

## 3D THEMATIC MAPS TO REPRESENT CRAKS LAYOUT OF VAULTED SURFACES

Fabio Luce\*

\*Department of Civil, environmental and mechanical engineering, University of Trento, Italy.

### Abstract

The Church of Sacro Cuore in Trento was an opportunity for the experimentation and the application of a procedural process aimed to verify the geometric shape of the frescoed vault and the mapping of the crack visible to return 3D qualitative data acquired. The representation of the surfaces is based on the acquisition of topographical data and photogrammetric shots to produce a single high-resolution image that coincides with the planimetric projection of the vault. At first this allowed to draw the cracks pattern in two-dimensional mode, integrating it with the information contained in the free-hand sketches then the projection of the curves of each crack on the surface of the vault has therefore resulted in a three-dimensional thematic model of crack pattern.

### Keywords

Topographic survey, photogrammetry, 3D thematic map

### 1. Introduction

The reflections developed in the text and supported by the images that follow have the purpose of showing the procedural steps followed in order to obtain a thematic map representing qualitative data, in particular the crack, and in a three-dimensional way with the aim of providing a graphic and digital model intended to assess more clearly the structural problems in relation to the performance of geometric variations highlighted.

Object of the survey was the church of Sacro Cuore in Trento<sup>1</sup>, in particular the coverage of the nave, that is characterized by a frescoed barrel spheroid vault with lunettes<sup>2</sup>, the groins and the

transverse walls to the development of vault, because of a state of degradation (fig. 1). The request of the client it was to provide a comprehensive mapping of the crack in order to assess the actual texture of the cracks to target the interventions of consolidation<sup>3</sup>.

Therefore the process moves on two different fronts: on the one hand, to show how graphic-numeric representation of the vault became the structure to describe thematically the qualitative informations based on the visual perception and on photography through objective data that allows to communicate "measured" geometry. On the other one, this research detects a structured sequence of operations that allows to produce thematic representations able to overcome the problem of informations reduction to the bi-dimensional plan, overall if the objects of analysis are architectural elements characterized by a clear three-dimensional expansion like vaulted surfaces and overall if it is necessary to give

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<sup>1</sup> The church "Sacro Cuore" or, more correctly called "Cuore Immacolato di Maria", is the main chapel of the Institute Sacro Cuore of Trento. It was built in the first decades of 1700 by Pietro Antonio Ghisi and the frescoes cover the dome and the vault of the church for an area of over 400 square meters. Decorations, dating back to 1735, were realized by the painter Antonio de Romedis who specifically realized the "Gloria del Paradiso" in the dome, "I dottori della Chiesa" in the pendentives and "S. Orsola", "I fasti dell'Ordine", "la Madonna Assunta" e "S. Giuseppe" in the vault of the nave. Since 1998 it is the subject of restoration works, concluded for the outside and being on the frescoes in the inside.

<sup>2</sup> Fallavolita, F. (2009). *Le volte composte*. In R. Migliari, *Geometria descrittiva - Volume II - Tecniche e applicazioni* (pp. 447-451). Novara: CittàStudi Edizioni.

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<sup>3</sup> «Church of Sacro Cuore in Trento. Photographic surveys of the vault of the nave and representative models of the surfaces»: research assignment commissioned by the Institute of Sacro Cuore of Trento (manager Dr. Laura Bellamoli) to LAMARC team (former DReM.M.), Department of Ingegneria Civile Ambientale e Meccanica, University of Trento. Research team: arch. Fabio Luce and arch. Cristina Pellegatta. Scientific manager: prof. arch. Giovanna A. Massari.

metric objectivity to data usually measured through “the sight”.



**Fig. 1:** General view of the frescoed barrel spheroid vault with lunettes of the church of Istituto Sacro Cuore of Trento.

## 2. Geometric and figurative description

The first phase consists of the acquisition of both metric and non-metric data set: on the one hand, in fact, topographic measurements and photogrammetric shots are acquired in order to define the geometric shape of surfaces; on the other the crack pattern of the vault is described both through photographs, general and detailed, and sketches in double orthogonal projections and axonometric projection, in order to integrate continuous data offered by photographs with discreet and selected one derived from direct observations.

In this way, in fact we want to provide a description of the object both from a geometrical point of view for a correct classification of architectural elements, and from a perceptual point of view, for a more targeted photographic acquisition in order to an effective recognition of characteristics of degradation.

