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THE ARCHITECTURAL DETECTION REVOLUTION: SANTA PRASSEDE, AN (ONGOING) SURVEY FOR KNOWLEDGE

Marco Carpiceci

Sapienza-Università di Roma

e-mail: marco.carpiceci@uniroma1.it

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Resum

Il rilievo architettonico è materia viva. Parlare del rilievo di un dato monumento significa quindi "sempre" descrivere un lavoro in essere. Il rilievo è l'operazione critica attraverso la quale si indaga una data struttura architettonica, la si misura, e la si rappresenta. Per Santa Prassede, al momento, ci sono quindi 35 scansioni che ricoprono gran parte dell'interno della chiesa. Mancano le altre cappelle laterali, la cripta e il campanile, che verranno rilevate quest'anno. Si provvederà anche a rilevamento cromatico delle zone interne coperte a mosaico. Per realizzare le riprese si utilizzerà una fotocamera digitale ad alta risoluzione ed un'illuminazione omogenea in maniera da eliminare alterazioni della luce nelle variazioni chiaroscurali e nelle zone d'ombra. L'elaborazione successiva prevede la realizzazione del *modello geometrico* (o *modello solido*). Una volta ottenuto questo si passa all'*analisi grafica*, ossia la scomposizione della struttura architettonica in elementi coerenti, tutto operato attraverso la rappresentazione. Una sorta di *reverse engineering* architettonico, che, partendo dall'oggetto così come lo si vede, ne ricostruisce gli elementi componenti, selezionandoli in base alla datazione, al materiale, alla funzione. Questo al fine di poter strutturare (ma non solo) ipotesi ricostruttive della consistenza del monumento nel corso del tempo.

Paraules clau: Santa Prassede, rilievo architettonico, scansione laser, rilievo cromatico

Abstract

The architectural survey is a living matter. The survey of a monument always entails the description of a work in progress. The survey is a critical operation whereby you can study, measure, and represent an architectural structure. In the case of Santa Prassede, there are at the moment 35 scans that cover most of the interior of the church. The other lateral chapels, the crypt, and the bell tower, which will be studied this year, are currently missing. The colour of the areas covered with mosaics will be also analysed. A high-resolution digital camera and homogeneous illumination will be used to avoid light variations in the chiaroscuro effects and in the shadows. Subsequent processing involves the elaboration of a *geometric model* (or *solid model*). Once this model is built, the next step is the *graphical analysis*, that is, the decomposition of the architectural structure in coherent elements. It's a sort of architectural reverse engineering, which, starting from the object as we see it, reconstructs the component elements, selecting them based on dating, material, and functionality. This is done in order to develop (but not only) a reconstructive hypothesis of the consistency of the monument over time.

Key Words: Santa Prassede, architectural survey, laser scanning, chromatic detection

Foreword

Architectural surveys are not objects, they are a living matter. Therefore, discussing the survey of a given monument always involves describing a work in progress.

Repeating these concepts, which are the basis of architectural surveying, is never a superfluous exercise. Too often is the survey supposed to coincide with drawings, or 'beautiful' drawings. Nowadays it is even identified with the point cloud: nothing could be more wrong. The survey is the critical operation through which a given architectural structure is explored, measured, and represented. There are purely instrumental phases in which metrical data is recorded, and there are processing phases that establish what to represent, how to do it, and for what purpose. Clearly, the processing phase is one that may have no end and thus may also involve the repetition or integration of the former. Today technology is in continuous evolution and its transformations offer the possibility of repeating the metrical phase, which therefore acquires an initially predominant role.[1]

The 'metrical' operations in Santa Prassede began in 2015 with a distinct purpose, that is, to obtain correct measurements for the Oratory of San Zenone. That year, eight laser scans were carried out to produce a black-and-white 3D model. The following year the survey was extended to the church, its three naves, courtyard, and access areas, which resulted in twenty-seven that were also to produce a black-and-white 3D model. Thus, at the moment, thirty-five scans—some of them redundant—cover a large part of the interior of the church, whereas the side chapels (except for San Zenone), the crypt, and the bell tower are not yet included and will be scanned this year (Fig.1).

The survey of Santa Prassede combines two closely related areas, namely research and teaching. In fact, thanks to the practical work done during field exercises, students can understand various aspects related to the world of representation, ranging from the collection of metrical data, to the elaboration of 3D models, the production of drawings capable of describing architecture, and the elaboration of audio-visual tools for the exploitation of Cultural Heritage.[2]

The post-scanning phase also includes chromatic acquisition through the execution of high-resolution digital photographs so that the point cloud and mesh model can be 'dressed up'.

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[1] For a general outline of architectural surveys, see CUNDARI 2012, CARPICECI 2012, BIANCHINI, 2013, and CARPICECI 2013

[2] This is an optional course that can be taken during the fifth year of the degree in Building Engineering and Architecture. The title of the course is "Architectural Survey and Computerized Image Processing" and it is mainly focused on the use of new laser technologies, drones, and software for digital processing (Sapienza University of Rome, Department of History, Design and Architectural Restoration).

