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(Article begins on next page)

THE BASILICA DELLA MADONNA DELL'UMILTÀ IN PISTOIA: SURVEY, ANALYSIS AND DOCUMENTATION

Grazia TUCCI, Alessia NOBILE, Maria RIEMMA

University of Florence, Faculty of Architecture,
Geomatics & Communication for Cultural Heritage Laboratory, Italy
grazia.tucci@unifi.it, alessia.nobile@unifi.it, mariariemma@hotmail.it

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Abstract:

The Basilica della Madonna dell'Umiltà is the most important example of Renaissance monumental architecture in Pistoia.

The geometric conformation of the church was devised by Giuliano da Sangallo with the assistance of his brother Antonio, of Francione and of Pollaiuolo; the Pistoian architect Ventura Vitoni was responsible for building the church and in the mid sixteenth century Giorgio Vasari designed and supervised the construction of the majestic 59-metre-high dome.

The dome with its copper-covered ribs, metal tie-rod reinforcements and sandstone lantern has become a fundamental part of the urban image of Pistoia.

In recent years the rapidly deteriorating condition of the monument attracted the concerned attention of the Ministry for Cultural Heritage and Cultural Activities, the Pistoia and Pescia Savings Bank Foundation and the Bishop's See of Pistoia.

A series of observations and studies have attempted a geometric-structural analysis; this analysis, although accompanied by uncertainty, inevitable when dealing with such complex organisms, can constitute a reliable base for diagnosing the problems.

The first phase of the restoration work, directed by the Florence Superintendence for the Architectural and Landscape Heritage, commenced in May 2008. During this phase the University of Florence carried out an instrumental survey of the entire complex which included a topographical survey and a laser scanner survey; a three-dimensional model of the monument was acquired and its structural geometry was verified.

1. INTRODUCTION

The present work aims to show the first results of the profitable cooperation between University research institutes, ecclesiastical institutions, banking foundations and the Ministry for Cultural Heritage and Cultural Activities in the definition and realization of a complex conservation intervention.

Our studies, aimed at the definition of a 3D data base in support of the project of the restoration and consolidation of the Basilica dell'Umiltà of Pistoia, have been conducted with well-established surveying techniques, such as topography and photogrammetry, united with more innovative techniques like three-dimensional scanning systems. The challenge was to extract the classic two-dimensional elaborations (18 tables to be produced over one year, in agreement with the Superintendence), starting from an unstructured 3D datum, which today is difficult to manage due to the large dimensions of the files and the absence of coded guidelines to follow for graphic restitution.

2. THE BASILICA

The Basilica di Santa Maria dell'Umiltà is one of the most important monuments of the city of Pistoia, and among the most significant legacies of Italian Renaissance architecture. The building of the temple was

decided upon in order to celebrate the occurrence of a miraculous event which took place on 17 July 1490 in the small parish church of Santa Maria Forisportae, the place of the present Basilica [7].

The change of the name and the definitive metamorphosis of Santa Maria Forisportae into the Basilica dell'Umiltà were ratified by the Bull of Pope Leo X in 1515.

The conception of the geometrical structure of the church was made by Giuliano da Sangallo, the architect of Lorenzo the Magnificent, assisted by his brother Antonio, and by Francione and Pollaiuolo; but the instigator of the construction was the Pistoian architect Ventura Vitoni; and later, in the mid-15th century, Giorgio Vasari was responsible for the design and realization of the majestic dome, which distinguishes and defines the city profile, being the fundamental reference point in the definition of the urban identity of the city of Pistoia.

The monumental complex is composed of a succession of different bodies of buildings which correspond substantially to the successive phases of its construction through the ages.

The new church is composed of a spacious vestibule, built in place of the small church, of rectangular design, with the central dome on pendentives, and lateral wings with barrel-vault roofing. The preparatory phase lasted for more than five years and the construction site for almost a century; it was characterized by either periods of great activity or long periods of stasis in the building process. The first stone of the Basilica was laid on 2 September 1495.

The vestibule completed, the houses adjacent to the wall were bought and pulled down in order to provide space for the octagonal building [1].

The octagonal prism developed vertically in a sequence of three grades of decreasing height and, even if the masonry of the piers was not complete, attention was drawn to the difficult problem of the roofing [4]. The building activity became so scarce that there was the risk that the unfinished structure would suffer decay. Cosimo I granted the necessary finances for the completion of the sanctuary and named Giorgio Vasari as the designer of the dome.

