to study and digitally document it in details as well as conserve and preserve it during the time. Therefore a 3D model can be exploited for numerous purposes.



Figure 1: Helicopter view and produced 3D model of the ancient medieval castle of Valer, Trento (Italy) modeled using images. The surrounding landscape has been modeled with classical aerial images and then the castle integrated in the landscape model using GPS points [Voltolini et al., 2007].

The generation of digital 3D models of archaeological objects or sites for documentation purposes requires a technique with the following proprieties:

- *accuracy*: precision and reliability are two important factors of the final documentation work, unless the work is done for simple and quick visualization;
- *portability*: the technique should be portable due to accessibility problem of many sites, absence of electricity, etc;
- *low cost*: most archaeological missions have limited budgets and they cannot effort expensive documentation instruments;
- *fast acquisition*: most sites or excavation areas have limited time of documentation not to disturb works or visitors;
- *flexibility*: due to the great variety and dimensions of sites and objects, the technique should allow different scales and it should be applicable in any possible condition.

Depending on several factors, different techniques can be used to model cultural heritage. Images and range sensors, often coupled with traditional topographic surveys, are the common techniques used to digitize historical buildings, landscapes, archaeological finds and other important ancient objects and the actual combination of multiple techniques comes from the complexity of some structures but also from the lack of a single technique able to give satisfactory results in all situations.

Image-based modeling techniques (mainly photogrammetry and computer vision) [Debevec et al., 1996; El-Hakim, 2002; Gruen et al., 2004; Remondino and El-Hakim, 2006; Voltolini et al., 2006] are generally preferred in cases of lost objects, monuments or architectures with regular geometric shapes, low budgets, good experience of the working team, time or location constraints for the data acquisition and processing. A typical example of a large architecture containing regular geometric shapes modeled using images is shown in Figure 1.

Even if, due to the cheaper equipments, image-based modeling is less expensive than range-based approaches, active sensors appear to be faster and easier to use by non experts. Many discussions are opened on this topic: indeed image-based modeling needs some experience in the acquisition and data processing and still some manual interaction while range-based modeling needs a lot of editing time and is unpractical in some field campaigns. Active systems can be divided into those based on time of flight and those working with the triangulation principle [Blais, 2004]. Time of flight systems (divided into those based on pulse principle and those based on phase shift between transmitted and received signal), work on distances between 2 and 1000 m and are generally used for great objects as for example architectures and large sites. On the other hand triangulation-based instruments (laser light or patter projection systems) work at shorter distances (0.1 to 500 cm), are more accurate and are generally used to model statues, sculptures and low reliefs. Also conoscopic systems are often used in cultural

heritage field but in particular for planar objects, as for example paintings and small coins, because they have better precision than triangulation-based systems but a smaller field of view.

An actual deficit of most of the active sensors is the lack of texture information, which are generally acquired with a separate digital camera and afterwards registered onto the range data for texture mapping purposes [Bernardini and Rushmeier, 2002].

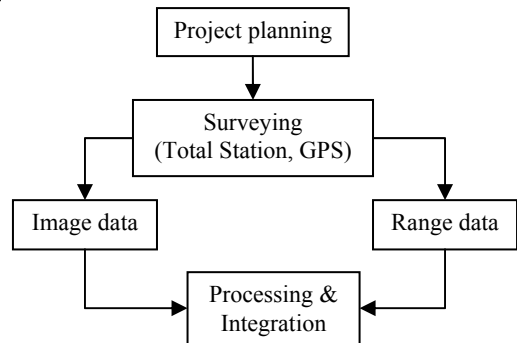


Figure 2. 3D modeling process using the different available techniques.

The typical 3D modeling process generally contains the following steps (Figure 2): (i) project planning, (ii) surveying (if necessary), (iii) image-based modeling, (iv) range-based modeling and (v) processing and integration. The integration of images and range data is not always necessary, as well as the surveying.