The processing then involves the development of the geometric model (or solid model), that is, the ‘translation’ of reality into a combination of known solid elements, such as parallelepipeds, cylinders, cones, spheres, and ellipsoids. Once this model has been obtained, the next step is graphic analysis (Fasolo 1962), in other words, the decomposition of the architectural structure into coherent elements by means of graphic representation. This is a sort of architectural reverse engineering, which, starting from the object as it appears, reconstructs its component elements, selecting them on the basis of dating, material, and function. The aim is to put forward reconstructive hypotheses of the monument’s consistency over time.

Current detection and processing techniques are not, however, as it would seem, definitive and absolute. The uncertainty factor also remains present in surveying instruments, and this only underscores the idea of architectural surveys as a form knowledge that is permanently in progress. It is thus easy to understand that teaching, which always happens at a given specific time, records the state of the art. But in the last few years master’s degrees, and even more so doctoral programmes, on the one hand involve students in the development of the techniques used to improve processing, and, on the other, are the result of a compilation, namely the application of different techniques to a specific case (such as ours, for example, in Santa Prassede).

Since we are still at the beginning of the journey, let us remember the current ‘boundary conditions’ of architectural survey.

The new architectural survey

The new practice of architectural survey places the numerical or point model as the central structure that should be able to describe the complete morphology of the architectural object. Each detected point can also have its apparent brightness, its reflectance, which is also recorded during the scanning phase. The mesh or surface model is then developed from the point cloud, resulting in a careful description of architectural ‘skin’. Afterwards, colour images are used to generate texturization. This represents only the initial phase of the survey, which consists of data acquisition and homogenization. The following phases, far more complex, are aimed at the infinite possibilities of development and exploitation: from restoration to conservation and communication.

Three ‘media’ have determined the evolutionary leap that has taken place in the field of architectural surveying: laser scanning, computer graphics, and digital photography. However, the geometric principles at the basis of the survey have not remained the same over time either.

In the 1980s, the concept of total station allowed the old theodolite to become the main surveying tool: a single station that was used to place all the surrounding points. But it was the new millennium that witnessed the birth of the instrument that brought new lifeblood to architectural surveys: the laser scanner. From then onwards, instead of only recording a series of significant points selected by the operator, it was possible to record all points; furthermore, the result was no longer a discretization according to a more or less limited choice, but a dense matrix of points evenly distributed in the space around the instrument. However, no matter how dense the cloud may be, it is not able to provide information on the geometry of the subject or its physical nature.

In addition to the position of any measured point, the laser scanner can provide its RGB component and apparent brightness. There is a huge gap between these two measurements though; whereas the chromatic component is recorded by a digital camera that retraces the entire scanning sphere, the brightness data is simultaneously recorded thanks to the emission of the instrument's laser beam. Therefore, while external light is needed for colour, brightness can be recorded even in the dark, as the scanner uses the laser's coherent light beam emission to measure reflectance.

Cloud processing software ensures the transition from point model to surface model, the formation of a series of surfaces made up of minimal plane elements identified by the points, that is, the mesh. The resulting model can then be enriched with chromatic and chiaroscuro effects. This completes the generation of an analogical, virtual representation that reproduces the object as if it were cloning it (Fig. 2).

Thanks to laser technology, polar surveying has reached a highly developed level, to such an extent that practically no survey can do without it. With the exception of some particular types of laser scanners that use triangulation systems, laser scans have a polar reference framework; a feature that must be kept in mind when preparing surveys, so as to try to cover all points of the architectural object with the minimum number of scans.

But regardless of the accuracy of the instrument, measurements are greatly influenced by the nature of the surface. Clear and sharp edges have a negative effect, especially when foreshortened, and the same goes for very glossy and reflective surfaces, very dark ones, or convex surfaces tangentially scanned (such as column shafts).

Lighting problems can be reduced by scanning in total darkness; this procedure allows recording not only Cartesian coordinates but also brightness data. The result is therefore a surface defined in black and white without any of the chiaroscuro problems introduced by illuminated and shaded surfaces (Fig. 3). The separate photographic capture, with appropriate and homogeneous illumination, produces a series of photographs that can then be applied to the scan at a later stage. This results in a three-dimensional model to which lights and shadows can be applied according to the desired effect rather than conditioned by the circumstances of the survey.

However, the point model can also be produced by means of a technology that uses a different non-polar but epipolar geometric model. In fact, a technology that exploits the dynamic and fruitful partnership between digital photography and stereophotogrammetry is increasingly emerging, namely photomodelling, whose geometric/analytical model is called epipolar geometry.

The stereo-photogrammetric model of photomodelling is processed by computer so as to facilitate the automatic determination of homologous points on the images. These points then allow the calculation of their position in space so as to generate a meshed and mapped point cloud. The automated model that allows this operation is based on an epipolar geometric system, and defines the rules for scanning frame pairs for the development of the numerical model.

In accordance with the basic concepts of stereo-photogrammetry, internal orientation, common to all frames, determines the position of the projection centre of each frame (the optical back nodal point), while relative orientation reproduces the reciprocal position of each pair of adjacent frames. Each pair of homologous points represents the position of the relative point in space. The geometric system with regard to which homologous points are automatically searched and identified is called epipolar. An epipolar line passes through each point of an image and has its homologue in the other frame of the pair, where the homologous point can likewise be found. In order to be spatially reconstructed, each point on the surface of an object must be present in at least two frames (Fig. 4).

