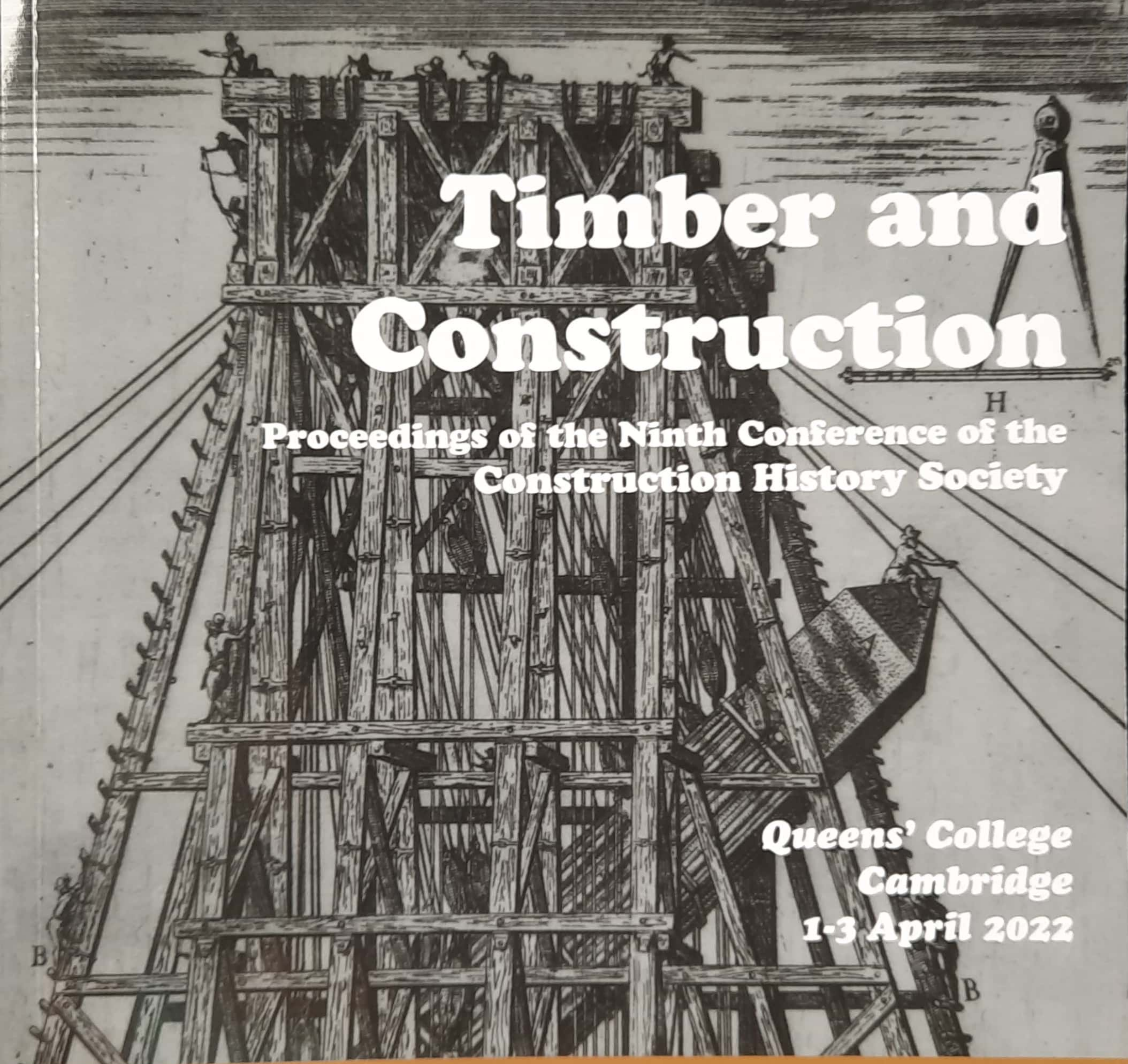

Timber and Construction

Proceedings of the Ninth Conference of the Construction History Society

Queens' College
Cambridge
1-3 April 2022

Edited by
James W P Campbell
Nina Baker
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THE SEVENTH ANNUAL CONSTRUCTION HISTORY SOCIETY CONFERENCE

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In memory of Thelma Seear

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Wooden vaults in Naples between survey and construction knowledge: the case of the church of *Santa Maria Egiziaca all'Olmo*

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Abstract

This paper deals with the wooden vault of the church of *Santa Maria Egiziaca all'Olmo*, interlacing historical data with outcomes of field research through an interdisciplinary work. The study analyses the individual parts composing the vault through the critical reading of documents preserved in the Neapolitan archives, a series of comparisons with other coeval wooden vaults and the analysis of the results of the geometric survey [1].

Introduction

Vaults made of wooden ribs and reeds spread throughout the Italian peninsula with numerous variations since the sixteenth century. The need to create lightweight structures, not necessarily walkable, led to the definition and adoption in distant contexts of a construction system that has its roots in Roman technical culture. Although, for obvious reasons of preservation, no Roman wooden vault has survived to the present day, traces of holes in the ancient walls – as in the case of Pompeii and Herculaneum – allow us to hypothesise a *longue durée* of the technique, which, however, appears to come to a standstill during the Middle Ages.

According to the current state of studies, wooden and reeds vaults did not emerge in the Neapolitan context till the second half of the sixteenth century [2]. During the Middle Ages wood was a well-established choice as construction material for floors and trusses. In this respect, the 1521 translation of Vitruvius' treatise may have played a pivotal role in the revival of light building techniques and paved the way towards the adoption of wooden vaults in construction. However, it was the eighteenth century that saw the greatest proliferation of these types of vaults in Naples. In the aftermath of the strong earthquakes that struck the city in the late seventeenth and early eighteenth centuries, wooden vaults started being preferred to the common heavy vaults in yellow tuff in view of their intrinsic lightness.