In most of the projects, it is difficult to select which technique is better to use. As also demonstrated in the research community [El-Hakim et al, 2007; Rizzi et al, 2007], in many terrestrial applications, image-based modeling and laser scanner can reach very similar results. Nevertheless, to achieve a good 3D model, that respects required level of details, the better way is to combine different techniques. In fact as a single technique is not able to give satisfactory results in all situations, concerning high geometric accuracy, portability, automation, photo-realism and low costs as well as flexibility and efficiency, image and range data are generally combined [El-Hakim et al. 2004; Lambers et al. 2007; Voltolini et al., 2007]. When comparing photogrammetry and active sensors, the former is traditionally used and well suited to record edges and textures, whereas the latter is usually better suited to record surfaces. Therefore both techniques have been successfully combined in a variety of applications, allowing the use of the inherent strength of both approaches. Nevertheless, the last researches in the image-based modeling field have demonstrated the potentiality of the technique in retrieving dense surface model with all the small details without neglecting precision and reliability of the results. Using

advanced algorithms [Remondino and Zhang, 2006] dense point clouds of complex and free-form objects can be almost automatically retrieved. This is possible combining feature-based and area-based matching algorithms in order to obtain a detailed 3D reconstruction. Also shape from shading approaches [El-Hakim, 2006], in addition to stereo matching algorithms, aids to reach fine geometric details from images. Very similar results to active sensors are therefore achievable using images, but in a fraction of time and costs. Therefore we can safely say that with the appropriate surface modeler algorithm, there are no differences between image- or range-based approaches and that the aspect that is no more decisive in the choice of the modeling technique is the accuracy and details of the final 3D model, at least in most of the terrestrial applications. Typical factors still involved in the choice of the technology are the costs, ease of use, portability and usability, experience of the operator, location constraints, object dimensions and final goal of the modeling. Image-based 3D models derived with 'structure from motion' approaches [Pollefeys et al., 2004] are not of great interest for precise and detailed heritage documentations, but mainly useable in quick visualization and VR applications. Indeed documentations without fine geometric details and surface irregularities, even if presented with texture details, will exhibit smoothness of the surface, flat-looking and not recovered important details.

### 3. VISIBLE, IR AND UV IMAGE INFORMATION AND INTEGRATION

Analyses and studies on cultural heritage are the basic for conservation and maintenance during time of the historical structures. Image data are probably the most complete source for documentation and conservation purposes, allowing the derivation of geometric as well as texture information.

Within the electromagnetic spectrum, we generally work in the visible part, as standard CCD/CMOS camera are built with a sensitivity inside this band. Nevertheless, thanks to recent hardware developments, we have at our disposal other instruments which allow us to collect image data also in the infrared (IR) and ultraviolet (UV) part of the light spectrum. This is really useful for more deep documentation and investigation of heritage.

Infrared information is useful to study deeper artworks and in particular paintings, to monitor historical buildings and to evaluate structures that have to be restored. Infrared thermography transforms the thermal energy emitted by the objects in the infrared band of the electromagnetic spectrum into a visible digital image. In this way it is possible to see features of structures or paintings that otherwise are not visible to the human eye. Indeed this non-invasive technique allows to know back structure of frescoes and paintings, analyze composition of buildings, reveal padding, older layers, hidden structures, pentimenti and preparatory drawing (Figure 7) as well as provide a state of conservation of building façades, vaults and general architectural structures (Figure 4,5,6) [Moropoulo et al., 2001; Pelagotti et al, 2007]. Furthermore, by means of an infrared camera it is possible to find and to determinate air leakage through exterior walls and roofs, thermal irregularities, water penetration and moisture accumulation. In particular, the moisture in old buildings is common and it can destroy structural integrity and nurture mould. We should distinguish between near-, intermediate- and far-infrared (thermal). The sensors able to record infrared radiations are usually designed only to collect radiations within a specific bandwidth. Indeed the infrared band is pretty wide

(0.78  $\mu\text{m}$  to ca 1000  $\mu\text{m}$ ) and often subdivided into smaller sections that relieve different features. Near-IR images can be acquired with dedicated filters while thermal IR information requires special IR cameras. Modern thermal IR imagers resolve surface temperature differences of 0.1°C or less. With this high sensitivity, they can evaluate subtle thermal phenomena, which are only revealed in the form of slight temperature gradients.