Uniform surfaces pose reconstruction problems, and therefore it is always necessary to have a minimum variation of surface texture, otherwise it is not possible to obtain a proper morphological reconstruction. Likewise, modelling photographs must be taken with the autofocus, automatic exposure mode, and automatic image stabilization switched off, so that all parameters remain constant for all shots. This ensures homogeneity between frames and allows a more accurate result for all automated operations.

The most recent technology in the field of architectural survey, now still under development, is that of aeromodels or UAVs (Unmanned Aerial Vehicles), commonly known as drones. The most widely used drones are equipped with four vertical axis propellers that allow remote-controlled flight from the ground by means of a special remote control equipped with display and levers. A camera mounted on the drone is capable of taking photographs and filming videos. Furthermore, drones cannot only help survey objects that can only be accesed through difficult and rough paths, but also the parts of a building that cannot be reached without great difficulty and special means, such as roofs and tower tops. Moreover, drones can also be very useful for archaeological excavations, wich are characterized by wall structures of limited vertical development but whose conformation and extension would involve innumerable individual scans.

Drones result from the merging of three different technological fields, namely radio-controlled aircrafts, digital photography, and photomodelling. Increasingly sophisticated algorithms, combined with ever-growing computing and visualization capabilities are rendering photomodelling technology more precise and reliable. In addition to this, digital photography has now achieved results and a processing potential that can no longer be compared with those of the past, bringing quality and operability even to optical chamber systems of progressively decreasing size and weight. Finally, the refinement of radio control and remote control technologies from tablets and smartphones have made navigation with drones increasingly easier.

Currently, the most sought-after drones are the light ones, both in the range below 2Kg and under 300g.[3] It may seem rather obvious that drones up to 2Kg have better wind stability, flight range around thirty minutes, and cameras with medium size 20 Mpixel sensors. However, the enormous transportability of some drones under 300g should not be disregarded, while their flight time is limited to ten minutes, they are equipped with small 10-13 Mpixel sensors.

Be it ground-based or aerial, photography greatly enriches architectural surveys, a reality that, until a few decades ago, was only partially conceivable. However, the acquisition of chromatic data does not always lead to usable results. When a coloured surface is surveyed, for preservation or restoration purposes for instance, the recording methods must follow strict criteria. This is even more so when painted surfaces are a distinctive feature of the building under consideration, as in the case of painted façades and frescoed or mosaic interior walls.

Chromatic surveys, produced in digital format, are destined to remain unchanged over time, always offering the same visual impression. Yet even this kind of documentation presents technological and physical problems. Whereas shape measurements are absolute and record the position of each surface point, colour measurements do not record the actual colour of the surveyed surfaces, but only their chromatic appearance at the time of capture. Photography must therefore meet two basic requirements for colour detection: light matching and colour matching.[4]

With regard to light, it may seem trivial, but if one takes pictures of the façade of a building at various times of the day, it is immediately evident how changeable its appearance is, above all, by virtue of its changes in luminosity. Photographs not only record hue but also brightness. Architectural surveys should record the objective colour, that is, the one not modified by any light

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[3] In Italy, the Italian Civil Aviation Authority (ENAC) has recently updated the Regulations for remote control aircrafts, establishing in Article 12, Paragraph 1, that, "Specialized operations carried out with UAVs with an operational mass at take-off of less than or equal to 2 kg are considered non-critical in all operational scenarios (...)." The same Article 12, Paragraph 5, reads, "Specialized operations carried out with UAVs of take-off mass less than or equal to 0.3 kg with rotating parts protected from accidental impact and with a maximum speed of less than or equal to 60 km/h (....) are considered non-critical in all operational scenarios. The pilot, who is not required to hold a certificate (...) must in any case ensure that operations are carried out in compliance with the rules."

[4] On colour surveys, see Carpiceci 2011, and Carpiceci, Colonnese 2014.

source; but this would only be achievable through the suppression of any shadow or chiaroscuro variation, which still seems impossible today.

Flat, small, and accessible surfaces can often be evenly illuminated; for others, however, more approximate conditions have to be provided.

In the survey of exterior elevations, shading is the only way to provide the most uniform illumination possible. Overcast days are normally used to have as little shade as possible. The problem of colour saturation, which assumes obvious proportions in shaded areas, can easily be circumvented with post-production correction of contrast and local brightness.

Indoors everything is entrusted to the total management of light sources. The canonical practice used for the reproduction of paintings is well known: illuminators and diffusers are positioned in such a way as to make the surfaces homogeneously covered before photographs are taken.

Another problem regarding luminosity is the lack of surface roughness, which when present facilitates homogeneous illumination. Glossy surfaces are affected by the phenomenon of reflection, and therefore pose a real obstacle to chromatic measurements: the more shiny the surface, the more light it reflects, even showing the light source and producing blown out images. When this phenomenon is generated by glass surfaces, the image can be taken using polarizing filters applied to photographic optics, and in some cases these filters can also be applied to light sources.

