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The vaulted system of the Basilica of S. Ambrogio in Milan: A cross-feature in the Basilica's life. Restoration and interpretation

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ABSTRACT: The study of the construction of an historical building always includes several grades of complexity depending on the available sources and their accuracy, and on the interpretation of accessible information. This essay offers a novel integrated approach to the study of the construction history of the roof system of one of the greatest monuments in Milan: the Basilica of S. Ambrogio. Different types of vault are analyzed, using historical drawings and photos, archival documentation, geometrical and laser scanning surveys, aiming at narrating the construction history of the vaulted system of the church, which can be integrated with future studies and analysis. 3D models help the realization of hypotheses that are based on the existing literature, historical drawings and interpretations.

Keywords: 12th–20th centuries, Milan, Vaulted System, 3D Modeling, Restoration

1 INTRODUCTION

The Basilica of S. Ambrogio was founded in the late fourth century by Archbishop Ambrogio and was part of a wide project that aimed at making Christianity part of the urban spaces, by creating a monumental center in Milan and spreading places of worship throughout the suburbs (Lusuardi Siena 1997, 35). It is in this frame that Ambrogio's project of establishing four churches, approximately located at the four cardinal points, took place: S. Ambrogio (Basilica *Martyrum*, S. Nazaro (Basilica *Apostolorum*), S. Simpliciano (Basilica *Virginum*), S. Dionigi (Basilica *Prophetarum*). The Basilica of S. Ambrogio was built on a former pagan, and later Christian, funeral area (Ambrosioni 2003, 89).

From its foundation to the present days, the Basilica has gone through many changes over the centuries that have deeply influenced its morphology, arrangement and constructive materials and which sometimes have been hidden behind its uniform appearance. Starting from the late fourth century, when Archbishop Ambrogio founded it, it was completely renewed in the Middle Ages during the Romanesque reconstruction in the arrangement that still characterized the church. Architects such as Donato Bramante, Pellegrino Tibaldi and Francesco Maria Ricchino worked on many projects inside the Basilica: the *Canonica*, the *Atrio di Ansperto*, and the decoration of the dome. Later, in the nineteenth century a relevant restoration was carried out, supported by the Abbot of the church, Francesco Maria Rossi and his architects (many figures were involved in this work—for a better understanding see: Capponi et al., 1994). During the Second World War, the Basilica suffered many damages (Marucci 2004) due to its close proximity to the *Casermadei Veliti Reali* (Zanoli 1845, 429), and architect Ferdinando Reggiori was in charge of the restoration work.

Although the church is considered as an *unicum*, one of the greatest example of the Romanesque architecture in Lombardy (Peroni 1987), it has always been an 'uninterrupted temple', as Gatti Perrer well documented in her publication (Gatti Perrer 1995), where architects, artists and abbots worked and expressed their will. The construction history of the roof system (wooden roof and brick vaults) mirrors the historical stratification of the church.

2 METHODOLOGICAL APPROACH

The integrated approach used in this study is based on three main sources: (i) historical and archive research—documents, photos, drawings; (ii) geometrical survey and Building Archaeology analysis—accomplished with laser scanner and photogrammetric image acquisition; (iii) study of historical interpretations and suggestion of new ones. This phase is based on the data cross-check between the sources (i) and (ii), and the correlation of the geometrical-dimensional data with the historical ones was fundamental. The study of