### 2.1 Metric description: topographic and photogrammetric survey

To describe geometrically the vault it has been necessary to acquire a series of topographic points useful for the definition of the generatrix curves that compose the surfaces. For this reason

it was decided to establish a small topography grid that is an open traverse consists of two station points<sup>4</sup>: the first placed at the third sector from the main entrance to the nave and the second placed in the loft above the portal. The choice is depended on the need to solve the occlusions problem both of some parts of the vault due to the presence of the ribs between one sector and the other and of certain juts such as the decorative band placed in correspondence of the vault springer. Each arc has been defined by not less than five points, in most cases chosen in a friendly position thank to the numerous color variations found in frescos. The grid points was also noted on sketches structured to provide a framework for the design view, a space containing a grey-scale photograph of the surveyed area and a section reserved for text annotations.

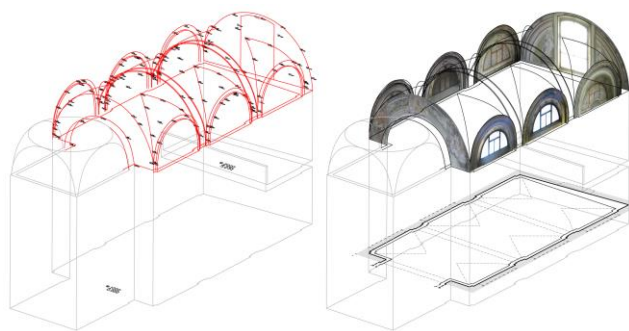
The metric description of the vault involved the acquisition of photogrammetric shots through a semi-metric analogue camera<sup>5</sup>, necessary for the definition of the geometry of the vertical walls that delimit the development of the vault, in particular for the geometric definition of the generatrix of the lunettes: for this reason eight shots are acquired, six related to lunettes of each groins and two relating to transverse walls (fig. 2).

The photogrammetric survey has obviously also involved the central sectors of the vault, with the corresponding groins: they are acquired through photographs from the ground and from the loft acquired with optical axis kept orthogonal to the approximate median plan of the surface portion framed<sup>6</sup>. As should be inferred below, this second set of shots will be employed primarily for processing a zenith image that, unless the perspective distortion inherent in the photographs, will be used as the basis for the digital reading of the lesions of the vault.

<sup>4</sup> Operation conducted with Topcon GPT 1001 total station and software Geopro Meridiana 2011.

<sup>5</sup> Semi-metric analogue camera Rollei 6008. The choice of a semi-metric analog camera and not a more common digital camera depends on the fact that we wanted to minimize the problem of the image distortion already in the acquisition phase because this would further weaken the possibility to get the full correspondence between geometric model and planar processing of zenith photographs of the vault.

<sup>6</sup> On photography techniques, see De Luca, L. (2011). *La fotomodellazione architettonica* (pp. 33-69). Palermo: Flaccovio Editore.



**Fig. 2:** Topographic and photogrammetric model output of survey operations. Model developed through Geopro Meridiana 2011 and Geopro Photometric 2009.

## 2.2 Visual description: photographic and “on-sight” survey

After the first metric acquisition step, it has been necessary to systematize the acquisition of qualitative data because, if on the one hand, «*the measurement of visible forms examines only one characteristic of multiple objects, to identify the different degrees of quality considered and to express them with a real number*», on the other «*the description resorts to visual perception and photography to develop the first hypothesis of data ordering*»<sup>7</sup> therefore, released from numeric data, it was necessary to find a suitable tool for cataloging. For this reason it was considered appropriate to describe the preservation conditions of the vault not only through photographs - this decision would have required the interpretation of data in the later stage of restitution - but also through interpretative sketches, that is to say, diagrams drawn *in situ* containing information already partially selected and processed.

To simplify the process of acquiring it was decided to evaluate on sight and note the cracks on the according to three width orders: "big", indicated by the value 1, the cracks with a thickness exceeding 10 mm, "medium", value 2, those with a thickness estimated to be between 5 and 10 mm and "small", a value of 3, those with thickness less than 5 mm. To the “on-sight” survey was joined the photographic one with the goal of having “redundant” photographs of all

decorations and frescoes from different acquisition positions in order to ensure greater precision in the location and evaluation of the size of all lesions in question.