He consolidated the existent structure, as he considered it to be incapable of supporting the weight of the roof, he raised the edifice beyond the third cornice to give a solidier impost base to the dome, inserted chains at the edges of the annular courses, identified as the weak points, except in three parts where the bodies of the building of the vestibule and the greater chapel guaranteed solidity to the building.

In the spring of 1569 the dome was completed in its load-bearing structure, but only a few years later the first cracks were reported. Vasari himself carried out the first restoration operations: he inserted chains to the inside and outside of the new extensions [3]. But due to the continuing presence of the cracks, the Granduca Francesco I entrusted the consolidation project to Bartolomeo Ammannati, who traced the instabilities back to Vasari, in particular the great weight of the lantern; he inserted four chains in the dome, strengthened the piers, judged to be jointly responsible for the sagging of the roof, and he built the undersides of the arches in stonework in correspondence with the chapels, thus cancelling the original decorations [9].

The remedies of Ammannati allowed the overcoming of the most acute phases but did not eliminate the causes of the problems, which reoccurred cyclically. In the middle of the 1700's also the internal dome was encircled because of the detachment of the middle ribs of the masonry compages of the dome.

From this moment, little is heard until 1935, the year in which Superintendent Poggi asked the engineers Niccoli and Sanpaulesi for a deep study of the static conditions of the Vasarian dome. Sanpaulesi observed numerous cracks in the piers and the two calottes; he also noticed worrying detachments between the two calottes and between the two calottes and the ribs.

The last restoration was carried out in 1966 with the work of Superintendent Albino Such, who substituted two Vasarian chains, revised the roofing by once again making good the cracks with cement mortar and by restoring some elements of the decorations [16, 13].

From this date, the prolonged absence of interventions of either maintenance or conservation of the monumental complex has caused a general state of decay. To be noted are the detachments and collapses of the external brickwork of the external faces, with masonry left unfinished at face view; the decay of the lantern sandstone: the loss of lapidary fragments of the vestibule, both of the lacunars of the caissons and the perimeter cornices; lastly, structural instabilities of the vestibule and dome.

These conditions of marked deterioration have attracted the attention of the Ministry for Cultural Heritage, the Bishop's See of Pistoia and the Pistoia and Pescia Savings Bank Foundation, who by the drawing up of a protocol agreement on 5 March 2008 have allowed the first restoration interventions, planned and carried out by the Superintendence for Architectural and Landscape Heritage of Florence, Pistoia and Prato of Florence.

It is into this context that we are placing our contribution, marked by means of the research agreement 'The execution, instrumental survey and graphic restoration of the Basilica dell'Umiltà at Pistoia', and stipulated

between the Superintendence and our Department (the ex-DIRES). The acquisition of the three-dimensional model of the monument, to verify the structural geometry, supported the study of the static situation of the monument, for the analyses of the structural stability and for the consolidation project of the dome and vestibule.

3. 3D DIGITAL SURVEY

The spatial articulation of the structure, the geometric complexity of the ambient and of the vaulted spaces, the richness of the decorations, all these have called for the integration of different measurement techniques (classic topographical and satellite systems, and 3D scanning systems and digital photogrammetry). The pre-established objective was that of supplying info-graphic representations with high levels of detail, metrically correct and in conformity with the finality of the survey and the scale of graphic restitution individualized as most opportune for the analysis of both the structure and the decorations.

3.1 Survey planning

The planning phase of the survey represents a fundamental part of the whole acquisition process. In the specific case of the Basilica, given the large dimensions of the construction (Table 1) and the complexity of the space, due to both the spatial articulation and the decorative richness, the acquisition process has involved a careful survey and the drawing up of a programmed register of the survey (Table 2).

Table 1: Main characteristics of the surveyed building

Dimensions of the building	about 60 m x 25 m
Max difference in height into the church	about 61 m (from the ground floor to the top of the cross on the dome)
Surveyed area at ground floor	about 1.500 m ²

The major difficulties faced during the acquisition phase are related to:

- the need to reach some restricted spaces of the structure (for example, the vertical connections, the angular ways which narrow from bottom to top, the compressed space between the two calottes at the level of the impost of the dome up until the lantern);
- the need to document the high level of detail in some decorative elements (for example, the lacunars in the vaulted space and the large domes of the vestibule, the arch undersides of the minor and major chapels, the church ornaments, the balustrades with small bronze columns, the marble dossals and the high altar);
- the importance of defining the thickness of the masonry so as to reveal the external parameter. This finality, probably the most time consuming, has involved the individualization of some spaces surrounding the Basilica to plot the externals, in particular the dome. The dense urban building tissue in which the architectural complex is placed inevitably implies the shortened acquisition of surfaces due to the impossibility of obtaining the appropriate distances (between about 80 and 120m). From this, there was the need to raise where possible the scanner to the level of the windows and the surrounding terraces.