the existing geometrical surveys was necessary in order to achieve this step. Starting from the present arrangements and going back to the previous ones, a virtual subtraction process was used to analyze the roof system of the church, virtually removing the historical layers as the process of excavation used in archaeology. The research was supported by a laser scanning survey that helped capture the geometrical and spatial complexity of the church. Although a detailed geometrical-dimensional survey with laser scanning techniques hadn't existed before, historical-geometrical surveys used to offer a reliable source of information, not only for their dimensional accuracy, but also for the interpretation of the church reported in these drawings. Most of these geometrical surveys are from the nineteenth century: the boards by Ferdinando Cassina, before the restoration of Abbot Rossi (Cassina 1844), the ones by Heinrich Hübsch, who also studied the Basilica before the restoration, and in his plan he presumably marked in black the oldest parts of the church (Hübsch 1863, 110), the accurate drawings by De Dartein, collected in his *Étude sur l'architecture lombarde* in 1865 (Bella 2013), and the hypothesis reconstructions of the church by Landriani (Landriani 1889). More recently, the drawings by architect Reggiori before and after the Second World War represent important sources for the study of the Basilica, because they also show parts and elements that he could analyze and measure among the ruins, but that are nowadays no longer visible. Most of the drawings by Reggiori are collected in the S. Ambrogio Archive. All the existing drawings and dimensional surveys were analyzed and compared with the laser scanning surveys and direct observation in order to better understand the geometrical complexity of each vault. The goal of this research is to understand the vaulted system in its material, constructive and technological aspects, trying to unveil not-yet-fully-analyzed aspects of a well-known building that has been studied extensively in the literature, through a data cross-check process. Ideally tracing a *file rouge* from transformation to transformation throughout the Basilica's life cycle, the research wants to be the first step leading towards a specific analysis of the construction history of the roof system, based on the study of the existing literature and on the direct observation of each architectural component.

3 ROOF AND VAULTED SYSTEM

3.1 *Introduction*

In the Basilica, it is possible to outline several types of vaults characterized by different shapes, construction time, techniques and materials. The mosaic dome of S. Vittore in Ciel'Oro chapel is probably the best-known vault in S. Ambrogio, together with the lunette vaults of Bramante's *Canonica*. The quadripartite rib vaults of the church, with the pillars that mark the rhythm of the nave, are of the same typology as the ones of the Narthex, although their ribs have different shapes. Other typologies are: the groin vaults in the aisles, the *matronei* and the *Atrio di Ansperto*; the barrel vaults and the small domes in the chapels of the north and south aisle; the presbytery dome, made of 8 irregular masonry webbings. They are a perfect example of the restorations that occurred in the Basilica over the centuries because different past events influenced their transformation background, starting from the recent one—the aerial bombing during the Second World War.

This chapter analyzes the restorations of the vaults, including the wide theme of the Basilica roof system and its related topics, showing the main transformation in each period and using the 3D model to support hypothesis and reconstructions.

3.2 *Restoration due to the damages of the Second World War*

Architect Ferdinando Reggiori is a recurring figure in the Basilica's life cycle, due to his prominent role in the restorations of the church both before and after the Second World War. Regarding the roof system, the main interventions are related to the damages of the aerial bombing during the summer of 1943. Only 4 out of the 13 spans of Bramante's Portico were not demolished, but even if they were not completely destroyed, they were in a dramatic state of conservation because the roof of the first floor was torn down. Other damages occurred to the wooden roof of the church, that was wiped out, leaving the extrados of the vaults exposed, and to the vaults of the crypt that were ruined because of the fall of the presbytery slab (Marucci et al. 2004; Reggiori 1949; Reggiori 1959, 253). In the reconstruction of the Bramante's *Canonica* (columns, arches, vaults, walls) Reggiori used the debris from the damages as much as possible. He managed to reconstruct one span of the *portico* (columns, masonry arch) with these materials, whereas for the others he used new ones (Reggiori 1959, 259). The *Canonica* is made of two lunette vaults, with same dimensions and characteristics, located to the east and the west sides of the main double-height span, which covered a rectangular space (25 6 m) of 6 span each. The lunette vaults of the *Canonica* were probably realized to allow the natural light to reach the north chapels through a space covered by barrel vaults. Thanks to thermo camera image acquisition, it was possible to see the brick texture,

made of stretching bricks arranged in concentric rectangles, a usual constructive technique for this kind of structures. Although the *Canonica* was restored during the nineteenth century—double-height pillars, church door and tie-rods (Capponi 1987, 68) – there is no record of any kind of work or transformation of the vaults in this period.