## 3. Construction of digital model

The restitution of metric and thematic data produces a geometric and figurative digital model considered as a geometric digital frame able to show the thematic information collected. To this end, the representation model is built from 3D vector file generated by the processing of topographic data, subsequently integrated with photogrammetric and “on-sight” survey data. The combined processing of data acquired *in situ*, in fact, allows to produce a single model, rigidly structured and above all able to accommodate three spatial models characterized by different features: the first is a vector-raster model generated mounting horizontal and vertical section planes, elevations and photo-plans (by-plan 3D model); the second, a wireframe model created placing each edge in its real position; the third, a surfaces model, made by the “digital skin” of the architectonic structure.

### 3.1 Construction of geometric shapes

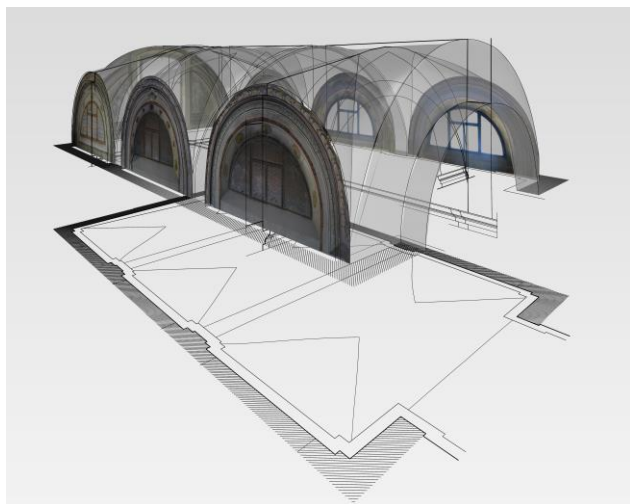
The second phase consisted essentially in the reorganization and archiving of data acquired during survey operations *in situ* and in the subsequent processing of them. The first operation performed has been to structure a 3D file of restitution based on the vector file generated by the treatment of topographical data: an ordered set of layers and UCS necessary to navigate easily the complex and often hardly recognizable iconographic apparatus of the vault. The survey points grid allowed both to return the object geometries, interpolating object-points of the ribs of the groins with b-spline, and to generate lunettes photo-plan thank to the rectification of metric shots. Consequently it is obtained a wire vector-raster unitary model composed by both the curves of the groins and by the photo-plans of the lunettes, intended as a proper geometric framework about the investigated architectural structure.

The next step was to virtually reconstruct the “skin” of the barrel vault with lunettes: were created, in fact, mesh surfaces modeled starting from curves previously returned in order to

<sup>7</sup> Massari, G. (2014). Rilievo dell'architettura. Modelli scientifici e rappresentazioni tematiche per la conoscenza, l'intervento, la comunicazione. In M. Cunaccia, M. Dallemule, C. Betti (Ed.), *Monumenti. Conoscenza, restauro, valorizzazione. 2003-2008* (p. 169-177). Trento: Provincia Autonoma di Trento.



obtain the geometrical frame on which return thematic data about the crack pattern (fig. 3).



**Fig. 3:** Output of the restitution of metric data. Model developed through Autodesk AutoCAD 2015 and McNeel Rhinoceros 5.0.