3.2 Survey campaigns

The in situ work has been carried out in five measurement campaigns (Table 2).

Table 2: Summary of the activities during the five campaigns

	1 st campaign	2 nd campaign	3 rd campaign	4 th campaign	5 th campaign
Times	April 2008	July 2008	October 2008	January 2009	April 2009
Instruments	1 scanner phase shift 2 total station 1 calibrated digital camera	1 scanner phase shift 2 total station 3 digital camera	1 scanner phase shift 2 total station 2 gps 3 digital camera	1 scanner time of flight 1 total station 2 digital camera	1 scanner phase shift 1 total station 2 digital camera
Working team	2 (6 people)	2 (6 people)	2 (6 people)	1 (3 people)	1 (3 people)
Working days	6	4	4	3	3
Scan positions	46	48	19	4	47
Points	about 370 million	about 820 million	about 420 million	about 16 million	about 1,5 billion
Files sizes	10 GB	18 GB	8 GB	1 GB	20 GB
Topographic vertices	19	14	16	0	0
Targets	51	70	37	15	263

The metrical survey has been done in relationship to the priorities given by the Superintendence: the vestibule, the octagonal hall, the sacristy, the annular corridors of the second and third kind, the tambour and the impost of the dome.

3.3 Topographical framework and reference system

A topographic net, including the internal and external vertexes of the Basilica, has been created. The measurement operations have been conducted with both a total station and geodetic GPS receivers. The total station was used for the survey of the internal network of the complex and also for a large part of the external network. The use of the GPS along the streets adjacent to the church has not been possible because of the tall buildings which limit the reception of the satellite signals. The use of the GPS has however been fundamental in surveying some vertexes in elevated positions not directly connected to the total station net.

The net was important in three successive measurement campaigns:

- *Campaign I*: the realization of the principal network of the framing includes the vertexes of the exterior of the Basilica, along via della Madonna, and in the interior in the portions of the vestibule, including the attic, the ground floor of the octagonal Hall and in some rooms of the manse;
- *Campaign II*: the completion of the ground survey of the rooms of the manse and the survey of the ‘ring’ corridors between the ground floor of the octagonal hall and the import of the dome;
- *Campaign III*: the extension and completion of the external network through new ground vertexes, on the lantern and on the structures in elevation.

All the vertexes have been materialized in a permanent way and accurately monographed in order to describe the locations and coordinates in the pre-established reference system.

The maximum planimetric range of the network, which is presented elongated in the parallel direction of via Madonna, is equal to circa 480m x 170m, while the proportional development ranges from 0 to circa 47m (Figure 1).