The case of the church of *Santa Maria Egiziaca all'Olmo* in Naples should be framed in this context and period. (Fig. 1) Its vault made up of wood and reeds is an exceptional case due to its elliptical layout, made more complex by the presence of many overlapping layers at the extrados of the vault. The research activity has been focused on the development of a methodology for the analysis of this case-study, conducted with an interdisciplinary approach, between survey activities and historical-constructive studies, under the guidance of Profs. Massimiliano Campi and Valentina Russo of the Department of Architecture of the University of Naples Federico II [3].

In view of the complexity and poor accessibility of the vault, combining the results of the geometric survey with the information derived from the historical investigation has been a clear requirement for the analysis of the vault. The geometric survey, carried out by means of digital photogrammetry, has allowed the identification of dimensional and colorimetric characteristics as well as the exact position and size of the wooden elements of a significant portion of the vault, otherwise not detectable with traditional methods. This experience has highlighted the limits of the technologies currently available for surveying these structures, thus posing new research questions.

Figure 1: Naples, Church of Santa Maria Egiziaca all'Olmo: view of the church and the vault.

The church and the vault: a brief historical overview

The church of *Santa Maria Egiziaca all'Olmo* is part of a large monastery founded in 1342 in one of the poorest neighbourhoods of the city to house repentant prostitutes. The structure is the result of numerous interventions carried out over the centuries and was built on a chapel, under the name of *Santa Maria di Cerleto*, which existed before the foundation of the monastery [4].

Between the end of the sixteenth century and the beginning of the seventeenth century, the church and monastery underwent major restoration works [5], but the intervention that gave the structure part of its current configuration dates back to the 1680s. The nuns, who belonged to the high aristocracy of the Kingdom of Naples, were eager to celebrate the social role of the monastic community in the city and to give the complex greater magnificence, displaying a new strategy of persuasion towards the lay community, a result of the Counter-Reformation. The lavish decorations and furnishings were, in fact, used as a tool for religious propaganda.

The project was entrusted to the architect Dionisio Lazzari [6] who, between 1683 and 1688, worked on the transformation of the church and the layout of the small square in front of it. It should be pointed out that the current urban situation, not dealt with in this essay, is the result of a significant urban evisceration carried out at the end of the nineteenth century [7].

Lazzari's work was drastically interrupted by the violent earthquake that struck the city in 1688 and by his death in 1689. Work continued under the direction of other architects and engineers until the first half of the eighteenth century [8]

Dionisio Lazzari, in order to integrate the church with the surrounding medieval secular buildings, rejected the solution of a monumental façade. The interior space was conceived following the Baroque trends of the period. The single nave was designed on an elliptical plan with five rooms on each side, three of which were used as chapels. The altar area was covered by a dome accentuating the development of the major axis of the ellipse. Regarding the idea of the nave on an elliptical plan, Lazzari was certainly influenced by the experiments carried out in the first half of the seventeenth century by Fra Nuvolo in the church of San Carlo all'Arena, which was undoubtedly an important reference [9].

The original vault covering the nave, of which no trace remains today, was probably designed as a heavy tuff structure, similar to the one in the church of *San Carlo all'Arena.* According to some historiographic hypotheses, it was probably visible from the outside [10]. This vault was set on a portion of masonry (ring), a partial trace of which is still visible today. The work carried out at the end of the twentieth century, which involved raising the structure with the construction of a high reinforced concrete kerb, overlapped the pre-existing structure, leaving only the impost of the original vault visible in some parts.

The vault collapsed for unknown reasons in 1742. In that year, the deed drawn up by the Neapolitan notary Giovan Battista Cantilena [11] informs us that a large part of the church had collapsed and that the task of drawing up a new project and rebuilding the structure had been entrusted to the architect Michelangelo de Blasio [12]. The document is extremely interesting in that it provides information on the materials to be used. As for the vault, it was planned to build it with a structure of wood and reeds. The sudden collapse probably induced the architect to create a false vault, lighter than the existing one, which would not weigh too heavily on the new walls [13].

It should be noted that in the same year the choir vault of the church of Santa Maria Regina Coeli in Naples also collapsed and was rebuilt in 1743 using wood and reeds. Although in that case the geometry of the structure was different; the two vaults have in common not only the material and partly the dimensions, but also the presence of an imposing wooden support structure, probably built in different periods. (Fig. 2)

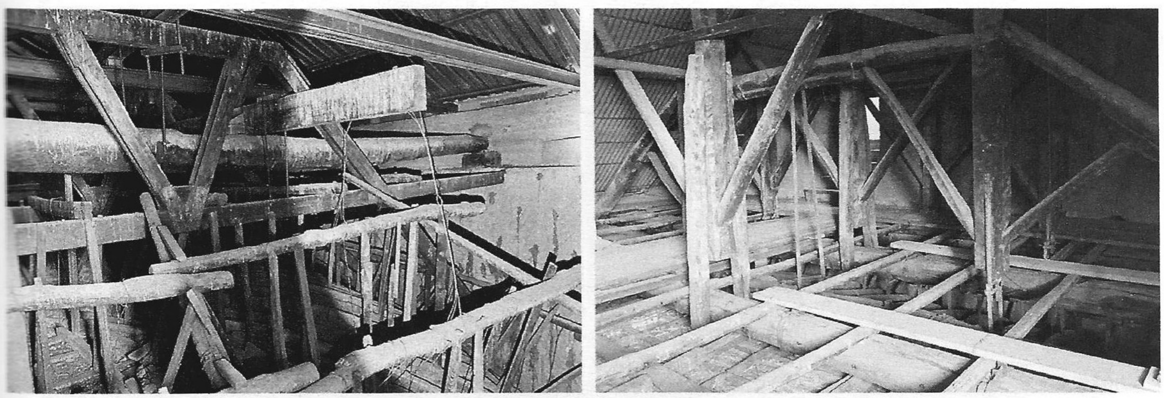

Figure 2: Naples, Church of Santa Maria Egiziaca all'Olmo (on the left); Church of Santa Maria Regina Coeli, choir (on the right): view of the extrados of the vault and the supporting structure.