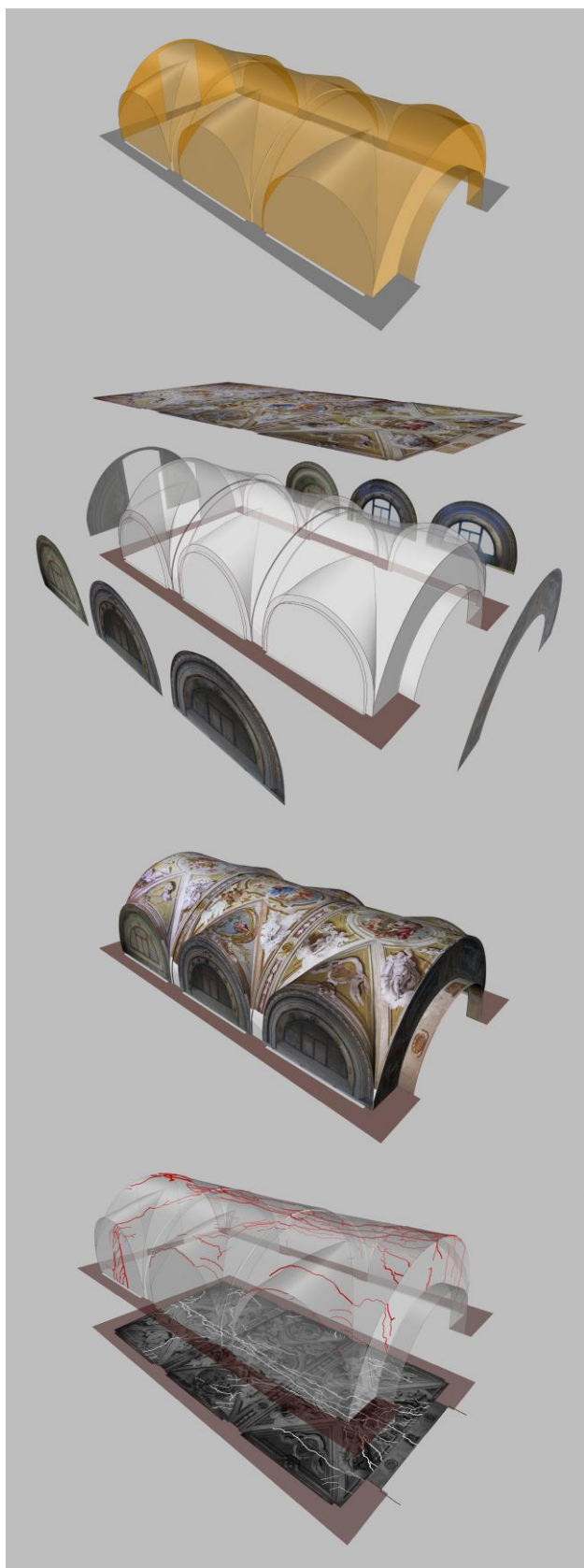
### 3.2 Construction of visual appearance

The description of painted surfaces, useful also for the proper return of crack pattern, is entrusted to a projective transformation of three photogrammetric shots mosaics in a single high-resolution image coincides with the planimetric projection of the vaulted space.

Distortive component linked to perspective projection proper of photographic images did not allow to use these shots as obtained in situ, but it was necessary operation of deformation: this operation, carried out on the three sectors of the vault, was performed by exporting a planimetric projection of geometric restitution of vaulted space from the digital model with the survey points grid. Keeping this network of lines and checkpoints was possible to deform the image until a transformation from a perspective image in orthographic projection; the final image, produced in high-resolution, was obtained by



**Fig. 4:** Transformation sequence of photographs of the vault in a pseudo orthogonal projection.



**Fig. 5:** Sequence of operations carried out to obtain the 3D thematic map. From top: surfaces geometric model; application of textures to the model; figurative model; thematic model.

mounting the three portions processed individually (fig. 4). In this way, finally, it was possible to reconstruct a figurative map, that is to say, the texture will be applied to surfaces model previously processed, according to the process of normal mapping<sup>8</sup> (fig. 5).

#### 4. Construction of a 3D thematic map

The resulting image thus produced has been inserted in the overall geometric model and, in addition to "dress up" the digital model, allowing to play its visual appearance, it made possible to mark up the plan of the vault from the bottom to top and its crack layout. The latter operation resulted in the vectorization of cracks directly on the overall image, facilitated thanks to information from photographs and from sketches drawn "on sight".

