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PART 1 - Construction history and survey of historic timber roofs

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Cover illustration: Lattice roof trusses in the nave of Jät church, Småland, Sweden, 1225–1226 by Robin Gullbrandsson. © Robin Gullbrandsson (2022)

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EDITORIAL

REMARKABLE HISTORIC TIMBER ROOFS. KNOWLEDGE AND CONSERVATION PRACTICE

Part 1 - Construction history and survey of historic timber roofs

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The culture of timber structures dates back to the origins of construction and extends its branches to the industrial era when the culture of metal structures gradually replaced it. This phenomenon crossed all of Europe, developing particularities in different geographical areas and simultaneously becoming characteristic of other parts of the world. The function of covering and protecting buildings with timber elements, in particular large spaces such as theatre halls, church naves, or warehouses, has been implemented using construction types of considerable invention even more than static analysis. The outcomes are often unique in their kind and based on the wisdom and competence of engineers, architects, and master carpenters, who made their advancements following cultural, technical-scientific, and socio-economic factors.

Today these timber structures represent a fragile heritage threatened by natural and anthropic actions, and they are mainly the subject of fragmentary and episodic research activities, often dictated by the occurrence of fires, collapses, damage, or imminent dangers. Nevertheless, the study of historic timber roof elements has reached good dissemination within the scientific community, considering its relevance for the more general issues of use, conservation, and safety of the built heritage. The conservation of valuable carpentry works for their safety poses interesting challenges since operating on artifacts built in the context of extinct or radically evolved technical cultures is never trivial. Their modifications over time, their state of conservation, and their interaction with the rest of the buildings are often unknown and not easily predictable.

This special issue has the ambitious goal of helping to outline the current international panorama of research on historic timber roof structures, especially those with great span or peculiar technical relevance. The collection of papers is divided into two volumes: the first is focused on the history of timber roof construction, and the second is on the investigation, analysis, and intervention for roof preservation.

This introductory contribution is written to comment on construction history. The studies are developed by researchers from different countries and disciplines. Some declare in their career to work in the field of Construction History; others belong to other sectors such as Historic Building Conservation, Building Survey, or Historic Building Structures. As it is well known, in the Italian academic context, the distinction between sectors in the field of civil engineering and architecture (ICAR) is relevant, and it favors the isolation of research and discourages the integration of different working methods. As mentioned on the website of the Construction History Society, "Construction history is not blind to the importance of conservation and repair work, but it is focused on establishing and studying the history of building construction and not on how buildings should be repaired". In any case, understanding construction history is vital for all those involved in the maintenance and repair of historic structures. Therefore, the first aim of this collection is to fill the gap among different methodologies and approaches.

Most of the studies presented here are based on bibliographic and/or archival research, illustrating innovative approaches to knowledge and documentation. These studies may rely on historical treatises and handbooks, reminding us that the dissemination of knowledge in Italy and Europe passed through treatises and handbooks or the transfer of expertise among architects, engineers, and master carpenters. From this perspective, the historical-typological profile of notable timber roofs, with a focus on structural concepts, construction details, and joints, is fascinating.

Some studies go directly to the origin of wooden trusses. According to Nicola Ruggieri, indirect evidence of roof carpentry organized as a truss system seem to have been found in the Mediterranean basin, at least from the Iron Age. However, these are isolated cases that probably did not have a decisive influence on the evolution of the roofs in the immediately following eras. Full awareness of the potential and systematization of the truss system occurred in the Roman scope, and only in Late Antiquity did such an organization of the roof structure start to be notably widespread, especially in the basilicas. In the conceptualization process of trusses, a considerable contribution is to be recognized to the Etruscan and Phrygian civilizations. The author gives us examples and evidence to support his statements on lost timber artifacts of ancient times.

In the German area, a research project has been focused on reconstructing the lost wooden structures of a more recent past; this is the case of Clemens Knobling, whose aim is to reconstruct the destroyed Munich roofs on the basis of archival sources and archaeological research on the remains of buildings. The results show a great variety of structures, constantly reflecting the current developments in roof construction. Among them, there are also quite experimental solutions. The results are presented as detailed scale models. Italian influences are often evident in these roofs. As Knobling reminds us, every region has peculiarities in building construction, and, in fact, there have been systematic studies on roofs within cities and regions, like in Basel, with the work of Thomas Lutz and Gerhard Wesselkamp, or in Thüringen and Sachsen-Anhalt with Thomas Eißing's work.

Belgium also has a remarkable heritage of historic timber roofs traced back to the 12th century. Louis Vandenabeele notes that this country's interest in historic timber roofs grew during the 19th century with the Gothic revival movement and the construction of national identities. New light was shed on medieval timber structures in European countries through publications by architects such as Augustus W. N. Pugin or the Brandon brothers in the United Kingdom, Eugène E. Viollet-le-Duc in France, and Friedrich Ostendorf in Germany. In Belgium, the architect Pierre F. Langerock compiled several volumes on important Flemish buildings in the 1880s, with particular attention to roofs. This comparative typological analysis is an essential aspect of the research on timber structures.

The open roof structures – that is, open to the interior and without tiebeams – of Norwegian stave churches were studied in the mid-19th century and attained interest even outside Scandinavia, as Robin Gullbrandsson remembers. The development of buildings archaeology and the advent of dendrochronology in the 1970s and 1980s got a foothold even in Scandinavia, giving birth to new methods and raising questions in the research on medieval churches, often revising earlier stylistic datings. Wood construction, more than any construction element, show peculiar solutions to specific problems; this is due to the flexibility of the structural system, its adaptation to building transformation, and its properness to substitution. The accurate study of wood is fascinating because it needs attention and a deep look into detailing, for example, carpenter marks. Scarce attention to detail has led to inadequate and inaccurate interventions. Gullbrandsson reminds us that people can properly maintain and preserve only what they know.

Some studies show the transformation of timber roofs over time, including partial or complete replacement or integration with elements made of different materials. This is the case of the Bruntál Tower (Czech Republic) analyzed by Lucie Augustinkova, an example of a polyfunctional half-timbered tower modified in the 16th and 17th centuries. Very similarly, some studies in Italy give a critical description of significant projects due to the complexity of the technical-construction choices or the importance of the building.

Original solutions are investigated by Enrico Genova and Giovanni Fatta in the residence of the princes of Butera in Palermo. These include timber trusses of the roof, partitions and ceilings on the second story of the examined part of the building, and metal and timber elements used to hang partitions and ceilings from the overlaying trusses. The restoration works offered the opportunity to enlarge the documentation: surveyed buildings can be conceived as a comprehensive repository of information about Sicilian timber structures and their technology from the 18th to early 20th century. In particular, the use of suspended building components such as floors or partitions was not marginal in the architectural heritage of Sicily, although recurring solutions have not been clearly defined yet. It is feasible to think that these solutions were found to cope with Sicily's scarcity of wooden elements.

Similar insights on suspended ceilings, with a similar approach to one in Palermo, are also offered by Arianna Tosini in Rome. In this case, the research is not only supported by a detailed survey but also by the reading of early 19th century texts by Jean-Baptiste Rondelet and Giuseppe Valadier, illustrating two different criteria for creating coffered ceilings: in the first one, the coffered ceilings are directly connected to the roof trusses, providing for the lining of the tie beams; in the second one, the coffered panels are nailed to wooden frames hanging from purlins placed over the tie beams.

The study aimed to highlight the importance of these building techniques of the coffered ceilings in the churches of Rome. So far, this topic has not been explicitly addressed. In fact, according to the author, there is a lack of a detailed illustration of the different structures built and a broad picture of the different construction typologies, while studies of ceilings in the field of art are highly developed. Studies usually focus on the diffusion and the evolution of forms over time, starting from the second half of the fifteenth century to the early twentieth century. Preserving the structure of the coffered panels and the richly decorative and chromatic quality repeatedly required interventions, even of considerable extension, to prevent collapses, replace damaged parts, and restore various surfaces. However, the lack of knowledge on the topic and the scarce consideration of the ancient wooden carpentry, especially when used above the extrados of the ceilings, led to inappropriate interventions, up to the complete replacement of the ancient technological system.

Daniela Pittaluga stresses how studies on timber structures should be complete, obtained thanks to indirect sources (archive and bibliographic research) and direct ones: archaeological analyses (stratigraphic, mensiochronological, mineralogical-petrographic, and wall textures), thermographic and ultrasonic analyses. Specifically, she wanted to show the entire path of the analysis conducted in one church in Liguria and list the individual steps by which it was possible to draw, in the end, a weighted conclusion. Tiziano Mannoni used to say that it is not the quantity of data collected that makes history but the critical analysis of those concerning the problems. In this regard, this research highlights the extent to which critical analyses help arrive at a fruitful conclusion. The result of the study was also to discover wooden vaulted roofs that have elements in common in the same region.

According to Angelo Landi and Emanuele Zamperini, the constant comparison of the bibliographic and archival data with that of the real and present consistency of an important church in Cremona, Italy, its construction techniques, wood species, and decay not only allowed to understand and interpret the construction and maintenance acts, framing them in the more general social and economic context of the time, but also made it possible to expand its history beyond the boundaries of the original construction, although split into two phases, towards the numerous, and sometimes minute, maintenance works during four-hundred years of service life.

Finally, the history of roof construction is traceable between memory and innovation. The memory has to do with roofs because structures often lose their original configuration, and the initial concept is forgotten when elements are deeply renovated. Roofs usually consist of statically undetermined structures, and they are the result of the expertise of the master builders of their time; newly renovated configurations may follow the principles of the Science of Construction. New restored solutions come from the loss of confidence in the old construction or from the belief that the new science and the new building practice bring a consistent improvement in structural safety. Perhaps, this merely derives from the total lack of knowledge of the old techniques, in other words, from memory loss.

The presented studies are based on accurate research on historical documents and surveys, considering the conservation state and the structural behavior of the original structures. Detailed surveys are also the basis for the rehabilitation of the roofs. With the term "memory", we stress the importance of building tradition, expressed through the choice of wood, the knowledge of how to join the pieces, and the experience gained in thinking about the element arrangements and the installation sequence. The studies trace the life of roofing systems, from their conception to their current configuration, through the alternation of the memory of the construction tradition and technological innovation. When technical innovation goes beyond the construction tradition, in a certain sense, it modifies the extent of knowledge. The word tradition brings with it the terms "*tradere*", or "betray", which represent the process of transferring knowledge over time, accompanied by a continuous renewal, a continuous rethinking of the same things. Today, in fact, not all the steps in the design and execution process of roofs are known. The direct observation and the geometric survey of these structures are perhaps not sufficient to complete all the knowledge; we could probably approach the understanding of historical techniques by trying to reconstruct the original objects, using the materials available at the time as far as possible. Of course, if we wanted to redo those objects today as they were and where they were, we would be forced to use the tools offered by our current technology, which suppose greater precision in processing and greater control of the quality of materials, ending up with different products. In fact, today, we are prone to reduce work-related risks and increase the perception of safety – or objective safety – during the life of each construction. In any case, the construction tradition is an essential aspect of the restoration field. According to Paolo Marconi, more than twenty years after the 1972 Charter, modern technologies applied to ancient structures have revealed their limits in many cases.

For this reason, some recent trends push towards the recovery of a pre-modern tradition in architectural restoration, reactivating past techniques. In Italy, a revision of the ministerial charter of 1972, especially for architectural monuments and historical sites, promotes an approach to restoration based on teaching traditional techniques, combining resources in local raw materials, environmental factors, and cultural traditions. The aim is to re-evaluate a type of intervention that consists in the alliance between properly collected and disseminated historical knowledge and professional and entrepreneurial forces (from the associations of builders to craft associations) in order to re-propose a vision of the physiological mutation of architecture that confirms the philologically active role of restoration, guaranteeing the significance of the artifact and a conscious continuity. The life of these structures through centuries testifies to this continuous process of memory transfer and transposition and continuous translation of knowledge through maintenance, renovation, and reconstruction operations.

WOODEN STRUCTURES OF THE CLOCK TOWER IN CASTLE BRUNTÁL

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Abstract

The article deals with the timber structures of the Clock Tower in Castle Bruntál (Czech Republic). In the text, the development of the Clock Tower is explained, and timber structures are described and classified. Presented knowledge is based on the partial historic building investigation of the roof truss of the castle and the Clock Tower, which was achieved with the help of art history and architectural methods. The constructional solution is explained in the context of towers built at a similar time and the purpose of which was similar as well.

Keywords

Castle Bruntál, Tower, Renaissance, Half-timbered structure, Timber-framed structure.

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1. INTRODUCTION

Renovation of the castle Bruntál (Fig. 1) started to be prepared in 2020. Atelier 38 worked out a design "No. A382013 Renovation of the roof of an object of Muzeum in Bruntál" that had been ordered by the Muzeum in Bruntál, a state-funded organization. Even if the castle has been a national cultural heritage since 2002, there is only minimal knowledge about its construction development. Performing partial historic building investigation of the castle focused on the roof truss of the castle, and the Clock Tower was part of pre-design work [1].

2. METHODS

New knowledge of the castle Bruntál was achieved with a set of methods of historic building investigation. These are, first of all, archival search, history of structures, and history of art methods. Employing natural science analyses was principal, especially dendrochronology for dating elements of castle and tower roof truss. The ARCHICAD images were used, and proficiency in historic building projecting was utilized to mediate obtained knowledge of the structure [18].

Fig. 1. *Map of Czech Republic with the recording of the town Bruntál, 2020 (Drawing M. Ferko)..*

3. CASTLE BRUNTÁL

The town of Bruntál was established as the king's town, probably at the beginning of the 13th century. The precursor of the castle, the town castle Bruntál, dates back to the first half of the 15th century [2]. From the second half of the 15th century, Bruntál was in the pledge of Lords of Vrbno, who moved their seat there and started to call themselves the Bruntal family of Vrbno. Jan Bruntal of Vrbno the Younger participated in a rebellion of the Bohemian nobility against the Habsburg monarch. After the resistance movement was defeated at the Battle of White Mountain (Schlacht am Weißen Berg, Bitva na Bílé hoře), he left the country, and his property, including Bruntál demesne, was confiscated. In 1621 Bruntál became the property of the Order of Brothers of the German House of Saint Mary in Jerusalem (the Teutonic Order), the Grand Master of which at that time was the brother of the winner of the Battle of White Mountain, the brother of the Roman Emperor and the Czech king Ferdinand II, the Bishop of Wrocław, Charles of Austria (Carl von Österreich) (1620-1624). The demesne was in property of the order on a modified scale until 1848; afterward, the order owned the castle until 1939 [3].

At the end of the Middle Ages, the town castle Bruntál developed into a three-wing building, the northeastern, northwestern, and southern. In the Renaissance period, the town castle was converted into a castle [4], and four pillar arcades were built in the castle courtyard (Fig. 2). In 1764, the castle was destroyed by fire. From 1765 to 1768, a new roof truss was installed [1]. Construction conversion of the castle in the second half of the 18th century is proven by a set of historical designs from Deutschordens-Zentralarchiv [5].

During the conversion of the central part of the southern wing into a stair hall at the end of the 18th century, proven by design documentation, the roof truss of this wing was converted. In the second half of the 19th century, the ceramic roof covering of the castle was to be replaced by a roofing slate.

When the Grand Master of the order was the archduke Eugen of Austria (Eugen von Österreich), an extensive repair of the castle was performed. Corbels were installed in the roof truss; these corbels served as auxiliary structures and helped to operate scaffolding or platforms for façade conversion. The condition is evidenced by historic photographs of 1913.

Renovation in the Modern age was performed in the second half of the 20th century. The roof of the castle and tower was repaired in 1963. The roof truss was significantly renovated in the first half of the 1990s [1].

Fig. 2. *Castle Bruntál, aerial photo.*

4. CLOCK TOWER IN BRUNTÁL – STRUCTURE CHARACTERISTICS

The Clock Tower (Fig. 3) is part of the northwestern wing of Castle Bruntál. It extends the ground plan of the wing into the castle courtyard. The ground plan of the bottom part of the tower is rectangular, while the top part forms an octagon. The roof of the tower is formed by two onion domes and a lantern located between them. The bottom onion dome continues into the plated lantern and the top onion dome. In the lantern, there is a fixed bell in a static position and a bell of 1672 with colored relief of Our Lady, cast by Johan Grosch in Nysa [8]. The top onion dome continues into a finial with a circular tin case. The bottom part of the tower is lined with stones mostly; the upper floors are usually lined with bricks. There is a half-timbered structure in the top part of the tower, the timber parts of which are made of spruce, fir, and larch [6]. The timber framework is located on two top floors of the brick part of the tower and was placed on the inside face (Figs. 3 and 4). The structure is formed by wooden frames and St. Andrew's crosses between them (Fig. 5). The bottom part of the structure is composed of standard beams. The St. Andrew's crosses are located in the top part, below the roof truss. The elements are connected with woodworking joints with pegs. Thus, the half-timbered structure can be seen inside only. On the top floor of the brick part of the tower, the timber framework con-

Fig. 3. *Castle Bruntál, Clock Tower elevation, the roof of the Clock Tower, Bell with the bas-relief of Our Lady in the Clock Tower. (Photos by the Author, 2020).*

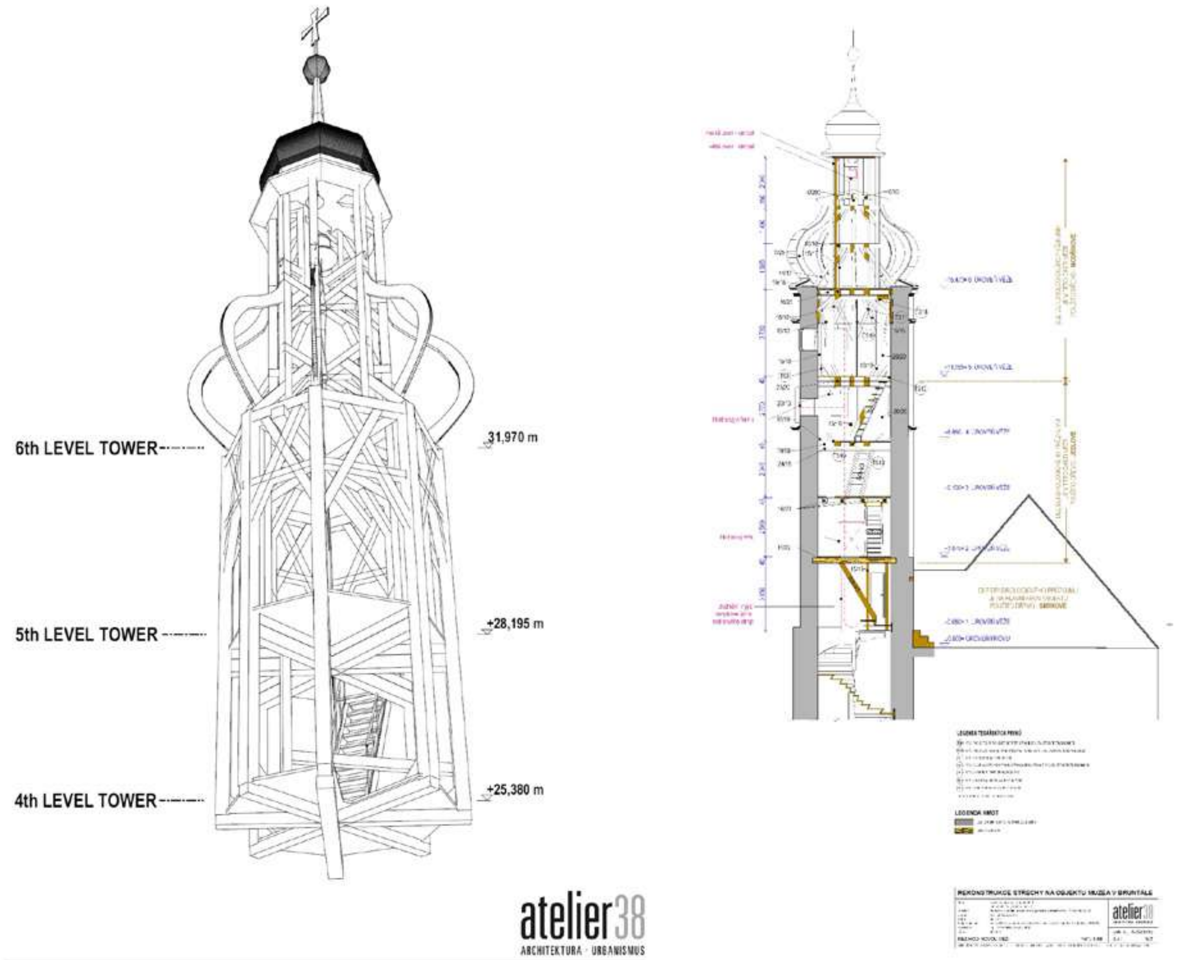

Fig. 4. *Clock Tower, construction scheme of timber structure. (Drawing, Jakub Sollich, Atelier 38).*

Fig. 5. *Clock Tower, half-timbered construction, the traces of the older timber construction. (Photo, 2020).*

sists of two polygons and posts – the internal and the external. Ashlar pieces complement the posts. There are horizontal mortise holes on the floor below on posts of the timber framework. These holes might have been left after a previous structure without any woodwork joints with the timber framework. There are noticeable imprints of round wood on walls at the level of the St. Andrew's crosses. It is not sure whether they relate to the bottom line of mortise holes.

The roof truss of the tower leans against an octagonal frame formed by plates of the half-timbered structure of the top floor of the brick part of the tower (Fig. 6). On this structure, another structure of octagonal ground plan forms the saddle of the tower roof truss. This saddle passes through the bottom onion dome to the lantern. It makes up the supporting structure of the lantern there. Timber centering is cut out of board which is the youngest way of timber centering production. The bottom part of the onion dome is made up with the help of timber sprockets as it was commonplace then. On the roof truss of the tower, there are a few initials and the date "1927" written with paint there. The top onion dome was not accessible when the historic building investigation was performed.

The communication scheme of Castle Bruntál is quite simple. The central vertical communication axis is the Clock Tower. The roof truss of the castle is accessible from two staircases. The first one is located in the tower, and the other leads to the entrance closed with a trap door in the central part of the southern wing. The roof space is divided by gable walls into several fire zones. A timber spiral staircase from the tower can access the roof space.

A right-angled portal into the tower is in the bottom arcade, therefore, at the level of the first floor of the castle. Above the portal is a stone relief with a coat of arms of

Fig. 6. *Clock Tower, half-timbered construction, timber construction in the tower, the traces of the older timber construction, photo, 2020.*

Commander Heinrich Karl Alois von und zu Werdenstein (1739-1770). The relief was placed there secondarily.

5. THE RENAISSANCE TOWER IN CENTRAL EUROPE

Timber was common building material applied in the construction of towers in the past. The upper parts of towers were timber-framed or half-timbered from the Middle Ages. In the Early Medieval Period, timber structures of upper parts of habitable towers were recorded, especially in Western Europe [9]. Timber-framed or half-timbered structures were usually used in fortifications to build hoarding (brattice, brattice).

Timber towers can be seen very rarely in European sacral architecture nowadays. They might be compared to bell towers from Western and Southern Europe [19]. An example of such towers can be a recently renovated bell tower in Pembridge in Herefordshire; dendrochronologically dated back to 1207-1223 [17]. Timber-framed towers with slab shuttering were constructed in the Late Medieval Period, mainly in churches [14]. Towers were either timber-framed in their full heights (St. Catherine's Church, Ostrava - Hrabová), or the timber-framed structure was installed on upper floors only (Štramberk, the tower of a former parish church which was also a tower of a town wall) [11].

There were many towers with various purposes constructed in the 16th century. The amount of available information on the architecture of towers in the 16th century is influenced by a large number of these structures that have been preserved, at least in Central Europe. They are mostly church towers or town towers that served as guard towers or watchtowers as well. These towers might be constructed similarly. Towns often paid for the construction of the church towers since they served as watchtowers and guard towers afterward and were owned by the towns. By the Church of St. Thomas of Canterbury, the town had built a tower still in its property. In 1587 the non-Catholic patricians in Nový Jičín paid for the construction of a church tower that served as a guard and watchtower. The Church bought the tower from the municipality in the first half of the 20th century.

Only two objects of similar age have been documented in the Moravian-Silesian Region; the city tower called Hláska (former watchtower) in Opava [15] and the Church of St. Nicolas tower in Bílovec [16]. The upper floor of Hláska in Opava from 1614 was, as well as in Bruntál, constructed with the help of a half-timbered structure on the inside face. The inside structures on the upper floors of the tower are similar to the ones in the tower of the Church of St. Nicolas in Bílovec from 1614-1615. Although the tower has been rehabilitated, the timber framework has not been preserved.

Baroque towers offer interesting structural parallelism. The half-timbered structure was also used in the tower of the Former City Hall in Moravian Ostrava (nowadays Ostrava Museum). This structure was placed on the outside face of the tower; therefore, it was visible from the outside [11].

The development of tower roof trusses is similar to other roof truss structures. Traditional Gothic roof trusses were commonplace in tower roofs by the mid-16th century, as well as in other roofs. The Renaissance brought a new element – Onion domes (structures by Baldassare Maggi in Southern Bohemia). The round shape of these towers is formed by a set of timber centering supported by supporting structures with posts into which the timber centering was fixed afterward [14].

6. RESULTS - THE DEVELOPMENT OF THE CLOCK TOWER IN CASTLE BRUNTÁL

There is no information about the roof of the town castle. The oldest mention of the castle's roof comes from the 16th century. The principal pictorial source is a map of Bruntál demesne of 1579 [7]. On this map, there is a veduta of the aristocratic seat in Bruntál depicted in quite a simplified form; even then, it had the character of a castle. The age of the hipped roof, with reference to the veduta and the battlemented parapet, is unknown.

Researcher Samek dated the construction of the Clock Tower to the end of the 16th century or the turn of the 16th and 17th centuries [3]. However, the construction of the tower consisted of more phases of building development. The disposition of the tower indicates that the bottom part of the rectangular ground plan, covered with sgraffito work nowadays, is much older than the arcades of the inner courtyard. The bottom floors of the masonry part of the tower date back, according to the disposition analysis, before the 1550s. No tower is depicted on the veduta of the map of Bruntál demesne of 1579 (Fig. 7). However, the veduta might be significantly simplified, and the tower is not necessarily depicted there. Dendrochronological dating confirms that. Since the dendrochronological dating of the timber ceiling on the bottom floors of the octagonal tower failed, its age cannot be defined. The bottom level of the timber framework was constructed after 1577 [6], i.e., when the castle was still the property of the Bruntál family of Vrbno. It

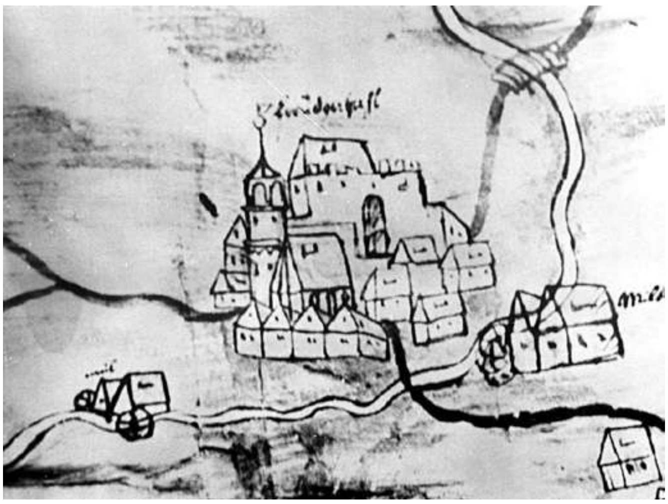

Fig. 7. *The map of the Bruntál demesne, 1579 (A. Peschke, Die Karte der Herrschaft Freudenthal im Jahre 1579)..*

might have been built by Hynek Bruntal of Brno the Elder (1559-1596). Above mentioned dating relates to the tower up to the height of the bottom cordon in the octagon. There is no evidence of the appearance of the upper floors or the roof in those days. We may speculate about it being damaged or destroyed by fire; on two posts of this bottom half-timbered, the 4th floor of the octagon, there are signs of burning [1].

The half-timbered structure of the two top floors of the tower indicates that there have been two building phases of the construction. The posts of the framework are doubled; on some plates, there are noticeable mortise holes left by a structure that had been removed; this can be seen in the entry to the upper floor. The top level of the timber framework, i.e. the 5th floor of the octagon with the St. Andrew's crosses, was added after 1618. We do not know whether it was when the castle was the property of Jan Bruntál of Vrbno and in Heraltice the Younger (1617-1621) or the property of the Teutonic Order.

The age of the tower's roof, comprising of two onion domes and the lantern, is not certain, either. The construction might relate to the report of 1667 from the Teutonic Order archive, mediated by Ph.D. Niesner. The roof of the castle, covered with ceramic tiles, was repaired then [10]. In the tower's lantern, a bell was still cast by Johan Grosch in Nysa in 1672 [8]. The bell is fixed in the static position (only the clapper moves) in the tower, as well as another bell in the static position. The age of the roof of the tower can be dated back to the end of the 1660s or the beginning of the 1670s.

Two vedutas by Friedrich Bernhard Werner from the first third of the 18th century are a precious source of information on the development of the castle (Fig. 8). These vedutas have been preserved in the form of hand-drawn replicas from 1763 [12]. The time relationship between the shape of the roof truss and Werner's vedutas is not very straightforward. The drawing has red roofs of the castle and green tower domes. The report from the Teutonic Order archive defines the roof covering as made of fired ceramic; the tower might have been covered with either copper plating with patina or painted shingles.