Unfortunately, the above-mentioned deed does not go into more detail on the new vault and does not provide explanatory drawings of the structure. Instead, a drawing of the new wooden truss was attached to the document, which presents two peculiar aspects: the structure was based on a continuous wooden kerb, which was unusual in the local construction practice, and it was reinforced, in the lower part, by two inclined beams whose ends were embedded in the masonry [14]. (Fig. 3)

No subsequent transformation or consolidation of the wooden vault is known. It was slightly damaged by the earthquake of 1805 [15] and apparently unaffected by the work on the church roof carried out in 1944, after the bombing of World War II, and following the devastating earthquake of 1980 [16]. The latter restoration intervention which took place between 1986 and 1989, was not very respectful of the historical background and included the construction of a massive concrete kerb and the replacement of the old wooden trusses with new steel elements. Although the bills of quantities do not describe the work carried out in detail, a visual analysis of the vault shows that it was consolidated with steel tie rods, which connected the various parts of the roof and of the vault.

Of the old wooden truss, only the horizontal tie beams have been left *in situ*, resting in some places on wooden supports, and in others, embedded in the concrete kerb. The discontinuous wooden bearing plates could represent the trace of what remains of the continuous kerb designed in 1742 by the architect Michelangelo de Blasio. Unfortunately, the presence of many overlapping layers, not easily datable, undermines the comprehension and the study of the structure.

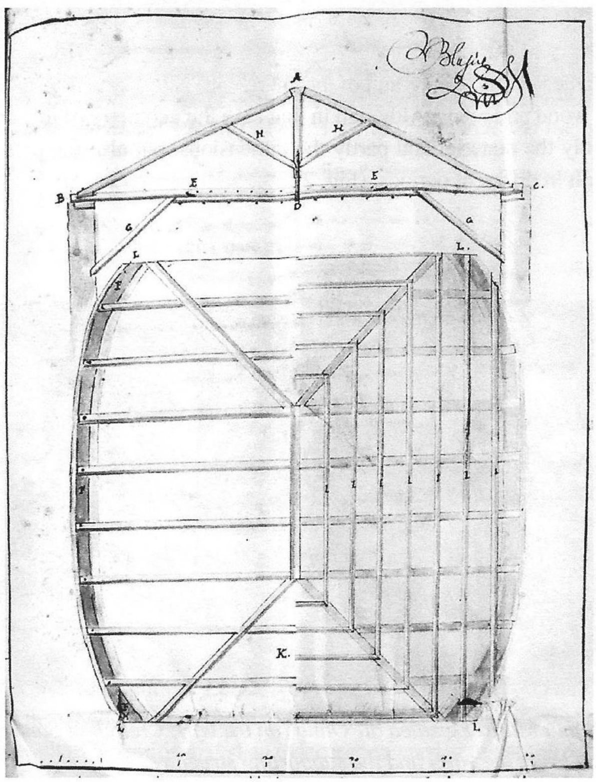

Figure 3: M. de Blasio, project of the new wooden roof, 1742 (from Borrelli (note 13, p. 51, ASNA)

The wooden vault between survey and knowledge

The phase of knowledge and analysis of the vault, of its morphological, dimensional and geometric characteristics, developed from survey drawings. This has allowed us to know and support the analysis of the changes that have occurred over time [17]. The wooden vault of the *Santa Maria Egiziaca all'Olmo* has a very complex architectural structure, which determined the need to plan the survey phases accurately. It required a collection of heterogeneous data that led to the creation of a digital database that describes the current state of conservation [18].

The articulated form of the wooden vault has required careful planning of the survey phases, both in terms of the use of technological instruments and data management procedures. With these premises, it was appropriate to identify suitable tools to overcome the environmental conditions of the object of study, outlining the survey campaign in detail and choosing the most suitable method for studying the elements of the vault. This has been an opportunity to test protocols for the use and management of relevant technologies.

The survey operations have been preceded by various inspections, necessary for a direct knowledge of the object and following the assessment and conformation of the area to be surveyed. In the operational approach that characterized the survey and the subsequent phases, the research has addressed in the first instance the problem relating to the accessibility of the wooden vault as it is placed at a height of 17.34 metres from the entrance to the church. Therefore, it has been essential to study the church as a whole and the access points to the extrados of the vault. It can be reached through two openings located at the upper ends of the nave, from the side of the dome (at a height of 17.34 metres) and from the entrance pronaos (at a height of 15.50 metres), currently being restored. In the latter case it was not possible to proceed with the acquisition phases of the metric data but, through the visual analysis and the photographic survey, it has been possible to deduce useful information for comparison with the portion of the vault actually surveyed. (Fig. 4)

Figure 4: Naples, Church of Santa Maria Egiziaca all'Olmo: view of the extrados of the vault from the two openings (side dome on the left; side pronaos on the right).

The only point of collection of data for the survey, in fact, is a window (1.20 metres x 1.50 metres) located on the side of the dome accessible from the sacristy. From this space there are several flights of stairs, very narrow, without resting landings and handrails that culminate on an outdoor terrace at a height of 10.66 metres. Then, two wall ladders, one composed of five rungs, the other of ten rungs, has allowed us to reach the height. (Fig. 5)