Every measurement operation involves a process of approximation; and this happens because the survey translates some components of the object (such as shape) into a series of numerical data. Colour is not exempted from this rule; on the contrary, it is one of its silent victims..

Cameras generally use a Complementary Metal Oxide Semiconductor (CMOS) type sensor, consisting of a rectangular matrix of photoreceptors that can transform light intensity into electric energy. Each photodiode records only one colour band, but the end result is an image in which each pixel has three RGB components. The final colour is therefore not only measured but partially interpreted. Corrective software processing, together with high image resolution, ensures that the interpretation provided by the matrix does not deviate excessively from the direct perception of the subject. Moreover, our retina, and in particular the fovea, is structured with an analogous system of photosensitive cells (the cones) each of which record a different frequency range, resulting in chromatic vision.

The CIE (Commission Internationale de l'Èclairage) 1931 diagram describes the totality of colours perceptible to the human eye. The areas that various devices are able to reproduce are represented there and generally have triangular boundaries. Three primary colours identify the vertices of a colour space that contains the chromatic range (gamut) that these three colours can reproduce (Fig. 5). Additive reproduction systems such as, for example, monitors are based on the RGB (Red, Green, Blue) trio, for experience proofs that these three colours are the necessary and sufficient condition for reproducing a gamut that almost completely satisfies our eye.

Cameras also have this reproduction system and they usually feature two colour spaces: sRGB and Adobe RGB. The former (sRGB) corresponds to most display devices and provides 35% of the total colour space visible to the human eye. Adobe RGB offers up to 50% coverage of the total colour space, but requires devices capable of an equally wide gamut. Nowadays, no recording devices are capable of wider coverage.

Despite their great potential and the methodological turning point new technologies have brought about, they have not produced a radical transformation of results; at least not for that part of the architectural survey that continues to be identified with drawing. In fact, a gap has opened up between drawings and digital models, whose main virtue resides in their ability to simulate reality and reproduce exterior appearance.

The point cloud (even if coloured) is only a set of coordinates describing the surface of the object. The visualisation of the model satisfies the eyes of the viewers as they navigate through the simulated space, giving them the feeling of owning the real object. However, this is only a large amount of metrical data that has yet to be processed.

We are only at the beginning. For any restoration, conservation, and plain research project, it is necessary to work critically on the data, to process and modify it according to a predefined purpose. The cloud represents only a crystallization of the shape and appearance of the architectural object; one that must subsequently be ‘treated’ in order to be read, studied, measured, and developed. The point model itself, while having recognizable formal characteristics, must be transformed into a geometric model so that it can be communicated and understood. Likewise, in order to fully grasp and explain a digitized architectural object, it needs to be translated, not only into a graphic representation but also into a specific three-dimensional model suitable to convert metrical data into information that is meaningful and useful for our understanding of space.

It is certainly an established fact that architectural surveys have experienced a great technological expansion thanks to the development of the most recent technologies. It is also true, however, that one must be wary of the ephemeral fascination and emotionality of the ‘real-like illusion’ that these technologies easily offer, and rather direct results towards those representations that favour the quality and legibility of data, as well as the transfer of organized and tangible knowledge.

At the beginning of the history of computer science, steering a straight course meant obtaining the same quality and graphic precision from the computer as what could be achieved by manual drawing. Today representations have been enriched with new multimedia formats, but it is necessary to ensure that these are accompanied by a complex and critical production of drawings and images, including two-dimensional ones, especially in order to understand, describe, and communicate architecture.

Scanning and future programmes

In 2015, the only aim of the survey was to cover the Oratory of San Zenone, therefore the task was completed with only eight scans (Fig. 6-9).[5] The entrance from the right side nave (north-east) to the chapel is highlighted by two large architraved columns and dominated by a large arched window. The interior has a quadrangular floor plan with four corner columns and three quadrangular niches. The roof is a groin vault with no edges, that is, the four ribs are rounded off and convey the stress loading to points behind the protruding large columns that only seem to support it. Above the niches there are three windows, only one of which—the one behind the altar—is not blind, allowing light to enter from the north-east.

Only the surfaces above the level of the abaci and the entrance architrave, as well as the window sills, proved to be unreachable. It was therefore assumed that these parts would not be scanned but reconstructed by direct measurement. To cover the columns (almost) completely, several scans were carried out, leaving only a small portion at the back corner of the planimetric square unexplored.

To complete the 'campaign' we also carried out a scan of the chapel of Cardinal Alain de Coëtivy and its basic architectural layout: a rectangle covered by a barrel vault.

In 2016 the survey was extended, as far as possible, to the entire basilica. We started from the inside of the main south-east entrance that, through a covered staircase, leads to a courtyard (Fig. 10). The façade of the church is still extant and the columns visible inside the perimeter walls remain as evidence of the original presence of the four-sided portico. The central nave is covered by a wooden ceiling coffer and marked longitudinally by a sequence of pairs of columns interspersed with rectangular pillars.

The presbyterial area, raised due to the presence of the crypt, is framed by a large triumphal arch. Unlike the transept, which matches the naves, this area is closed to the sides by two walls with large columns with entablature. An imposing ciborium is at the centre.