The fire of the town and castle in 1764 did not threaten the Clock Tower. However, given the three wings of

Fig. 8. *F.B. Werner, Castle Bruntál. (Drawing, 18th century, Biblioteka universytecka Wroclaw).*

the castle, the fire might have been the cause why a new roof truss was installed in the period of Grand Master Charles Alexander Emanuel of Lorraine (1761-1780), the brother-in-law of Queen Maria Theresa [13].

In the Modern Age, the entrances between the floors in the Clock Tower were shifted. Ladder staircases were used again.

The tower's roof was reconstructed in 1927; the roof cladding and the timber centering might be from that time. On the roof truss, the number "1927" is written with paint [1].

7. CONCLUSIONS

The historic building investigation of the roof truss of the Castle and Clock Tower in Bruntál showed some interesting facts and connections. The tower is older than the professional literature stated. The bottom part of the rectangular ground plan might be even from the late Gothic period. The central part of the tower, of the octagonal shape, was added before the 1550s.

The upper part of the tower, of the octagonal ground plan, was added after 1618. During further construction, the timber framework was placed on the inside face of the tower, and this timber framework was fixed into pre-installed posts. There are several other towers of similar composition in the neighborhood, i.e., in Moravia and Silesia, that are of similar age. It is, especially the city tower Hláska beside the city hall in Opava. The tower is a bit older, its upper floors are also half-timbered, or more precisely, they are timber replicas of the original timber framework from 1614.

The purpose of the tower in Bruntál seems to be mixed, at least in the Renaissance period. The mortise holes in posts and marks left by round timber might indicate the existence of an inner timber structure. The use of the structure, with regard to good visibility of the courtyard and its neighborhood from this floor, might be defensive and also guarding. I think that this structure was disegned only for crossbowmen. The using of the firearms leave trases – blackening caused by smoke.

In the mid-seventeenth century, the tower got its current appearance, with two onion domes and a clock, and it served as a bell tower as well. The tower in Bruntál is an exciting example of a polyfunctional tower modified in the 16th and 17th centuries.

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HISTORIC HANGING PARTITIONS: ANALYSIS OF A RELEVANT APPLICATION IN PALERMO

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Abstract

This paper describes historic technical solutions used to suspend lightweight partitions from timber trusses in one of the most relevant aristocratic residences in Palermo. The study examines part of the building, namely a masonry box 24-m long and 10-m wide. This large space, articulated in two storeys, was divided into rooms by lightweight walls and ceilings. The construction analysis of these partitions and the above roof trusses was carried out through an observational study during the recent restoration of the building. The main focus of this paper is a complex system of reinforcements and load-bearing elements – made of timber and wrought iron – used on the second floor to suspend a couple of tiled brick partitions and the related timber vaulted ceiling from the corresponding roof trusses. This solution, realized between the late 19th and early 20th century, employs a series of timber rafters, one timber trussed beam, and three groups of single or paired iron tie-roads. While analyzing the technical details of this system, the study contributes to documenting the use of suspended building components in the historic construction of Sicily.

Keywords

Suspended partition, Timber truss, Trussed beam, Wrought iron tie-rod, Vaulted ceiling.

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1. INTRODUCTION

Monumental buildings offer a significant point of view to examine local techniques of historic construction and their relation to the practices described in historic treatises. The purpose of using magnificent buildings as proof of prosperity and authority assured considerable financial resources for their construction, but it commonly required original solutions to overcome technical problems, such as covering large halls. Furthermore, huge investment in representative parts of the building was frequently balanced by the use of ordinary solutions in less visible spaces. This dichotomy is quite common in aristocratic residences and increases the importance of focusing on these buildings, when the historical practice of local construction is studied in relation to economic resources, supply of appropriate materials, and technical knowledge of architects and workers.

From this perspective, the residence of the Princes of Butera in Palermo is a relevant combination of original and recurring technical solutions in the architectural heritage of Sicily. As a result of the addition and transformation of several constructions, this building was repaired after a violent fire in the second half of the 18th century and further enlarged during the 19th. Some aristocratic spaces were modified and decorated up to the first years of the 20th century. Partially damaged during the Second World War, the building was then divided, and a portion, which included a group of noble rooms, served as a school before being used again as a residence and for events. After the last restoration (2016-2021), the residential function is being matched with the use of the building as a private museum and cultural center.

For both size and richness, the residence of the Princes of Butera in Palermo – usually named *palazzo Butera* – is one of the most relevant urban mansions of the Sicilian aristocracy. Its recent restoration has been an important chance to observe and measure construction details, which would have remained otherwise invisible or out of reach. Therefore, these restoration works offered the opportunity to enlarge the documented knowledge about the construction of Sicilian historic architecture. In particular, *palazzo Butera* is a comprehensive repository of information about timber structures – roofs, floors, partitions, ceilings – and their technology from the 18th to early 20th century.

2. OBJECTIVE

The architectural heritage of Sicily shows expressions of significant originality, both technical and artistic, in the use of timber construction for building components. Relevant cases can be found in Palermo, such as the ceiling of the Palatine Chapel [1] or the pyramidal roof structure which covers the urban gate named *Porta Nuova* [2]; original technical details have been analyzed in several monuments, for instance, the internal connections of tie-beams in the trusses of the town cathedral [1]. However, it is generally possible to describe the historical use of timber frame partitions and roof structures in Sicily through the main schemes identified in recent literature and historic treatises [3–7]. Indeed, architects involved in the local great buildings improved their education outside the island and mastered the coeval technical culture. In Palermo, the local application of these schemes has been analyzed systematically, and recurring solutions have been identified [8]. Furthermore, knowledge about the local use of timber frames has been enlarged through the examination of buildings under restoration or in a state of severe decay [9].

In *palazzo Butera*, the use of timber is not limited to the structural elements of floors and roof: timber frames were also employed diffusely to adapt the building to the changing needs of its owners. Consequently, in its two noble storeys, this residence includes several examples of timber partitions and ceilings, referred to renovation works dating back from the late 18th to early 20th century. This practice of realizing lightweight building components – able to organize a large space without adding severe loads to timber floors with long span and limited stiffness – was widely used in Sicilian historic construction, as observed in noble buildings and religious convents.

Palazzo Butera, with two monumental 80-m long façades along *via Butera* and the city seafront, results from the union of previous structures and further additions. Its evolution is partially visible in the two orientations of the seafront façade, which suggest dividing the building into a North-Western and a South-Eastern wing. The depth of the building is 15.2 m at the junction between the wings, 18.7 m at the North-Western boundary with *palazzo Benso,* and 16.9 m at the South-Eastern boundary with *palazzo Pirajno*. The roof is borne by thirty open-joint trusses (and a partial one), whose spacing varies from 1.9 m to 2.8 m, with a maximum of 3.1 m (Fig. 1).

In the North-Western wing of the building, the intermediate load-bearing wall (A in Figure 1) is closer to the façade along *via Butera*. The space between this façade and the intermediate wall is divided by a series of transverse walls, placed at a distance of 5.5 to 6.5 m from each other. Conversely, on the other side of the intermediate wall, the first transverse load-bearing wall (B in Figure 1) is 23.7 m far from the external boundary with the adjacent building (*palazzo Benso*). This huge masonry box (length 23.7 m, width ranging between 10.1 m and 11.3 m) characterizes the two aristocratic storeys of the building. Historic timber works, here realized in different periods, aim to solve the structural problems of long span and divide the large indoor space into several rooms. Focusing on this part of *palazzo Butera*, this study analyzes timber and iron elements used to realize lightweight components on the second noble storey and to transfer part of their load to the roof structure above.

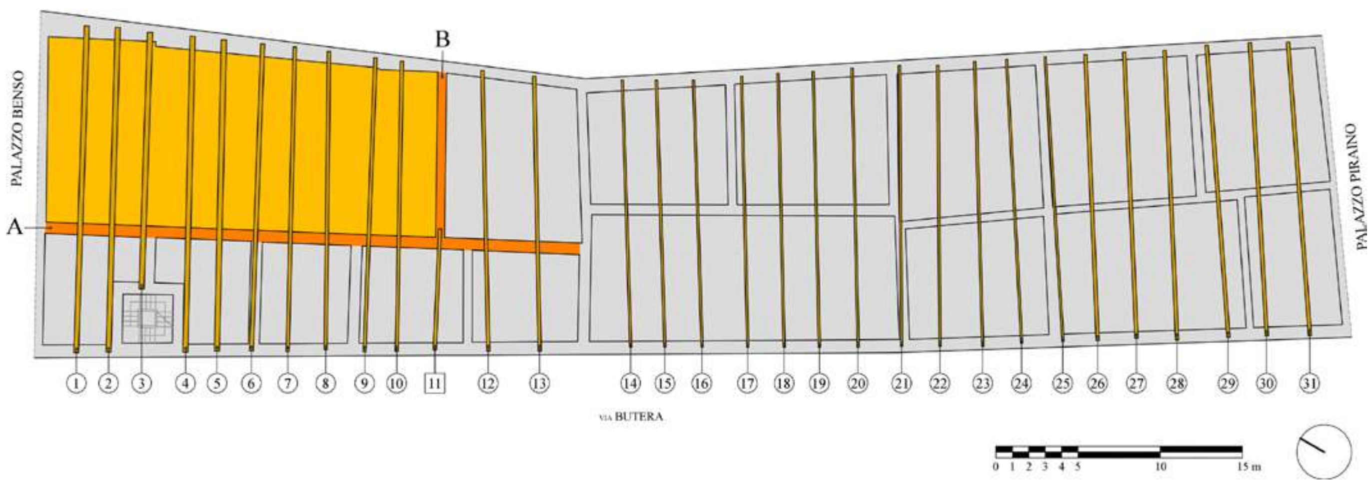

Fig. 1. *Scheme of the location of trusses in the roof structure of palazzo Butera. Yellow identifies the part of the building this study focuses on.*

3. METHOD

The construction analysis of suspended components in *palazzo Butera* is based on the observational study carried out between March 2018 and January 2020, during the recent restoration works. Photographic and geometric surveys of building components have been conducted, focusing on all historic timber works on the second noble storey and the entire roof structure. Their construction features have been compared to technical details frequently observed in the local architectural heritage [8] and with solutions suggested by historic construction treatises [5–7].

Different restoration phases between early 2018 and early 2020 allowed direct and detailed inspection of trusses and extensive investigation of their connections, in order to verify recurrent features and detect singular solutions. The analysis was also integrated with documentary photographs of previous phases of this restoration, when the replacement of floor timber boards and the demolition of recent non-traditional additions showed non-visible construction details, then concealed again.

Trusses of the North-Western wing were subject to considerable works of repair and reinforcement between the late 19th and early 20th centuries, but archival documents about these works have not emerged so far [10]. Therefore, trusses placed over the hanging partitions, which this paper deals with, have been examined by analyzing the entire roof structure. This analysis allowed consolidating temporal hypotheses concerning reinforcements of trusses, in order to identify those strictly related to the suspended partitions.

4. TECHNICAL ANALYSIS

The analysis focuses on the following technical elements: timber trusses of the roof, partitions and ceilings on the second storey of the examined part of the building (Fig. 1), and metal and timber elements used to hang partitions and ceilings from the above trusses.

4.1. TIMBER TRUSSES

The thirty open-joint trusses of the entire building roof are based on a typical construction scheme (Fig. 2). Differences among trusses are mainly related to building geometry and to reinforcements realized by the first decades of the 20th century. The trusses cover a significant span, ranging between 15.2 m and 18.7 m. For this reason, each tie-beam is made of two parts, whose adjoining heads are just placed side by side – the overlapping length is about 2 m – and connected by a couple of timber dowels along the entire width of the joint. Nonetheless, only historic iron bolts with nut and washer are visible in the ten trusses over the analyzed area (1-10 in Figure 1), where signs of previous timber dowels have not been observed. Loss or breakage of almost all timber dowels demonstrates that the described connectors were undersized. The rough internal joint of the tie-beam takes advantage of the intermediate load-bearing masonry wall which the connected heads are laid on. However, equilibrium was maintained also through the weight of floors – joists and boards – built in a large part of the attic, especially in the South-Eastern wing.

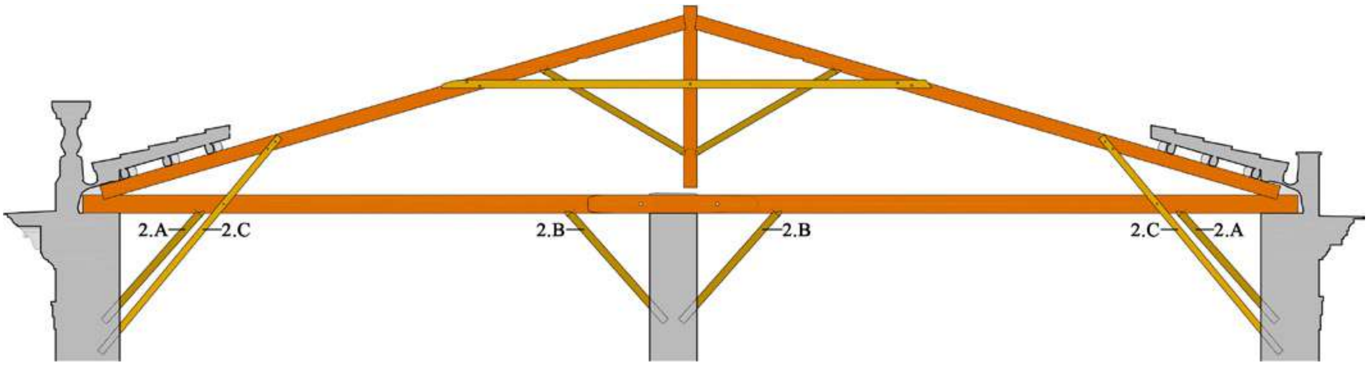

Fig. 2. *Basic scheme, common to all trusses inside the roof of palazzo Butera. The position of the intermediate load-bearing wall, which is almost central for trusses 14 to 31 (Fig. 1), does not influence the scheme. Frequent size of cross sections (width x height in cm): tie-beam 16-22 x 19-25; rafter 14-23 x 18-28; post 13-18 x 14-20; secondary tie-beam 8-9 x 10-14; struts (also the additional ones) 8 x 8 or 10 x 8 or 10 x 12.*

Rafters and tie-beam are joined through a front notched connection, namely a V-shaped indentation notched in the upper face of the beam. This joint is almost entirely hidden inside the wall and by reinforcements (as in Figure 3). Iron nails are probably inserted obliquely, given that they are used in the analogous connection between rafters and post. Each rafter has the support of one strut, which is joined with a notched frontal connection

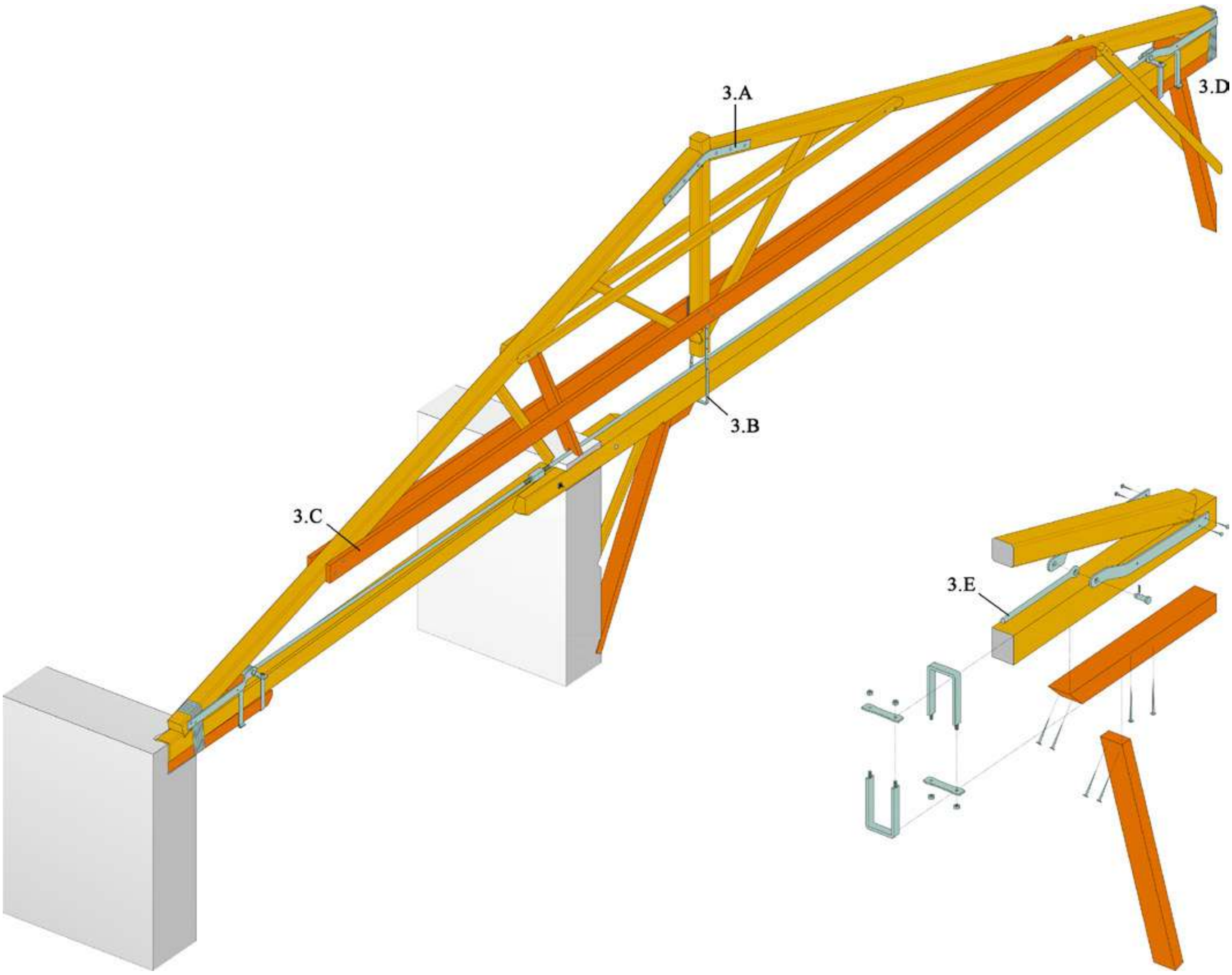

Fig. 3. *Scheme of trusses 1-10 (Fig. 1) with wrought iron and timber reinforcements. The joint between tie-beam and rafter was reinforced by a timber bracket, connected to the tie-beam by nails and a couple of iron fasteners. A thin iron strip was used to wrap together bracket and rafter.*

and iron nail to both the rafter and the bottom part of the post. A couple of secondary tie-beams are nailed to the sides of rafters and the post.

The construction scheme of the truss is completed by external diagonal struts, which support tie-beam and rafters. In detail, the underside of the tie-beam is joined to four timber stiffening struts: two (2.A in Figure 2) are inserted in the outdoor stonewall, the remaining (2.B) on the intermediate load-bearing wall. A couple of external diagonal struts (2.C) are nailed to the sides of each rafter; in some cases, nails have also been observed between the external struts of rafters and the tie-beam, thus suggesting the aim to stiffen the connection between the two main elements of the truss.

Trusses show more systematic traces of historic timber and metal reinforcements in the North-Western wing. Standard solutions are observed in the use of metal elements: an iron plate (3.A in Figure 3) reinforces the connection between rafters and post, while an iron strap (3.B) complements the open joint between post and tie-beam. The strap frequently shows irregular geometry, because the two parts of the tie-beam cannot have the same average plane. Furthermore, trusses were repaired by adding new secondary tie-beams (3.C) or by changing several timber elements; the connection between tie-beam and rafter was reinforced systematically (3.D), and the external struts supporting the tie-beam were replaced. These works probably date back to the beginning of the 20th century, as suggested by similarity to the timber components used to replace part of the roof structure in the South-Eastern wing in 1929.

In the ten trusses over the analyzed part of the building (1-10 in Figure 1), a wrought iron tie rod (3.E) is observed over the timber tie-beam. These tie rods can be dated between the late 19th and early 20th centuries according to shape and material. The tie rod is made of two bars: each ends with an eye on one side and is threaded on the other. A parallelepiped sleeve joins the threaded heads with the function of a turnbuckle; a large iron spin connects the eye to a fork made of two curved iron plates fixed to the sides of the rafter. Couples of similar iron ties were employed in 1929 to rebuild two trusses in the South-Eastern part of the roof, but their use as reinforcement can be observed only in the North-Western wing, where they were added to all trusses. Therefore, this supplementary tie rod is not strictly related to the works (paragraph 4.3) aimed at suspending underlying partitions from the roof trusses.

4.2. LIGHTWEIGHT PARTITIONS

Lightweight partitions divide the examined part of the second noble storey into rooms covered by timber ceilings generally shaped as vaults. Thin-tile vaults were widely used in the rest of the storey, but restoration works have shown no trace of them in the portion described in this paper, despite the signs of floor observed at the level of trusses. The second storey suffered several changes when used as a school in mid 20th century, but neither historic partitions are homogeneous in age and construction. This non-homogeneity is evident by comparing two couples of historical lightweight walls in the analyzed portion.

One couple of partitions consists of timber frames. One of the two lightweight walls is particularly interesting since it is made of two parallel frames (Fig. 4). The first one is composed of rough timber studs, connected to the top plate and to intermediate laths by cross halving joints reinforced with iron nails; a layer of woven reed mat supports the plaster. The second frame seems more recent: squared timber studs, joined by a top plate, are sporadically linked to the first frame by means of thin wooden connectors; irregular pieces of timber boards served as a base for the finishing. The cavity between the adjacent frames is occupied by two diagonal braces (Figure 4, left). The two frames are different in height, and their top plates support vaulted timber ceilings, which are sensibly different in shape and construction. Both vaults are hanged at wrought iron tie rods connected to the trusses. In the larger ceiling, the mid section of the ribs are borne by a group of aligned iron bars, which pierce the same tie-beam and are blocked against its extrados (Figure 4, middle); a second group of iron tie rods supports the basis of the vault, which is the top plate of the second timber frame, and are suspended from joists laid on consecutive tie-beams (Figure 4, right). The same joists support a secondary timber joist, pierced by tie rods bearing the ribs of the smaller vaulted ceiling. Upper heads of iron ties are threaded and fixed to timber elements by means of nut and washer.

Fig. 4. *On the left: timber partition made of two different frames, one covered by irregular pieces of timber boards and the other by woven reed mat. The transverse partition is a single timber frame covered by woven reed mat on the side of the room and by timber boards on the external side. In the middle: a larger vaulted ceiling over the timber partition. On the right: connection of a couple of ceilings over the two frames of the partition.*

The second couple of partitions (Fig. 5) consists of thin-tile brick walls and supports a timber ceiling shaped as a trough vault.

As expected in the local historic architecture [8], the shape and stiffness of this ceiling are assured by extrados ribs (Figs. 5 and 6): in order to respect the curved shape of the ceiling, each rib is made of two layers of small pieces of timber boards, nailed one to the other. The bottom head of the rib lies on masonry in a hole or on the timber top plate of the partition. The top heads of the ribs converge towards diagonal ribs (7.A in Figure 7), placed at the intersections of the four curved surfaces of the vault. Since the ceiling covers a rectangular room, two ribs of the bigger curved surfaces are continuous (7.B), and the diagonal ribs converge in couples towards their vertical sides. Horizontal laths with rectangular sec-

Fig. 5. *Thin-tile brick partitions and corresponding timber vaulted ceiling. Some iron tie rods are visible on the surface of the lightweight wall.*

tion complete the frame and are nailed in notches to the intrados of the curved ribs. Bays of this timber frame are covered from the underside with woven reed mat, used as support for plaster.

The practice of hanging timber ceilings to the above elements of the building structure was common in the local historic construction. Especially in large rooms, several solutions have also been observed, in which iron ties and timber bracings are used to limit the deformation of the frame [11]. In the case analyzed in this study, ceilings are ordinary in size, and the solutions used to hang the vaulted ceilings are usual. Nonetheless, as far

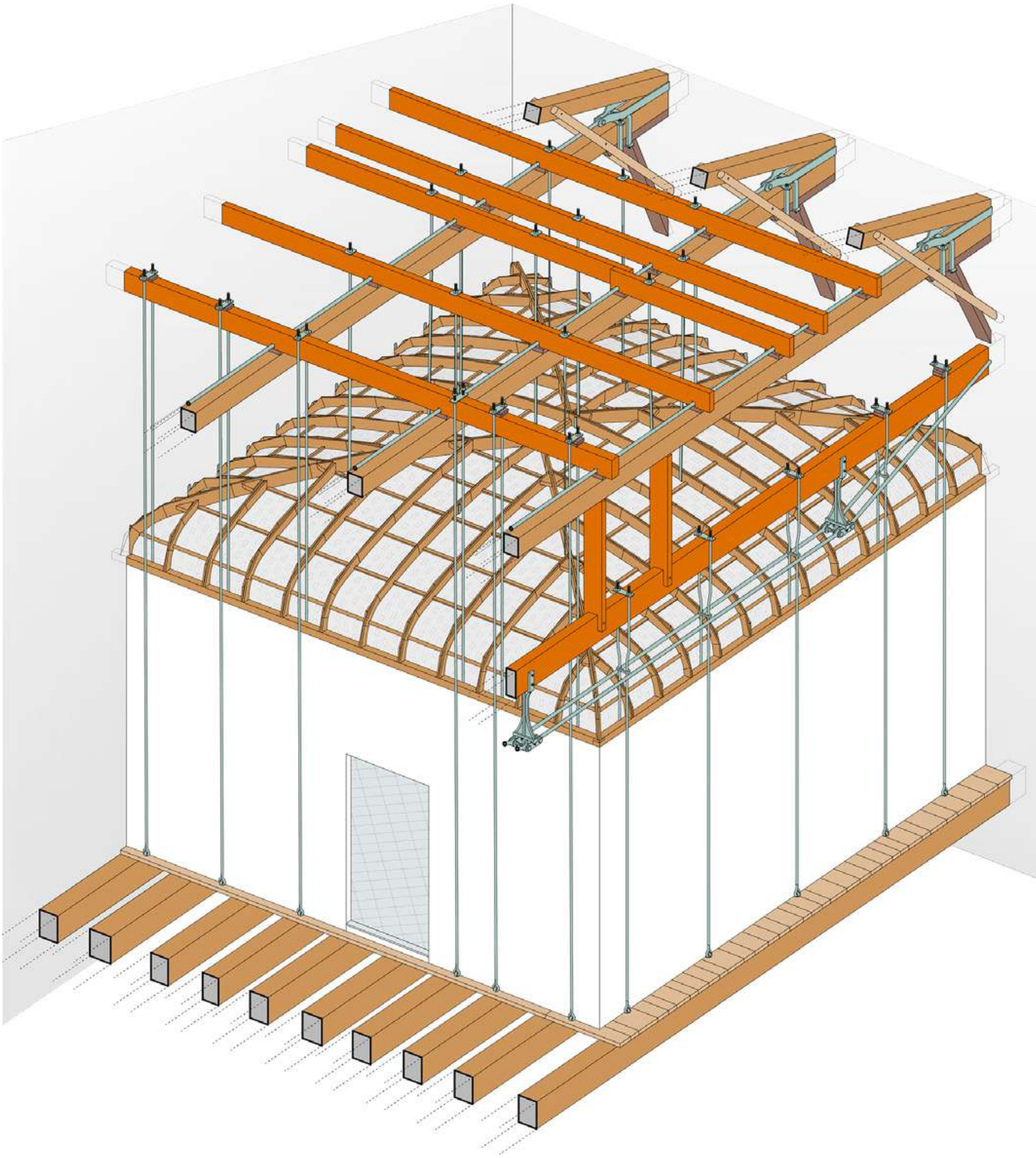

Fig. 6. *Construction scheme of thin-tile brick partitions, corresponding timber vaulted ceiling, and connections to the roof timber trusses on the second storey of palazzo Butera. The average cross dimensions of floor beams are 0.25 m x 0.35 m, while the distance between beam axes is 0.70 m.*

as the thin-tile brick partitions are considered, timber vault and lightweight walls are both suspended, and this results in an interesting system of timber and metal elements, which connect partitions, the ceiling, and trusses (Fig. 6).

4.3. HANGING ELEMENTS

The two thin-tile brick partitions and the corresponding timber ceiling in the North-Western corner of the second noble storey are suspended from the trusses above them. The timber vault, which lies on top of the lightweight walls, is suspended by means of twelve iron plates used as tie rods. The bottom head of each tie wraps the rib and is fixed to its sides. The top of the iron tie has a circular section and ends with a threaded head, which pierces a timber joist and is blocked against its extrados with nut and square washer.

Iron ties are connected to the most stressed sections of the timber frame. One tie rod (7.C in Figure 7) is connected to the mid transverse section of each diagonal rib. Another one (7.D) bears the central rib of the two secondary curved surfaces of the vault. Three iron ties support the two main ribs: one is located in the center (7.E), where the main transversal rib and two diagonals converge; the others (7.F) bear the rib in the middle of each curved surface.

Groups of three iron ties are suspended from the same joist, lying on the stonewall (boundary with *palazzo Benso*, Figure 1) and on the tie-beams of the first three trusses. The joists (7.G) are four and lie on timber pieces, used to regulate the tie-beams on the overside; notches in the intrados of the joists were necessary because of the supplementary iron ties described in paragraph 4.3. Since the aspect and transverse section are similar to the timber elements used to reinforce the trusses, it is reasonable that the joists were put in place in the same period.