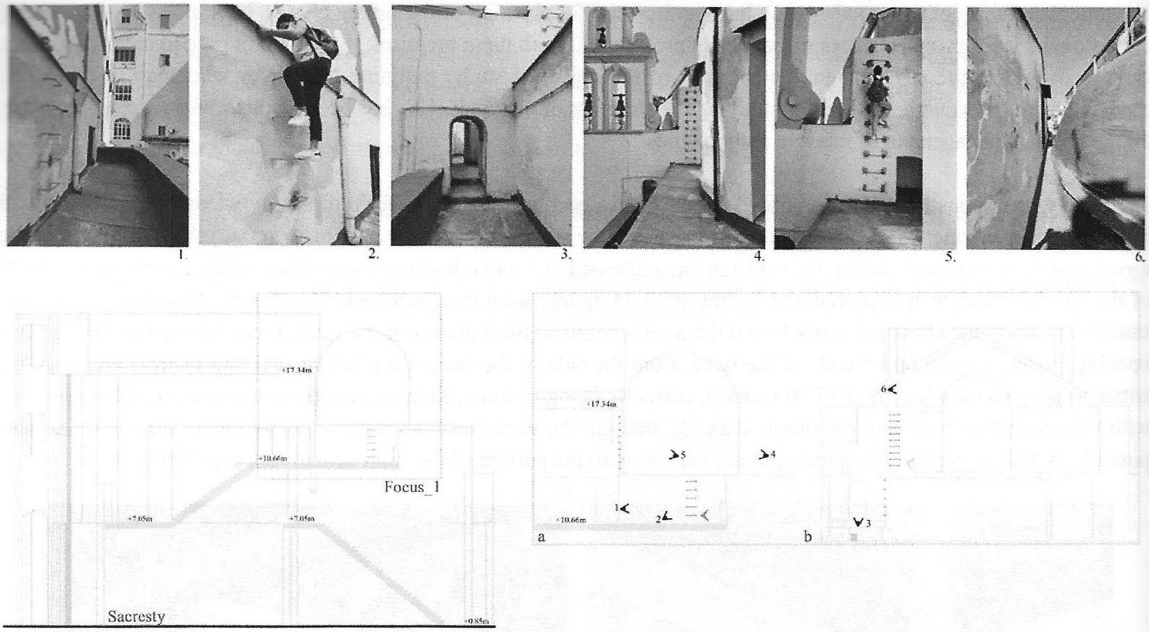

Figure 5: Diagram showing the environmental criticalities of the survey.

Through a very narrow space of 0.30 meters between the dome and the vault it has been possible to reach the opening from which the extrados of the vault is visible, protected by a two-pitched roof. On the basis of these limitations, as regards the survey phases, the methodology of digital photogrammetry was chosen. Among the survey techniques that in recent decades have profoundly transformed the methods of data acquisition and restitution, digital photogrammetry is certainly one of the most interesting. Thanks to the new Structure from Motion (Sfm) applications, this technique allows the acquisition of a three-dimensional product, which is fundamental for the purposes of documentation, analysis and representation. The result is a three-dimensional model with levels of accuracy similar to those generated with active optical sensors *(range-based)* as laser scanner, Lidar, etc. In the field of Cultural Heritage, the use of the methodology based on passive optical sensors *(image-based)* is increasingly widespread, considering the need to couple the accuracy of the metric data with a colorimetric representation capable of expressing the qualities of the object [19].

The points of the station would not have been sufficient, and it was not possible to use 3D and 2D targets fundamental for the alignment between the scanning positions during data processing. The tools used were therefore a professional reflex camera and a smartphone, two practical, inexpensive, small and easily transportable objects. In addition to the difficulties already described, particular attention was paid to the data acquisition phase as the window is placed at a higher level than the extrados of the vaults. It was not possible to integrate the direct metric survey on the elements of the vault to scale the three-dimensional model obtained from photogrammetry. The window space and other measurements taken in situ were used as a reference. At the same time, the highly variable lighting conditions required the planning the photographic shots in order to avoid areas of shadow and overexposed areas in the captured images. Furthermore, the reduced acquisition space has not allowed a view of the vault as a whole but only a small portion, which has been used as a guide to reconstruct the remaining part by analogy. A second photogrammetric survey has been carried out for the interior of the church.

Data has been collected through photographic acquisitions with a Nikon D5000 digital SLR. To guarantee a sufficient amount of information, it was decided to use both a parallel and convergent axis acquisition technique producing an average overlap between the images acquired for the different datasets of about 70 percent. Then, 38 frames were taken using a digital camera, with manual mode, without the use of flash and with a focal length of 18 millimetres.

The complexity of the vault has required a second survey phase aimed at determining an integrative model of the missing parts. Not being able to lean out further from the window, after the first photo shot, with the integrated camera of the smartphone, Iphone12PRO, two videos were recorded. In this case, a special telescopic rod for photographic purpose has been used with an extension ranging from 0.70 metres to 1.50 metres. This telescopic rod, with the smartphone mounted at the end using the anchor support, has made it possible to record videos, capturing further information. At the same time, an additional photogrammetric survey was carried out inside the church using the same instrumentation and acquisition technique. Through this survey, the intrados of the elliptical vault was outlined.

Once the data acquisition phase was completed *in situ*, the processing phase has been carried out with the aid of two photogrammetric programs. From the first program, 3D Zephir, the frames from the videos shot have been extracted while from the second, Agisoft Metashape, all the data have been processed in a single workflow [20]. The Self-Calibrating Bundle Adjustment of the photogrammetric application automatically oriented the images. The SfM algorithms has allowed the simultaneous estimate of the three-dimensional structure of the scene (Structure) and the position of the camera (Motion), i.e. the internal and external orientation parameters of the camera.

With these premises, and following the consolidated photogrammetric processing, after the alignment of the frames, the first step obtained has been a sparse cloud of 47,755 points. Once the alignment was correct, the dense cloud was created with the thickening of the dimensional and colorimetric points. From the dense cloud of 47,140,749 points, the polygonal model of 3,142,715 faces and 7,340 vertices was generated, which was reconstructed by organizing the points of the cloud into polygonal mesh surfaces. In this case, the model has been enriched with attributes capable of describing the surface aspects, restoring the visual apparatus of the artifact. Once the polygonal model was obtained, it has been possible to generate the final model through the texture from which the orthophotos for the redesign of the vault were extrapolated. The data was then combined to identify all the elements and reconstruct the form of the vault. (Fig.6)

The same methodological process was also conducted for the survey of the extrados of the vault. In this case, 125 images were acquired.