In Figure 3 it is reported a thermal IR analysis of a painting, where the thermography reveals the frame structure and the heating induced by a lamp in front of the artwork.



Figure 3. Visible and IR images of two paintings.

Figure 4 shows another example of the visible and IR information where we can see a hot pipe that goes across the ceiling. This heat could damage the fresco but the quick identification of these bugs can save the structure.

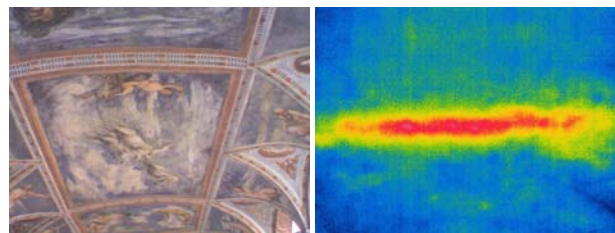


Figure 4. Part of the ceiling of the Romanino's courtyard, displayed with visible and thermal IR images.

As we can see in Figure 5 the identification of the heat pipe affecting and slowly damaging the frescos is clearly visible from the floor upstairs..

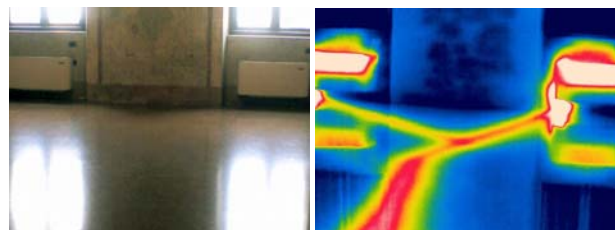


Figure 5. The effect of heating installation on the floor upstairs the frescoed courtyard.

Infrared thermography is also used to monitor various porous materials during capillary rise, with the intention to evaluate in non-destructively way the presence of moisture (Figure 6).



Figure 6. Moisture on a wall: visible (left) and IR images.



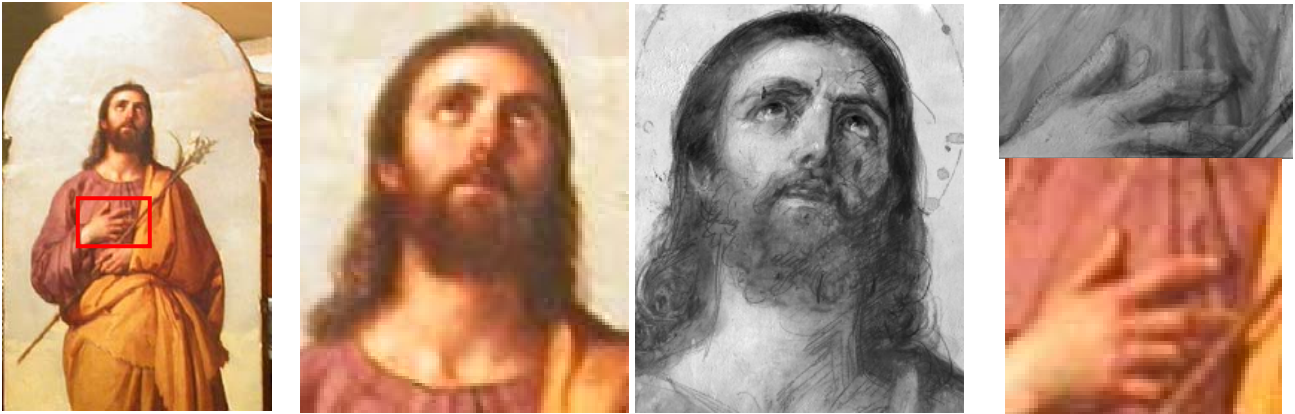


Figure 6: Infrared analysis of a Podesti's painting of S.Giuseppe (XIX sec.), located in Rome, Italy. A closer view of the IR image shows the preparatory drawing (center) as well as a pentimento (right images, where a finger is not appearing in the visible image). Image courtesy of Art-Test, Italy, www.art-test.com.