A fifth parallel joist (8.A in Figure 8), similar in height but wider than the previous four, bears six couples of iron ties (8.B), which are used to bear one tile-brick wall,

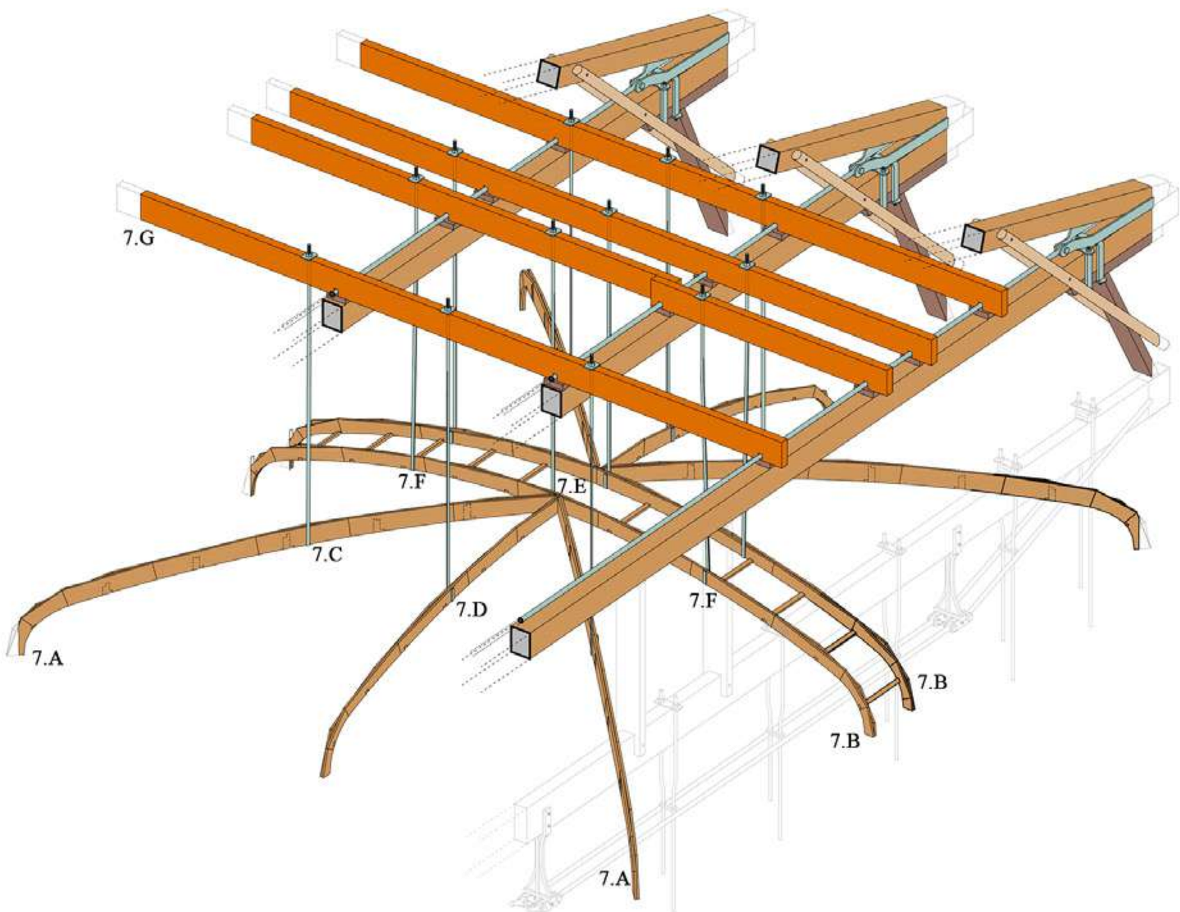

Fig. 7. *Scheme of tie rods and suspended ribs of the vaulted ceiling, together with the bearing joists placed on the tie-beams of trusses. One of the joists is made of two shorter elements with the same cross section as the others. The average distance between the three trusses is 1.6 m.*

although this lightweight partition is transverse to the underlying floor beams. The ties of each pair adjoin the raw partition on the two sides. At the top, the threaded heads of the paired ties are fixed to a plate located on the extrados of the timber joist. At the bottom, each tie ends with an eye. The corresponding eyes of the paired ties are linked by the hook ends of a short iron plate. At the base of the partition, the six plates bear an iron plate, whose width is approximately the same as the raw thickness of the lightweight wall. During the recent restoration of the timber floor, this plate was visible under the doorstep of the partition when the boards were dismantled.

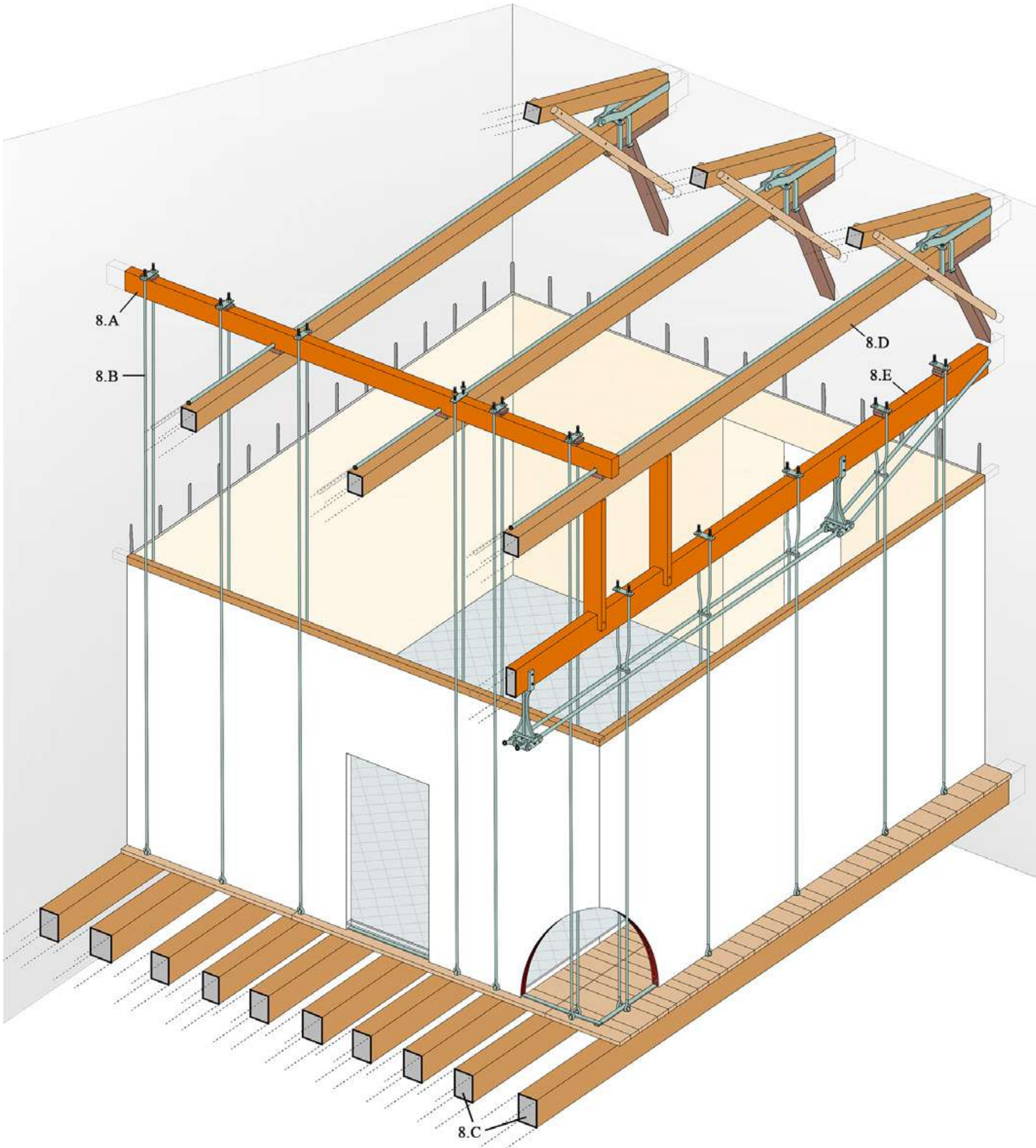

Fig. 8. *Scheme of the system used to suspend the thin-tile brick walls from the roof trusses.*

The most relevant work was realized to suspend the second brick-tile partition. The latter is parallel to the floor beams, and its position corresponds to the span between two of them (8.C), which is covered by a layer of 5-cm-thick timber planks, the last remains of the boards existing before those dismantled in the recent restoration. The presence of an iron plate between planks and partition is suggested by analogy. This lightweight wall is located under the third truss of the roof, approximately on the same vertical plane. Consequently, the five couples of ties should have been connected to a single tie-beam (8.D), which already bears an additional load transferred by the transversal joists. Therefore, in this case, the paired ties are suspended from a trussed beam (8.E), which runs under the truss.

The trussed beam consists of a timber beam with two metal struts and paired tie rods. Each strut is ribbed; the related detail is shown in Figure 9. The top head is shaped like a fork, where the timber beam, which bears the tie rods of the partition, is inserted and fixed by means of bolts. In the span between the struts, two vertical timber elements lie on the trussed beam and reach the tie-beam of the third truss at the underside, serving as intermediate supports against the additional load of suspended elements (namely, part of the ceiling and transverse partition).

The strut becomes wider when compared to the intermediate section moving to the bottom. The bottom head is shaped in order to guide and bolt two pairs of short iron plates. Apart from the connection to the strut, each pair of plates has two couples of corresponding holes. A thick iron pin passes through each couple and is blocked against the plates by a flat head on one side and a thin piercing plate on the other side. The pin blocks an iron tie bar, between the paired plates, by passing through its eye head.

Each tie rod is made of three bars. The intermediate one ends with an eye at both heads and runs horizontally below the underside level of the trussed beam. In the lateral bars, the head connected to the strut is an eye,

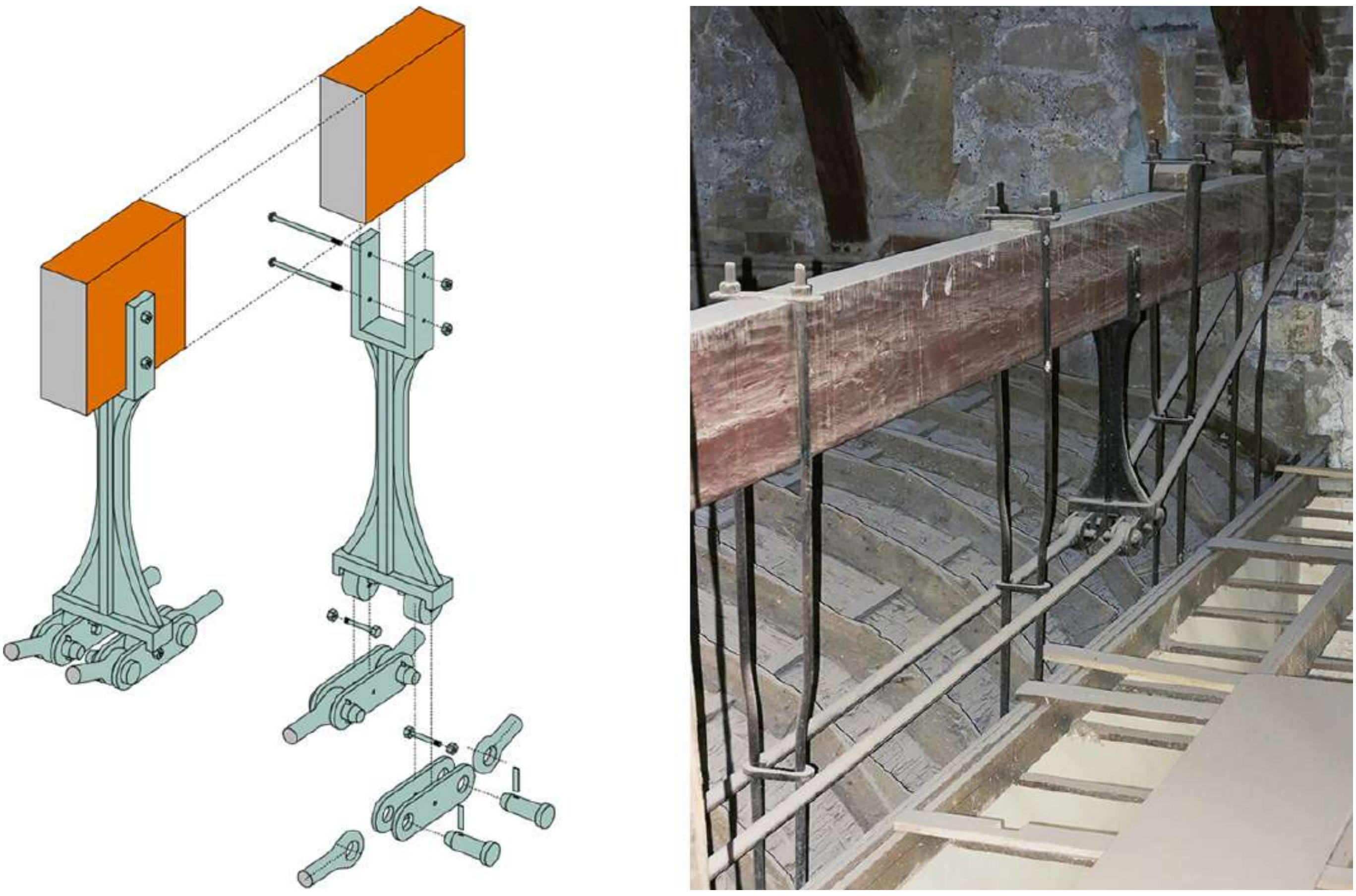

Fig. 9. *On the left: scheme of the metal struts of the trussed beam used to suspend a thin-tile brick partition. On the right: picture of one of the two struts.*

while the other head reaches the side of the timber beam but is concealed in the wall. It is reasonable that the joint between bar and beam is similar to the solution observed in a couple of trusses replaced in the South-Eastern wing of the building. In these trusses, a pair of supplementary iron ties runs above the tie beam and is connected to the rafters by means of a thick iron pin, which pierces the rafter and blocks the eye heads of the tie rods. Wrought iron plates, nailed to the lateral sides of the rafter and pierced for the passage of the pin, prevent the latter from damaging the timber element.

5. CONCLUSIONS

Large dimensions of monumental masonry buildings required the solution of structural problems, frequently related to the construction of floors and roofs, but also aimed at limiting loads caused by the partition of indoor space. Technical treatises suggested several solutions, especially with the diffusion of iron in building practice during the 19th century. Despite the knowledge and expertise of designers involved in the construction or renovation of representative buildings, technical solutions were largely influenced by local practices, as well as by the cost and availability of materials and building products.

The construction examined in this paper, namely a system of timber and iron elements used to suspend lightweight partitions and ceilings from roof trusses, is original but not innovative in its technical details. It is based on the use of devices, such as tie rods and trussed beam, which were well-established in the period of construction, namely between the late 19th and early 20th century.

The use of suspended building components – such as floors or partitions – was not marginal in the architectural heritage of Sicily, but recurring solutions are not defined, given the peculiarities of the buildings where they have been described so far. Therefore, the system examined in *palazzo Butera* contributes to documenting the local application of suspended partitions and advancing knowledge on the technical features of hanging building components. Besides contributing to construction history, detailed analyses of peculiar applications provide helpful information for examining comparable technical elements and identifying appropriate solutions for their conservation.

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Authors contribution

Enrico Genova: conceptualization, data curation, investigation, methodology, writing.
Giovanni Fatta: conceptualization, supervision, writing.

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THE GENESIS OF TIMBER TRUSSES: "UNEXPECTED" AFFINITIES BETWEEN ROOFS CARPENTRY IN ETRURIA AND PHRYGIA DURING THE ANTIQUITY

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Abstract

The genesis of wooden trusses is a very controversial issue as the archaeological data, scarce and incomplete, are not very explicit.
Indirect pieces of evidence of roof carpentry organized according to a truss system seem to have been found in the Mediterranean basin, at least since the Iron Age. However, these are isolated cases that probably did not have a decisive influence on the evolution of the roofs in the immediately following eras.
Full awareness of the potential and systematization of the truss system occurred in Roman areas, and only in Late Antiquity such an organization of the roof structure started to be notably widespread, especially in the basilicas.
In the process of conceptualizing the trusses, a considerable contribution is to be recognized to the Etruscan and Phrygian civilizations. Besides having in common an advanced development of timber structures, these societies show diverse "coincidences" in material culture. In fact, for both populations, relying on the iconography of figurative products, the articulation of the widely used roof carpentry is comparable to a truss, at least in the essential members and in their arrangement.
The contribution also provides information, with particular regard to that of construction nature, about the oldest existing wooden carpentry, dating back to the Early Phrygian period and belonging to the roof of the burial chamber of the "MM" tomb of the ancient city of Gordion (currently the village of Yassıhöyük, in Anatolia).

Keywords

Timber truss, Antiquity, Etruscans, Phrygians, History of the construction.

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1. INTRODUCTION AND METHODS

The need to absorb the thrust deriving from a sloping roof, functional to respond to the correct flow of rainwater, must have been one of the construction problems to be solved in the evolution from the first makeshift shelters of prehistoric times to the most definitive homes.

The solutions, of an empirical type, adopt, in general, two different structural "philosophies": counteract the rotation of the pitched roof through the mass of the vertical structure or, alternatively, create a system of members organized according to a truss, which transfers the internal forces in a "closed" flow path with no pushing component. A third possible "way" has been left out, that is, adopting some constraint with high stiffness between the two inclined elements, a complex condition to achieve in the historical context of this contribution.

The genesis of wooden trusses is a little-explored topic in the literature with often conflicting and oscillating opinions between an older dating that considers their use as early as the sixth century BC in the Magna Graecia context [1, 2] and a more "cautious" position that recognizes an extensive use of trusses at least since the Hellenistic age [3, 4].

However, both hypotheses have raised many perplexities as they rely on inferences deriving from indirect and uncertain data and inevitably lead to formulating divergent theses [5-8]. In fact, although there is episodic evidence of trusses since the Iron Age, for example, the one engraved on the stele of San Vitale in Bologna, dating back to the eighth century BC [5, 9], a full awareness of the potential and the systematization of this system took place within the Roman realm. Only during the Late Antiquity, there was a notable spread, especially in the basilicas, of such an organization of roof carpentry [5, 6, 7, 8].

The slow and gradual conception process of the truss took advantage, among the various contributions, of the Etruscan and Phrygian material culture. Despite belonging to very distant geographical areas, these civilizations show "curious" links, perhaps apparent, and share a high degree of advancement around the wooden structures with possible early construction of roof structures similar to trusses with regard to the stresses transferred among the members.

The study, part of broader research on the origins of wooden trusses in the Mediterranean basin, relied on sparse archaeological evidence and, above all, on indirect shreds of evidence such as the iconography of figurative products that reproduce roofs.

The picture outlined is based on powerful interpretative "tools", in some cases neglected by the literature of the sector, which are the laws of statics and construction rationality used in the execution of the roofs of buildings during the Antiquity.

2. RESULTS

2.1. ETRURIA AND PHRYGIA IN ANTIQUITY

The hypothesis of an Anatolian origin of the Etruscans and of the Orientalizing cultural phenomenon that developed in Italy between the eighth and sixth centuries BC [10] was proposed, among the most authoritative sources, by Herodotus (Stories, I, 94, 5-7) with a wide echo in the Antiquity.

This thesis of some links between the Etruscan civilization and Anatolia has sparked a heated debate since the nineteenth century. Although in the last century the academic Etruscology, under the authoritative push of Pallottino, believed that the problem of Etruscan origins had been solved, the question reopened recently. In fact, the discussion has come back alive thanks to a new "point of view", mainly generated by studies on the genetics of ancient populations. Therefore, the position that based the origins on the – not quite fast – evolution of an indigenous people in the Villanovan era, which led to the birth of the Etruscan *ethnos* in substantial continuity, is enriched with further contributions. The latter interpretation admits the possibility of modest phenomena of immigration that may have affected the territory of central Italy at the end of the Bronze Age [11].

It is always and in any case incorrect to "enclose" the Etruscans in a sphere of singularity as a phenomenon that is extraneous to the surrounding world. In fact, the diffusion of religious and fantastic motifs from the East, during the Orientalizing phase, in other areas of the Mediterranean basin – for example, in Greece, in a sort of *ante-litteram* globalization –, in addition to the ornamental and figurative taste, is not to be considered secondary [12]. Despite this, the congruence among cultural factors, even related to construction, in the Etruscan and Phrygian civilizations seems so evident that it still influences modern opinions [10]. For example, a particular expertise in metalworking is known in both civilizations. During the Iron Age, Phrygia's territory stood out as Anatolia's most prominent metal producer [13]. A similar development can be assumed for woodworking. In this regard, Vitruvius (*De Architectura*, II, 1, 4) attributes a continuity with the territory of Phrygia in the use of wooden structures for houses, indirectly recognizing some *ab antiquo* knowledge linked to timber carpentry. Profound knowledge is evidenced by the finesse and complexity of numerous wooden finds discovered in the Early Phrygian period (ca. 950-800 BC) tombs.

Similarly, in Etruria, a privileged condition for the presence of metalliferous resources (iron, copper, lead) gave a considerable impulse to the birth of advanced metallurgy; evidence can be found in the bronzes, gold, and silvers of the Orientalizing tombs of Caere, Vulci, Vetulonia, and Palestrina, whose decorations, in some cases, recall those made for the royal Tomb of Gordion, the ancient capital of Phrygia.

Furthermore, the concordances concerning aspects of the religious and funerary sphere are perspicuous. The grandiose Etruscan hypogea tombs imitating the house and the splendor of the grave goods evoke, in fact, oriental origins. Moreover, the 6th century BC cube and aedicule tombs of Etruria give the impression of a direct correlation with the rock facades of the sanctuaries of some areas of the Anatolian territory, datable between the 8th and 6th centuries BC. These artifacts faithfully imitate the shapes of real buildings, including the roof, in the most minute details.

2.2. THE WOODEN ROOF CARPENTRY

The graffiti engraved on the front of the Megaron 2 in the Phrygian citadel of the ancient Gordion, depicting buildings dating back to the 9th century BC [14], is of remarkable interest for the genesis of wooden trusses.

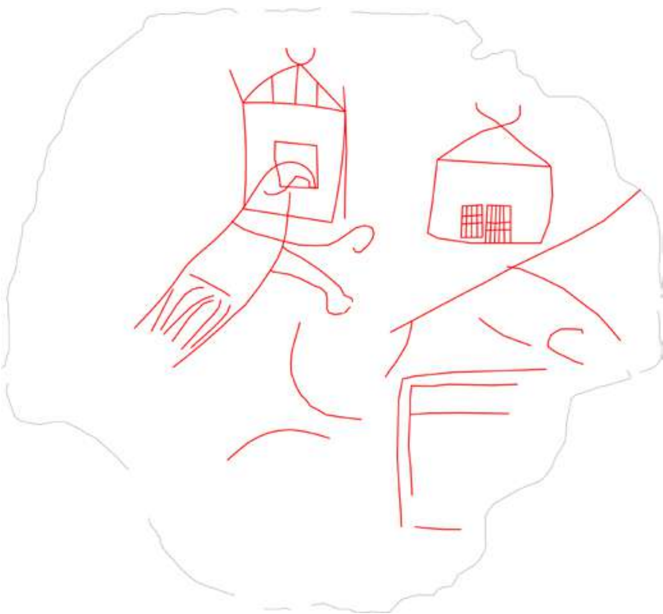

Fig. 1. *Graffiti engraved on the front of the Megaron 2 in the Phrygian citadel of the ancient Gordion. (Redrawn by the author from Berndt-Ersoz, S (2006) Phrygian Rock-Cut Shrines: Structure, Function, And Cult Practice, Brill Academic Pub).*

The sketched lines reproduce the front of buildings with pitched roofs, whose high slope leads to the hypothesis of using a thatched covering, according to archaeological evidence [15]. The hut depicted on the left of figure 1 is particularly interesting for its details. The structure, probably made of wood, comprises frames whose posts continue beyond the base of the roof.

The *tectum* carpentry is drawn as composed of two inclined elements, a vertical prop and a tie-beam – more appropriately, the latter has to be merely defined as the upper closing element of the wooden framing –. This member, in fact, has the primary purpose of integrating the two posts preventing their rotation, a consequence of the horizontal thrust deriving from the wooden rafter. In the construction phase, it is easy to encounter stability problems for the wooden post if subject to the thrust of the inclined roof member without the aid of the top constraint created by the horizontal member. In the tympanum, two other vertical lines are arranged symmetrically with respect to the central prop, acting as queen-posts, helpful in creating an intermediate constraint for the rafter stemming its deflection. This arrangement is similar to what was carved in the cube tomb of the necropolis of Peschiera (Tuscania, VT) and the main chamber of the Mengarelli *tumulus* (Cerveteri, RM). The joint in which the three members – tie-beam, post, and rafter – concur is of complex execution. Hence, it can be inferred that these members were juxtaposed, assuming that the transmission of the stresses, especially tensions, was delegated to metal fittings and vegetal ropes. This configuration is plausible, considering a relatively high inclination of the thatched covering with low values of the horizontal component of the thrust and, therefore, of the tensile stresses in the horizontal member. It is a reasonable hypothesis that the connection between the two rafters benefited from a scissor-type joint, with recesses made in both members. This geometry allowed to keep the two inclined elements on the same plane in order to center both rafters on the chord. The prop is essential to withstand and transfer to the horizontal member loads deriving from the *acroterion* depicted on the ridge, which, in both the graffiti, is made by continuing the rafters beyond their junction.

The Etruscan marker of an inhumation tomb, found in the necropolis of San Vitale near Bologna and dating back to the end of the 8th century BC, is slightly later [5, 9]. A hut is engraved on this stele, whose roof structure is characterized by a configuration similar to that depicted in the front of Megaron 2. The central post of the hut continues until it intercepts the ridge of the roof, assuming the static role of a king post. As in the Anatolian drawing, the two rafters benefit from two struts which, with the same role as the queen-posts of Gordion, constitute further supports for the rafters, limiting their displacements.

Fig. 2. *Stele found in the necropolis of San Vitale, Bologna (Inv.: 11683, Archaeological Museum of Bologna).*

This organization of the roof carpentry corresponds to what is depicted in the facade identified with no. 9 [15] reproduced into the rock of Kes Kaya (actual Turkey), where, in addition to the two struts, a king post is carved. This last member is the recurring and dominant element in the tympanum compositional scheme and other rock sanctuaries in the Phrygian Highlands. The sanctuary, imitating a real building in detail as in Etruscan funerary architecture, consists of one or more facades. At the entrance, there is a niche in which the divinity statue was placed. The sloping type roof emphasizes an extreme variability with slope values between 18° and 53°. Such morphological features lead to hypothesizing the representation of buildings with different covering. As is known, the thatched covering requires significant slopes for proper rainwater control.

The use of clay tiles, effective in the disposal of rainwater even with a modest slope inclination, is a phenomenon attested in Anatolia only from the 6th century BC [21].

In some examples – e.g., facade no. 16 in Arslankaya [16] and Malta's monument in the Ihsaniye district – the king post highlights a protrusion at both ends. In some artifacts, such as the stele found in Bahçelievler, Ankara, which portrays Kybele and dates back to the seventh century BC, the king-post is represented in the essential morphological characters of a column, with a shaft, capital, and base. In the context of Magna Graecia, similarly, columns are depicted in the tympanum of the southern slab of tomb 24 in Paestum (5th century BC) and, in Sicily, in the *cippus* of Gela, dating back to the 6th century BC [8]. For the Italian term *colonnello* (king post), an etymological derivation from *columna* (column) has been supposed, considering the similar static role exercised by both structural typologies [22]. A possible explanation for this peculiarity could be that the resistant section expands in the transverse plane, near the constraint, in order to stabilize the compressed element and, at the same time, facilitate the transfer of stresses between the members. The presence of construction devices aimed at improving the constraint at the base of the king-post is essential to ensure equilibrium in the construction phase before the installation of the ridge beam. In other words, it could be the reproduction of a connecting cleat arranged transversely to the structural unit, similar to those, for exam-

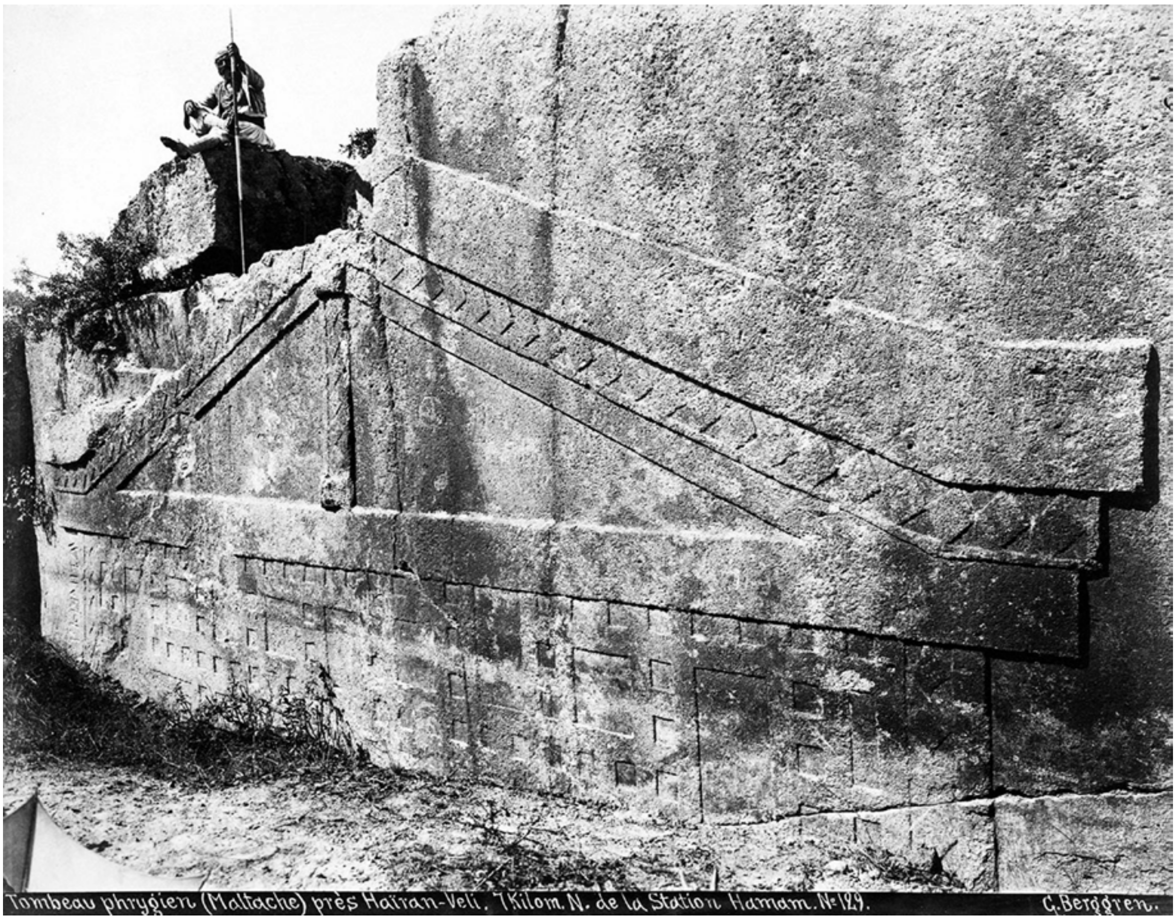

Fig. 3. *Malta's monument in the Ihsaniye district. (G. Berggren's photo, 1889).*

ple, that join the king-post to the ridge-beam belonging to the trusses of Saint Catherine of Sinai – the oldest known surviving trusses – dating back to the 6th century AD.