Reggiori rebuilt the vaults, the columns and the walls of the south-west side of the Portico and from the comparison of the façades before and after restoration it is possible to notice other differences in the shape and dimension of the windows. This is because Reggiori decided to put the windows in the middle of the exterior spans of the *Canonica*, and no longer align them according to the interior space of the north chapels as it was in the nineteenth century.

3.3 *Interpretive restoration during the nineteenth century*

Thanks to the records of Abbot Rossi, who kept traces of the restorations through a letter exchange with his friends (Rossi 1884), architects Gaetano Landriani (Landriani 1889) and Fernand De Dartein—and especially the latter who realized an impressive notebook about the church during his stay in Milano (Bella 2013) – it has been possible to have a first understanding of the restorations of the nineteenth century. Strangely enough, the works on the vaults are not mentioned in the *Programmi dei lavori* (Works Program) that the Restoration Commission compiled in order to define the necessary interventions (Bisi et al. 1857a-b).The reason that brought to integrate the vaults with new elements or sometimes to rebuild them was their bad state of conservation. As Abbot Rossi recorded, some of the vaults were completely rebuilt; others were restored through the addition of wooden wedges in the cracks and then covered by a new layer of plaster (Rossi 1884, Lettera CXXVIII, 176). Also, the first vaults of the nave were badly damaged, as were the ones in the aisles and in the *matronei* (Rossi 1884, Lettera VII, 25–26). The vaults of the nave, of the aisles and of *Atrio di Ansperto* were rebuilt, including the arches and the ribs—except for the ones of the Narthex on the ground floor. 3 webbings out of 4 of the second vault of the nave needed to be rebuilt, just like the vaults in the aisles (Rossi 1884, Lettera CXXXI, 183). In his letters Abbot Rossi often used terms, such as *rifare* (redo) or *rifabbricare* (rebuild) and it would be of immense value to understand their real meaning, because it would help to better appreciate the relevance of the nineteenth-restoration. Also, De Dartein's records are really interesting because they offer dimensional data (Bella 2013, 166–167), such as the thickness of the ancient vaults, which were used to correlate the drawings made by Reggiori with the ones of this research. The thickness of the vaults has gone from 0.40–0.45 m (and even 0.50 in the upper parts and at the level of the corbels) during the ancient times to 0.25 m in the nineteenth century. One interesting features of the Romanesque vaults, highlighted by De Dartein's drawings, is the presence of *voûtes de decharge* (discharge vaults) located at the four angles of the extrados of the vault aisles. It is a system used to compensate the different angular levels through the thickness of the keystone, leveling the plane of the floor (Bella 2013, 85). Through a data cross-check between the records by Rossi and by De Dartein, it has been possible to have a more comprehensive understanding of the vault restoration projects in the nineteenth century that can be summarized as follows.

Nave: first span—vault was rebuilt, ribs were kept; second span – 3 out of the 4 webbings were rebuilt, ribs were kept; third span—vault and ribs were rebuilt (this vault had already been rebuilt, probably in the late twelfth century—until the nineteenth century it was characterized by two rib vaults with pointed arches, see section 3.4).
Aisles: all the vaults were rebuilt both on the ground floor and the level of the matronei, except for the first and half of the third vaults of the west aisle on the ground floor.
Narthex: all the vaults were rebuilt, except for the ribs at the ground floor.
Atrio: the upper parts of the vaults were rebuilt.

The result is an overview of the restoration of the vaulted system, which raised a new interesting question when put in correlation with the geometrical-dimensional survey. Each vault presents the same geometrical features (dimension and shape of the ribs, curves of the webbings, constructive materials), so this opens some possible scenarios: either they were all restored even if there is no record of it for some vaults, or some were left untouched. A future investigation of these vaults could be carried out to analyze their masonry texture and material, in order to have a final comparison.