The difficulties of the data acquisition phases have not allowed the overall reconstruction of the wooden vault but the dimensional and colorimetric information obtained from the survey operations, albeit limited, has been fundamental for the definition of the individual elements and for the hypotheses of chronological reconstruction. On the basis of the survey carried out, in fact, it has been possible to analyse the elements in their three-dimensional form. Subsequently, this information has been isolated with representative methods at multiple levels of detail, and at various scales of representation. (Figs 7, 8, 9)

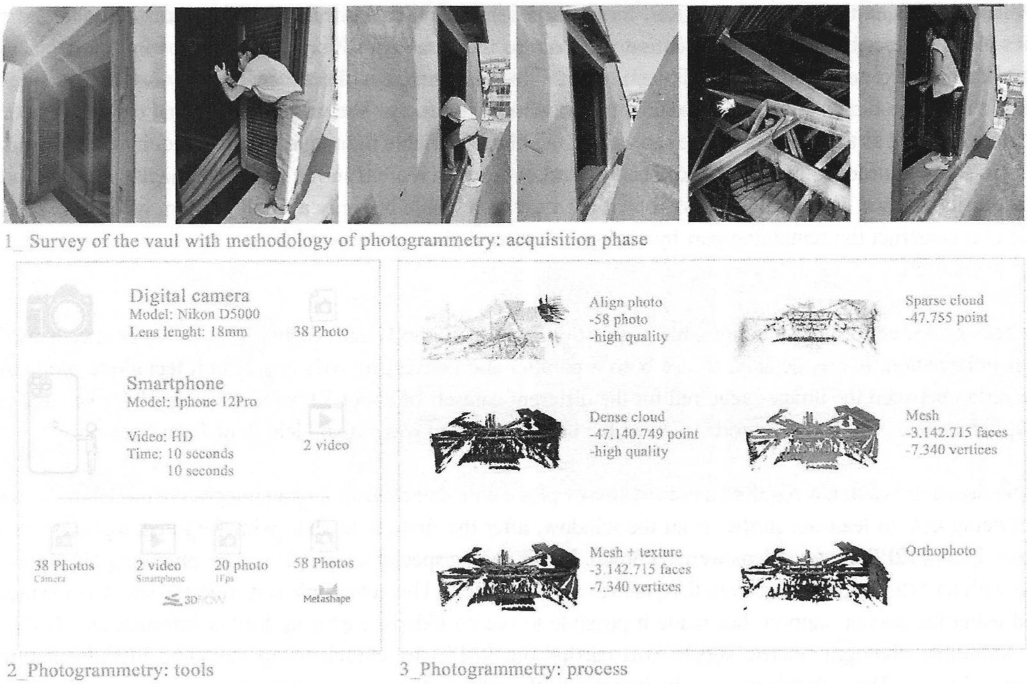

Figure 6: Acquisition, processing and elaboration of data obtained by photogrammetric survey.

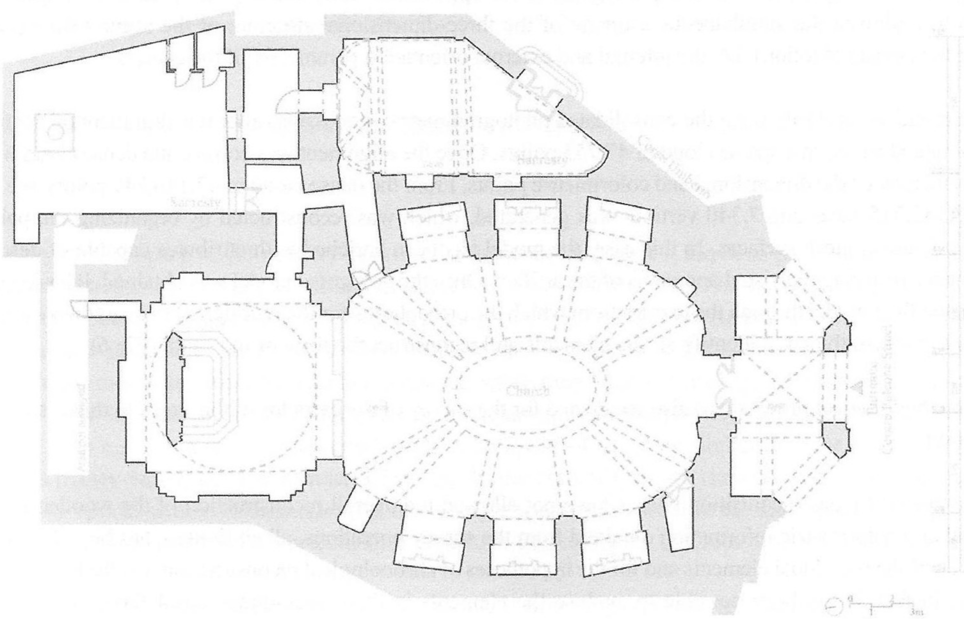

Figure 7: Naples, Church of Santa Maria Egiziaca all'Olmo: plan.