This solution is a structural device that evokes what has been recognized by recent studies [9, 19], regardless of possible symbolisms, in the iconography of the wall paintings of some Etruscan tombs – for example, those of the necropolis of Monterozzi at Tarquinia (VT) and of Pianezze 2 tomb at Grotte di Castro (Vt) – executed during the Orientalizing period.

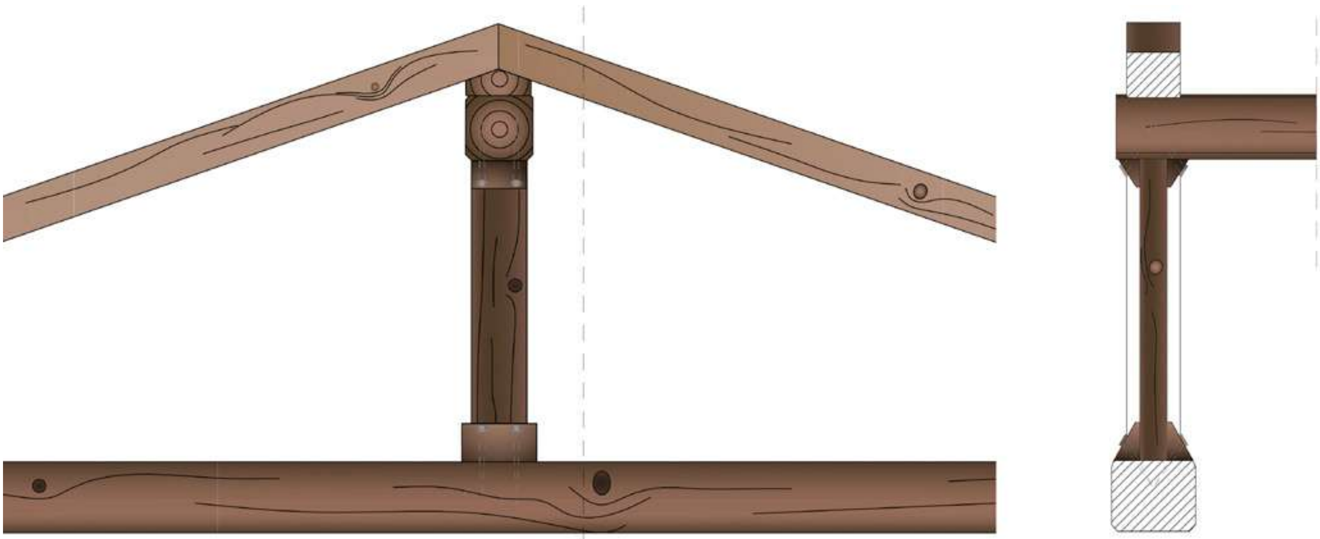

Fig. 4. *Reconstruction hypothesis of the carpentry carved in the Phrygian sanctuaries.*

Fig. 5. *Burial chamber of the tomb of Barone Kestner in the necropolis of Monterozzi, Tarquinia (VT).*

In fact, in these examples, the support of the ridge beam assumes the characteristic hourglass shape in a time horizon that goes from at least the middle of the 6th century BC [20]. The enlargement of the section at the top evokes a corbel, helpful in connecting the *columen* to the vertical prop [9]. In the lower part, this shaping probably refers to a useful geometry to guarantee the equilibrium of an element stressed by compressive-bending stresses. It is strictly rational from a static point of view that the enlargement of the base depicts two triangular cleats or, more generally, inclined elements placed laterally to the prop to counteract the rotation in the plane of the structural unit. In addition, the constraint at the base stiffened by the presence of the cleats reduces the effective length.

The sculpted tympanum does not provide conclusive clues to be able to hypothesize whether, for the sanctuaries of the Anatolian plateau, the configuration of the roof is organized according to a truss system and, therefore, whether the stresses among the members draw closed paths. In fact, essential information on the type of connections and, therefore, the transmitted stresses is lacking.

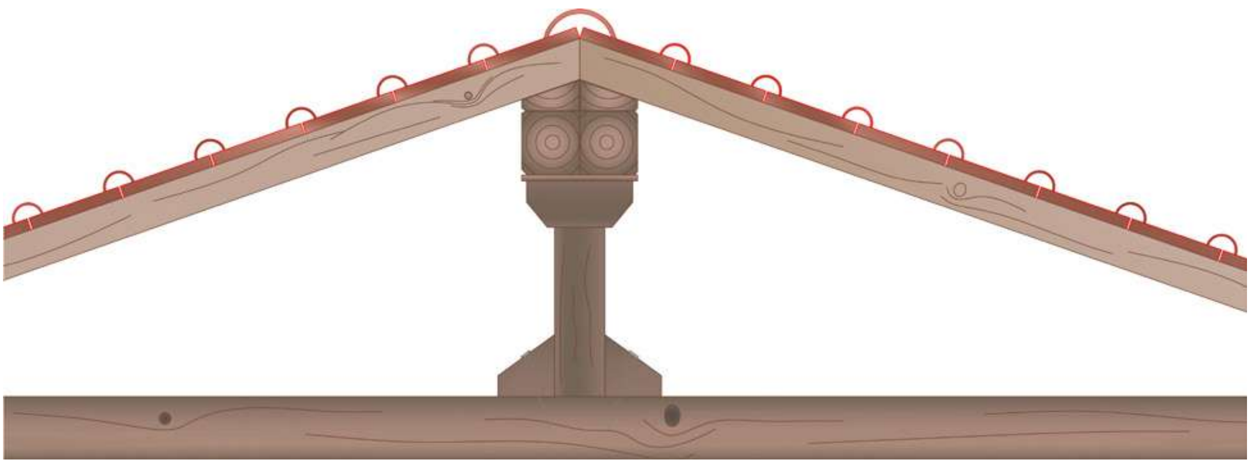

Fig. 6. *Reconstruction hypothesis of the carpentry depicted in the Etruscan Orientalizing period tombs.*

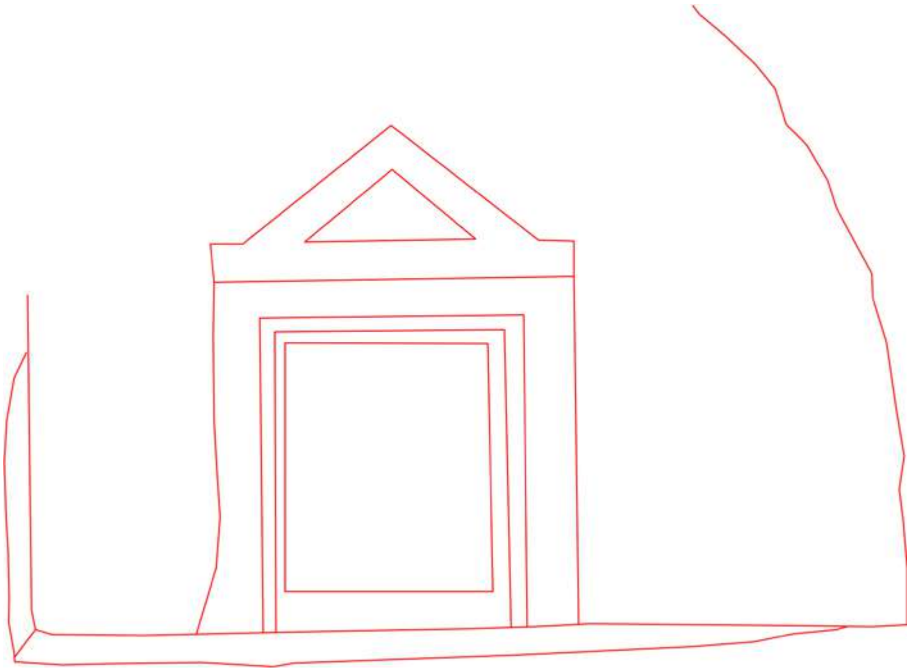

Fig. 7. *Phrygian façade (n. 19) at Demirli Koy. (Redrawn by the author from Berndt-Ersoz, S (2006) Phrygian Rock-Cut Shrines: Structure, Function, and Cult Practice, Brill Academic Pub).*

However, in some facades (e.g., Bahâayiâ - façade/shaft monument *No. 28* at Gökbahçe based on [16]; Mal Taâ - façade/shaft monument *No. 24* - in the Köhnüâ valley; Façade *No. 19* at Demirli Köy; Façade *No. 13* at DöÅer Asar Kaya based on [16]) the presence of a considerable extension of the horizontal member beyond the junction to the rafter, a type of shrine roof called Chinese roof [23], could refer to the shaping of the horizontal member, rational from the static point of view, applicable to contrast the horizontal thrust deriving from the inclined element.

Fig. 8. *Bronzetto dell'Offerente tomb in the necropolis of San Cerbone-Casone, Populonia (LI).*

However, the thesis inspired by the configuration that characterizes the aedicule tomb of the Bronzetto dell'Offerente in the necropolis of San Cerbone in Populonia (6th century BC) remains valid: the continuation of the horizontal member sculpted beyond the joint could reproduce a beam, whose own weight, increased by the load deriving from the roof covering, guarantees equilibrium by counteracting the tendency of the common rafter to translate. The roofing carpentry in this example is composed of inclined lithic slabs but most likely paraphrases a wooden structure, which is contrasted to the foot by a sandstone (i.e., *panchina*) crowning beam.

Fig. 9. *The "West Tomb" in Midas City (Yazılıkaya) in the Phrygian Highlands.*

A different organization of carpentry – the *columen* is depicted above the rafters, referring to the typology known in Italy, in modern times, as "*tetto alla lombarda o alla toscana*", which differs from the "Piemontese" typology where the king-post directly supports the ridge beam – compared to that presumed for the sanctuaries is the one that appears in the "West Tomb" in Midas City (Yazılıkaya) in the Phrygian Highlands, dating back to the 6th century BC. The representation of the interior is remarkably realistic and shows a roof characterized by a considerable inclination. Although not providing any detail on the joints, the craftsman depicts the elements of the secondary roof frame. In fact, the purlins are carved into the rock and the common rafter that rests in correspondence with the posts with the interposition of a perimeter beam. The common and principal rafter perfectly unloads its weight on the post without shear stresses in the horizontal member. The ridge beam, resting on the truss and, in turn, supporting the common rafters, is represented in a pseudo-circular section; the other members appear quadrangular in shape. Horizontal member and king-post have similar dimensions, hierarchically superior, compared to the rafters and common rafters, characterized by a more modest resistant section.

2.3. THE OLDEST SURVIVING WOODEN CARPENTRY

The historical sources of Antiquity, both Latin, Assyrian as well as Greek, are in agreement in pointing out the government in the Anatolian region of an important dynasty – Midas – between 733 and 677 BC, coinciding with the heyday of the Phrygian civilization, during which technical and technological innovations made possible to create wooden roofing structures capable of overcoming notable spans [24]. Evidence of such an advancement in the construction culture can be traced in some *tumuli*. More than 100 specimens located around the ancient capital Gordion can be dated between the 9th and 6th centuries BC. The most impressive in size, recognized by tradition as belonging to King Midas, is the Tomb called "MM" [25], dating back to around 740 BC.

With a diameter of about 300 meters, the *tumulus*, made up of clay, earth, and stones [26], rises to approximately 53 m, enclosing the burial chamber made entirely of timbers. The internal measurements of such a burial chamber are 5.15 m x 6.20 m, with a height of about 3.20 m [26]. The vertical structure, consisting of overlapping rectangular section members, widely varying in height, rests on a pine and cedar floor. Members' variability, from about 18 cm to 48 cm, is presumably due to the necessary adaptations to the geometric characteristics of the available Juniper roundwood logs immersed in a filling of stones surrounding the entire burial chamber.

The sloping roof, different from the flat roofs of the other *tumulus* tombs, for example, those called "P" and "W" in central Anatolia, represents the oldest surviving wooden carpentry. Both partially collapsed structures are roofs of the flat type with beams arranged side by side for mechanical reasons to prevent material from penetrating through the upper covering interstices. They are devoid of particularly advanced devices from a technical and technological point of view.

Relative to *tumulus* "P", the carpentry comprises two orders of black pine beams arranged side by side. The upper framework, consisting of 12 beams with a span of more than 5.2 m, is linked to the vertical wooden structure through half-timber joints, with recesses in both orthogonal members. The 11 outermost members, with a higher section and longer than 7 m, continue consistently beyond the vertical structure [27].

The "W" *tumulus* roof is organized according to a single frame of 13 beams, which cover a 3.3 m span, with a variable height between 21 cm and 48 cm and a thickness of about 22 cm [27].

The main "MM" roof frame is represented by wooden elements composed and shaped like a tympanum. These are two members placed side by side – whose width is about 34 cm, the height of about 42 cm, and cover a span of 11.5 m [26] – arranged with two additional overlapping rectangular elements. Such timbers are surmounted by two additional wooden elements that longitudinally taper at both ends, creating a triangle.

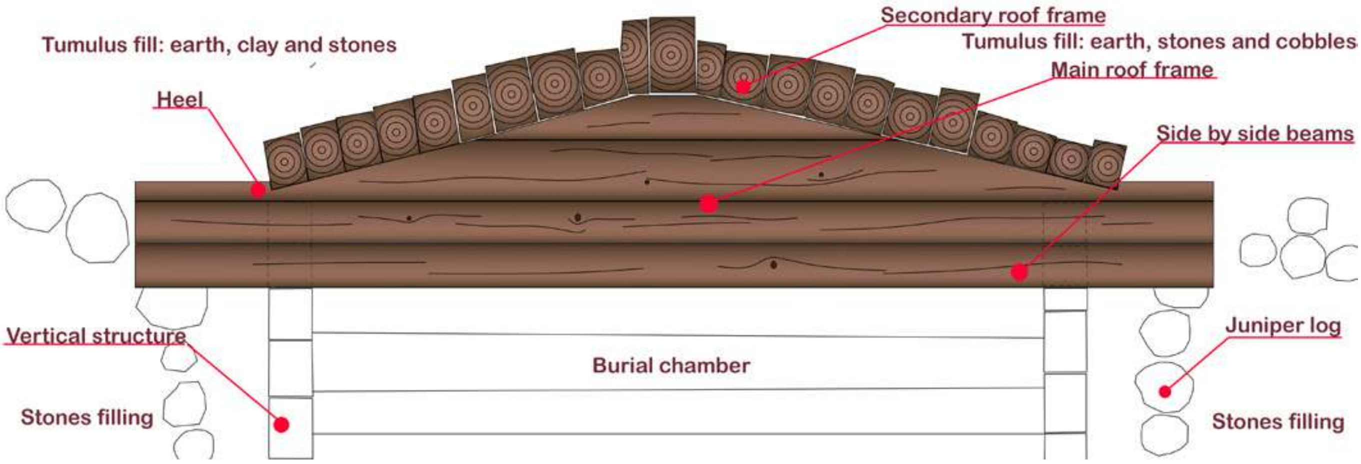

Fig. 10. *Detail of the carpentry roof of the tumulus tomb "MM".*

The side-by-side elements have "double T" – shaped tenons on both beams' transversal section ends, able to receive a mortise and counteract the distancing between the two members in the transverse plane. At the current state, they are significantly deformed with maximum deflection approximately in the middle and with a crack which – triggered at the lower edge due to excessive tensile stresses – continued horizontally on the lateral face breaking the fragile bonds between the wood grain. Over the side-by-side elements, there are 28 wooden pegs [26] aimed at improving the cooperation between the components of the triangular portion, whose boundary lines are perfectly matched horizontally. It should be emphasized that the size and number of such constraints are insufficient to make an effective connection, although they are useful for keeping the members in place during the several phases of the installation process.

The secondary roof frame is organized peculiarly and finds few comparisons in the wooden structures of Antiquity.

Pseudo-rectangular section beams are arranged perpendicularly to the described gable and placed side by side. The motivation is to avoid the fall of material into the sepulchral chamber, as well as of mechanical nature. When the load is applied, these beams, similar to voussoirs of an arch, generate sliding along the gable's inclined upper edge, which is contrasted by recesses made to the impost. Such a configuration causes compression transversal to the central axis of the beam and, therefore, friction, which helps absorb the bending stresses deriving from the load of the ground above. The central members, continuing beyond the support of the perimeter wall, consist of a more marked trapezoidal shape section, helpful in putting the system into compression. The recess mentioned above at the beam end – properly called heel – receives the horizontal component of the purlins thrust and generates tensions in the members making up the gable. Therefore, the heel is subject to shear stresses parallel to the wood grain, supported thanks to the contribution, near the junction, of the compression deriving from the above-ground weight. A rationalization of the resistant section is to be recognized, which extends the height, although composed of autonomous elements devoid of effective bond, near the centreline where the flexural burden is most significant. As described, it can be said that the stresses transferred among the members create a "closed" flow path for the internal forces, similar to a truss.

3. CONCLUSIONS

In the herein paper, it was preferred not to go into what has been a controversial "archaeological" debate linked to Etruscan origins. From this study emerges the undeniable and notable contribution that the construction culture of the two people had on the evolution of wooden carpentry in a time horizon between the 9th and 6th centuries BC. Furthermore, the paper highlights the "coincidences" between the Etruscan and Phrygian civilizations.

The various clues in the presented investigation, mainly interpreted according to the laws of statics and construction rationality, made it possible to reconstruct, albeit with the prudence imposed by decidedly exiguous and incomplete data, the wooden carpentry in the Etruscan and Anatolian areas.

The huts reproduced in the engraving discovered in the Megaron 2 and the stele of San Vitale, although they show many similarities in the articulation of the roofing elements, could be the result of autonomous construction development. In any case, in a pioneering way, the framing of a truss in its essential elements is defined in both reliefs. Nevertheless, it is worth noting that the configuration, rather than tending to create a truss system with awareness, derives from the need to tie and conclude the framing at the top.

However, such an organization of the roof members remains identical in the iconographic schemes of the Phrygian reliefs between the 8th and 6th centuries and in the Etruscan figurative products of the 6th century. This almost immutability led to believe in the achievement of an optimization of the structural type, at least from the point of view of equilibrium.

Throughout the contribution, no hypothesis is provided regarding the classification of the examples described as trusses, as data in possession, particularly on the type of connections, are not adequately explanatory. In fact, any attempt to depict the morphology of the nodes, given the absence of clues, can only be conjectural. Therefore, it is impossible to infer whether the members are or whether there are notches to transfer tensional and shear stresses. However, it should be noted that for the carpentry used in the "MM" Tomb of Gordion, even if the articulation of the resistant elements shows various peculiarities, the internal forces triggered in some of the timbers, thanks to the particular joints, are comparable with those of a truss.

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HISTORIC TIMBER ROOFS IN BELGIUM: OVERVIEW OF MATERIALS AND STRUCTURES (1150-1960)

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Abstract

Belgium has a remarkable heritage of historic timber roofs that can be traced back to the 12th century. This contribution provides a review of 60 years of research on Belgian timber roofs and outlines their developments from 1150 to 1960. The focus is firstly put on wood resources, a crucial parameter for roof construction in a scarcely forested landscape. Then, the evolution of structural concepts over 800 years is discussed based on illustrations of remarkable roofs. Moreover, this broad overview raises several questions that open up new prospects for future investigations.

Keywords

Historic roof construction, Timber, Historic woodlands, Trade, Wood qualities, Carpentry, Heritage, Belgium.

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1. INTRODUCTION

From the late middle ages to the creation of a modern state in 1830, the Belgian territories passed successively under the ruling of Burgundy, Spain, Austria, France, and the Netherlands. In modern history, this small strip of land descending steadily from the Ardennes forest towards the North Sea went from a forerunner of the industrial revolution to a colonial empire and a battlefield of two World Wars. The turbulent history of Belgium has inevitably swept away a significant share of its built heritage, with wooden structures on the front line. Yet plenty of timber roofs have survived arsons and bombings and provide a tangible testimony to a fragmented history.

This contribution provides a broad overview of timber roof construction in Belgium between 1150 and 1960, based on a review of the research carried out on this topic in the last 60 years. To summarize this long period in a comprehensive way, this review focuses on two key aspects in light of the most recent findings: the supply of timber and the evolution of roof types. Additional topics are introduced along with these two aspects, opening the path for further explorations through the bibliography.

1.1. PRINTED SOURCES

The interest in historic timber roofs grew during the 19th century with the Gothic revival movement and the construction of national identities. New light was shed on medieval timber structures in neighboring countries through publications by architects such as Augustus W. N. Pugin, Eugène E. Viollet-le-Duc, and Friedrich Ostendorf. In Belgium, architect Pierre F. Langerock compiled several volumes on important Flemish buildings in the 1880s, with particular attention to roofs (Fig. 1) [1]. In daily practice, the Gothic revival encouraged numerous Belgian architects to document and copy “national” medieval roofs, as exemplified by the works of Henri Beyaert and Pierre V. Jamaer in the second half of the 19th century.

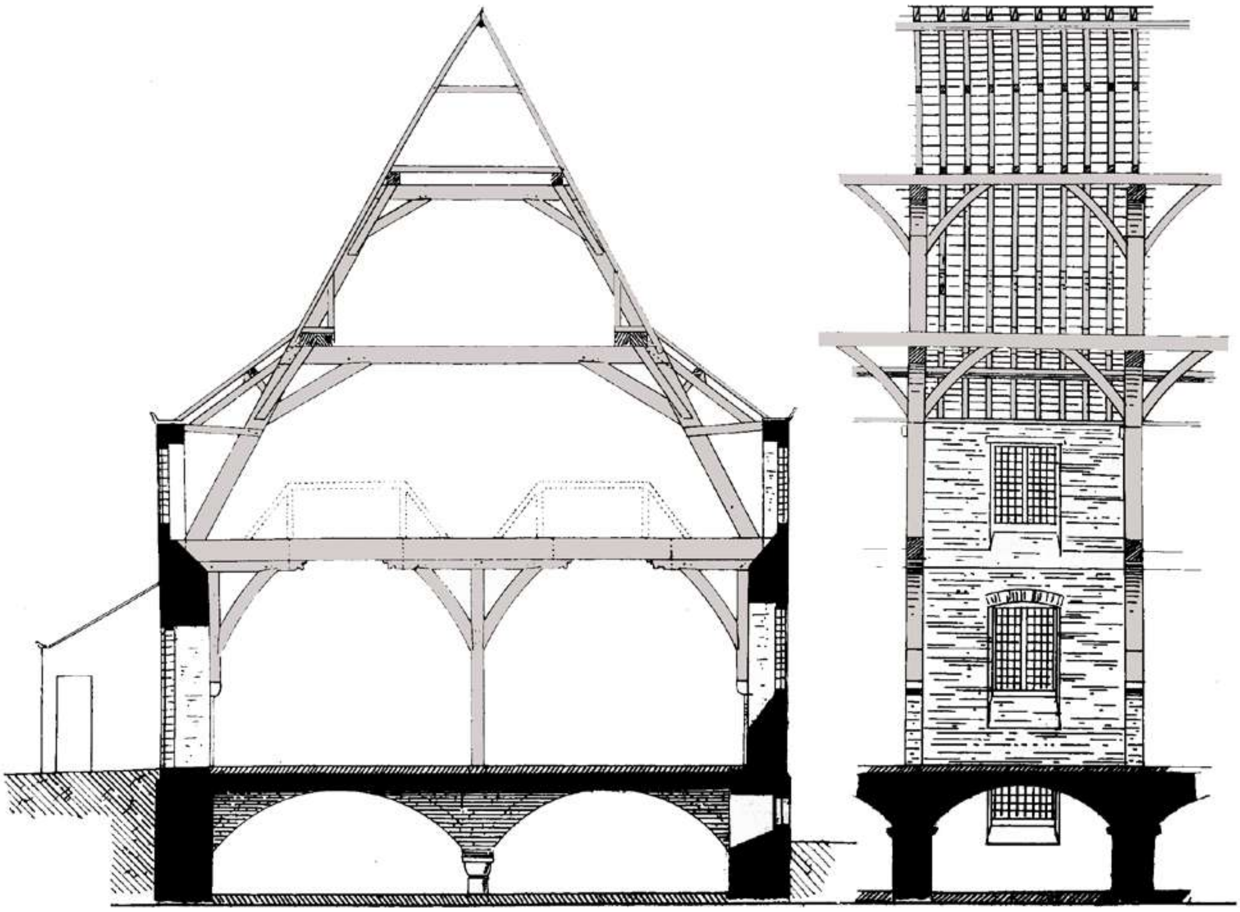

Fig. 1. *The roof of the Groot Vleeshuis in Ghent (1408-1417). (Image source: Langerock (1887) [1], adapted by the Author).*

Furthermore, a valuable source of information on carpentry typically lies in treatises aiming at theorizing and divulging this craft. These books emerged in 17th century France with authors like Mathurin Jousse (1627); two centuries later, their number soared with Johann K. Krafft (1805), Amand-Rose Emy (1837), Paul-Joseph Ardant (1840) [2], and many others. In 19th century Belgium, authors like Armand Demanet (1847) [3] and Eugène J. D. Roffiaen (1858) [4], both engineers and professors at the Military Academy of Brussels, published detailed insights into local construction. Unfortunately, illustrations of Belgian roofs are rare in such publications, as these engineers mostly copied French and British examples.

1.2. HISTORICAL RESEARCH

In 20th century Belgium, publications on Romanesque and Gothic architecture by Lemaire (1906) [5] and Brigode (1950) [6] brought to light numerous medieval timber structures in the provinces of Brabant and Hainaut. However, a thorough analysis of timber roofs in the vein of French architect Henri Deneux (1927) emerged only later with a study on medieval roofs in the old county of Flanders by Janse and Devliegher (1962) [7, 8]. Despite difficulties in dating some structures accurately, the authors proposed the first documented evolution of roof types and carpenters' marks. After years of field work, Janse further contributed to documenting some Flemish cases in his monumental publication on historical timber roofs in the Netherlands [9].

The obstacle of precise dating was brought down by dendrochronology (i.e., the analysis of tree rings), revolutionizing the study of historic timber structures following its wider use in the second half of the 20th century. In Belgium, the possibility to date precisely wooden elements was first applied on a large number of roofs by Hoffsummer (1989) [10] to establish a typological evolution in the basin of the river Meuse, Belgium's main timber trading route. This work paved the way for two further publications on the evolution of roof types supported by absolute dating – thereby establishing new dendrochronological curves and dating numerous historic buildings – which extended the study area successively to Wallonia [11] and Northern France and Belgium [12, 13]. It is worth underlining that the later works provided the first nationwide overview of roof types from the 12th century onwards.

In the last two decades, a renewed interest in the documentation and the rehabilitation of historic timber structures led to a large number of studies. To name but a few, researchers have focussed on specific buildings [14–17], building techniques [18, 19], on cities [20, 21] and regions [22]. These works focused mostly on the middle ages and, to a lesser extent, on the early modern period. They contributed not only to the detailed description of hundreds of roofs but also to broaden the scope of research from building archaeology to the history of trade and construction, with growing attention to timber supplies and building contexts. Further investigations have extended the research scope to timber structures of the 19th and early 20th centuries [23, 24]. Moreover, since 2013, a multidisciplinary team of experts has undertaken a research project on timber roof frames from the 12th to 19th century in the Brussels region [25–27].

As can be seen, research on historic timber roofs is rather active in Belgium. Universities and heritage agencies play an active role in documenting this type of built heritage, as shown by the steady number of publications, reports, and colloquiums in the last decade. Since the elevation drawings of Langerock, the field has evolved to encompass a broad context: forestry, supply networks, knowledge, tools, marks, use of iron, etc. The increasing use of dendrochronology has undeniably contributed to this development, making roofs a key element for the documentation and dating of the built heritage.