3.4 *The "Barlonghe" vaults*

One of the most impressive transformations occurred to the vaulted system is the nineteenth-century restoration of the vault in the first span of the nave. The drawings of the church by Cassina (Cassina 1844, Tav. XXV-XXXV) show the Basilica before the restoration: there were two rib vaults (*Barlonghe* vaults) with pointed arches—the ribs of the west one were square, while the ribs of the east one had a toric section. During the restoration, a trace of the supposed original vaults was

found and this was the reason why Abbot Rossi decided to tear down the two vaults and rebuilt them as they were before and as shown in a drawing of the Raccolta Beltrami (Rocchi 1995, 179). The *Barlonghe* vaults were probably built after the collapse (around 1193/94) of the previous one, which caused the ruin of the pulpit, as some documents of the twelfth century report (Ambrosioni 2003, 103). The collapse was limited to the first vault (there is no records of damages occurred to other parts) and a hypothesis could be a localized failure of the vaulted or roof system, due to structural weakness. In fact, the construction of the *Barlonghe* vaults allowed the realization of a different roof system: wooden trusses and not beams lying on the transversal walls, as shown in the longitudinal section by Cassina (Cassina 1844, Tav. XXXII). Thanks to the detailed drawings of the *Barlonghe* vaults made during the nineteenth-century restoration, it has been possible to model them and visualize the 3D of the church as it was before the intervention. In order to make the transformation easy to visualize, the vaults were placed along a chronological line, where it is possible to see the changes occurred over the centuries (Figs. 1–2). The vaults of the nave have been further analyzed, with a special focus on the *Barlonghe* vaults (Fig. 3).

3.5 *The restoration of the dome by Tibaldi*

The dome is made of 8 curved segments and the curve of the webbings is a parabola with pointed arches: the ray of the curves is 7.1 m, while the diameter of the springing is 11.4 m. The four pendentives at the angles help to unload the weight of the dome on the pillars.

In the nineteenth century drawings of the church, i.e. the section by De Dartein, it is possible to see that the presbytery is covered by a cross vault as nave and aisles (Bella 2013, Tav. X). In another drawing, the dome is covered by a wooden roof—this was another hypothesis made by De Dartein (Bella 2013, Tav. V). In his drawings, Landriani provided the probable previous arrangement of the dome with wooden structure (Landriani 1889, Tav. V-VI) and also Reggiori agreed with that version (Reggiori 1945, 22). For Landriani the dome, as we can see it now, was built approximately around the end of twelfth century or the beginning of thirteenth. This idea is mainly based on the observation of the pillars of the church which all have the same dimension and horizontal section, which proves that the pillars weren't built to bear different loads, and also on the belief, widely spread in the nineteenth century, that craftsmen in the eleventh-twelfth centuries were not able to build a complex vaulted structure, such as the dome. However, there is no evidence of a previous wooden roof for the presbytery, so the question is still open. The dome was restored by architect Pellegrino Tibaldi, who is also responsible for the renovation of the wooden choir of the church, as commissioned by Carlo Borromeo (Reggiori 1945, 22). It is difficult to understand if and how Pellegrini restored or rebuilt the existing dome. The main interventions are related to the stucco decoration, made in a *cassettonato* style with four angels at the corners, and the lantern that replaced the previous one. Both the decoration and the lantern were changed during the nineteenth-century restoration (Capponi 1995, 229).