A value added in the study of cultural heritage is of course the integration between 3D data, visible and IR images. In order to use IR images, it is necessary to calibrate the IR camera.

The infrared camera used in our tests is a Flir P640 that works in the range between 7,5 and 13  $\mu\text{m}$  and provides for images with 640x480 pixel with a pixel of 25  $\mu\text{m}$ . The camera acquires also images in the visible spectrum, with a resolution of 1280x960 pixels. As for a traditional digital camera, the infrared one has been calibrated by means of photogrammetric bundle adjustment. Special targets have been used for the infrared sensor and a dedicated testfield has been realized (Figure 8a). In order to obtain clear target in the IR spectrum, some tests on the emissivity of different materials have been done (Figure 8b). The recovered interior parameters are useful for further applications like 3D modeling and texture mapping.

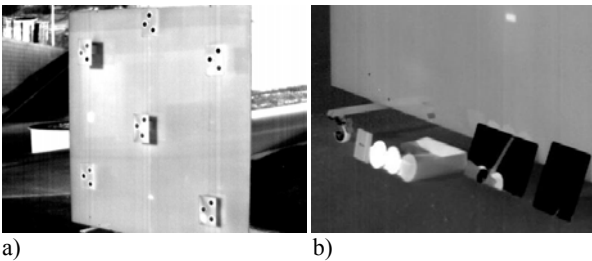


Figure 8. Testfield for infrared camera (a), Emissivity tests (b).

On the other side of visible spectrum there are UV (Ultraviolet) radiations. UV is an electromagnetic radiation with a wavelength shorter than 0,4  $\mu\text{m}$  but longer than soft X-rays ( $10^{-2}$   $\mu\text{m}$ ). In artwork studies, near UV images are mostly used to identify different varnishes and over-paintings, in particular with induced visible fluorescence imaging systems [Pelagotti et al., 2006].

#### 4. THE ROMANIO LOGGIA

The Romanino's Loggia (Figure 9) is an internal courtyard of the Buonconsiglio Castle, a medieval castle located in Trento (Italy). The Loggia spans ca 20x8 m, is ca 7 m height and it was decorated by Romanino between 1531 and 1532. During the last years we have performed some 3D documentation of the loggia and recently we have added some important data. The heritage structure is a good testfield to acquire data with different instruments and then integrate them.



Figure 9. The Romanino's Loggia and its frescoed vaults.

##### 4.1 3D data integration

The Romanino's Loggia of the Buonconsiglio Castle is a complex structure where both image-based and range-based techniques have been used to reach a detailed and photorealistic 3D model. In the past we have modeled part of the structure using images [El-Hakim et al, 2005] and recently we have applied advanced image matching algorithms [Remondino and Zhang, 2006] to retrieve the 3D model of some vaults (Figure 10, above).

But the complete model of the Loggia has been realized combining semi-automated measurements on images (SRL Kodak DCS Pro with 13 Mega pixel) with range data (Leica HDS 3000). This choice was due to the complex shape of the ceiling and from the difficulties in acquiring good images for all the parts of the structure. Figure 10 shows the final 3D

model of the whole Romanino's Loggia. The main structure of the courtyard has been reconstructed by means of semi-automatic image-based modeling while the ceiling has been modeled using a laser scanner. Common points between the two models were used to merge them.