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[5] The hypography in Fig. 6 is a particular form of planimetric representation that, instead of looking downwards, looks upwards, that is, 'from below'. As a result, the section line is the basis for the specular image of the traditional floor plan and instead of the pavement it allows to 'see' the intrados of vaulted surfaces, ceiling coffers, and all the lower parts of the roofs.

Given the morphological complexity of this area, which results from eighteenth-century renovations, a series of scans were carried out with the intention of subsequently covering the shadow areas detected during the recording (merging) of the point clouds.

This year we should conclude the internal scanning phase with the crypt, side chapels, and bell tower. We will also try to record as many exterior surfaces as possible, such as the porch portal to the south-east and the north-east wall.

Photomodelling drone techniques will also be tested to cover inaccessible upper surfaces, but always indoors. Unfortunately, Rome is now closed to drones and therefore it will be difficult, if not impossible, to be able to fly them over the roofs of Santa Prassede. Perhaps the surrounding buildings and hotels could still offer high places from which to enrich the 3D data of the general model.

From a chromatic point of view, we will start the photographic coverage of San Zenone, followed by that of the central nave and the apsidal area.

Once the model is complete, the definition of the geometric model will be set in motion, and with it the decomposition of elements for the graphic analysis and architectural reverse engineering.

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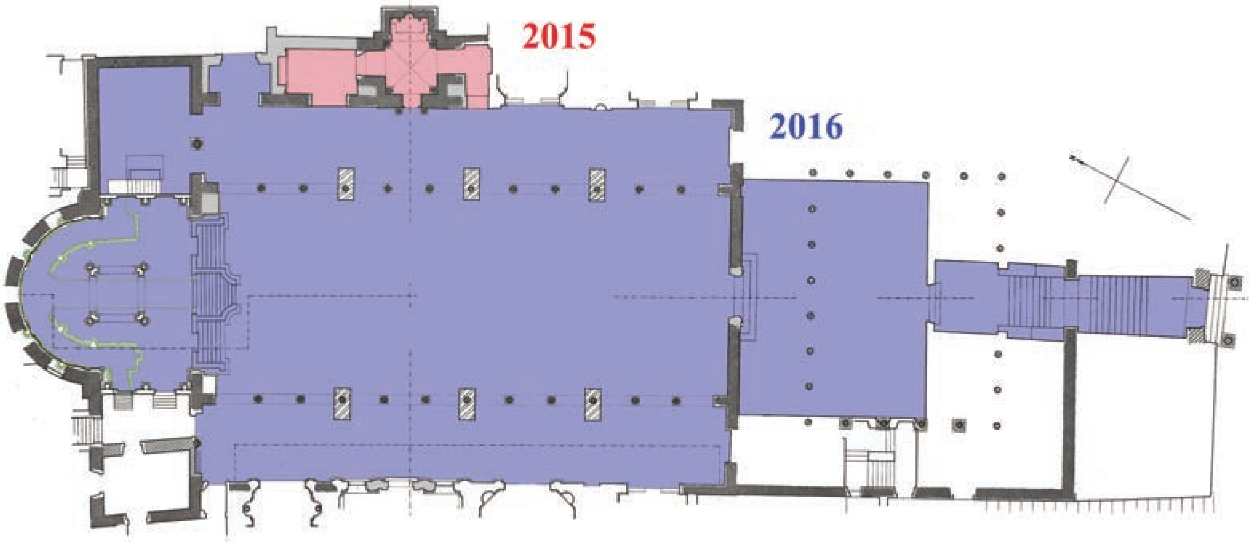

Fig. 1 Area scanned in the first two years of activity in Santa Prassede.

Fig. 2 Rome, San Paolo fuori le Mura, ciborium. Three aspects of architectural relief: chromatic survey using digital photography, morphological survey through the rendering of the geometric model, and decomposition of the object into assembled elements.