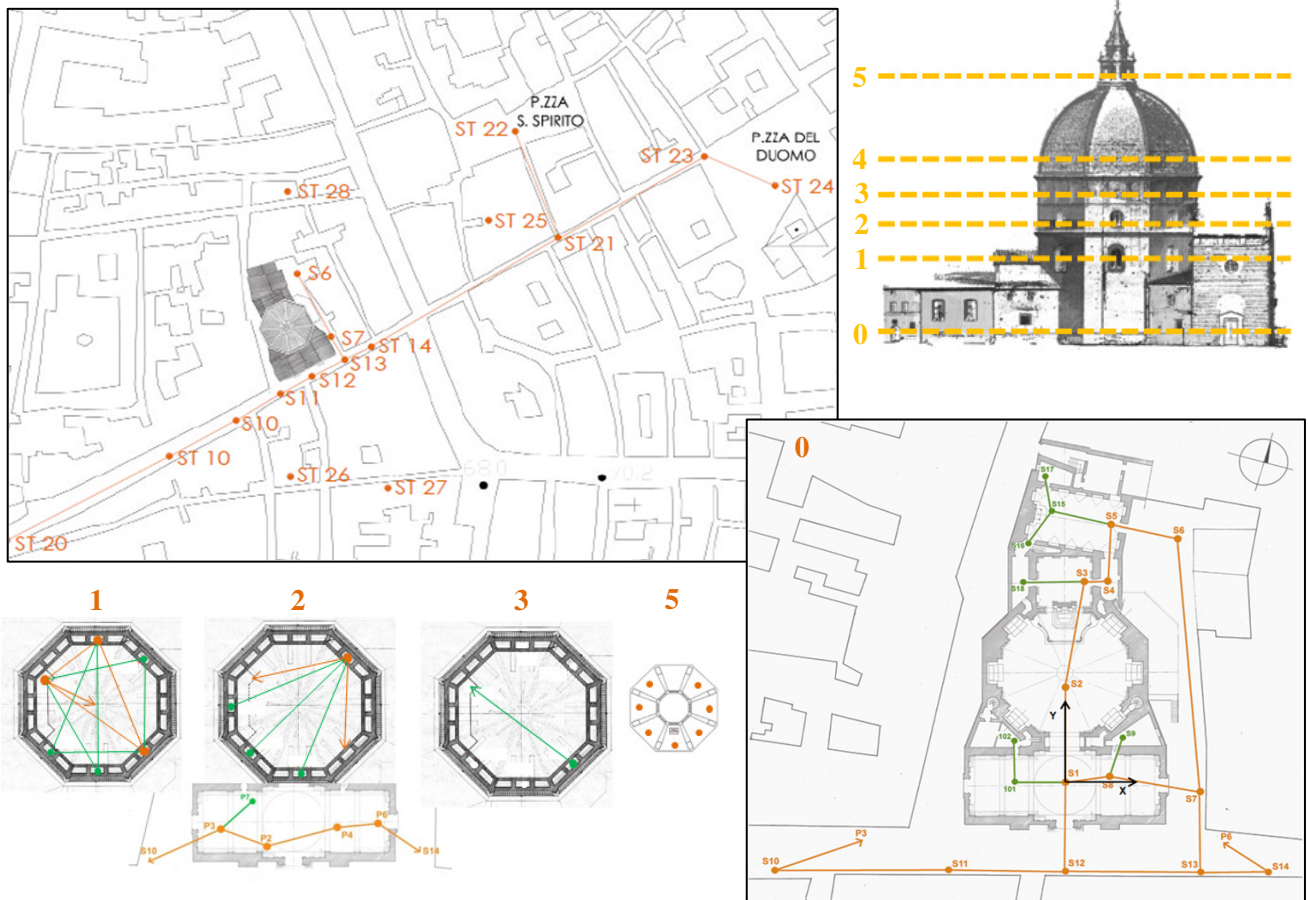


Figure 1: Internal topographic network, scanned at levels, and the external network

3.4 3D scanning

The scans resolution has been planned each time for the formal and dimensional characteristics of the investigated spaces. To estimate the acquisition times both the times of the execution of the scans and the times for the moving and orientation of the sensor have been evaluated.

The planning phase of the scans has been fundamental in forecasting the different positions of the scanner, the extensions of the singular acquisitions of the subject and the position and type of target.

The most problematic parts found are:

- the arrangement of the reference frame in order to ensure the correctness of the operations of roto-translation of the points obtained from the different stations;
- the acquisition of the space between the two calottes.

In all the survey campaigns a phase shift scanner has been used, except in the fourth campaign where a time of flight scanner (Leica ScanStation2) has been used, in order to obviate the instrument/subject maximum distance (circa 100 - 150m).

The high working speed has permitted the realization of a number of significantly important scans. The alignment of the scans has been organized according to projects, each one of which contains the data relative to significant portions of the surveyed spaces:

- *Campaign I*: the internal, external and extrados vestibule;
- *Campaign II*: the octagonal hall (level 0, 1, 2);
- *Campaign III*: manse, external (via Vitoni and interior courtyard);
- *Campaign IV*: the dome-external;
- *Campaign V*: the spiral staircase, tambour and impost of the dome.

4. GRAPHICAL OUTPUT

Starting from the complete model of the points, the elaborated graphics agreed with the Superintendence have been extracted:

- for the whole *architectonic complex*, scale 1:50 - four plans, at level 0,1,2,4; the longitudinal section (Figure 2); scale 1:100 - the plan of the roofing; 3 views, one of Via Vitoni, one of via della Madonna and one of the interior courtyard;
- for the *vestibule*, scale 1:50 - two plans of the extrados, one architectonic and one structural; three sections, one longitudinal and two cross-sections; the photo-mosaic view of the main façade; scale 1:20 - the development of the barrel vault;
- for the *octagonal*, scale 1:50 - two sections, one cross-section and one diagonal.