2. MATERIAL SUPPLY

The Belgian territories, independently from their ruling power, have always faced unequal access to wood resources, resulting in intricate supply networks. As there can be a considerable distance between a roof and its supply woodlands, the documentation of ancient trade routes and the identification of woodcutting areas rely on two strategies. On the one hand, in the last two decades, the application of dendroprovenancing (i.e., the use of dendrochronology to locate the origin of trees based on similar growth conditions) on roof structures has considerably advanced the understanding of timber supplies since the middle ages, providing unprecedented insights into the evolution of trading and forest management. On the other hand, with the potential of narrowing down the origin of trees to specific places, archival material can provide crucial evidence in this area of research, especially in light of on-site findings like shipping marks.

2.1. LOCAL FORESTS

The deep Ardennes forests, described by Petrarch as «inhospitable and wild woods where men at arms go at great risk» (Original text: «boschi inhospiti et selvaggi onde vanno a gran rischio uomini et arme») in 1333, have provided a chief source of hardwood as far as one can trace. For example, early archaeological evidence is given by the tie beams of the roof of the Church of St-Denis in Liège, cut in 1012-1019d, from oaks that grew for more than 300 years in a dense forest [15]. In the middle ages and through the early modern period, the vast majority of roofs erected in Southern Belgium consisted of locally-sourced oaks, which were floated on the river Meuse and its tributaries [11].

North of the Meuse basin, woodlands were scattered as early as the 12th century, although some have subsisted, such as the Sonian Forest near Brussels (Fig. 2). In this part of Belgium, woods were generally less dense than in the Ardennes forests, resulting in shorter and knottier trees that characterize traditional carpentry in Brabant [22]. Towards the end of the middle ages, increasing clearings led to the production of trees showing a faster growth rate, a trend clearly visible not only in Hainaut and Brabant but also in the Ardennes region [28]. In the vicinity of Brussels, although oak from the Sonian forest or the Meuse basin was always preferred for the largest spans until the turn of the 19th century, ongoing investigations have shown that its

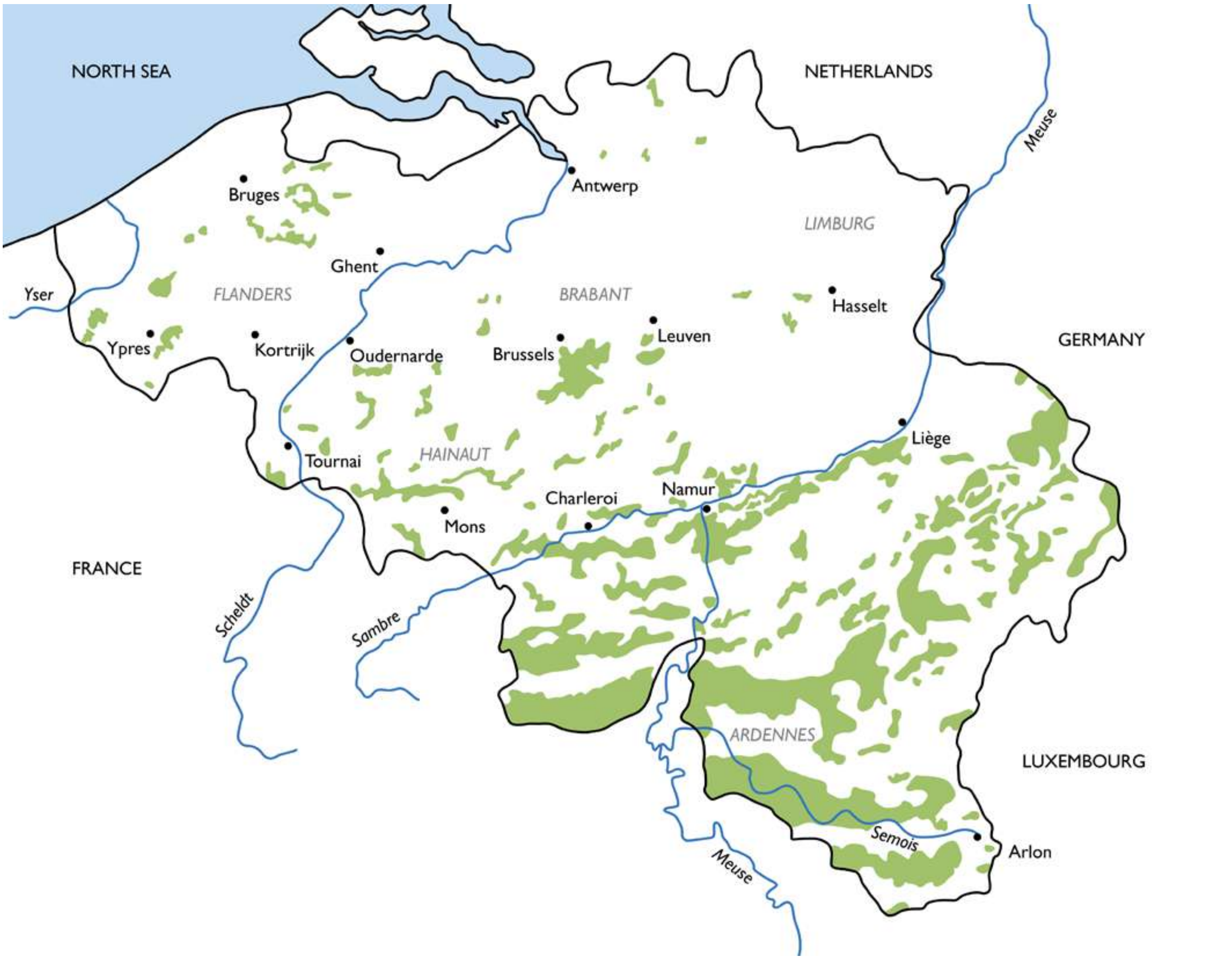

Fig. 2. *Schematic map of Belgium showing its woodlands in the 1770s according to the maps of Joseph de Ferraris. (Drawn by the Author).*

scarcity forced the introduction of many other species in vernacular architecture, such as elm, alder, and poplar [25].

2.2. URBAN FLANDERS

The supply of wood was more precarious in Flanders, one of the most urbanized parts of Europe, where intensive deforestation had already occurred in the 10th century. Towns like Ghent, Bruges, Ypres, Oudenaarde, and Antwerp required large quantities of long and straight grain timbers that could hardly be found in the immediate surroundings. Therefore, from the 13th century onwards, these cities turned towards Dordrecht, where merchants could purchase high-quality timber [29]. Strategically situated in the delta of the Meuse and the Rhine, the Dutch city received rafts descending from both the Ardennes forests and the woody Rhine basin. From there onwards, timber could be floated along the coastline towards Flemish ports. Dendrochronological and archival evidence attest to this trade, highlighting the predominant use of oak from the Meuse basin. The oaks used in the prestigious Flemish roofs of St John's Hospital in Bruges (1226-1241d), in the Bijloke Hospital in Ghent (1251-1255d), and in the Church of Our Lady in Damme (1283-1298d, 1299-1337d) were all sourced from Southern Belgium [20, 30, 31]. Furthermore, clear traces of floating squared timbers on the Meuse have been recorded in many Flemish roofs, with timbers having holes that enabled the assembly of rafts with ropes and marks affixed by merchants (Fig. 3) [29].

2.3. BALTIC TIMBER

As early as the 13th century, high-quality oaks were shipped from Gdansk to Bruges for shipbuilding and art objects [32, 33]. This long tradition of overseas timber trade proved crucial when local woodlands dwindled to unprecedented levels in the first decades of the 19th century. Indeed, only the immense forests of the Baltic Sea region could meet the rising demand of early-industrialized countries like Great Britain, France, and Belgium. Over the course of the century, there was a tenfold increase in foreign timber imports into Belgium, the majority of which did not consist of oak but Scots Pine (*Pinus Sylvestris L.*) [24]. After being floated on rivers, wood was squared or sawn and shipped by boat to Antwerp (predominantly) from the coastline of the Baltic Sea and Norway. After breaking with the traditional use of oak, softwood became more common in Belgian carpentry. The inversion of traditional timber flows was facilitated by the development of railways from the 1830s onwards, enabling the transport of wood from Antwerp to all parts of the country, including its most southern provinces.

The depletion of Belgian woodlands initiated in the middle ages was brought to a halt around 1850. Indeed, despite a growing population, the century-old trend was reversed in the second half of the 19th century by a combination of factors: the transition from charcoal to mine coal, plantation campaigns (mostly pine and spruce), stricter forestry regulations, and a tremendous increase in foreign timber imports [34].

In Belgian buildings, the ubiquitous use of Baltic timber is not only characterized by a change in wood species but also by records of shipping marks (Fig. 3). These widespread marks were scribed, hammered-stamped, or painted (as still the case today) on timber passing through Norwegian and Baltic ports. The interpretation of these signs referring to wood qualities, dimensions, merchants' names, and ports of shipment can provide straightforward information about the sourcing of the material and its properties [35]. Furthermore, the Baltic origin of modern Belgian roofs has also been established by dendroprovenancing, a first example being the sheds of an industrial site in Brussels (1835-1851d) which were linked to forests in central Sweden [36].

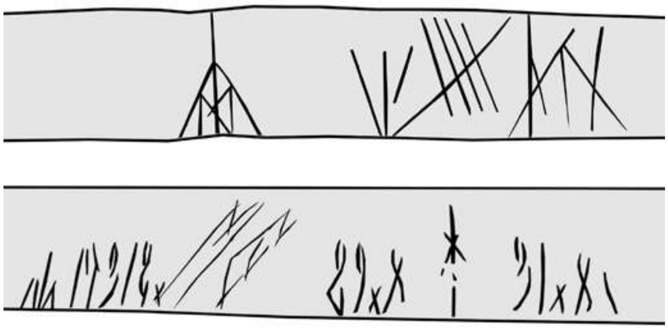

Fig. 3. *Transport marks recorded on timber roofs in Belgium. Top: City hall of Bruges (1278-1288d), local oak [29]. Bottom: St Peter's Church in Jette (1878-1880), Pinus Sylvestris shipped from Gdansk [24]. (Drawn by the Author).*

3. ROOF STRUCTURES

From a structural point of view, the most direct access to Belgian timber roofs from the medieval and early modern periods lies in the typological classification of Hoffsummer [12, 13]. In this general overview, Hoffsummer has offered 45 sections of Belgian roofs among 300 cases. The dissertation of Vandenabeele (2018) [24] covers the modern period, with a hundred structures built between 1800 and 1914. Besides these nationwide overviews, in-depth insights are provided for particular regions and cities through the works of Hoffsummer (1995) [11] in Wallonia, Nuytten in Brabant, Van Eenhooge, et al. (2018) in Bruges and Broothaerts (2021) [21] in Vilvoorde. In the near future, these studies will be completed by an inventory of roof frames in the Brussels region [27].

3.1. COMMON RAFTER ROOFS, ALSO CALLED "SINGLE-FRAMED ROOFS"

The oldest-known timber roofs in Belgium cover the Cathedral of Our Lady in Tournai (1138-1148d) (Fig. 4A) and the Church of St Barthelemy in Liège (1141-1151d) (Fig. 4B) [12, 16]. In Liège, the tie beams of the Church of St Denis (1012-1019d) show mortices indicating the shape of a previous roof replaced at the end of the 12th century [15]. These early structures found in Romanesque churches are common rafter roofs; they are formed by a dense array of identical oak frames spaced about 1 m apart so that the common rafters directly support the roofing battens without the need for intermediate supports. Each frame consists of a tie beam supporting a series of struts, reaching up to the rafters, which are inclined at about 30°. This simple system presents the disadvantage of consuming a lot of wood, which was increasingly hard to supply.

Around the turn of the 13th century, in the north of France and Germany, a distinction appears between main frames resting on a tie beam and secondary frames without tie beams but only one or several collars in the upper part of the rafters. In Belgium, early examples of these lighter roofs inclined at about 45° can be seen in the churches of St Laurentius in Ename (1170-1180d) and St Vincent in Soignies (1185-1200d) (Fig. 4C) [12]. While this system saves timber and gives room to raise vaults between the tie beams, the common rafters of the intermediate frames are poorly supported – a problem later solved with the introduction of purlins. Visually, the absence of closely arranged tie beams drastically changes the appearance of the roof, which can be turned into a vaulted ceiling interrupted by just a few beams. This solution became frequently applied in 13th century Gothic buildings such as the Church of St Anthony in Liège (1247-1255d) (Fig. 4D) and the Bijloke Hospital in Ghent (1251-1255d). If the horizontal stability of the walls is allowed, the tie beams could also be completely dismissed, as one can see in the chapel of the Bijloke Hospital (1260-1265d) or the Church of Our Lady in Damme (1283-1298d, 1299-1337d) [30, 12].

3.2. PURLIN ROOFS, ALSO CALLED "DOUBLE-FRAMED ROOFS"

The intermediate support of the rafters was improved during the 13th century with the introduction of purlins, or horizontal timbers spanning from frame to frame, which support the secondary frames. With Gothic architecture and the increasing use of slates, the inclination of roofs commonly reached 60° from the mid-thirteenth century onwards. Since such roofs were subjected to larger horizontal wind loads, the purlins helped limit the deflection of the secondary rafters. By connecting the frames and the gable walls, purlins also significantly improved the longitudinal bracing of these structures. In Belgium, proto-purlin roofs can be observed in St John's Hospital in Bruges (1226-1241d) (Fig. 4E) and in the quite similar roof of the Bijloke Hospital in Ghent (1251-1255d), where two couples of plates support the rafters [20]. However, the introduction of these horizontal elements was likely an attempt to provide "raised wall plates" on which to erect the upper part of the roof. Therefore, "real" purlins resting directly on main rafters are found shortly later, also in Flanders, on the roof of the Church of St Walburga in Veurne (1265-1275d) (Fig. 4F). The new arrangement of purlins on rafters, but also the use of diagonal struts transferring the concentrated loads to the king-post, make this roof type a breakthrough. In France, an early example of this system is the roof of the Cathedral of Amiens (1284-1305d) [12]. Moreover, the main frames are connected by a system of crosses which provide an efficient longitudinal bracing.

Later on, the purlin roof also made its way into rural architecture, as exemplified by the imposing barn Ter Doest in Lissewege (1370-1385d) [39]. Whereas these examples still exhibit a combination of purlins and secondary frames, the intermediate structures became increasingly lighter in later developments. In the 15th century, the upper collars connecting the common rafters started to be removed, paving the way for roofs only consisting of main frames, purlins, and simple rafters [12].

3.3. TRAPEZOIDAL PORTAL FRAMES

In the 13th century, trapezoidal portal frames appeared in Flanders, as firstly observed on the roof of St John's Hospital in Bruges (1226-1241d) (Fig. 4E). This characteristic portal frame, called *schaargebint* in Dutch, resembles the English base cruck roof and the later German *Liegender Stuhl*. The *Liegender Stuhl*, which appeared in the late 14th century, differs essentially in the connection between the portal frames and the longitudinal plates, which do not support common rafters (like a purlin) but rather the collar beams or the collars of the secondary frames. Unlike other systems, it requires relatively short pieces of timber as several trapezoidal frames can be piled up on top of each other without in-

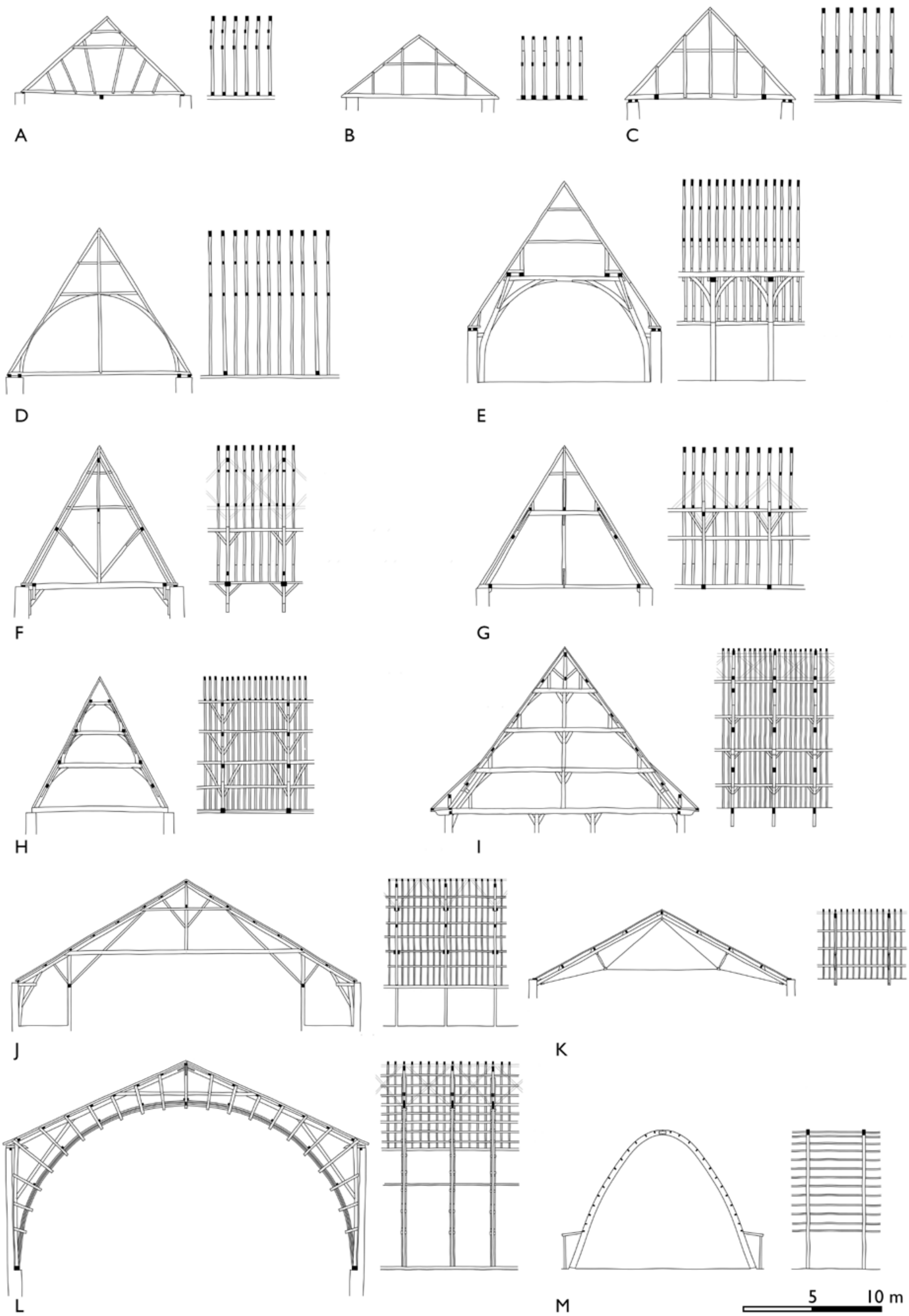

Fig. 4. *Evolution of historic timber roofs in Belgium (1150-1960) illustrated by 13 preserved examples. (Drawn by the Author). **A.** Cathedral of Our Lady in Tournai (1138-1148d), **B.** St Barthelemy Church in Liège (1141-1151d), **C.** St Vincent's Church in Soignies (1185-1200d), **D.** St Anthony's Church in Liège (1247-1255d), **E.** St John's Hospital in Bruges (1226-1241d), **F.** St Walburga's Church in Veurne (1265-1275d), **G.** St Paul's Cathedral in Liège (1251-1252d), **H.** Sablon Church in Brussels (1452-1487d), **I.** Grand Curtius in Liège (1599-1600d), **J.** Bourla Theatre in Antwerp (1829-34), **K.** Riding hall in Hermalle-sous-Huy (1856), **L.** Riding hall in Liège (1837), **M.** Chapel N-D Reine des Cieux in Watermael-Boitsfort (1956).*

creasing the required length of timbers. In Belgium, the use of this system was particularly well adapted to the shortage of long pieces of oak. After St John's Hospital in Bruges, other early examples of trapezoidal frames covered the Bijloke Hospital in Ghent (1251-1255d), the Cathedral of Saint Paul in Liège (1251-1252d) (Fig. 4G), and the Cathedral of St Michael and St Gudula in Brussels (1274-1275d). The ward of John's Hospital in Bruges (1270-1285d) provides the first example of two stacked levels of trapezoidal portals, opening the way for up to three or four levels in the following centuries. From barns to palaces, this system remained ubiquitous until the modern period. To cite just a few remarkable examples, oak roofs based on this system can be found in the Church of Our Lady of the Sablon in Brussels (1391-1393d, 1452-1487d) (Fig. 4H), in the Groot Vleeshuis in Ghent (1408-1417) (Fig. 1), in the Grand Curtius in Liège (1599-1600d) (Fig. 4I) and the Minimes Church in Brussels (1706-1713d).

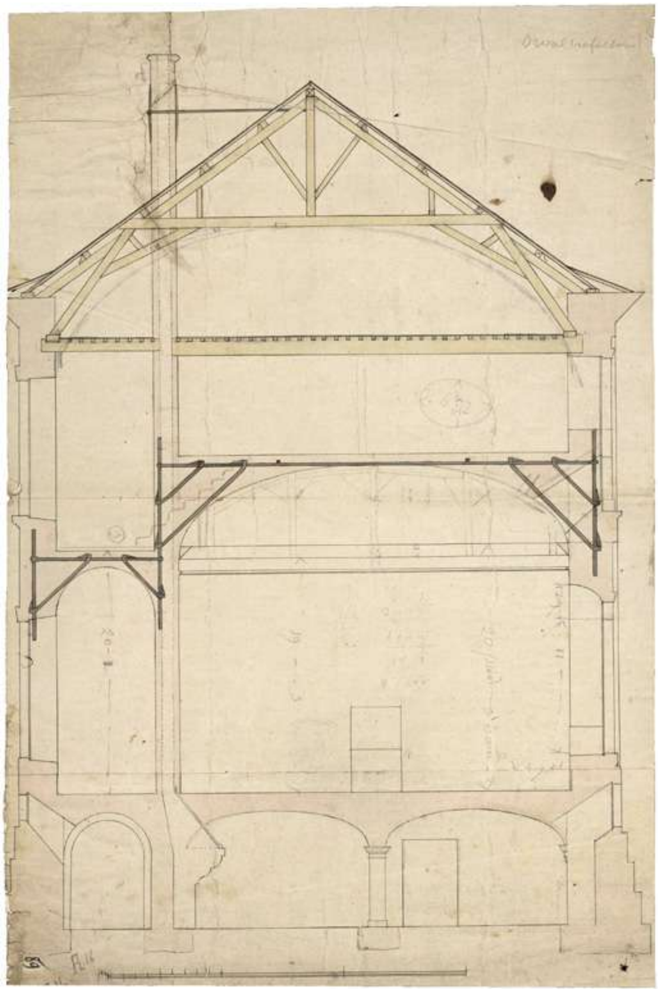

Fig. 5. *Refectory of the Orval Abbey (1768-1776) by Laurent-Benoît Dewez (1731-1812). Iron is not used in the roof but in the masonry vaults. The abbey was destroyed in 1793. (Image source: Algemeen Rijksarchief/Archives générales du Royaume, T006 -89).*

18th century carpentry could certainly deserve further research in Belgium, but at present, there is no indication that major changes occurred during this period. This remarkable stability has been confirmed by recent investigations in Brussels, Bruges, and Vilvoorde [21, 20, 37]. The archive of one of the most successful architects in the Austrian Netherlands, Laurent-Benoît Dewez (1731-1812), provides dozen of plans of Belgian roofs predominantly relying on a trapezoidal portal frame topped by a simple king-post truss (Fig. 5). Despite his observations of queen-post roofs in Italy and his classical influences, the 18th century architect did not apparently introduce new roof types into his homeland. Hence, although many variants can be distinguished, the Belgian "roofscape" is undeniably dominated by trapezoidal portal frames from the 14th to the 18th centuries. The control of carpenters' guilds certainly contributed to this constancy until their organizations were banned under French rule in 1795.

3.4. MODERN ROOFS

The turn of the 19th century marks a break with previous carpentry traditions in Belgium. The Italian king and queen-post trusses, which had started to spread to the rest of Europe during the 17th century, were extensively applied in neighboring countries in the second half of the 18th century to construct theatres with flatter roofs (25-30°). After the Napoleonic wars, French examples provided the inspiration for the roofs of the Monnaie Theatre in Brussels (1818-1819) and the Royal Theatre in Liège (1819-1820) (Fig. 6). While these two roofs were still built in oak, the architect of the Bourla Theatre in Antwerp (1829-34) (Fig. 4J) decided to combine oak and softwood for the short pieces and the longest elements, respectively. As such, in the first decades of the 19th century, the influx of Norwegian and Baltic timber into Belgian harbors initiated not only the gradual replacement of oak with softwood but also the discontinuation of the trapezoidal portal frame suited for material from local forests. These decades of rapid changes also correspond to the fame of French engineers such as Amand Rose Emy (1771-1851) and

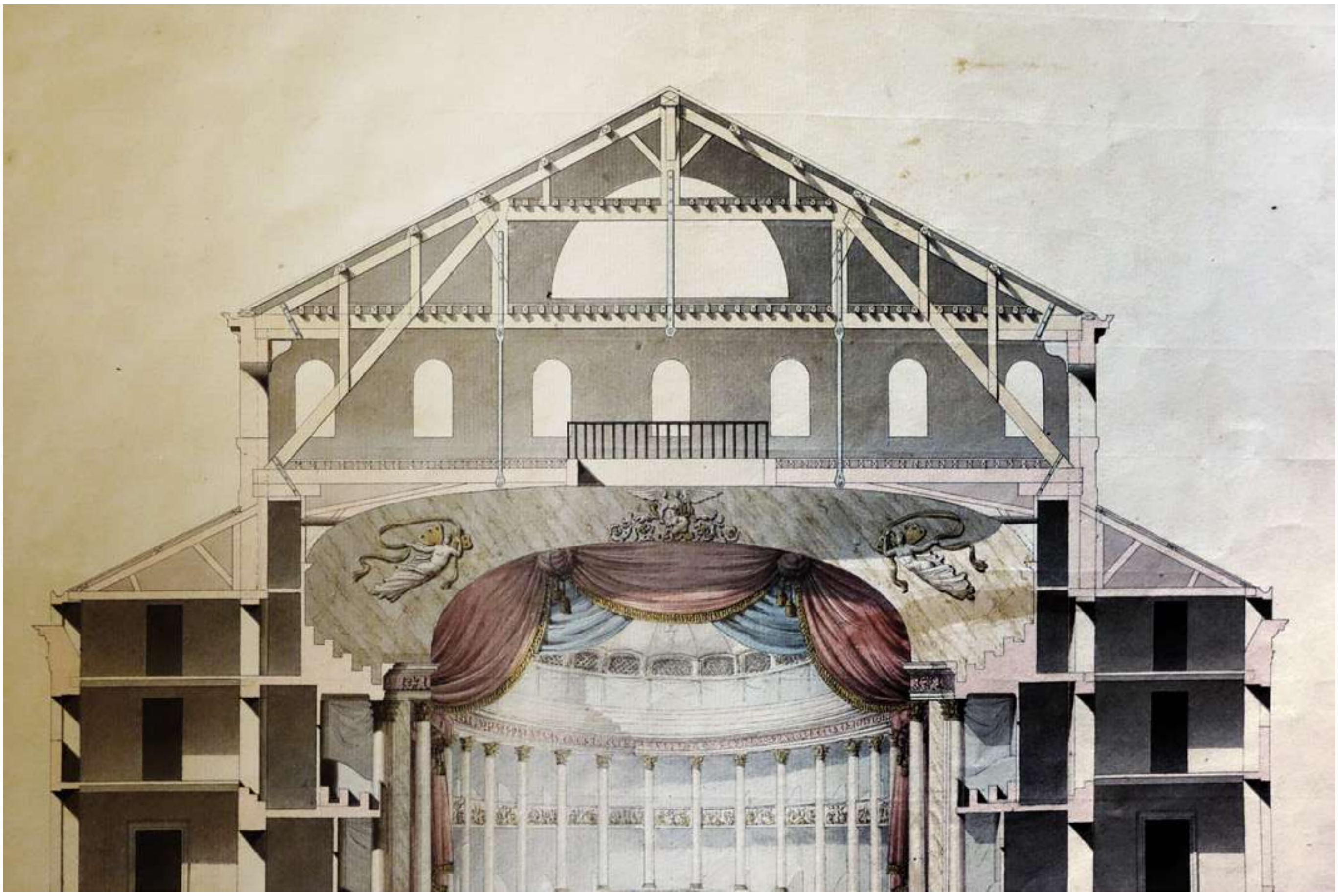

Fig. 6. *Roof of the Royal Theatre of Liège (1818-1820) by Auguste-François-Joseph Dukers (1792-1831). This original roof was demolished only recently. (Image source: Musée de la vie wallonne, Liège).*

Paul-Joseph Ardant (1800-58) [2], who developed and publicized innovative systems for military riding halls. A rare example of this early phase of timber engineering is preserved in the Fonck barrack in Liège (1837) (Fig. 4L), which closely reproduces the system of Emy. Although other wide-span laminated roofs have been lost, smaller examples can still be seen in the Grand Hospice in Brussels (1824-27) and the Hospice des Indigents in Tournai (1842). This second roof faithfully reproduces the system of French architect Philibert de l'Orme (c. 1514-1570) [24].