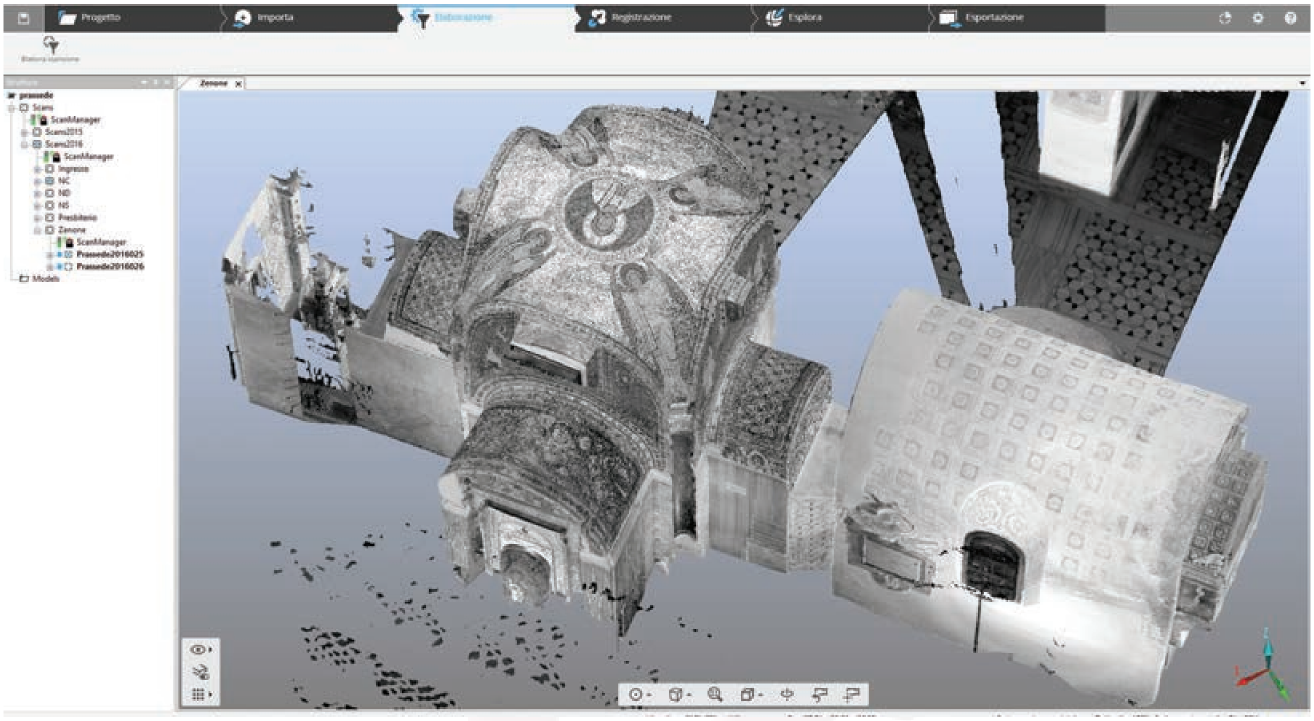

Fig. 3 Rome, Basilica of Santa Prassede, chapel of San Zenone. Reflectance laser scanning, performed indoors, allows the visualisation of architectural morphology in an unusual way, and is therefore able to show new aspects that are not generally considered.

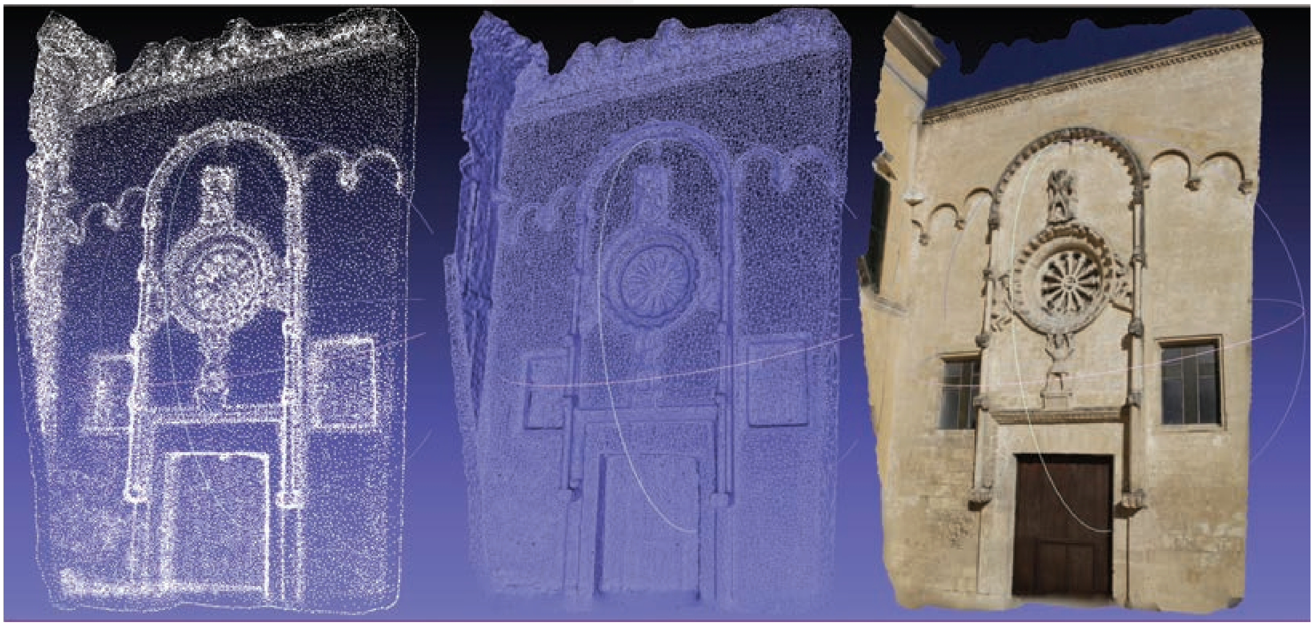

Fig. 4 Matera, San Domenico, façade. The three phases of photomodelling: determination of the point cloud; determination of mesh surfaces; mapping with colour data captured by the camera.