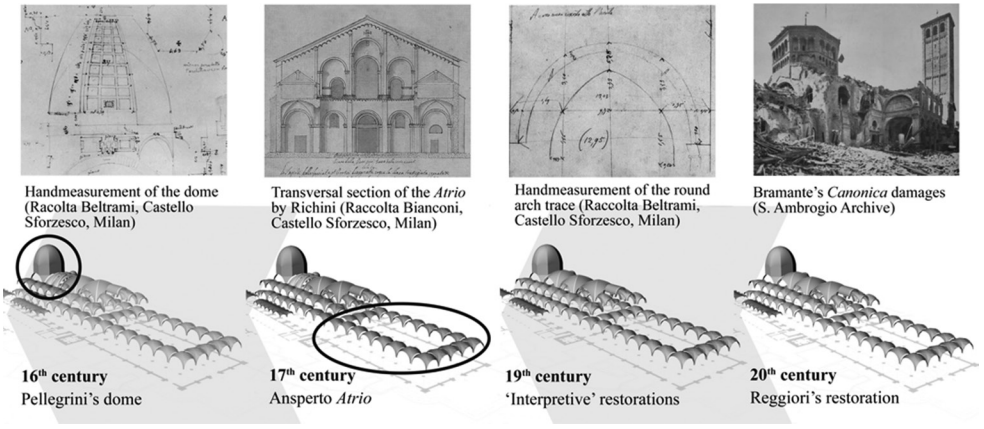

Figure 1. Chronological line of the vaults (twentieth-sixteenth centuries).

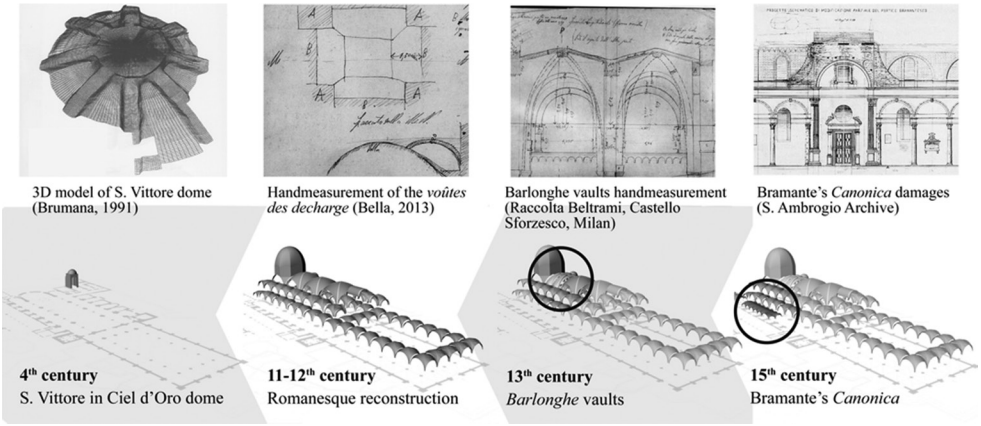

Figure 2. Chronological line of the vaults (fifteenth-fourth centuries).

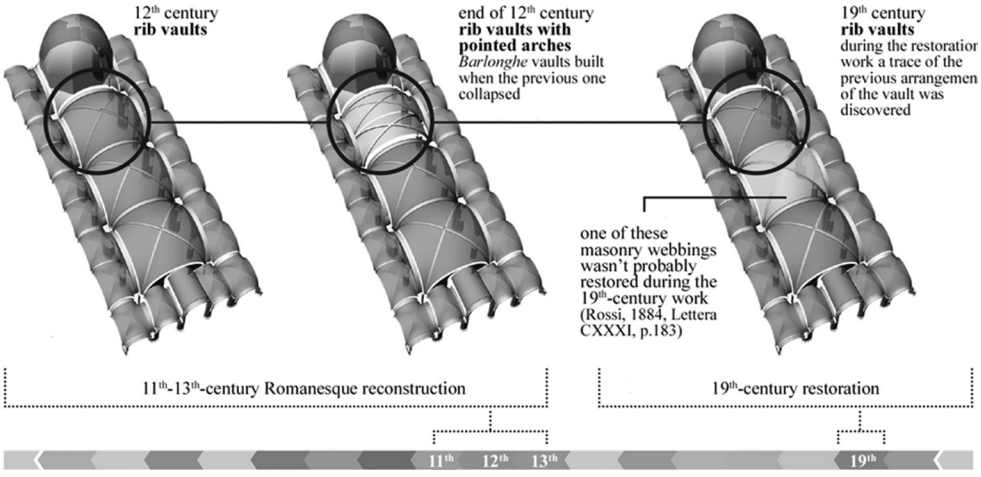

Figure 3. Chronological line of the Barlonghe vaults (nineteenth-eleventh centuries).