In the 1840s, iron was introduced to Belgian roof construction. An early example is the Church of St Joseph in Brussels (1842-1849), covered by an entire iron roof [40]. In the second half of the 19th century, timber was not abandoned in roof construction but instead combined with iron to take advantage of the properties of each material. The famous composite system of French engineer Jean-Barthélémy Camille Polonceau (1813-59) was widely applied, for example, in a riding hall at Hermalle-sous-Huy (1856) (Fig. 4K) and in the Centrale Werkplaatsen in Leuven (1863-64). Innovative uses of slender softwood elements and iron ties did not occur without collapses or the need for reinforcements. For example, one collapse occurred shortly after the construction of the Marché du Parc in Brussels (c. 1855), while the roofs of the Bourla Theatre (1829-34), the Fonck barrack (1837), and the Wiertz Museum in Ixelles (1855) were all reinforced. Nevertheless, these unsuccessful designs could be understood and corrected owing to structural analysis.

The second half of the 19th century is consequently characterized by a great variety of roof structures: king-post trusses, queen-post trusses, trusses with timber rafters and iron ties, and trusses inspired by iron structures, among others. Next to the mainstream use of foreign softwood, oak was practically only used when exposed in prestigious buildings, such as the Gothic re-

Fig. 7. *The roof of a chemical factory in Willebroek (1926) built with the German system Kübler. The collapse started in 2013, and the building was torn down in 2017. (Photo by the Author).*

vival Broodhuis in Brussels (1873-95). The introduction of steam-powered sawmills in Northern Europe around 1850 and the increasing standardization of timber formats in the following decades led to faster construction methods relying heavily on iron connectors. Yet, besides simpler joints, no major innovation occurred in Belgian timber construction around the turn of the 20th century, as exemplified by the roofs of the institute St Jean-Baptiste de la Salle in Saint-Gilles (1908) and the panorama of the Battle of Waterloo (1912).

During this time, novelty came from abroad, starting with the German railway hall at the Brussels International Exhibition of 1910. This hall included a 43-meter-long roof built with glued laminated (glulam) arches according to the patent of Otto Hetzer (1846-1911). Although still poorly investigated, it seems that some German systems were imported in the interwar period, such as the roof of a chemical factory in Willebroek (1926) based on the patent of Karl Kübler AG (Fig. 7) [24]. However, it was only in the 1950s that glued laminated timber was produced in Belgium by the firm De Coene in Kortijk. The chapel Notre-Dame Reine des Cieux built by the company in Watermael-Boitsfort (1956), is seemingly the last standing example from this period (Fig. 4M). Two years later, modern timber engineering was truly put forward on display at the Brussels International Exhibition in 1958. De Coene and the Dutch company Nemaho contributed to the construction of numerous temporary structures in glued laminated timber, while the firm SAZ (Scieries Anversoises/Antwerpse Zagerijen) built pavilions according to a system of nailed profiles patented by the Swedish engineer Hilding Brosenius (1905-2004) [23].

4. CONCLUSION

In spite of its turbulent history, Belgium has preserved a remarkable amount of timber heritage that shows the evolution of carpentry at the crossroads of Europe from the 12th century onwards. As highlighted in this contribution, the current state of research allows us to trace an overarching sequence of developments from 1150 to 1960. Starting from dense rafter roofs built with local oaks in the 12th century, the ensuing shortage of wood resulted in an early transition to lighter purlin roofs and the use of short elements in trapezoidal portal frames around the mid-thirteenth century. Regardless of ruling powers and foreign influences, the traditional Dutch portal frame remained deeply rooted in local carpentry practices until the end of the 18th century. The industrial revolution opened a new chapter of timber construction, characterized by replacing local oak with foreign softwood and abandoning traditional roof types. Novel wide-span timber structures were introduced under French influence in the first half of the 19th century, after which Belgian roofs receded from the forefront of innovative timber construction. Engineered timber structures, such as glulam, were imported sporadically from abroad (especially Germany) in the early 20th century and later fully adopted by Belgian builders only in the 1950s.

In the last decades, the undeniable interest in Belgian timber construction has led to a large body of knowledge and growing attention to the preservation of old roofs. However, remarkable modern roofs are still frequently demolished or replaced due to poor recognition of their heritage value. Thus, there is still much to be done in terms of research and preservation, especially regarding roofs erected in the last 300 years. As highlighted in this broad overview, interesting topics for further research could be the early challenges to traditional types in the 18th century and the introduction of foreign systems in the 20th century. Moreover, as many important roofs have been destroyed – the French Revolution and the two World Wars bear a large part of this responsibility – further research could include reconstructions from archival material, as recently initiated in Germany [38]. Hence, the growing interest in timber construction and the many historic roofs still discovered each year in Belgium highlight a promising future for this area of research.

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ANCIENT WOODEN ROOFS IN THE AREA OF GENOA: THE STRUCTURE WITH A CURVILINEAR PROFILE OF THE PARISH CHURCH OF COGOLETO

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Abstract

A particular roof is that of S.M.Maggiore church in Cogoleto. The 19th century church has an upper two-pitches roof and a lower roof underneath with a curvilinear profile. Both insist on the same perimeter, but they have no direct connection between them as far as it is visible. Therefore, the study focused on understanding this part of the building. This understanding of the building was obtained thanks to indirect sources (archive and bibliographic research) and direct ones: archaeological analyses (stratigraphic, mensiochronological, mineralogical-petrographic, and wall textures), thermographic and ultrasonic analyses. A particular effort had to be made in studying the details and reading the stratigraphic signs on the wood (this aspect is usually little developed). Extending the analysis to the entire building was necessary for a better understanding. This study highlights a sequence of interventions in the church over the past two centuries; previous structures were usually preserved while new elements and stratifications were added. The two structures were chronologically different: the upper one is the most recent but was designed to preserve the older one below. Another interesting fact that emerged is the particular shape of the lower structure: a wooden roof with a curvilinear profile. This form of coverage is not particularly widespread in this part of the Ligurian territory. In any case, it is unusual for the historical period in which it was built (19th century). The research, therefore, focused on the reasons for this particular choice and the study of the dynamics of the 1877-78 construction site. It also allowed us to understand better this specific structure's functioning, its technology, and its relationship with the remaining parts of the complex. The historic curved profile roofs highlighted differences in material and installation technique.

Keywords

Wooden roofs, Historical architecture, Curvilinear profile, Stratigraphic analysis, Multidisciplinarity.

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1. A CAREFUL READING FOR A CORRECT IDENTIFICATION

Today, the Parish Church of S. Maria Maggiore in Cogoleto has a rectangular plan and a pitched roof system on different levels. The south elevation is characterized by three orders of windows of different shapes, and a pronaos is present at the lateral access. The apse and the central nave have a vaulted ceiling, and the *orchestra* has a barrel masonry vault (Fig. 1). This conformation results from a late 19th century rebuilding; previously, on the same site, there was a church (already mentioned in the documents in 1554) of smaller dimensions that strongly influenced the subsequent construction choices.

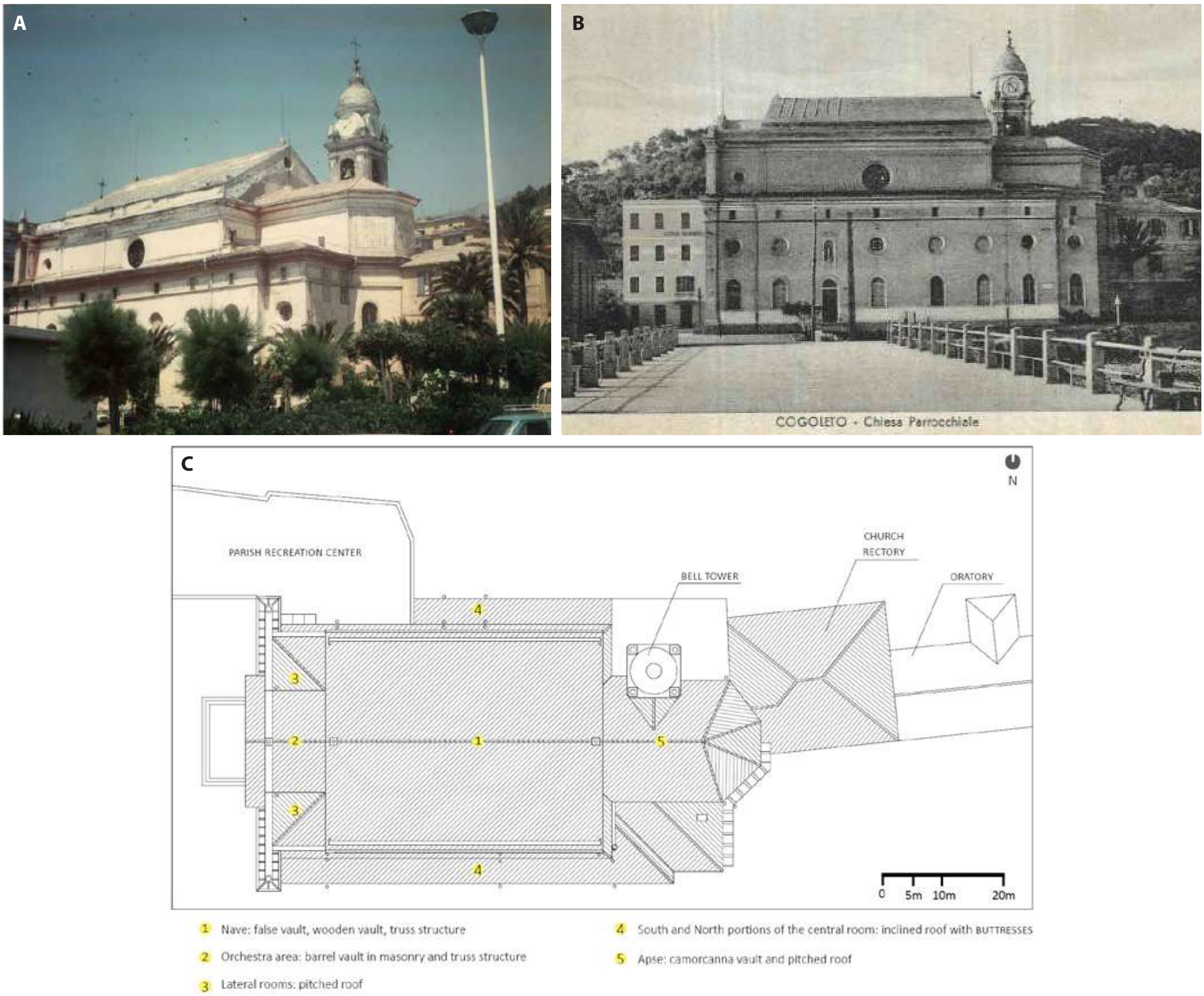

Fig. 1. *A-The Church at the end of the 1970s. (Image source: ASABAP Liguria, S. Maria Maggiore Cogoleto). B-The Church at the end of the 1930s (Image source: F. Biamonti archive). C-Roofing plan 2019 (Image source: Accomasso 2019).*

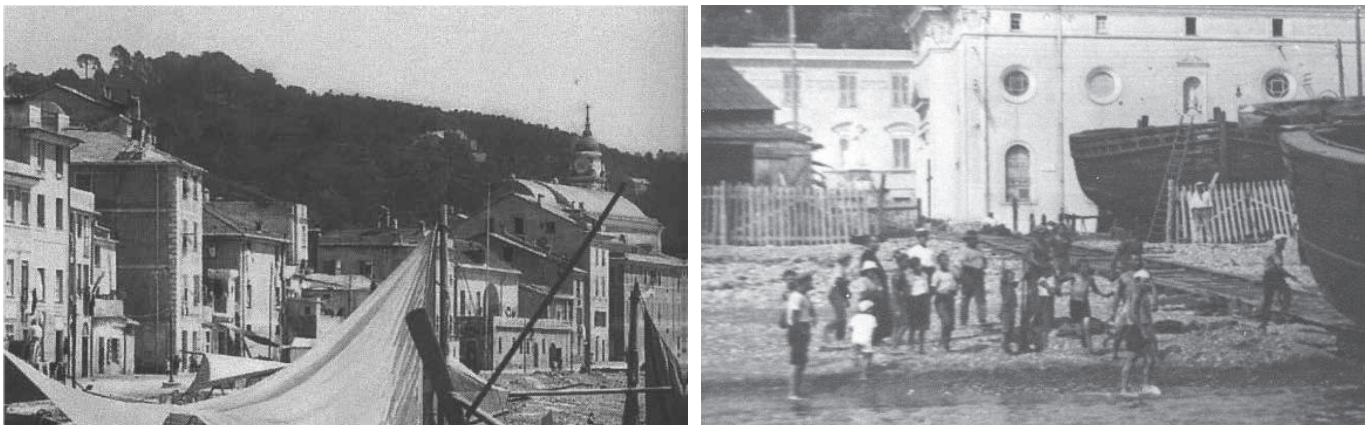

Fig. 2. *Cogoleto 1898. The Church with a curved roof (Image source: R. Cattani archive).*

The historical reconstruction of all the events was possible thanks to a careful examination of the published sources, numerous unpublished documents found in various archives (see acknowledgments), the use of material sources, and their comparison. The consultation of all these documents made it possible to collect detailed pieces of information also on the choices of materials, the tools used, and the workers participating in the work. In order to avoid hasty and superficial deductions, it was essential to compare the various indirect sources [1], distinguish their purpose (informative, scientific, etc.), their reliability, and then proceed to their comparison with the direct sources. Direct sources were used to identify the chronology of the construction of the church walls: stratigraphic analysis, mensiochronological analysis of the bricks and lithotypes [2, 3], and mineralogical analysis of the mortars. Thermographic analysis of the walls allowed the identification of openings that are now hidden. The wooden structure of the roof was well studied with archaeological analyses and instrumental investigations (in particular thermographic analyses, sonic and thermo-hygrometric surveys were carried out to understand the state of conservation).

In this article, in particular, we will focus on the complex stratification that characterized the roofs of the church.

2. THE INTERVENTIONS ON THE ROOFS

One of the most recent substantial transformations that have taken place in these roofs is the one made by Eng. Bianchi in the early 1900. This intervention was necessary because, at the time, there were evident and consistent infiltrations, especially in the portion exposed to the north wind. Therefore, it was decided to keep the wooden structure of the curved profile roof (1877-78) (Fig. 2), removing only the covering mantle (traces of this intervention are still visible on the old structure), and overlay a simple two-pitch covering on it. The overall height of the church has therefore increased, but only in this central part of the complex. It is still possible to see the different textures of the perimeter walls on which this new roof was set in the church attic. However, the most particular roof structure of this complex that aroused our interest is the late 19th century one: the curved profile roof that currently appears to be still preserved and protected by Bianchi's intervention.

3. THE DYNAMICS OF THE BUILDING SITE OF THE 19TH CENTURY RECONSTRUCTION OF THE CHURCH

The dynamics of the 1877-78 building site for the construction of the curved profile roof are of particular interest. The shape of this structure recalls the already known "inverted keel vaults", which is unusual for the time and the territorial context [4]. It was possible to reconstruct a detailed progression of the processing phases by consulting correspondence, estimates, and receipts from suppliers. It was also possible to hypothesize some reasons for this particular choice. In fact, the decision seems to be due not only to a need/desire not to interrupt the religious functions during the construction site (we recall in this regard that the enlargement/rebuilding of the church takes place on the same site as the previous one, dating back to the 16th century) but also to the possibility to contain the costs by recovering as much material from the old church as possible. The material dismantled from the old church was immediately reused in the new one. A fairly accurate estimate of the reused materials from the ancient church was made from archival documents. This information also allowed us to formulate some credible hypotheses on the conformation of the old demolished church. 1877 was the year of preparation of the construction site: initially, the bell tower was inspected to reinforce and conserve it, the costs and possible savings were evaluated, the contract was signed with the designated builder, the disassembly of the organ was organized, and some construction details were decided, such as the position of internal niches. In June, the population (the population of Cogoleto participated in voluntary work to help the progress of the construction) began excavating foundations for the new church around the perimeter of the old one, still in use at that time. 1878 was the year of construction of the new building (the largest church): the letters are much more numerous and refer to the progress of the works. The documentation is enriched with estimates and payment receipts that allow us to trace the companies and artisans involved in the construction site. The first phase of the work, for which we have documentary evidence, concerns the consolidation of the bell tower structure, which also required raising the floor level of the church under construction. Therefore, the first pillars of the nascent construction were connected to the reinforcement structure of the bell tower; after that, they proceeded with the construction of two more pillars and the arches of the lateral chapels at the Sancta Sanctorum. This reinforcement suggests that the new building originated near the presbytery. The greater thickness of the wall connected to the bell tower, which is still visible today, is the consequence of these reinforcement structures. Subsequently, they constructed the supporting walls to reinforce the new roof, removed the existing choir, and demolished the pre-existing sacristy. Then they began to think about the choice of the wattle for the vault of the new church. Once the masonry was finished, the reinforcement work on the roof began between February and March 1878, entrusted to specialized artisans. The "wall plate beam" (wooden beams placed along the perimeter walls of the building to bind the walls and to guarantee a better distribution of loads) were placed first, then the ribs. The works suffered some slowdowns, probably also due to the sudden collapse of a part of the vault of the central nave of the old church, which still remained within the perimeter of the new building. Once the construction of the perimeter walls was completed, the demolition of the remaining part of the previous church began: the population actively collaborated. The new church roof was most likely built in two phases, first on the side parts of the church and then above the presbytery and the orchestra: this was deduced from the analysis of written documents (arrival times of the various materials on ancient site yard). Very special solution, the building to be demolished was kept on the side until the new perimeter walls construction around it and part of the roof were completed. We retrieved a very detailed list of the construction expenditure item; engineer Giuseppe Mazzardo filed it on June 26, 1877. This list includes the quantities of materials recovered from the old church (see Tab. 1). We understand that the purpose was to obtain savings by recovering as much material as possible from the old church, especially from the ancient cover (see Tab. 1).

Architectural element	Quantity	Unit Cost (lire)	Total Cost (lire)	Savings (lire)	Savings (%)	Note
Roof structure and cover	980.00 m^2	12.00	11,760.00	4,760.00	40.5	Recovery of timber and slates from the roof of the existing church; lime and sand provided free of charge by the population
Wooden floor frames and wooden ceiling	75.00 m^2	10.00	750.00	250.00	33.3	
Arched ceilings	730.00 m^2	5.00	3,650.00	1,650.00	45.2	
Cover with slates on the sides	190.00 m^2	9.00	1,710.00	310.00	18.1	Probable recovery of existing church slates
Iron chains	4,000.00 kg	0.50	2,000.00	1,000.00	50.0	Iron recovery of the existing church; free labor blacksmiths in the country
Unexpected costs	-	-	1,720.00	-	0.0	-
Total (including other elements)			96,076.00	53,076.00	55.2	
Total net final cost				**43,000.00**		

Tab. 1. *Detail of costs and savings regarding the roof and the vault.*

Most of the expected savings concerned the construction of the roofing system for the new building; in fact, the subsequent recovery percentage values were envisaged: arched ceilings: 45.2%; timber and slates for reinforcement and roof covering: 40.5%; wooden floor frames and underlying ceiling: 33.3%; roofing with slates on the recess of the sidewalls, external part: 18.1%. In addition, a saving of one-third of the total cost of the windows was expected, but without specifying the number and type of reusable artifacts from the previous church.

Fig. 3. *Diagrams with the percentage of recovered material from the previous church for the roof's construction. From left (in red): recovery of arched ceilings, recovery of timber and slates for the roof, recovery of wooden floor frames and underlying ceiling, recovery of the lateral part coverage.*

Finally, regarding the iron ties, of which a 50% savings was expected, the altars and balustrades, for which a saving of 47.1% was assumed. Some considerations can also be made regarding the overall construction costs of the church of Santa Maria Maggiore. Engineer Mazzardo's forecasts indicated a total cost of 96,076 Lire with an estimated savings of 53,076 Lire. According to others [5], however, a plausible estimate of the total expenditure for building construction could be around 80,000 Lire. If we trust this second source, the savings would be lower than those initially foreseen, even if in any case of a certain weight.

What are the reasons for these disparities between the different sources? We can assume a smaller quantity of recycled materials or a too optimistic estimate of the amount of free labor. In addition, the site documentation testifies to a different choice of methods for some work phases than the initial forecasts, which could be another explanation for the difference. However, on the saving of materials for the roof structure of the church, it seems conceivable from the data consulted that there was a substantial adherence to the estimated recovery percentages.

3. THE STRUCTURE OF THE CURVED PROFILE ROOF

The indirect sources consulted in archival research did not provide any detailed survey of the roof structure. Below is the result of a detailed on-site survey carried out on the roof in the portion currently accessible. A particular effort had to be made in studying the details and reading the stratigraphic signs on the wood (this aspect is usually little developed in the archaeological research of the elevation of historical structures) [6]. It was decided to proceed with a detailed survey of the curvature of a portion of the roof (the one located in the middle) and to consider all the others with a similar profile. The first section of the profile, with a lower slope, was found considering different leveling planes. Linear measurements in cartesian coordinates were also carried out for the portion with a steeper inclination. It was so possible to trace the exact profile of the wooden rib. The restitution was facilitated by the comparison with the intrados profile already detected during the diagnostic analysis of the reed vault (the diagnostic analysis was performed according to a precise protocol, see [7]). Subsequently, all the ribs making up the roof and the secondary framework were surveyed, thus understanding the complete distribution of the structure. The structure of the curved profile roof is therefore made up of twenty-one wooden ribs, nineteen of which are 10 cm thick (made up of 2 side-by-side boards) and the remaining two, symmetrical with respect to the centerline of the vault, 15 cm (made up of three tables placed side by side). The ribs have a particular profile, rounded in the intrados, while the extrados has a particular profile that characterizes the roof. Along the extrados profile, the slate slab roofing anchoring marks can still be seen, even if the slate slabs were removed. To the main transverse framework of the wooden ribs, the secondary longitudinal framework formed by wooden boards, 4 cm thick, arranged at a center distance of approximately 1.5 m, is connected by nailing. These boards are placed perpendicular to the surface of the vault. Each board has special holes in which the "pacconcelli" of the underlying reed vault are housed (the 'paconcelli' are small rafters that form the load-bearing structure of the reed vault).

4. HYPOTHESIS ON THE PREVIOUS CHURCH: THE CHURCH OF 1554

A first hypothesis on the previous church (the ancient 16th century church) was formulated based on indirect sources: iconographic and cartographic images [8,9] of the Cogoleto area, reports of pastoral visits to the church of the 16th and 17th centuries, and details in the archival documents on the percentages of materials to be recovered from the old church for the construction of the new church of 1877. In particular, all the sources from the 16th century to 1876 describe a church that has not changed in volume and has only undergone transformations in the furnishings and finishes. Nevertheless, what shape did the 16th century church roof have? Is it possible that the shape of the previous roof was also recovered in addition to the recovery of the timber? Did this second hypothesis allow a more significant recovery of material? Otherwise, for the roof of the 1877 church, the curved profile shape was made using smaller wooden elements connected, allowing for a good recovery of material. At the moment, we cannot give a precise answer to many of these questions yet. In fact, portions of ancient wood and connecting elements with different wood added later were identified in the part that it was possible to inspect. Various marks and engravings have been found on several elements. The elements on which the direct analysis focused were signs of previous workings, traces of fastening elements of different shapes and sizes from those of the 19th century, and particular graphic signs that suggested ways of recognizing the single element for its relocation. These same signs (predominantly Roman numerals engraved on specific portions of the wooden boards) are present on some but not all of the elements. This detail, for example, made us think about possible material integrations with new ones. To date, we reserve the right to complete the vault inspection on parts that are not visible for now. Based on these first elements, one of the most accredited hypotheses is that the ancient parish church of Cogoleto (the 16th century one) also had a curvilinear roof. Moreover, these latest analyses made it possible to confirm the hypothesis on the shape of the old roof with a reasonable degree of certainty.

4.1. IS THE VAULT OF SANTA MARIA MAGGIORE AN “INVERTED KEEL ROOF”?

The shape of the church roof built in the1877/78 appears unusual for the historical period in which it was built. The “inverted keel structures” are quite rare and, in any case, appear to be prevalent in other geographical areas and periods much earlier than the one under examination [10]. We, therefore, immediately tried to investigate whether the shape of the building, despite the apparent similarities, was really classifiable as an “inverted keel roof” and, if so, what the reasons for this choice could be. The new form for the coverage of the church of Cogoleto (Fig. 4) probably did not respect the project drawn up by the architect Dufour (the first designer in charge of the project). In fact, in a drawing of the façade project of the new Parish Church of Cogoleto, which could be attributed to Dufour, the church is represented with a double-pitched roof, different from the one actually built. Confirming this is the book *Maurizio Dufour: nell’anno 25° dalla sua morte*. It seems to support the hypothesis of a discrepancy between the planned roofing system and the one actually built. In fact, in the book, the author Luigi Traverso writes the following about the Church of S. M. Maggiore: «He did [Maurizio Dufour, ed] the design of the parish church of Cogoleto, but he did not direct its execution: various defects are proof of this appearing in that building, and especially in the anomalous shape of the roof» [11]. In documents dating back to the construction site period, the figure of Dufour appears marginally, while the letters of the Venetian architect Gioacchino Zandomeneghi, a former collaborator of Dufour, are more frequent. The design changes could be motivated by the desire to recover the material of the previous church as much as possible. In fact, as already reported, at the time of construction, it was estimated to make the roof with a recovery of about 40% of slates and wood. The direct observation of the structure also confirms this: the wooden ribs of the vault are made up of small boards suitably shaped and nailed together, which makes the hypothesis of reuse plausible. Numerous of them are engraved with numbers and symbols, perhaps indicating the reference points for assembly used when laying the roof reinforcement (Fig. 5). From some appraisals dating back to 1900 [12], the roofing system in question was built with the express intention of not placing chains that crossed the church ceiling transversely. This choice is compatible with an inverted keel structure that reduces the horizontal thrusts on the sidewalls on which it rests. However, from the same documentation, it also emerges that the ribs are made of poplar wood with common riveting, while inverted keel structures, as far as known to date from the literature, are usually made with better quality wood and with pieces of dimensions such as to require a limited number of rivets. Suffice it to say that about 1200 trees, corresponding to 1,200,000-1,400,000 m^2 of a forest, were used to build the five-lobed roof of the Church of San Zeno Maggiore in Verona. Furthermore, the choice of the type of wood in San Zeno was very accurate: larch wood was preferred, which had excellent mechanical characteristics and low combustibility. The material, before being used, also underwent numerous treatments: left for about a year under running water to purify it from microorganisms, it then underwent a drying process of about 24-36 months [12]. Nothing to compare, therefore, with the material and techniques used for the church of S. M. Maggiore, whose construction, as we have seen, was characterized from the outset by strong economic requirements. In Cogoleto, there were no particular structural reasons to justify the construction of a roof of this type as the stresses to which it is subjected are mainly of a static type. The construction of a roof with standard triangular trusses placed above a self-supporting wooden vault would have resulted in a lower height of the nave, maybe even lower than that of the previous church that the local population wanted to enlarge. Otherwise, scissor trusses could have been built, but this would create a risk, the generation of thrust on the walls. The greater use of “inverted keel” structures in Venetian buildings is justified because they rest on unstable ground and are subject to frequent settlements and consequent dynamic stresses [13]. From a careful observation of the boards that make up the portion of the curved rib in the Ligurian structure, it can be seen that the wood fibers are not parallel to the board’s shape. This fact shows that no curvature has been impressed on the material used but that the boards have only been cut according to this shape. This evidence constitutes a further aspect that would distance the technique used in the church of Cogoleto from that practiced in naval carpentry. In Cogoleto’s case, the wooden vault seems more responsive to the characteristics that Philibert De l’Orme described in 1561 (Fig. 6) for the construction of cheaper wooden roof structures with the use of small planks [14, 15] (De l’Orme 1561-2009). This construction method is an evolution of ship hull roofing which, while maintaining some structural characteristics, makes it possible to use lesser quality timber (see Cancelleria di Blois, 15th century). However, the vaulted roof of the ecclesiastical building of Cogoleto is not entirely relevant even to the techniques of De l’Orme as the assembly of the pieces of timber is carried out differently. In fact, the transversal framework is not made up of boards passing through the ribs with mortise joints but instead of nailed and shaped elements according to the center distance between the ribs. This difference, however, could be linked to the greater or lesser familiarity of the operators with some construction techniques rather than others. In fact, these changes can be included as “variations on the theme”, often unavoidable in construction practices when there is a change in time and/or a difference in a geographical context. The intrados of the vaulted structure of Cogoleto is covered with a reed ceiling which has made it possible to have a painted score for the nave of the church. The extrados of the structure housed the roof consisting of roofing slates. Subsequently, following structural problems in the early 20th century, the curved profile vault was covered by a two-pitched structure on wooden trusses.

The latter represents the current roof under which the previous structure has remained until today. The appraisals dating back to the early 20th century highlighted the need to build a new roof system above the wooden vault. Four main reasons led to this decision: 1. the reinforcement of the vault showed severe deformations accentuated by the absence of reinforcement tie-beams; 2. the slates of the roof covering were subject to lifting and falling; 3. it could not be considered a definitive roof for a church whose ceiling was susceptible to decorations of value and duration; 4. the repair work already carried out was not conclusive. Therefore, based on a project by engineer Bianchi, it was decided to build a new gable roof above the curved roof. This new roof is intended to give the church a new roof while protecting and preserving the historical one [12]. It was also planned to place four iron ties in cor-

Fig. 4. *A - Detail of the curved profile roof now devoid of the roofing mantle and protected by the gable roof. In the foreground, the reed vault of the inverted keel vault can be seen. B - Detail of the lower part of the ribs of the curved roof. C - Diagram of the curved roof structure (Image source: Accomasso 2019).*

respondence with the axes of the internal pilasters. The archival documents also made it possible to trace the list and measurements of the wooden carpentry and hardware needed for its construction. Therefore, comparing these measurements with those of the current structure during the direct survey operations was possible.