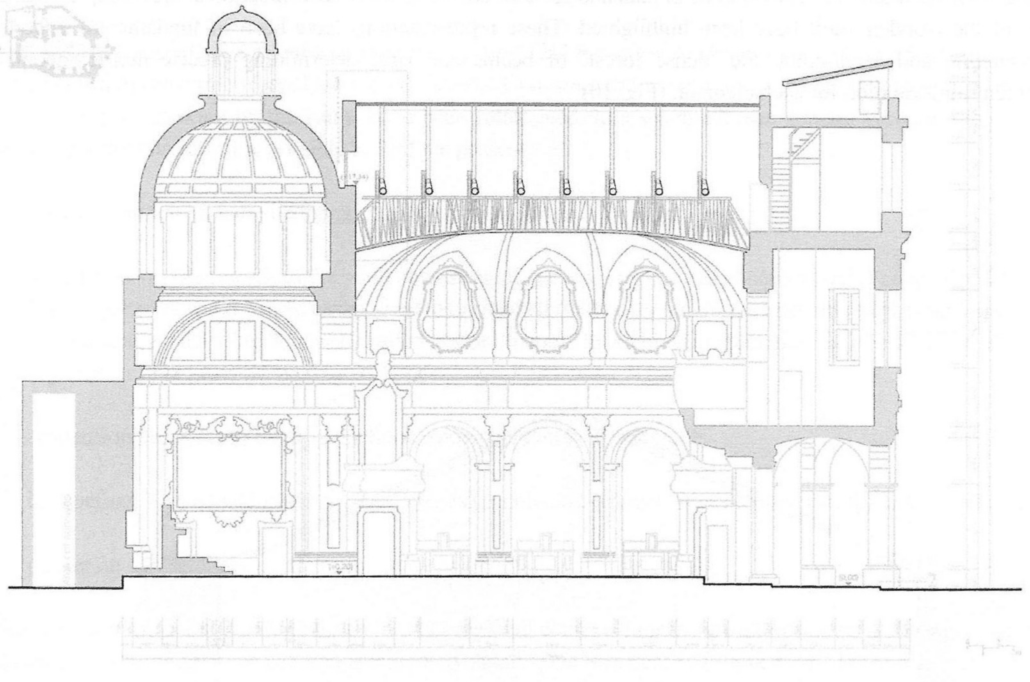

Figure 8: Naples, Church of Santa Maria Egiziaca all'Olmo: longitudinal section.

Figure 9: Naples, Church of Santa Maria Egiziaca all'Olmo: cross section.

Starting from the traditional elaborations in plan and section, drawn up from the orthophotos, the multiple distinguishing marks of the wooden vault have been highlighted. These representations have been of fundamental importance for understanding and cataloguing the 'dense forest' of beams and ribs, determining precise metric, geometric and colorimetric information for each element. (Fig. 10)

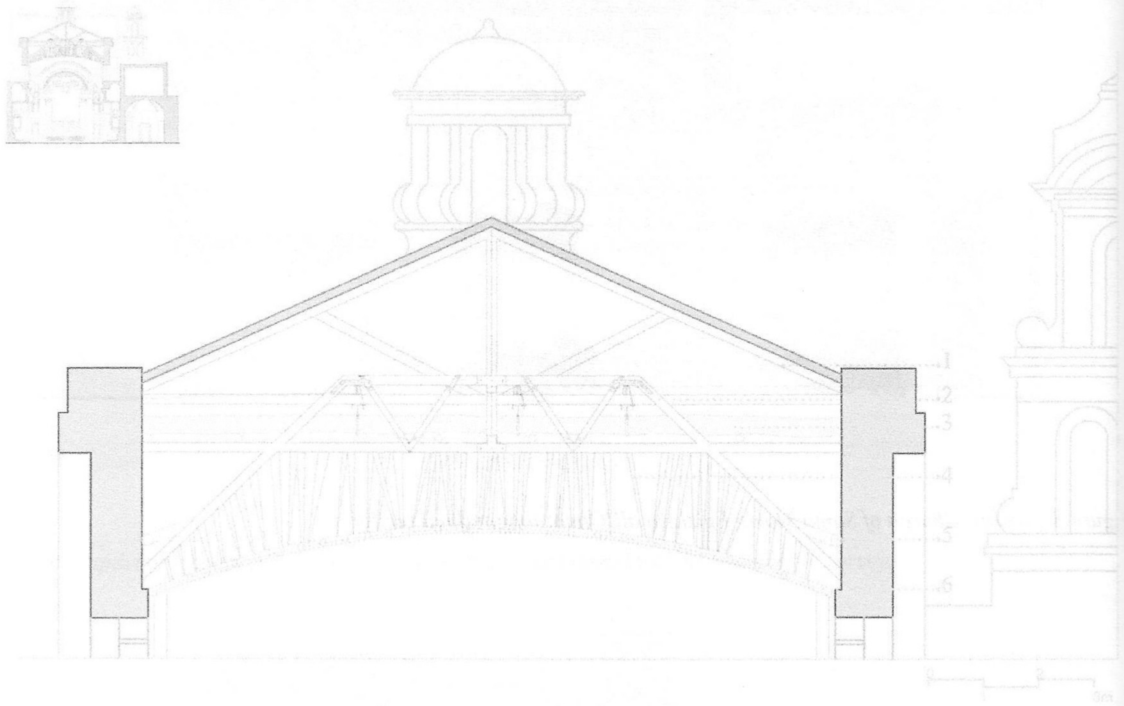

Figure 10: Naples, Church of Santa Maria Egiziaca all'Olmo: construction detail. 1) steel truss; 2) wooden reticular support structure; 3) tie-beam of the existing truss; 4) suspension elements; 5) wooden kerb; 6) wooden vault (ribs, restoni and reeds)

Construction features: parts of the vault and nomenclature

In order to correctly describe and interpret the parts that make up the vault of the church of *Santa Maria Egiziaca all'Olmo*, a comparison should be made with other Neapolitan wooden structures in order to frame the case under investigation in a wider context.

The eighteenth and nineteenth century technical literature on the Neapolitan area provides an initial and only partial vision of the wooden vaults, both in terms of the methods of execution and the parts making up the structures. For this reason, it has been necessary to start from the material data, combining field investigations with the interpretation of technical descriptions found in archive documents.

Construction features of wooden vaults in Naples

An initial, and only partial, direct and indirect investigation [21] has allowed the proposal of an initial outline of the various elements that constitute Neapolitan wooden vaults. Constants and variations in construction have been identified and the different parts making up the vaults have been catalogued. In a schematic and general view, starting from the extrados towards the intrados, it is possible to find the presence of:

1. a support structure, called armaggio;

2. a load-bearing framework of the vault consisting of curved profiles, called centine (ribs) coupled and nailed or held together by metal bands. Orthogonal to the shaped ribs are set transverse elements with a rectangular cross-section and a stiffening function, called restoni/listoni. In archival documentation, the ribs are also called fogliette or felle [22];

3. suspension elements to the truss or floor, known as ginelle or catinelle;

4. the coating. This can be made of woven reeds (canniccio), wooden sticks (called cerchj) or wooden boards;

5. plaster on the intrados.