3.6 *Ricchino and the Atrio di Ansperto*

In the seventeenth century (1631), the vaults of the Atrio di Ansperto were restored by architect Francesco Maria Ricchino, who replaced some capitals and bases of the columns, and rebuilt at least 6 vaults (Summa 1995, 389). In 1566, the record ofthe pastoral visit of Carlo Borromeo indicates that some vaults were falling apart; in fact, when the restoration by Ricchino started, some parts of the Atrio had already collapsed (Summa 1995, 389). Also, it is possible that the vaults were damaged by an accidental fire occurred in the Atrio in the fifteenth century as some documents report (Rocchi 1995, 200). These documents state that the hay, which was laid under the Portico, took fire and reached the wooden roof of the Atrio, so it is plausible that no vaults had already been built. Also, it seems that the hay was stored in the 3 aisles of the Atrio and not in the Narthex, which needed to be free by obstacles in order to allow worshippers to get into the church.

3.7 *The Romanesque reconstruction*

During the twentieth-century restoration, Reggiori built a gable roof with a concrete structure for the covering of the church. During the work, he found a trace on the back of the façade, made of two lines with different slopes. This was interpreted as a sign of a previous gable roof arrangement and, based on the comparison with the height of the vaults, Reggiori stated that it couldn't have existed at the same time that the vaults were built. Comparing the 2D drawings by Reggiori with the ones made

for this research, by means of laser scanning, it has been possible to visualize the trace together with the vaulted system through a 3D model. Because of some mistakes in Reggiori's drawings and the fact that no laser scanning survey was done on the extrados of the vaults, it has been difficult to match Reggiori's drawing of the gable roof trace and the one of the façade made for this research. However, this was achieved thanks to some fixed points taken from the Narthex (Fig. 4). Before Reggiori, other researchers proposed the idea that the church was covered by a wooden roof before the construction of the vaults. Landriani supposed that the church had a tiered façade with the nave covered by a wooden gable roof and the aisles with a single pitch roof (Landriani 1889, Tav. III). This is a common scheme in the early Christian churches (i.e. S. Sabina in Rome) and the nave had a clerestory in order to light up the interiors. If Landriani's roof hypothesis was confirmed, the traces found by Reggiori would be part of an intermediate historical phase between the tiered façade (early Christian period) and the gabled one (Romanesque reconstruction, still standing). In fact, Reggiori, as De Dartein, supposed that during the first phase of the Romanesque reconstruction the Basilica had a uniform roof system—a gable roof for Narthex, nave and presbytery (Bella 2013, Tav. III-IV, XI-XII).

3.8 *Hypothesis on a wooden roof arrangement of the aisles*

Related to this topic, other traces referring to something similar to beam footprints have been studied during this research. These traces are located on the north and south walls of the church at the level of the *matronei* (Fig. 5). There are two of

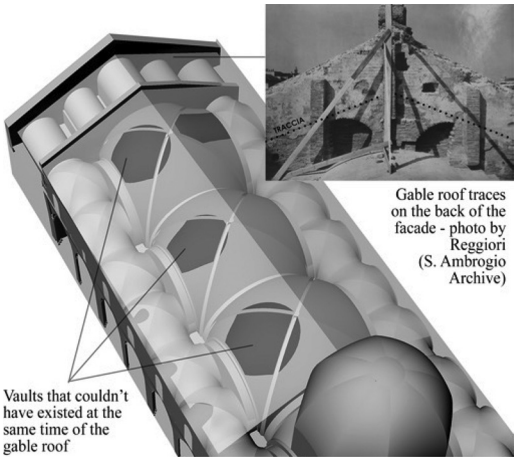

Figure 4. Hypothesis of the gable roof trace.