4.1 Plans, elevations and vertical sections

In architecture, with the term 'representation' is meant an ensemble of documents with the aim of showing and making known the 'monument', the subject of the study [15]. The distinguishing characteristic of two-dimensional vectorial designs is the ability to synthetically reproduce the actual state of a monument. In this case, such designs stemming from a cloud of points can also describe in a more detailed way the possible imperfections due to the inevitable alterations and damage caused by both time and man.

The task of interpreting the model of the points to individualize both the geometry and the anomalies is not an easy one for an inexperienced operator. The reading, which with other techniques of surveying is carried out in situ, is here undeniably in the phase of the graphic rendering.

The representation of the plans, views and section profiles has been realized through the geometric interpretation of the subtle lines of the clouds of points. However, often the individualization of a single section has not been sufficient to produce an architectonic design in the true sense. The morphological complexity and the articulation of the spaces have led to an inevitable movement of the section plane so as to intercept the significant surfaces. For example, the vertical sections made in the centre line of the sides of the octagonal have not been transferred at first in order not to secant the central columns of the mullioned windows of the second and third order, and, after, to intercept the centre line of the barrel vault in the annular corridors in parallel to the windowed space.

All the graphic representations are two dimensional, but keep their referential three dimensional homogeneity: every elaboration belongs to a plane where both the position and the lying position in the defined space of the adopted reference system are shown.