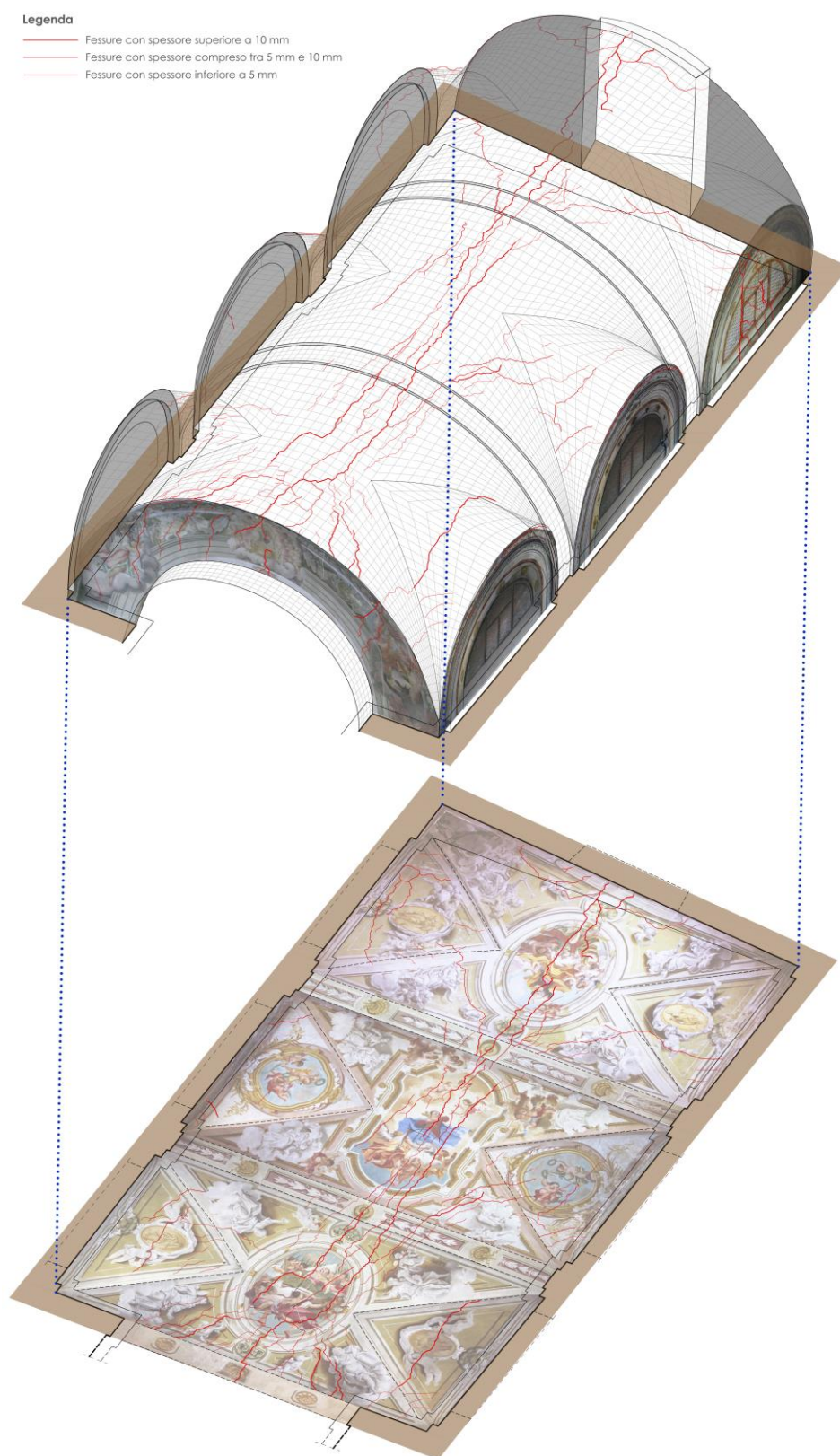
The cracks have been identified and classified based on the same three orders of width adopted during survey operations, attributing to each order a specific thickness value to be taken during the display and printing of the general model. The cracks returned in plan were then transferred on the spatial model through the projection of the curves in the normal way to the middle plane which approximates the surface of the vault in order to have a full match between the planimetric projection and the 3D model (fig. 6). The result is a series of 3D polylines corresponding to cracks derived from sketches, retraced on the photograph and placed in their actual spatial position and metrically controlled.

Got the unitary three-dimensional model that combines the wire drawing with raster images, two print layout have been produced: the one is thought to represent the vector model in scale 1:50 in axonometric projection, the other provides a unified image of the vault in 1:20 scale in the plan, view from bottom to top. In parallel it was produced a three-dimensional digital model explorable with both the 3D PDF viewer and Autodesk DWF viewer, both free applications that

<sup>8</sup> In 3D graphics, normal mapping, or "Dot3 bump mapping", is a technique used to simulate the complexity of surfaces relief without having to model in detail. A normal map is generally a RGB image generated by projection from a detailed object, which is made to correspond to the coordinates  $x, y, z$  of a surface normal, similar to its tangent plane, less detailed that represents the same object. Specifically, the operation was conducted with McNeel Rhinoceros 5.0 and Autodesk 3ds Max Design 2015 by applying the modifier UVW Map and Unwrap UVW.



allow you to turn on and off layers and query the model to learn about sizes, surfaces and volumes.



**Fig. 6:** 3D model of the crack layout in axonometric projection from bottom to top and planimetric projection of vault.