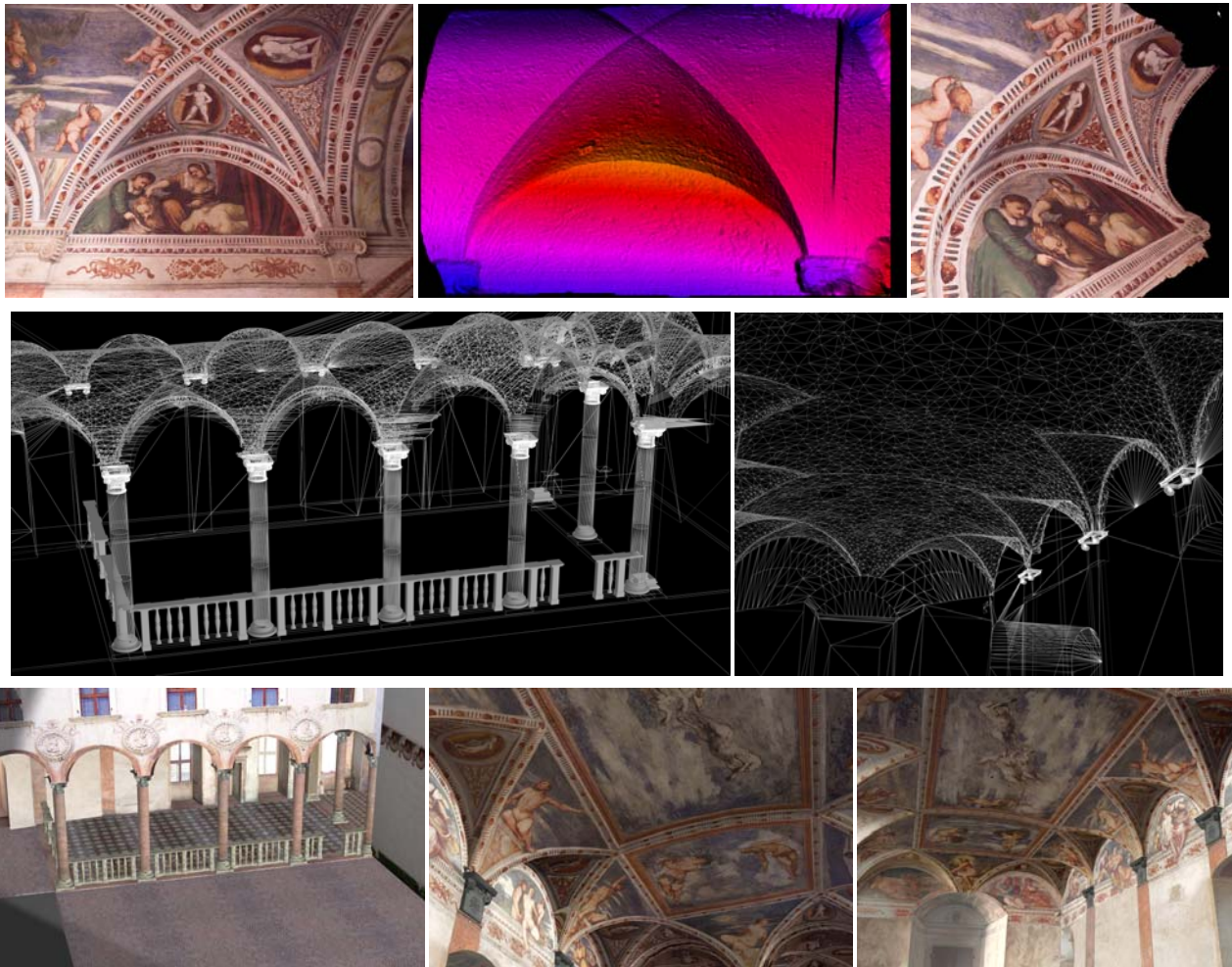


Figure 10. A frescoed vault and the surface model recovered with 3 convergent images, shown in colour-shaded and textured mode (above). 3D model of the whole Romanino's Loggia recovered integrating image- and range-based modeling, visualized as wireframe (center) and textured model (below).