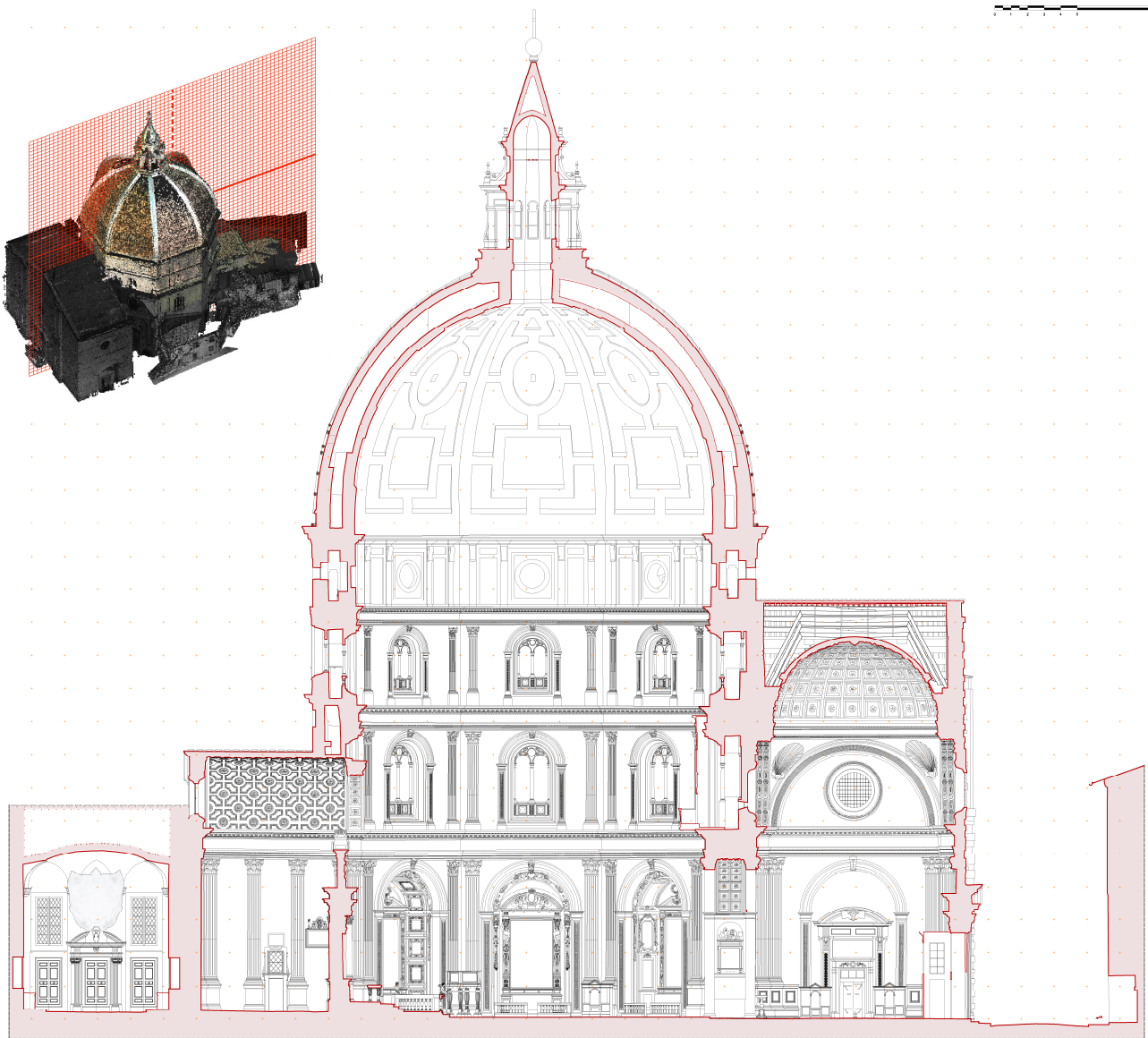


Figure 2: Longitudinal section of the Basilica. Original in scale 1:50

5. THE EXAMINATION OF THE RESULTS

The three-dimensional survey of the Basilica dalla Madonna dell'Umiltà has highlighted and made it possible to quantify the following:

- for the vestibule: the structural states, the numerous external out of plumbs, in both the perimeter walls and in the structure; the irregularities in the alignments of the lacunars of the vaulted parts; the rotation of the internal walls of the facades, principal and lateral, with consequent cracks in the junction zone between the vaulted parts and the impost (Figure 3);
- for the octagonal hall and the dome: the number of ribs (eight angular, eight central and sixteen median), their correct placing, form and dimension; the exact placing and dimension of the internal and external chains; the actual thickness of the two calottes; the building materials and techniques; the consolidation of the interventions; the internal connections, both horizontal and vertical; the cracks present on both calottes, highlighting the most damaged awnings; the links between the geometry, the structure and the deformations shown over time (Figure 3).

The new digital technologies both rationalise and streamline the survey procedures while also creating the new infographic representations that can easily adapt to the multiple needs of the scholars and operators (architects, archaeologists, engineers, restorers, historians) [10].