5. Conclusions

This research has the ambition to propose a possible solution to the communication of thematic data related to a crack layout or, more generally, to the representation of the deterioration of a surface with a strong three-dimensional development and that cannot be reduced in the information content using the traditional representations in double orthogonal projections (fig. 7).

This contribution also seek to synthesize the operations performed with the aim of identifying a concrete and replicable procedure apart from the object of investigation. Therefore, from a careful survey on field that integrates topographic

and photogrammetric procedures with perceptual data taken from the photographic survey and direct observation it is possible to builds a data-set useful to the development of a detailed three-dimensional digital model. Image processing and cancellation of perspective deformation allow you to generate a figurative basis useful to map the model in strict adherence with perception data that becomes a useful digital support to give metric control for the mapping of the lesions. Vectorized cracks, first on planimetric image of the vault and then projected onto the 3D surface, are shown in their real spatial position in order to ensure full match between reality and polygonal model.

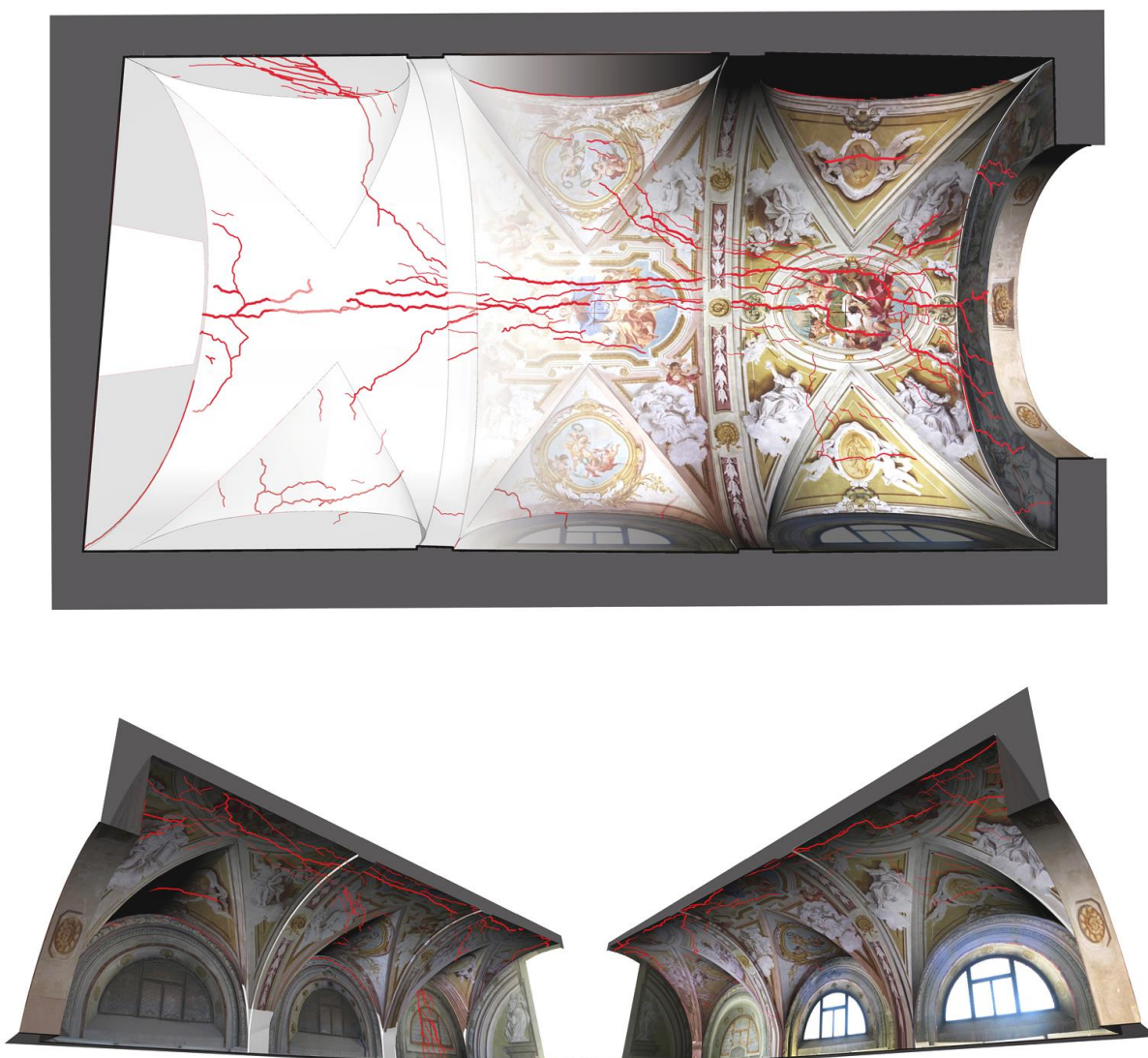


Fig. 7: Figurative model of vault and its crack layout: overhead view from bottom to top and perspective sections.