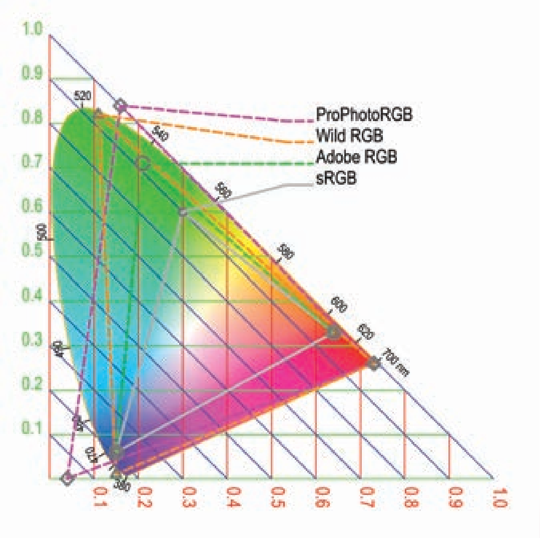

Fig. 5 The CIE 1931 diagram with the representation of the colour spaces (gamut) of some reproduction devices.

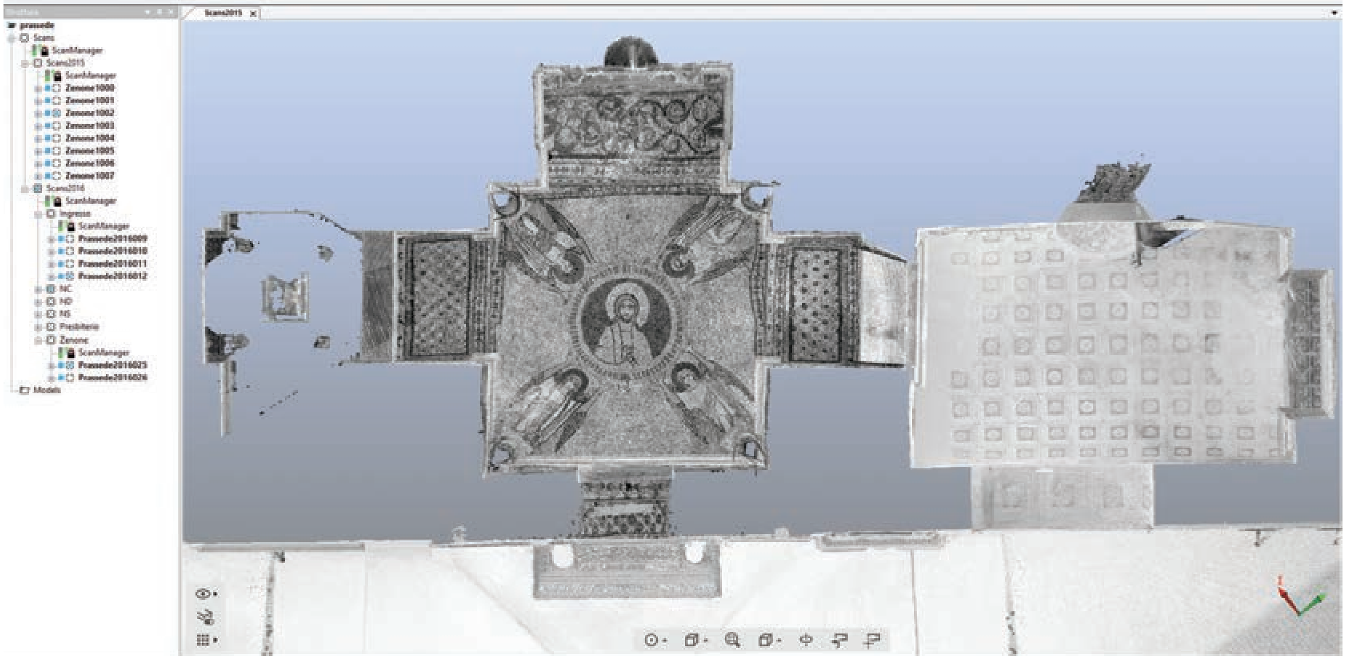

Fig. 6 Rome, Santa Prassede, Oratory of San Zenone. Hypography.

Fig. 7 Rome, Santa Prassede, Oratory of San Zenone. View of the entrance from the right side nave (north-east).

Fig. 8 Rome, Santa Prassede, Oratory of San Zenone. Longitudinal section facing north-east.