The particular shape of the 19th century roof (Figs. 7 and 10) did not prove to be adequate and problem-free. So why was that shape adopted? Could there be other reasons besides the recovery of material and the choice of an appropriate shape in terms of size and pushing action (as mentioned above)? We have relatively sparse news of the old church: it is known that its consecration dates back to April 11, 1554 [12] and that the complex already appeared to have the volumetric consistency of the church, which was then demolished in the 19th century. Other inventories of the 17th century [12] describe the movable and immovable property belonging to the Church of S. Maria di Cogoleto. From these papers, no substantial differences can be deduced from the building of the previous century. Even the pastoral accounts of the 18th and early 19th centuries and the cartographic and iconographic representations of these centuries show a church with a volume similar to that of the 16th century one: from all this, it can be deduced that there have been no substantial changes throughout this period. It can be assumed that the recovered wooden material may actually belong to the 16th century church. From these data, therefore, it would seem not so unlikely that the particular shape of this roof can consequently date back to a period in which, also in other territorial contexts, the first times "inverted keel" appeared. If this first hypothesis were confirmed, there could also be another reason for the revival of the curvilinear roof of the new church at the 1877 construction site: it would be, in fact, a revival of a model rooted in the collective imagination of Cogoleto for well over three centuries. To date, the elements in our possession seem to be going in this direction.

Fig. 5. *Details of some wooden ribs engraved with Roman numerals.*

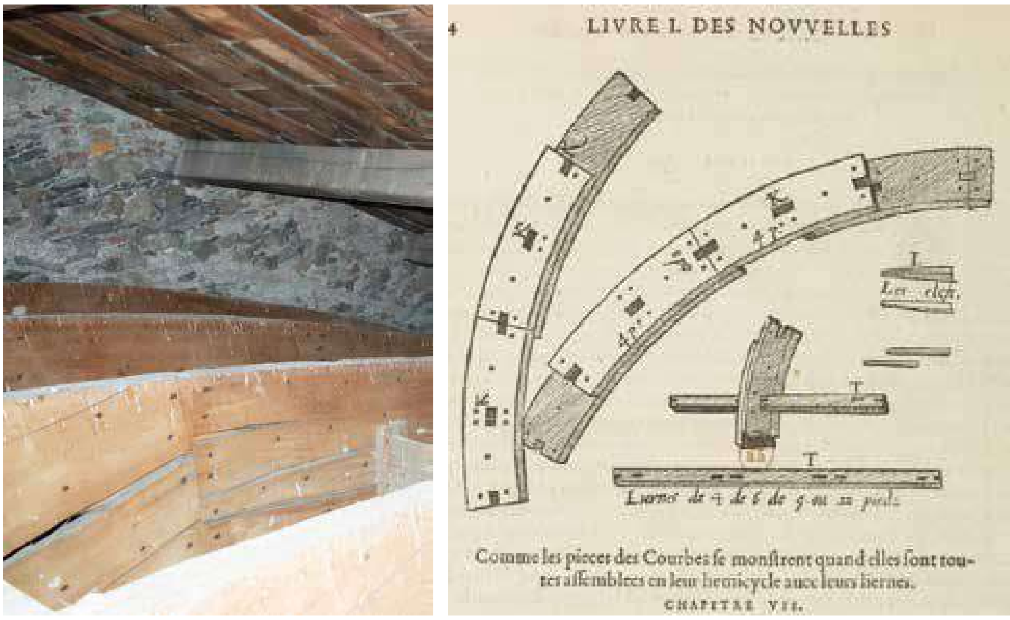

Fig. 6. *Detail of a wooden rib in which the trend of the wood fibers can be seen. Fig. 12 Drawing by de l'Orme on assembling small pieces of wood to construct his invention. (Image source: de l'Orme 1561, p. 43).*

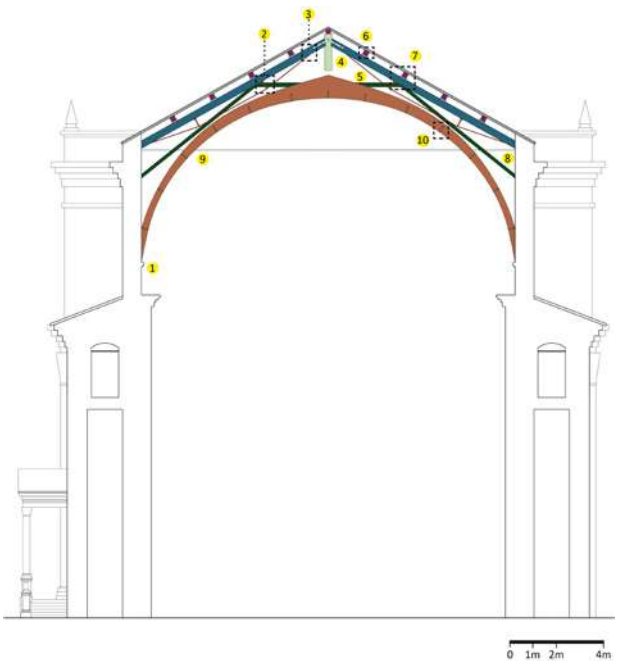

Fig. 7. *Cross-section of the curved profile roof and detailed images of the same (Image source: Accomasso 2019).*

5. OTHER CASES OF INVERTED HULL COVERAGE IN LIGURIA

In Liguria, other cases of wooden vaulted roofs have elements in common with that of the church of Cogoleto. In particular, two of them appear to be in a geographical area adjacent to Cogoleto and are chronologically contemporary with each other and the 19th century Cogoleto's structure. The first is the former spinning mill of Arenzano [16] (Fig. 8). The main frame of the roofing system consists of ribs with a partly curved and partly straight profile. Commonly its shape could be considered an inverted keel, although there are some differences with this typology. In analogy to the church of Cogoleto, the resistant section of the elements corresponding to the warps is obtained by joining wooden boards and not by curved woods: the fibers of the wood of the curved rib portion are not parallel to the shape of the board. Adopting this form could be motivated by the intention to decrease the entity of the horizontal thrusts by unloading most of the load vertically to the walls.

Fig. 8. *Former spinning mill in Arenzano.*

Fig. 9. *Former Martinez Hospital.*

The second building is the former Martinez Hospital in Pegli (Fig. 9), the roofing system of which, in 2006-07, was the subject of an in-depth diagnostic investigation [17]. The wooden frame of the roof is made up of a series of curved beams made up of several elements, in the longitudinal and transversal directions, joined together using nails at an irregular pitch of about 95 cm. The elements making up the beams have an average thickness of 4 cm and a height of about 22-24 cm. The ribs made with a series of reduced dimensions boards nailed together represent an element of similarity with the vault of the Cogoleto's church. Instead, the two shapes of the roofs appear different: while the former hospital of Pegli tends to have a pointed arch, the Church of S. M. Maggiore is more similar to a round arch. At this point, the question may arise whether there is a connection between these similarly shaped structures and whether, in some way, we can speak of reciprocal influences. For the moment, this part of the research is in progress as, at present, there are still several elements that cannot be given a precise chronological location.

6. CONCLUDING REFLECTIONS

«However, the distance that separates the simply probable from the very probable and the truthful is great. In order to know which category a final paper corresponds to, one cannot rely on the properties of the language used and the pleasantness of the graphic sign, as is sometimes led to do. Only by examining the path taken will it be possible to ascertain whether reliable conclusions have been drawn from correct premises» [18].

Specifically, we wanted to show the entire path, and we intended to list the individual steps by which it was possible to draw, in the end, a weighted conclusion. Tiziano Mannoni used to say, «it is not the quantity of data collected that makes history, but the critical analysis of those concerning the problems taken into consideration», and in this regard, this research highlights the extent to which the critical analyses help arrive at a fruitful conclusion [18]. In Liguria, therefore, there are other cases

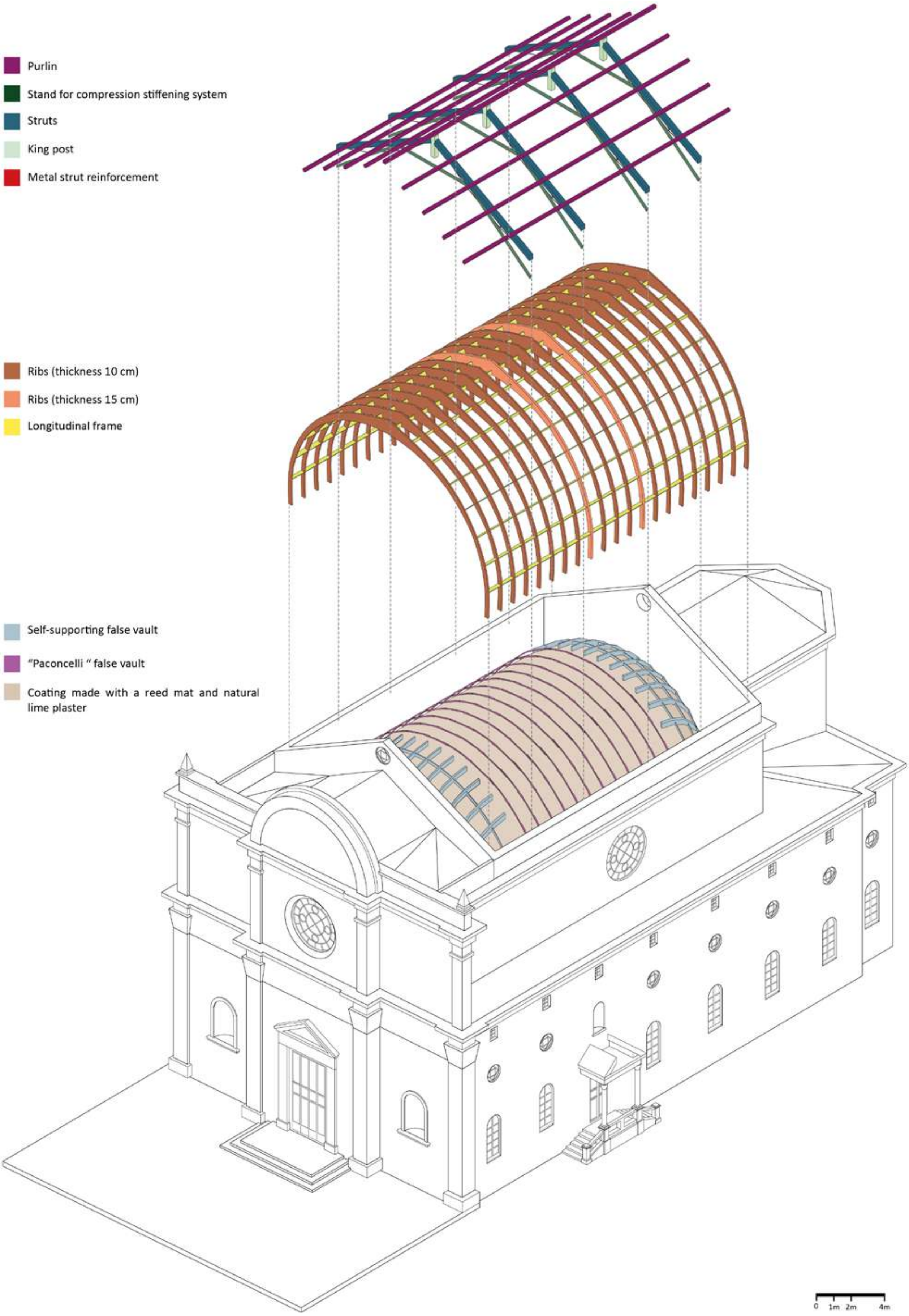

Fig. 10. *Roofing of the Church of S. M. Maggiore. The axonometric summary section (Image source: Accomasso 2019).*

of wooden vaulted roofs that have elements in common with that of the Church of S. M. Maggiore in Cogoleto. In conclusion, buildings with vaulted roofs in wooden carpentry are not unusual. However, it is difficult, and even simplistic, to classify such structures under rigid categories such as overturned keel or De l'Orme's invention. Often they are the result, as in the case of the Church of Cogoleto, of artisans' knowledge handed down from generation to generation. Elements of relevance to antecedent construction techniques are not excluded, but there is no evidence that these craftsmen can be considered shipwrights experts in naval carpentry [19]. Finally, it should be emphasized that the vaulted roof of the Church of Cogoleto was built in 1877-78 with the dual purpose of supporting the false reed ceiling and supporting the external roofing; in 1900 proved not to be able to perform both functions. Thus the truss structure was created, and a new roof structure was created above it. The considerations that can be made following cases such as the one described are various and articulated. In the future, further and more in-depth studies will try to answer the question of whether the case examined is the result of an intent to imitate the oldest inverted keel roofs (in which the variations present are "uncontrolled" elements) or whether it is a" development" of a new type of roof with a curved profile (with consciously desired elements and technical solutions different from the tradition). Another element to be explored is how much the tradition of shipwrights and the tradition of woodworking for boats has influenced the choice of a curved profile roof not so easy to make. could be a dendrochronological analysis of some of the boards of the wooden ribs of these vaults. Dendrochronological analysis on wooden boards of vault ribs could be a good future research activity; it could help undertending more deeply the history of this church and the other wooden structures. Another question still open, and which will be investigated in the future, is the following: «Could buildings covered with curved roofs built after 1877 in the area surrounding Cogoleto have drawn inspiration from the roof of the Cogoleto church? Can relationships and similarities be established? Can we speak of an impact of this type of coverage in the surrounding area?». In all cases, however, the approach to be taken in any restoration works will be the same: whether the example studied is a simple re-proposal, or an attempt, more or less successful, to imitate different construction models or a chronological variant that is configured in a certain time and a particular area as a "chronotype" [20–22], it is good that this structure is preserved. In conservation, it will be necessary to maintain the shape and, as seen from the analysis, also to take care of the more banal signs such as riveting, joints, and other minimal technological details. However, the maintenance of these structures will be, as Riegl affirmed, preserving the memory of a singular moment of an evolutionary process. As far as restoration is concerned, a maxim that it could be helpful to adhere to comes from a different disciplinary sector and can be recognized in Bloch's words: «The spectacle of research, with its successes and troubles, is rarely boring. It is the beautiful fact that spreads frost and boredom» [23]. Therefore, leaving structures like these to the future, even with the doubts and questions we have seen, will enrich the knowledge of pre-industrial historical structures. Paolo Torsello used to say in this regard, «[…] a good story does not limit itself to telling, but opens up new perspectives of thought... in short, it is not a truthful deciphering of the world but a provocative opening of horizons of reflection» [24]. The complexity of the fact-finding investigation, on the other hand, provides us with suggestions on how to carry out any restorations: paying attention to the preservation of the shape of the artifacts is not enough. Keeping the materials and the most minute construction details is also necessary. Sometimes, as in the example illustrated, it is precisely from these elements that important, if not decisive, information can be obtained. Thus this research can be an essential study for the knowledge of this particular structure that, in the words of Alois Riegl, still represents a singular moment in an evolutionary path [25].

Acknowledgments

Consulted Archives: ACC- Archivio Comune Cogoleto, ASG- Archivio di Stato di Genova, ASCC-Archivio Storico Civico di Cogoleto, ASABAP-Archivio della Soprintendenza Archeologia, Belle Arti e Paesaggio per la città metropolitana di Genova e le province di Imperia, La Spezia e Savona, ASD-SV- Archivio Storico Diocesano di Savona Noli, ASS-Archivio di Stato di Savona, BAV- Biblioteca Apostolica Vaticana, ACPC- Archivio della Chiesa Parrocchiale di Cogoleto.

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Authors contribution

"Conceptualization, methodology: D. P., Investigation: C. A., Funding acquisition, resources: D. P., Supervision: D. P., Writing original draft: C. A., D. Pittaluga, Writing-review&editing: D. P. Authors of paragraphs 1, 2, 3, 5 are C. A. and D. P., of paragraphs 4, 4.1, 6 and D. P., photos and drawings are by C. A. (except those for which specific attribution has been provided)".

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ANCIENT WOODEN ROOFS IN THE AREA OF GENOA: AN ALMOST INTACT 17TH CENTURY SALT WAREHOUSE

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Abstract

The study on the wooden structure of the roof of the former salt warehouse in vico Malatti 13, in the ancient Genoa port area, is part of a broader research plan. It includes several university research projects: PRA 2016 "The archeology of architecture in the restoration site" carried on by DAD (Dipartimento Architettura e Design of Genoa, Italy) with the Universidad del Pais Vasco (Facultad de Letras, Departamento de Geografia, Prehistoria y Arquelogia, Spain), PRA 2018 "Conservation and restoration: methods of analysis and strategies of monitoring", led by DAD in collaboration with CISAPSI (Coordinamento Intercomunale Studi e Analisi del Patrimonio Storico della Svizzera Italiana, Fado-Switzerland) and PRA 2019 "Conservation and restoration: methods of analysis and strategies for the maintenance of the material and restoration: strategies for a quality project", also led by DAD. The roof under study has a particular structure: the trestle structure. This building technique was widespread in the Genoese context between the 15th and 18th centuries. Nevertheless, this technique has not yet been widely studied. Another notable feature, the roof had remained almost intact since the 17th century, when it was built. The difficulty of access and direct inspection of the roof structure, combined with the need for constant monitoring for its conservation, required a particular methodological effort, and an analysis procedure was identified, making use of several sources and multiple tools. Besides this roof's characterization and technological specificity, the methodological aspect is fascinating, as it could also be adopted in other similar contexts.

Keywords

Salt warehouse, 17th century, Trestle structure, Archaeological study, Conservation.

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1. AN ANCIENT ROOF STRUCTURE IN THE MOLO DISTRICT IN GENOA: A POSSIBILITY OF KNOWLEDGE, A PERSPECTIVE OF CONSERVATION

The study described in this article is part of a larger research project that concerns the archaeological reading of elevated historic structures in the area of the Port of Genoa and their possibilities for conservation and enhancement (see acknowledgments). In particular, we wanted to focus on a wooden roof structure in one of the many salt warehouses in the Molo district in the 16th century: the Vico Malatti warehouse [1]. This structure has undergone few changes over time. A careful study of high-level archeology has allowed us to trace the primary phases. In agreement with the *Soprintendenza di Belle*

Arti e Paesaggio of Genoa, we also wanted to provide a methodological approach for its monitoring over time. This monitoring aims to preserve this structure in the best possible way, promptly intervening in the event of problems and thus reducing interventions on it.

2. THE SALT WAREHOUSES IN THE OLD PORT OF GENOA

The area of the ancient Port of Genoa, its piers, and warehouses constitute a particularly stimulating heritage from several points of view. This area is, in fact, interesting for its complex history, the abundance of written sources, and the large quantity and quality of archaeological and archaeometric data available [2]. The port, and everything connected to it, has been a resource for Genoa since the Middle Ages. Over time, this awareness has also led to investments and experiments. Here, the best materials, the most innovative, and the most daring solutions were tested. The research discussed in this article started precisely by analyzing the warehouses that existed in the port area, particularly in the Molo peninsula. The Molo and the Ripa have been the trade hubs for the Genoese economy since the Middle Ages [3]: a direct example is the Molo district's subdivision which co-occurs as the construction of the first pier and the creation of the Ripa.

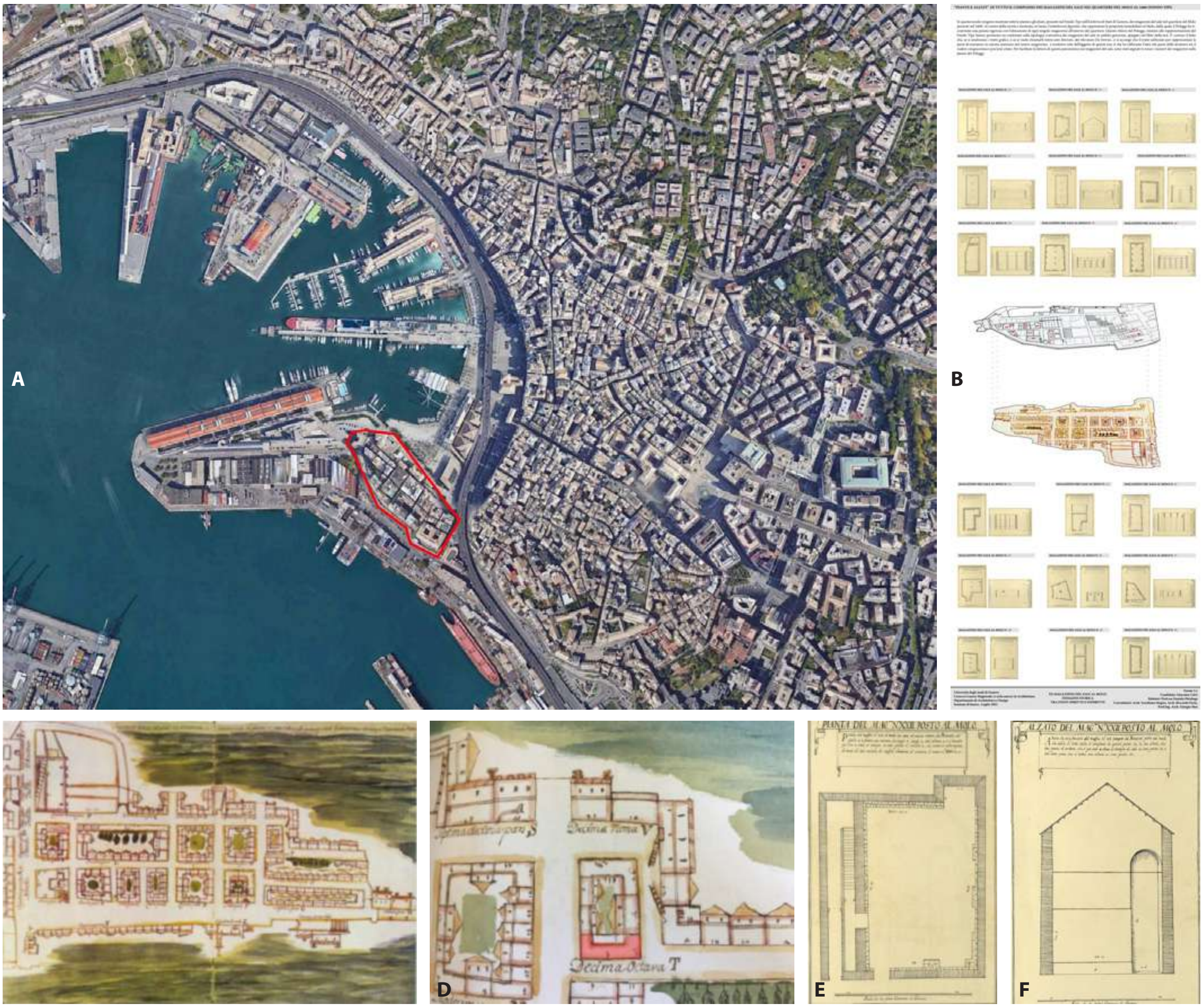

Fig. 1. *A, B- The Molo district today and the Molo district with the original numbering of the warehouses present in 1660 (Image source: [3] p. 201); C- Plan view of the district of the Molo, 1540 (S.a., Gabella Terraticorum sive Embolorum, code Figuratis (Archivio di Stato di Genova, Fondo San Giorgio, coll. E 65); D- Detail (highlighted in red) of the Magazzino del Sale n. 23 (now Vico Malatti 13) (Cfr. S.a., Gabella Terraticorum…, cit.); E, F- Plan and elevation of the warehouse n. 23 al Molo (on the left). (Image source: Piante et alzati delli magazzini e case che possiede l'Illustrissimo Officio delle compere di San Giorgio della Serenissima Repubblica di Genova, cavato da D. Leonardo de Ferrari Genovese l'anno 1660, in A.S.G., Fondo Tipi, pp. 34–35).*

Since then, the municipal consuls have understood the vocation of this strip of land as an ideal place to host all those types of workers who dealt with the construction, maintenance, and launching of boats and, more generally, with what they had to do with the maritime trade and shipping. The planned intervention aimed at giving a precise urban identity to the neighborhood, aware of its direct interaction with the reorganization of the Ripa and the creation of the Darsena and subsequently of the Arsenale as a sort of protected area. However, until the end of the 16th century, the Molo area appeared as a popular neighborhood, consisting of modest houses with a medieval layout, which had not entirely been influenced by the new ruling class's urban and architectural renewal. At the beginning and throughout the 17th century, the interest on the side of the public administration for the district concerns distribution management.

If, on the one hand, in the 17th century, we find a building overcrowding extended to the whole district that will stop at the end of the following century, on the other hand, we record a significant development of a new specialized commercial structure that we will find permanently throughout the 18th century and beyond, that is the warehouse. The salt warehouses reached 30 units in 1660, to which 4 larger ones were added during the 18th century [4]. In Genoa State Archives, in the "Tipi" collection, a precious document for the knowledge of the Molo district, the Tabula EMBOLORUM FIGURATIS, was found [1]. This Table represents the real estate properties at the Molo; it dates back to 1550 but portrays a situation from at least a previous century. From this table, it is possible to obtain quite detailed information on 18 salt warehouses present at the Molo, and most of them are provided with a planimetric representation and a section. From these data, however, it is not easy to understand what the roof structures were like, and many of these warehouses have undergone profound transformations over time. In Liguria and, more specifically, in the Genoese context from the 15th to the 18th century, it was typical the use of the "struttura a cavalletti" (trestle structures); however, at least for most of these structures, it is hard to hypothesize its presence [5, 6]. Fortunately, one specific warehouse has largely maintained the masonry and roofing structures almost intact: the salt warehouse in Vico Malatti 13. The latter has undergone few changes in ownership since the 17th century, so the PRA research focused on it.

3. "STRUTTURE A CAVALLETTI" ROOFING STRUCTURES

In traditional wooden construction, a particular structural type for the pitched roof is the "struttura a cavalletti" (trestle structures). This system is a typically local system that particularly characterizes the Genoese construction culture over a period ranging from the 15th to the 18th century, with episodes that also arrive at the beginning of the 20th century. Genoese examples of trestle roof structures are Villa Grimaldi "La Fortezza" in Genoa Sampierdarena, and Palazzo Doria in Loano [7], Villa Musso Piantelli in Genoa Marassi [8]. «This system is probably derived from naval carpentry; the main load-bearing elements themselves, having considerable dimensions, are sometimes masts and flagpoles deriving from the demolition of ships» [9]. With this type of technology, the main load-bearing structure of the roof is made up of one or more orders of wooden frames. "Trestle" is the «composite construction element used as vertical support. The Italian term, derived from "horse", refers to one of the possible configurations assumed by the element: when it is made up of a double pair of struts arranged upside down and joined at the vertices by a crosspiece, it has, in fact, a shape similar to the profile of a horse. A trestle can also consist of only two inclined struts, joined on the upper ends in contact, or converging on the two ends of a horizontal element. In this second case, we also speak of a "lame frame"» [10]. These frames, called "cavalletti", support the secondary structure and are made up of longitudinal beams (purlins or tertiary beams) of large dimensions that rest on more slender struts, through which loads of the roof are transmitted to the perimeter walls. In the case of wider roofs, the trestle system is created as a spatial structure, formed by multiple orders of overlaying trestles. The corner beams are, therefore, load-bearing and resting on the intersections of the two contiguous trestles of the various orders. In classic examples, the trestle is composed of three or four struts converging at the vertex, sometimes also connected by horizontal stiffening elements, arranged at regular intervals along its height. A horizontal crosspiece can be supported on trestles arranged under its opposite ends. In many cases, the planking of the roof also collaborates with the underlying structure. In the pyramidal structure roofs built with this procedure, the vertex is the joining point of the extensions of the diagonal beams, which are load-bearing in the final section [10]. The first series of trestles is set directly on the perimeter walls employing a wooden element, a "wall timber plate". It works as a load distribution element on/in the masonry; due to its shape and arrangement, the wall timber plate also exerts a certain action to contrast the horizontal thrusts, as if it were a ring beam. The elements made were rather rough as the processing was limited to the simple "rough-cutting" of the piece along the body and in correspondence with the heads, which were notched for realizing the unions of the various elements making up the structure. These joints were obtained by juxtaposing the parts and nailing them together or, to reduce the resistant section's size, by the coplanar juxtaposition of a secondary element to the primary one, nailing the two to the horizontal planking. The joints are not those typical of wooden carpentry, but rough elements secured by nails and, therefore, technically rough carpentry, but intellectually very refined [9]. The connections between the components of a trestle vary according to the materials used. The wooden struts and crosspieces can be overlapped, juxtaposed, nailed, or held together by brackets or metal strapping. They can also have interlocking carvings on the joining surfaces or be notched together. In other cases, the union of two elements was made using "gattelli" (wedges). These are wooden wedges nailed to the extrados of the lower element to create "positive" support for the overlaying element. This choice allows the adoption of relatively thin sections as it avoids supports and housings in "negative", such as to reduce the resistant section precisely in correspondence with the tensile stressed fibers. It is interesting to note how these wedges are common to the Ligurian and Piedmontese traditions, which vary in the different structural logic. The first one uses "gattelli" mainly in the tense edge, while the other uses them in the compressed edge. Even the ridge joining between two rafters is rarely achieved with a proper joint; it is often obtained by juxtaposing the two roughly hewn heads to create mutual support [13]. «Rare, in the Ligurian area, are the typical combinations of wood technology such as the tenon and mortise with retaining pin, the sawtooth, the "dart of Jupiter". However, these should not lead us to think that the local workers were less capable and attentive to the problem; rather, by carefully observing these artifacts, we realize that the solutions implemented have evolved and aimed at achieving a sort of structural optimization of the entire system» [9]. The trestle structure system has no rigorous models; it is not a complete and invariable structural system; there are, in fact, many specific cases and many exceptions. The specificities of the individual cases make any attempt at classification difficult [9]. The most important construction problem is the need to overcome the thrusts exerted at the roof level and transmitted to the lower load-bearing structures through the verticalization of the loads and their uniform distribution on the underlying walls [9]. To prevent dangerous horizontal thrusts from being concentrated in the critical points of the masonry, usually, no struts are placed at the corners of the masonry. Furthermore, there are often chains suitably arranged to counteract the lateral thrusts. These prevent the construction from trying to "open up" under the action of the thrusts.