## REFERENCES

- Apollonio, F. I. (2012). *Architettura in 3D. Modelli digitali per i sistemi cognitivi*. Milano: Bruno Mondadori.
- Bertocci, S., & Bini, M. (2012). *Manuale di rilievo architettonico e urbano*. Milano: Cittàstudi.
- Bianchini, C., & Ippolito, A. (2010). Survey, modelling and analysis of vaulted structures and domes: towards a systematic approach. In *XIII Congreso Internacional de Expresión gráfica arquitectónica* (pp. 95-100). València: Editorial de la Universitat Politècnica de València.
- Bianchini, C. (2001). Modelli discreti e modelli continui nel rilievo e rappresentazione informatizzata dell'architettura. In *Disegnare. Idee e immagini n.22* (pp. 51-60). Roma: Gangemi.
- Carpiceci, M. (2012). *Fotografia digitale e architettura*. Roma: Gangemi.
- Ciarloni, R. (2012). La logica delle forme. In Carlevaris, L., De Carlo, L., Migliari, R. (Eds.), *Attualità della geometria descrittiva* (pp. 267-282). Roma: Gangemi.
- De Luca, L. (2011). *La fotomodellazione architettonica*. Palermo: Flaccovio Editore.
- Di Marzio D., Jahier F., & Violini P. (2004). La documentazione preliminare al progetto di restauro degli affreschi del ciclo sistino della Scala Santa. In *Disegnare. Idee e immagini n.24* (pp. 80-90). Roma: Gangemi.
- Emler, T. (2002). *Il Disegno Automatico tra progetto e rilievo*. Roma: Officina.
- Giordano, A. (1999). *Cupole volte e altre superfici: la genesi e la forma*. Torino: UTET.
- Gorfer, G. (2003). *Trento città del Concilio*. Lavis: Arca Edizioni.
- Ippoliti, E. (2000). *Rilevare. Comprendere misurare rappresentare*. Roma: Edizioni Kappa.
- Macrì, V. (2000). *Le strutture voltate. Storia, architettura, rappresentazione*. Reggio Calabria: Biblioteca del Cenide.
- Mandelli, E., & Velo, U. (Eds) (2010). *Il modello in architettura. Cultura scientifica e rappresentazione. Materia e geometria*, n.18/2010. Firenze: Alinea editrice.
- Massari, G. A., Bernardi, F., Bonora, M. C., & Svaldi, K. (2007). Modelli digitali per la conoscenza e il progetto del costruito. Il castello di Malosco in Val di Non. In *Sistemi informativi per l'Architettura. Atti di: e-ARCOM 07, Ancona Portonovo, 17 - 19 maggio, 2007* (pp. 387-392). Firenze: Alinea Editrice.
- Massari, G. A. (2012). Rilievo dell'architettura. Modelli scientifici e rappresentazioni tematiche per la conoscenza, l'intervento, la comunicazione. In Cunaccia, M., Dallemule, M., Betti, C. (Ed.), *Monumenti. Conoscenza, restauro, valorizzazione. 2003-2008* (pp. 169-177). Trento: Provincia Autonoma di Trento.
- Massari, G. A. (2014). Per un rilievo "sostenibile". In *Italian survey & International Experience. Atti di: UID2014, Parma, 18-20 settembre 2014* (pp. 931-942). Roma: Gangemi.
- Migliari, R. (2009). *Geometria descrittiva – Volume II – Tecniche e applicazioni*. Novara: CittàStudiEdizioni.
- Musso, S. (2010). *Recupero e restauro degli edifici storici. Guida pratica al rilievo e alla diagnostica*. Roma: EPC.
- Musso, S. (1995). *Architettura segni e misura. Repertorio di tecniche analitiche*. Bologna: Esculapio.
- Sdegno, A. (2002). *Architettura e rappresentazione digitale*. Venezia: Libreria Editrice Cafoscarina.