Neapolitan wooden vaults, unlike those found in other regional contexts in Italy, are almost never self-supporting, except in rare cases where the room to be covered is extremely small. This is the case of some rooms in the historical flat of the Royal Palace of Naples, with a span of about three metres. In most cases, however, they are suspended from a support structure (listed in n.1 above) which may take one of three forms:

- a floor from which the vault is suspended;

- an inter-floor structure independent of the floor and consisting of equidistant beams, with their ends embedded in the masonry, to which the vault is connected;

- Lastly, a structure placed at roof level and autonomous with respect to the truss of the pitched roof. Supporting structures that are independent of floors and roofs are safer from a structural point of view. Connecting the vault to a floor that can be walked on or that is subject to possible vibrations could lead to localised stresses, undermining the equilibrium of a wooden vault.

The data available from direct surveys have been combined with indirect sources, in particular bills of quantities, mainly from the nineteenth century, and rates, such as *Tariffa del Genio*, dated 1838 [23]. According to this last one, woven reeds (*canniccio*) had to be made of large dry canes, crushed and tied with wooden sticks placed in squares of about 50 centimetres. The canes had to be covered with a layer of mortar about one centimetre thick.

The wooden vault of the Church of Santa Maria Egiziaca all'Olmo

The peculiarity of the church of Santa Maria Egiziaca all'Olmo lies in the complex support structure from which the vault is suspended. Observing the roof system of the church from top to bottom, thanks to the metric survey carried out, it has been possible to catalogue the different parts structurally connected to each other (Fig. 10):

- the steel roof, dating from the interventions after the 1980 earthquake (1989) and built to replace the existing wooden trusses;

- Tie-beams of the existing wooden trusses, without any structural function, resting in some places on wooden bearing plates and, in others, drowned in the recent reinforced concrete kerb;

- the wooden reticular support structure, consisting of rectangular section profiles, doubled, and connected by bolted metal plates. No information is available on the dating of this structure. Visual analysis of the wood and the nodes suggests that it may have been added or modified after the construction of the vault. In order to confirm this hypothesis, it would be advisable to carry out dendrochronological investigations and tests on the wood species;

- *ginelle/catinelle* (suspension elements) with the function of suspending the underlying wooden vault from the reticular structure. Such elements show a non-constant section and are nailed both to the ribs of the vault and to the base beam of the reticular structure;

- the actual wooden vault consisting of ribs, in some places doubled, placed at a distance between centres of about 40 centimetres and stiffening elements (*restoni*) fitted at right angles (distance between centres of about 35 centimetres). (Fig. 11) At the present time, the coating of the vault is not visible from the extrados due to a thick layer of dust. It is assumed, however, on the basis of historical data that it is made of reed.

It is worth emphasising that along the supporting walls of the vault there is a kerb consisting of wooden beams of circular cross-section placed one after the other and resting on beam bearing plates placed on the masonry. This wooden kerb serves as a support for a system of beams to which the suspension elements of the vault are attached. The grid of beams is only present at the ends of the elliptical area and serves as a support to the vault in the parts with the greatest curvilinear section. (Fig. 12)

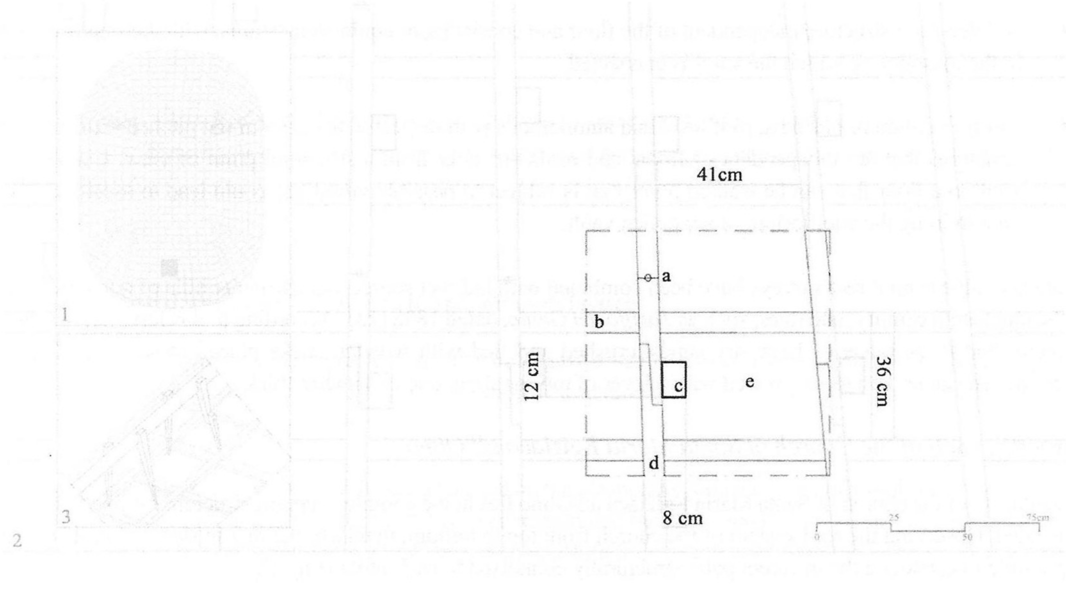

Figure 11: Naples, Church of Santa Maria Egiziaca all'Olmo: 1) hypothetical carpentry plan; 2) planimetric detail of the surveyed portion; 3) schematic drawing of the suspension elements (ginelle)