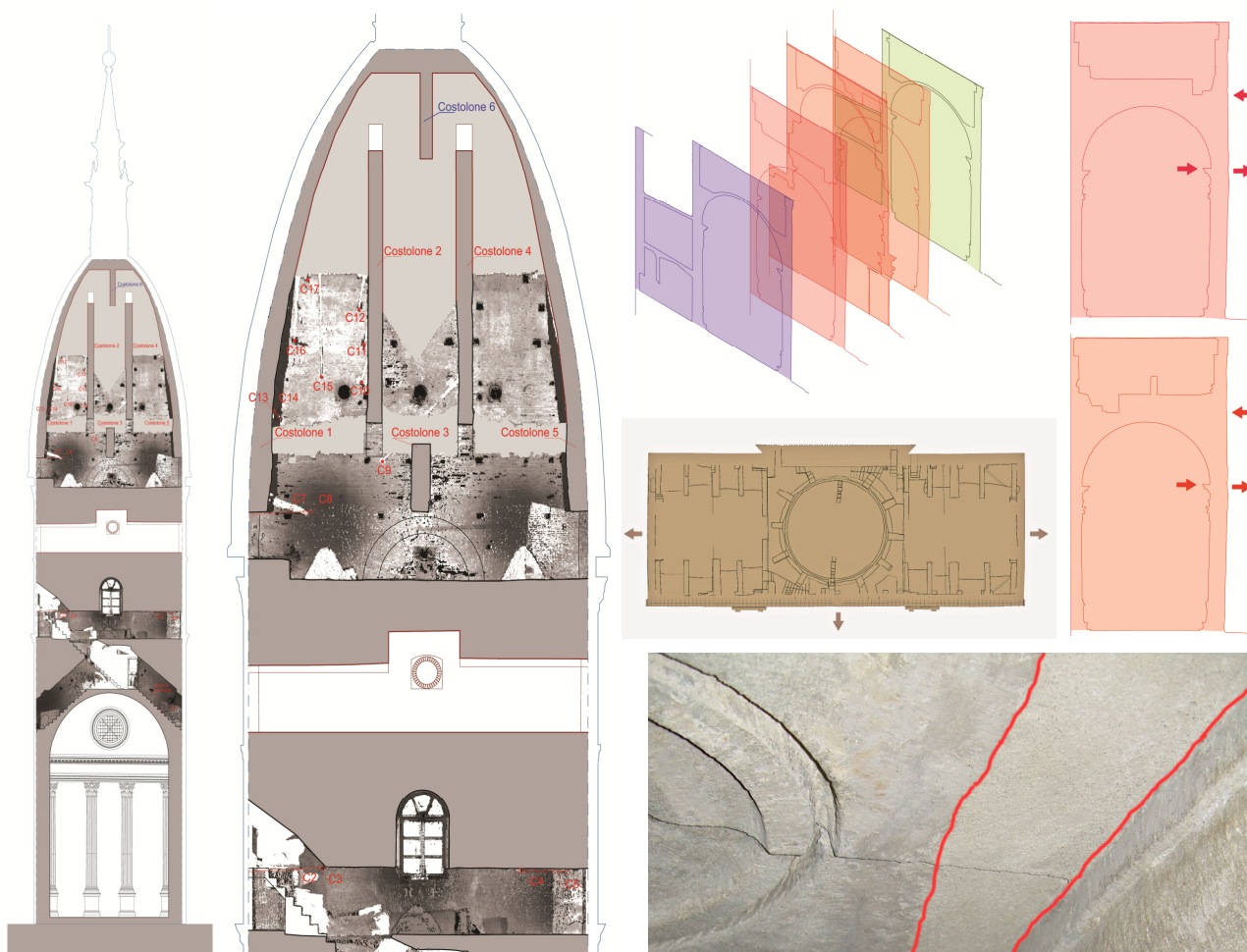


Figure 3: On the left, octagonal building: a view of a web with the cataloguing of the chains and ribs; on the right, vestibule: drawing of the deformations and a particular of the redressed cracks in the barrel vault.

The studies conducted *in situ* often do not make fully understandable the real situation characterizing a building of such dimensions and importance. It is sufficient to think of the repeated sense of disorientation to be had by following the annular ways, dark and narrow, due to the uniform replication of the building elements and the articulated system of the vertical connections between the differing levels (Figure 4).

It is exactly in cases like this that the 3D data base proves useful: the clouds of points, visualized virtually from an unusual view point which is generally impossible in reality, allow a perception of the general space of the structure, overcoming the physical limits and visual obstacles present in the real world.

Based on the graphic elaborations stemming from the survey, the structural engineers have been able to verify the structural behaviour of the structure and insert new metallic chains as a 'help' to the existent ones, where necessary.

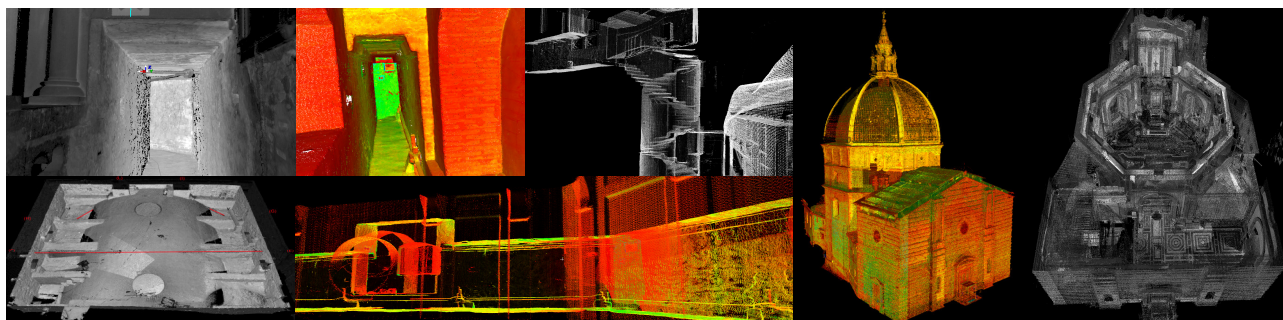


Figure 4: Three-dimensional views of the complete model showing the connections of the chains and the reduced spaces of the horizontal and vertical connections.

The present technology of geometrics offers surveying instruments of great interest to the sector of Cultural Heritage and ensure, if used knowingly, scientific rigour in the understanding process. However, it is important not to be led astray by the fascinating images gained from the laser scanner data but rather to optimize the documentation and representation processes necessary for the understanding of the structure under investigation [2].

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