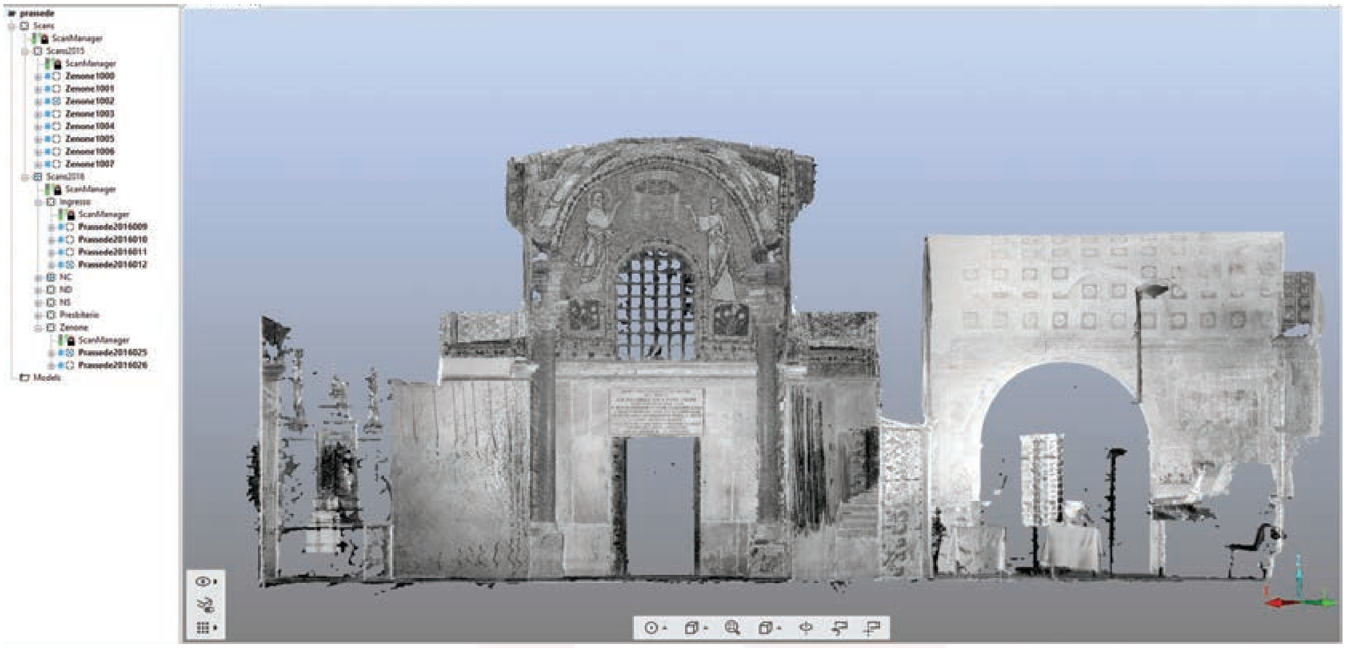

Fig. 9 Rome, Santa Prassede, Oratory of San Zenone. Longitudinal section facing south-west.

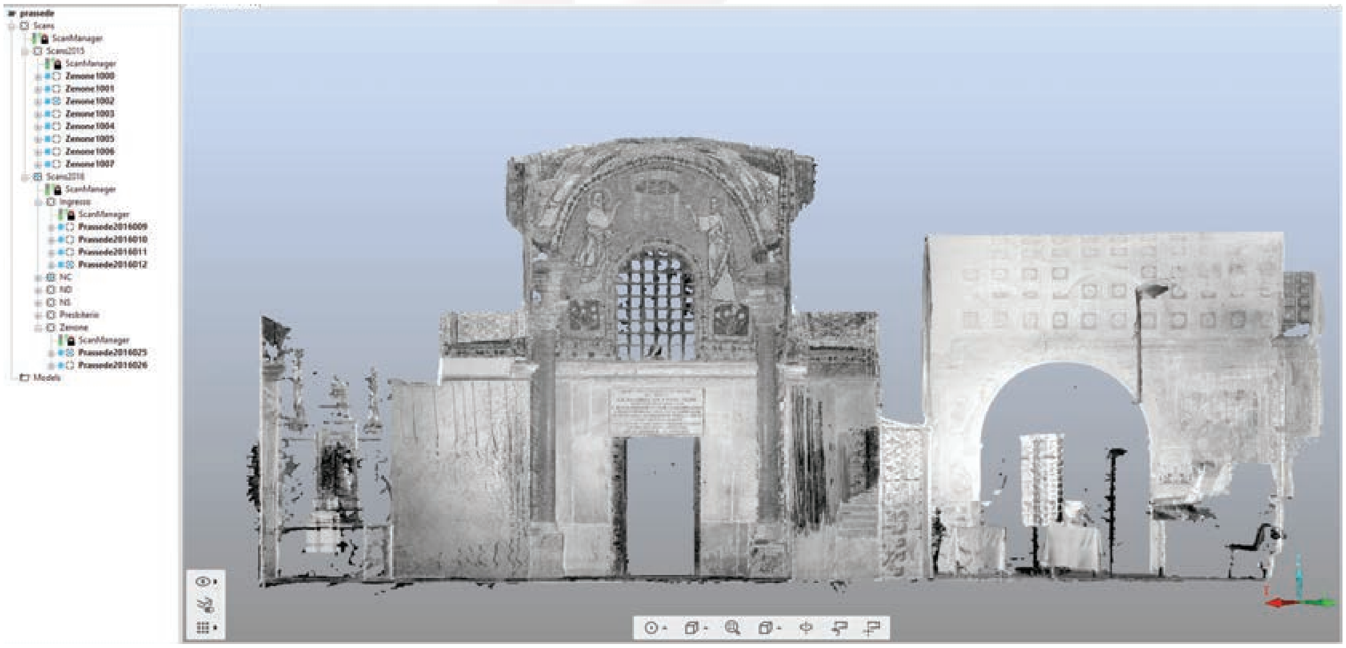

Fig. 10 Rome, Santa Prassede, front entrance. Longitudinal section of the entrance staircase and courtyard.