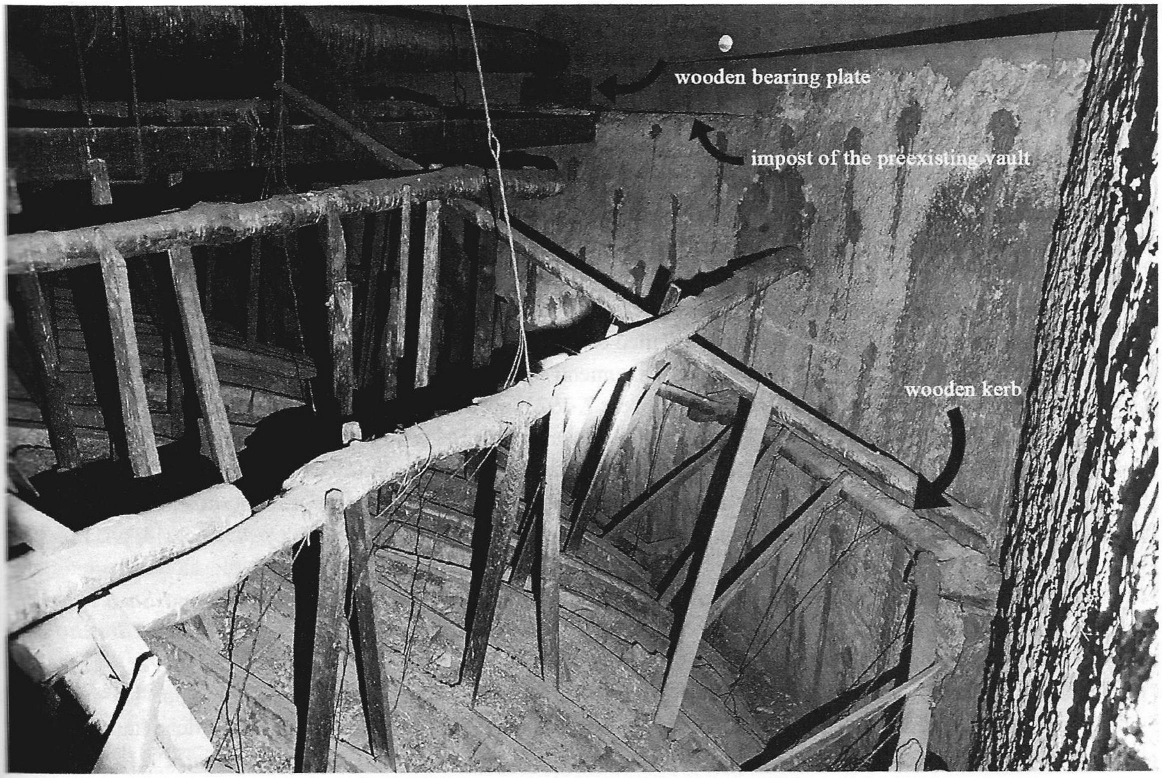

Figure 12: Naples, Church of Santa Maria Egiziaca all'Olmo: view of the wooden kerb.

At present, as already mentioned, a series of consolidations are visible, probably carried out between the second post-war period and the end of the 1980s. These are tie rods and hooping systems made of thin iron cables with the function of consolidating the connection between the support structure and the ribs. In addition, after the 1980 earthquake, the original truss tie beam and the reticular support structure were attached to the new metal truss by means of steel brackets. These interventions made the truss, the reticular support structure and the vault closely connected, thus modifying the original structural scheme that foresaw, for obvious safety reasons, the total autonomy of the vault with respect to the roof.

Conclusions

This paper represents the first result of a research in progress on the vault of the church of the *Santa Egiziaca all'Olmo* and, in broader terms, on the wooden vaults in the Neapolitan context. The experience carried out on the case study has made evident the need to combine historical research and direct knowledge of the building. Further innovative no-contact surveys and targeted investigations on the wooden parts could, in the future, support the hypotheses on the chronological transformations of the structure (dendrochronology and/or 14C.) and provide new findings. For example, the identification of the tree species could help to understand if the choice of the wood was mainly based on the mechanical properties or on the availability in the forest of the region. This combination of information and different expertise could open up new and stimulating fields of research.

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[1] Although the present paper is the result of a common research, L. Romano authors paragraphs 2 and 4, whereas M. Falcone authors paragraph 3. Introduction, conclusions, drawings and photos (2021) are by both the authors.
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[14] The drawing is published by Borrelli (note 11, p. 51) but it is no more attached to the related deed (ASNA).
[15] Naples, Diocesan Archive, *Vicario delle Monache*, b. 280D
[16] Naples, Archive of the 'Soprintendenza Archeologia, Belle Arti e Paesaggio per il Comune di Napoli', b.17/344
[17] M. Campi, A. di Luggo, R. Picone, P. Scala, (Eds), *Palazzo Penne a Napoli tra conoscenza, restauro e valorizzazione*. Napoli: Arte'm, 2018, pp. 31-36.
[18] A. C. Alabiso, M. Campi, A. di Luggo, *Il patrimonio architettonico ecclesiastico di Napoli- Forme e spazi ritrovati.* Napoli: artstudiopaparo, 2015, pp.17-31.
[19] L. De Luca, *La fotomodellazione architettonica.* Palermo: Dario Flaccovio Editore, 2011, pp. 19-29.
[20] P. M. Cabezos-Bernal, P. Rodriguez-Navarro, T. Gil-Piqueras, 'Documenting paintings using gigapixel sfm photogrammetry', *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLVI-M-1, 2021, pp. 93-100.
[21] Russo, Romano, Marulo, (note 2), pp. 87-102.
[22] ASNA, *Opere Pie-Spirito Santo*, fs. 48, ff. 218 recto; ASNA, *Ministero degli Affari Interni*, II versamento, b. 3602bis, n. 10.
[23] Corpo Reale del Genio, *Piazza di Napoli. Tariffa de' prezzi de' lavori che si eseguono dal Corpo Reale del Genio nelle fortificazioni e negli edifici militari di detta piazza*, Napoli 1838.