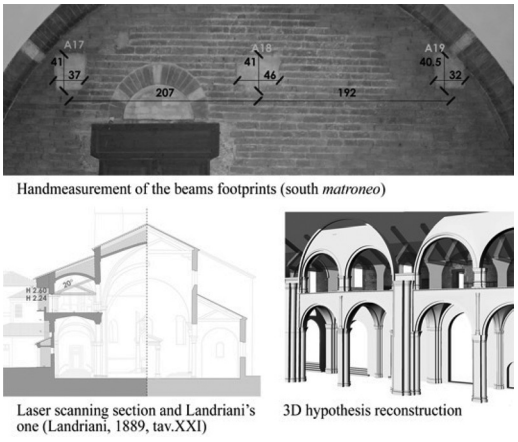

Figure 5. Hypothesis of beams footprints.

these elements per span, 2 m apart from each other, and have rectangular shape, dimensions around 0.5 0.4 m, at 2.70 m height from the floor. They were all surveyed during the research and no records have been found so far about them—no mention in the existing literature neither in the nineteenth publications, which is strange, because at that time the architects and the Abbot were interested in finding the 'original' traces of the first Christian church. At the beginning of the research, these rectangular shapes were considered as the 'signs' of a structure that supported workers during the reconstruction of the vaults in the nineteenth century, but their dimension is too big for this kind of purpose. Their constant distance and height seem to indicate that they are footprints of beams that were previously on the wall, and were probably part of a previous roof structure. It is also important to analyze the relationship between these elements and the windows of the *matronei*, which have the same dimension (1 3 m), except for two of them that are around 1 2 m. These two windows could have existed with a hypothetical roof structure based on the traces. It is also possible that these traces refer to semi-trusses rather than rafters, as in Landriani drawings. In fact, it is unlikely that the Basilica in Milan reproduced Roman models with clerestory—just think of the S. Simpliciano and the S. Nazaro churches. In order to visualize this hypothesis, the 3D model of the church was enriched with orthopothos that allow a detailed reconstruction of the wooden roof structure (Fig. 5).

3.9 *Previous arrangements—S. Vittore in Ciel d'Oro chapel*

According to the decoration of the mosaic, the dome of the S. Vittore in Ciel d'Oro chapel dates

back to the late fourth century or the beginning of the fifth one (Bertelli 1995, 346). The dome has a particular construction technique: it is made of tubi fittili placed in concentric circles (max diameter of the dome 4.5 m). These tubi fittili are interlaced with 8 radial ribs, also made of tubi fittili, that reinforce the extrados of the dome. These elements were reproduced in one of the first digital representations of the dome, realized in the 1990s (Brumana 1990; Brumana et al. 1991), where it is possible to visualize the construction technique of the dome. In 1864, the granite and cotto elements in the 4 angles of the dome were replaced by wooden beams, while new tubi fittili, with lime mortar and iron clamps, replaced the old ones (Rossi 1884; Lettera V, 19). Artist Camillo Agazzi was in charge of restoring the mosaic, some tiles of which were replaced with new ones (Rossi 1884; Lettera V, 20; Lettera XCIX, 138; Lettera CXXX, 181).

Through the thermos-luminescent analysis, a recent study (Galli et al. 2008) examined the *tubi fittili* dating back to the early Christian constructions of Milan: the dome of S. Vittore in Ciel d'Oro, the tetragonal structure of the S. Lorenzo church and the baptistery of the main Cathedral. The research results show that the 22 samples were realized in the Middle Ages and the 4 sample of S. Vittore were the only ones to create a homogeneous group (for the chemical composition) and dated back to the tenth-eleventh centuries. However, this result is not fully reliable, because of the little amount of samples and because there is no information about the position of these *tubi fittili* in the dome. This research opens new theories on a possible restoration of the dome in the Middle Ages, during which the same construction techniques as in the early Christianity were adopted.