#### 4.2 3D-IR integration

To analyze deeply the courtyard and perform conservation and restoration plans, IR images can be mapped onto the recovered geometry to perform quantitative analysis and not only qualitative ones. For the Romanino's Loggia, IR images have been acquired with a FLIR P640 thermal camera. In order to integrate IR data with 3D information, the IR images have been oriented selecting some common features visible both in the visible and IR images. Figure 11 shows the frontal part of the Loggia, modeled with a Leica HDS 3000 and afterward textured with a sequence of calibrated and oriented IR images. Also smaller structures like the vaults, digitally modeled using high-resolution images (SRL Kodak DCS Pro, 13 Mega pixel) and dense matching reconstruction, were afterwards textured using the IR information (Figure 12).

With this methodology the status of frescoes can be carefully examined and possible future degradations can be predicted having 3D information combined with infrared data.



Figure 11. The range-based 3D model of the frontal part of the Loggia and the IR textured model.

These sorts of inspections are essential to study the current conditions of artworks and for the preservation of cultural heritage.



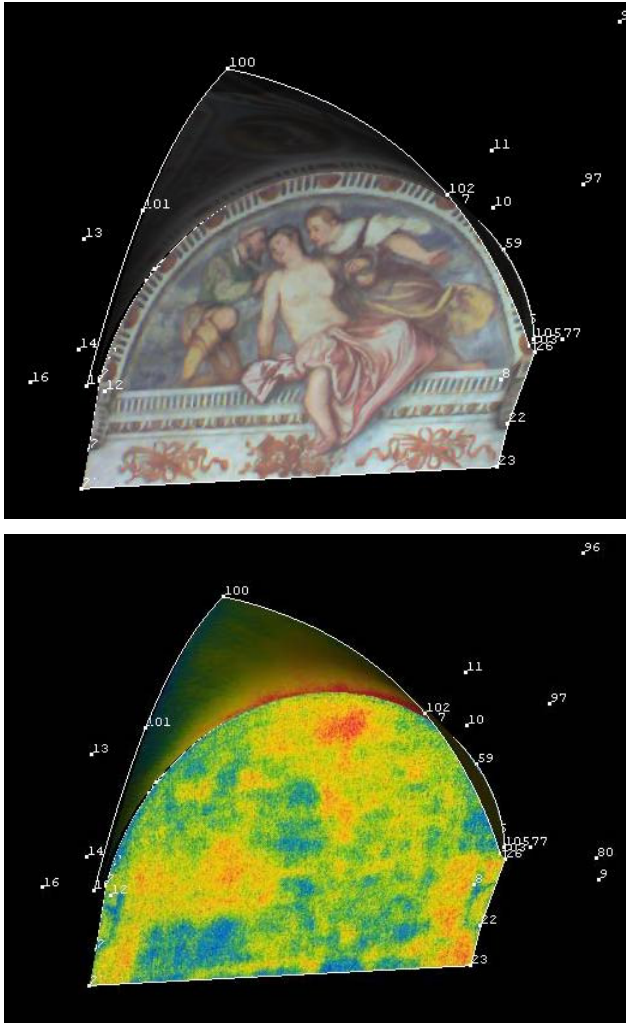


Figure 12. Visible and infrared 3D model of a vault of the Romanino's courtyard.

## 5. CONCLUSIONS

The objective of this contribution was to give an overview of the different techniques and the used methodology for the digital recording of detailed objects, monuments and large structures. Beside the well known image- and range-based approaches, we reported how infrared information can be really useful for documenting and analyzing cultural heritage. According to the IR section of the spectrum, different features are observable and they are all invisible to the human eye. Furthermore, when IR information is mapped onto a 3D geometry, quantitative analysis can be performed, as areas and distances can be metrically measured.

At the moment we cannot say which modeling technique is performing better than the other as there are many parameters involved. From our experience, we can safely say that the accuracy reachable using images or range sensor is the same in most of the terrestrial applications.

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