4 VAULTS AND BASILICA

Since the vaulted system was built, it has deeply characterized the architectural arrangements of the church. Its construction has changed the architectural space and perception of the Basilica and scholars have given much attention to their chronological dating, in particular to the ones of the nave, also because of their importance in the evolution of the Gothic and Romanesque architecture in Lombardy (Arslan 1953, 469).

According to Arslan, the rib vaults of the nave would date back to the first half of the eleventh century if they had been built together with the pillars. He came to this idea after observing the capitals of the Basilica, which are similar to the ones of S. Maria d'Aurona in Milan, which date back to the 1089. However, most of the capitals were changed in the seventeenth and nineteenth centuries (Summa 1995), so this hypothesis, mainly based on stylistic observation, should have taken this into account.

Rivoira dated the vaults back to the eleventh century, too, but before 1098, when the *Atrio di Ansperto* should be built (Arslan 1953, 469).

Reggiori supposed that the columns of the late fourth century were replaced between 1018 and 1050 with mixtilinear pillars in order to support the vaults. Then, the vaults of the aisles were built, and finally the *matronei* (Reggiori 1966, 119–122).

Dehio and Bezold believed that the Basilica had vaults since the first half of the eleventh century (Arslan 1953, 469), while for Porter since the end of the eleventh century (Porter 1917, 555). Only Lastrey and Frankl moved the dating to the second half of the twelfth century (Arslan 1953, 469).

Rocchi supposed a first phase, around the first half of the twelfth century, where the nave had transversal arc portals with a wooden roof, while the aisles were believed to already have had the vaults. He thought that, around the thirteenth century, the columns were inserted into the mixtilinear pillars in order to support the ribs of the vaults. This hypothesis is supported by the observation that the diagonal little columns of the pillars seem not to be built together with the pillars themselves (Rocchi 1995, 157). The construction of the vaults influenced the static behavior of the whole church. This is why during the research the topic of the vaults was analyzed in conjunction with two other themes—the masonry arch structures that lean against the north and south walls of the church (Stanga et al. 2017), and the out-of-plumb of the walls of the nave, whose range varies from 3 to 20 cm and indicates structural settlements. The first theme refers to unique masonry structures made of arches supported by pillars. It has an irregular shape and deformation both in the horizontal and the vertical axes. It is not possible to state the actual reason for their construction, but during the research a connection with the vaulted system was elaborated, imagining them as structures built to reinforce the static behavior of the church after the fall of the vault of the first span of the nave. Reggiori offered another point of view, suggesting that the arch structures, and the *matronei*, were realized to oppose the load of the vaults of the nave (Reggiori 1966).

5 CONCLUSION

The vaulted and roof system are a cross-feature in the Basilica's life cycle—they have continuously evolved and they are descriptive of the many transformations occurred to the church over the centuries.

Through the integrated approach, it has been possible to show the complex history of the vault construction of the Basilica, which depends on their historical stratification and on the strict connection with the restorations of the church. The constructive-material data have been examined not only in their entirety, but also in connection with the historical events and the written sources. By doing this, the data acquired their historical significance and they are inserted, as a tile, in the intricate puzzle of the historical phases of the church, while the 3D helps to better understand the reconstruction of each piece.

The research aims at organizing the construction facts through a virtual subtraction process, based on a data cross-check between existing literature and geometrical surveys, and to steer future studies on the materials and techniques used in the restoration that would be of great importance to shed further lights on those interventions. For instance, it would be interesting to analyze the first vault of the nave with thermo camera analysis and see which kind of materials and techniques were used to rebuild it in the nineteenth century and if they used recovered materials from the previous vaults. Another example of the relevance of future studies could be the analysis of the masonry texture of the second vaults of the nave and see if the webbings are different from the others, because at least one of them wasn't involved in the nineteenth-century restoration.

The research, which is based on the available knowledge and technologies, opens new horizons; it is an ongoing process, a starting point for potential future detailed material and constructive analysis.

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