4. THE FORMER SALT WAREHOUSE IN VICO MALATTI: AN UNUSUAL "STRUTTURA A CAVALLETTI" (TRESTLE STRUCTURE)

The roof of the former salt warehouse in Vico Malatti looks like a gable roof with a pavilion head, with a "trestle" supporting structure, integrated with other elements that collaborate in the overall balancing of the roof, which is achieved by using three "pseudo-trusses", or "lame trusses" in shipbuilding jargon.

The classic or Palladian truss is appreciated and used in the coverage of large spans due to its static pattern (similarly to the three-hinged arch), defined as "non-thrusting". It is subject to tensile stresses on the tie beam; otherwise, the horizontal thrusts would be burdened on the support of the rafters; to compression stresses in the strut, which reduces the free span of deflection of the rafters, discharging these stresses on the "post" (or "king pendant" that is the vertical stiffening element in the truss), which is subjected to traction due to the symmetrical forces transmitted.

The “pseudo-truss”, on the other hand, is composed of two common rafters, usually headed on the “wall timber plate” or at a slightly lower level in the masonry. The rafters then overlap in the ridge, and by two or more horizontal tie beams, placed in correspondence of the purlin (“terzere”), to which they also provide the support, therefore at about 1/3 and 2/3 of the height of the truss. Given the absence of the “post”, the rafters, and the tie beam present in the classic truss, the static scheme, in this case, is defined as “weakly pushing”, as all the elements of the “pseudo-truss” are subject to compression and bending. In some cases, to avoid the bending of the rafters towards the inside of the roof, a so-called pseudo-tie beam is placed at the center of the two inclined elements, subject to compression and bending stresses. This solution, however, creates strong lateral thrusts on the masonry; in fact, in these cases, the horizontal component of the thrust is contrasted by transverse iron chains in the perimeter walls in correspondence with the “pseudo-truss” [8].

The pseudo-trusses in the salt warehouse in vico Malatti are positioned at about 1/3 and 2/3 and 3/3 of the longitudinal axis of the structure, in turn, reinforced, headed into the masonry below the level of the wall timber plates, and from the southern transverse perimeter wall, in which all the purlins have their heads stuck, except the two of the north pitch. In our case, integrating other elements, such as the pseudo-trusses, makes our structure unusual because there are very few similar cases in Genoese architecture, which will be analyzed later. On the west and north perimeter walls, the circular section “wall timber plates” can sometimes be clamped on top of the masonry. Regarding the perimeter wall to the east, three distinct circular wooden elements are clearly visible, which act as “wall timber plates” when connected to the masonry or the truss and as tertiary beams where they are not supported. They are slightly offset from each other, and the two at the end have one head embedded in the transverse masonry and the other resting in correspondence with the interlocking of the rafters of the two central trusses, but at a slightly higher level. The roof is made up of two orders of purlins on all three sides, and the ridge; all these elements are supported both by their interlocking with the masonry and by the rafters and tie beams of the “pseudo-truss” to which they are connect-

Fig. 2. *The ancient roof of the salt warehouse in the Molo district (Genoa).*

ed, as regards the East and West pitches, and by props collaborating with the load-bearing structure, which from the analyzes all seem to be contemporary to the structure, except one, as regards the north pitch. The ridge is a rectangular section with a sharp rotating edge.

5. OTHER "TRESTLE STRUCTURES" WITH "PSEUDO-TRUSS" IN GENOESE ARCHITECTURE

The analyzed case of the roof of the former salt warehouse is unique as regards the complex of the former warehouses at the Molo since in no other case has the roof been preserved until today without undergoing changes or removals. The former salt warehouse in Sampierdarena was also investigated, but also, in this case, the roof was rebuilt after a redevelopment project by the Municipality of Genoa [11]. We thus moved on to the search for artifacts that, in the technological scheme of the trestle structure with the use of pseudo-truss, could be compared with the roof of the former salt warehouse and which are always part of the Genoese construction culture. Three examples of coverage have emerged, all of which can be placed in the time period that goes from the 16th to the 18th century. The first taken into consideration is the roof of the Church of San Rocco sopra Principe, a building initially from the 14th century but rebuilt in the Baroque style in the 16th century and located in the center of Genoa. The roof of the Church is a gable-type roof, structurally composed of the main framework of 3 pseudo-truss, whose tie beams, in this case, are raised with respect to the position of the rafters, due to the presence of the reed vault below and from 3 "cavalletti" (trestles). Purlins complete the main structure, two per pitch, which play the role of secondary elements for the trusses (on whose tie beams they rest) and the main elements with regard to the trestles (which rest on the tertiary beams). In this case, unlike vico Malatti warehouse, the tie beams of the pseudo-trusses are decidedly raised compared to the size of the rafters, not respecting the canonical position 1/3 and 2/3 of the height. This is due to the presence of the reed vault, as already mentioned [12]. In this case, the pseudo-trusses are positioned approximately at 1/4, 2/4, and 3/4, of the longitudinal axis of the roof, given the length of the building.

The other roof compared with the vico Malatti warehouse is that of the Church of the "Madre di Dio", whose structure was studied in detail in 1993/94 [8]. The building that survived the demolition of the entire neighborhood, called Madre di Dio, in the 1970s, was already heavily damaged by war bombing. In the Genoese context, the four-pitched roof has the typical structural scheme of the trestle structure on several orders, completed, however, by two "pseudo-truss" consisting of rafters arranged by the inclination of the pitches, which join in the ridge, making them support it. Here, the tie beams also serve as support for the tertiary beam, and the rafters are not connected to the wall timber plate but at a slightly lower level. Their role, in this case, is that of a pressure breaker for the tertiaries of the long sides.

The last coverage considered was that of the Church of San Filippo Neri in Genoa, whose structure was studied in depth [8]; the Church is a 17th century construction. In this case, the gabled roof structure is supported by the transverse perimeter walls, which, as in the case of the vico Malatti warehouse, collaborate with the wooden elements, and by three pairs of rafters or by three "pseudo-truss". In addition to the rafters, the trusses are kept in their place thanks to the support of props, as in the case of the tertiary sections of the northern pitch of vico Malatti. The peculiarity of these "pseudo-trusses" is that they consist of only three wooden elements: the two

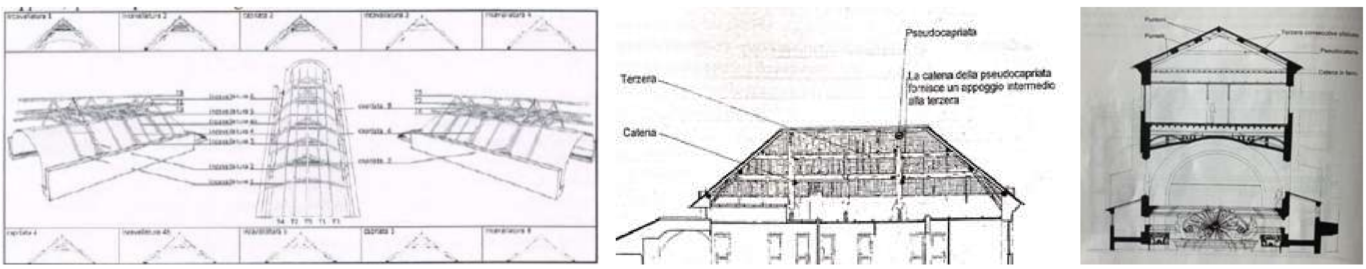

Fig. 3. *A- Scheme of the roof of San Rocco [12], B- Structural scheme of the roof [6], C- Cross section of the Church of S. Filippo Neri [8].*

inclined rafters following the pitches, and a pseudo-tie beam, connecting the rafters at the level of the first order of purlins, struts headed at the base of the perimeter wall, and also, in this case, it becomes the support of the ridge.

6. THE METHODOLOGICAL APPROACH ADOPTED FOR THE KNOWLEDGE OF THE "VICO MALATTI TRESTLE STRUCTURE"

During this study, we tried to trace a precise historical reconstruction of the former Magazzino del Sale and its development in the urban context to which it belongs and all its elements and construction phases. At the same time, we outlined a macroscopic pre-diagnosis of the conditions in which it appears today. The survey, the only one to date so detailed, of the structure was carried out, paying particular attention to the wall compartment and the wooden roof elements. The studies on the wooden roof, and the mensiochronological survey, are not enough for analyzing the problems that have arisen rigorously and completely. To date, with certainty, the entire structure of the warehouse in every single historical phase and every single element has shown how these direct analysis tools, once compared with the indirect historical sources, allow us to build solid starting points for a correct archaeological reading of the building [13].

The indirect sources have allowed us to establish the fundamental stages in the historical/evolutionary process of the warehouse. During the consultation in the State Archives, a written note was identified in the 1550 *embolorum figuratis*, stating the purchase of a ruin site, according to the reconstructions, in the current Vico Malatti 13 and owned by the Rovereto family. Then we found the first sketched drawing of a plan and an elevation of 1660, in which, what a century earlier was only a ruin, had been transformed into a three-story salt warehouse, with an external service staircase on the east side, still owned by the Rovereto family. No information and sources about the warehouse could be found for the next two centuries. Only at the end of the 19th century, a period in which the ownership of the warehouse passed to the Autonomous Consortium of the Port of Genoa, as evidenced by some documents, which, more than anything else, provided some information on the deteriorating conditions of the portal and the ground floor that was raised to street level in the first decades of the 20th century [1].

The reconstructions that followed the discovery of these documents in the various archives needed confirmation, and this was possible thanks to the comparison with the direct analyses performed on the structure. Compared with the manuals and other contemporary buildings [14, 15], a scrupulous visual pre-analysis of the roof and the mensiochronological analysis carried out in the masonry sector allowed us to confirm the theories and expand our knowledge of the structure. We now know, with reasonable certainty, how the roof and the masonry compartment have undergone several construction phases, of which the most macroscopic ones have been identified. The trestle roof with "pseudo-trusses" has undergone reinforcement additions with respect to its original structure in two phases, which have been identified in some rafters and tie beams of the trusses, and in the iron chains subsequently placed in the 17th century masonry, as seen in the mensiochronological analysis. In a certain way, these roof reinforcements also affected the masonry, as evidenced by the external buttress, in correspondence with the central "pseudo-truss" (B), visible from the shaft on the east wall. Even the masonry itself could be divided, macroscopically, on the basis of the studies carried out, into 3 main phases: the medieval/16th century structure of the ruin partially survived and is still visible today in the three marly limestone pillars on which the three arches currently rest and in the pillar on the north wall, the main 17th century brick structure, and the various infill or repairs that took place between the 19th and first half of the 20th century.

Furthermore, the visual pre-classification of the wooden elements, the thermographic investigation, the pre-analysis of the degradation of the roof covering, and the thermogravimetric and calcimentric investigation also allowed us to draw a first picture of the general condition in which the building currently is [16–19]. While no critical situations of deterioration were found for the main beam, it has been highlighted that some portions of the planking and the secondary beams need further investigation. In particular, as regards the part of the eastern pitch of the roof that borders the building of Vico Malatti 11, we have seen how the "ghiana" (a brick wall built on the slopes of the roof to convey rainwater [20]) on the slate mantle, which should drain the rainwater into the two gutter channels, does not perform its task correctly. This problem is causing the water to accumulate at this point and, given the low exposure to the sun that does not allow it to evaporate quickly, infiltrates the various broken pieces of the mantle. The infiltrating water is starting to deteriorate the planking and then the secondary joists, and, as seen in the thermogravimetric survey, partly the masonry. Furthermore, for the portion of the west pitch, where the skylight is present, water infiltrations were noted on the elements of the roof, and more generally, in all those points where the slate mantle shows cracks or exfoliation, such as not to be waterproof. In correspondence with the inclination of the two gabled pitches, it is supported by the partial overlapping of the rafters of the pseudo-trusses and the masonry.

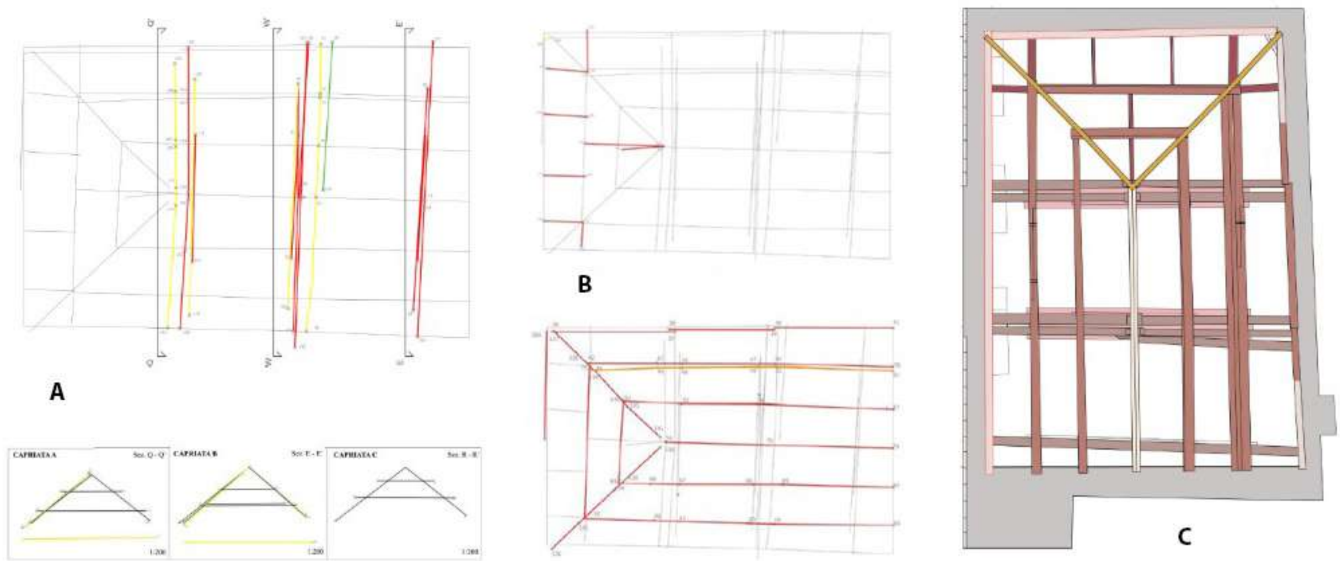

Fig. 4. *A-Draft survey plan and section of the trestle structures. B-Draft survey plans of props and purlins C-Detailed plan of the roof elements.*

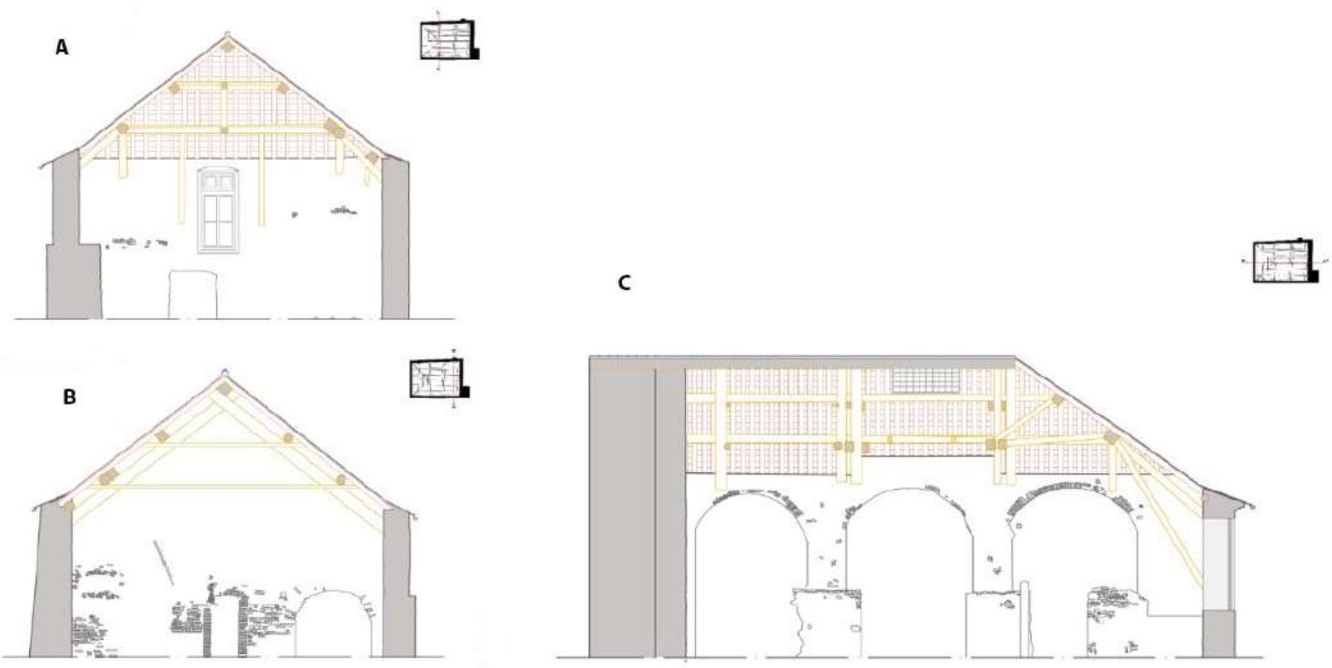

Fig. 5. *A-Transversal section A-A'. B-Transversal section b-b'. C-Longitudinal section D-D'.*

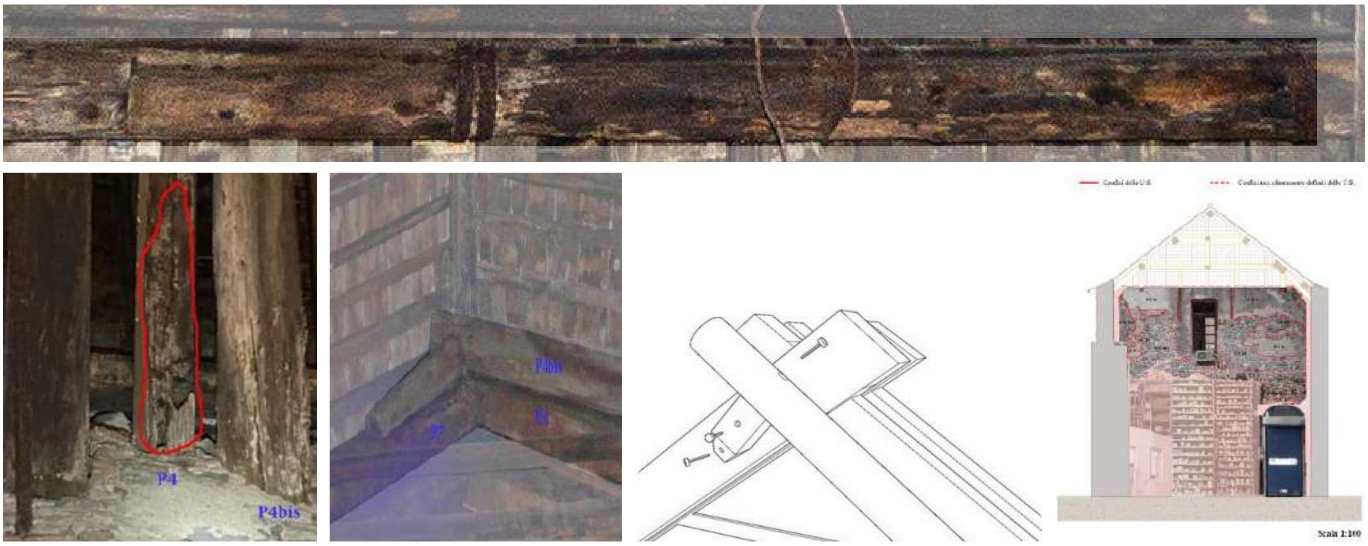

Fig. 6. *Parts of the roof showing interventions following construction [13, 16].*

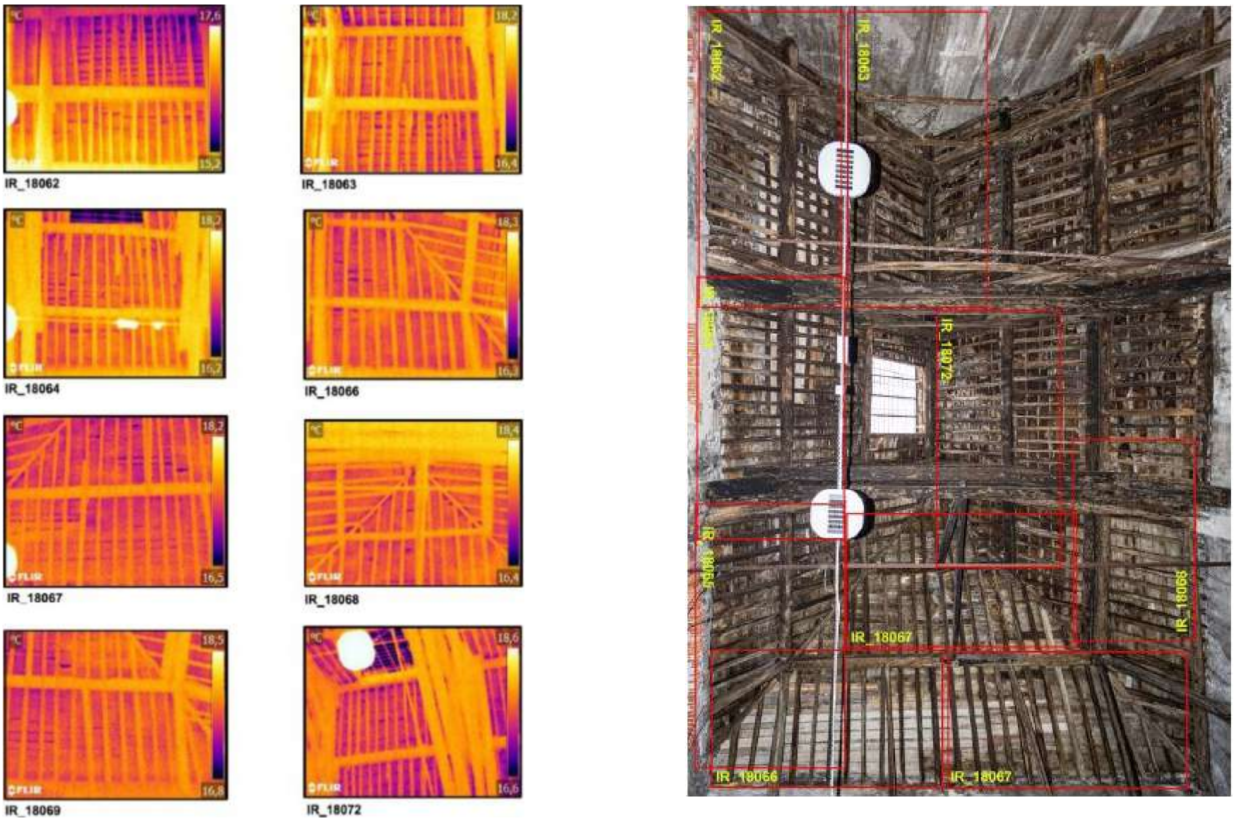

Fig. 7. *Thermographic surveys on the roof.*

7. CONCLUSION

Having no documentary sources on the evolution of this roof over time, we have only been able to hypothesize that some elements of the pseudo-trusses are the result of a subsequent consolidation of the structure, as a contrast to the load exerted on the perimeter wall, due to both the steep slope of the roof and its weight, ensuring an action that counteracts the overturning effects of the masonry. This first consolidation intervention consisted of the insertion of other rafters and wooden tie beams alongside the previous ones, but only in the case of truss A and truss B. Below these two, in correspondence with the consolidation rafters, two iron chains were inserted in the perimeter wall for further

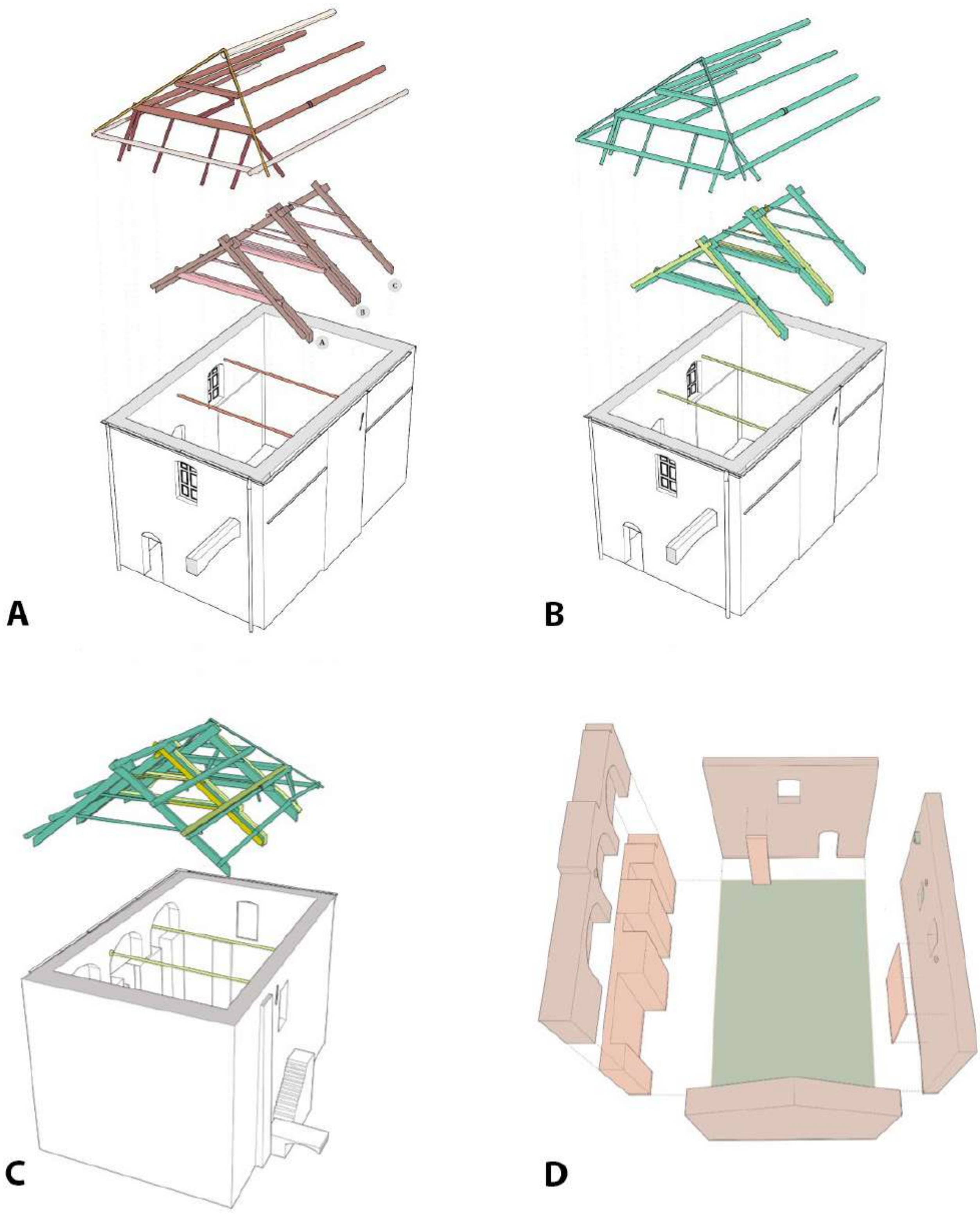

Fig. 8. *A-Exploded view of the roof's elements. B-Exploded view of the different construction phases. C-Exploded view of the stregthening phases. D-Chronological phases of the masonry construction.*

reinforcement. The understanding of these interventions was obtained with a stratigraphic analysis of the perimeter walls, a mensiochronological analysis of the masonry bricks, and a mineralogical-petrographic analysis of the mortar [13, 16]. The fact that these chains are not contemporary with the original structure was deduced from the analysis of the masonry to which they are connected: the 17th century masonry was "split" on purpose to insert the iron chains. The chains contrast the horizontal actions due to the strong lateral thrusts caused by this construction system. Proof of this is the addition on the external wall, in the shaft, in correspondence with truss B, of a buttress that helps to discharge the actions mentioned above.

Indeed, another subsequent intervention is the addition of a third rafter (P4bis) to reinforce the truss B on the east pitch due to the deterioration of the central rafter. In correspondence with the connection with the masonry, the latter has an extended lack in the cross-section, causing its mechanical performance to decrease. This problem was solved by side-laying another rafter, which connects to the P7 opposite one (Fig. 6) through the use of a "gatello", a wooden wedge nailed to the extrados of the rafter [1]. Doubt remains about the two tertiary structures in the first order of the east pitch. It is not known whether these were installed at the same time as the construction of the roof, therefore being part of the original structure, or whether the one with a square cross-section, which is placed above the one with a circular cross-section, was installed as a reinforcement to the structure at a later time. Not having had the opportunity to study the roof closely, we can only make assumptions based on the information provided by the history of the materials and construction techniques of the Genoese roofing structures.

Typically, the main load-bearing structures, such as rafters or purlins structures, were made up of elements from naval carpentry, usually made of oak. It can be assumed that this also happened in vico Malatti warehouse, mainly due to its location in the neighborhood of the pier, where all the naval workers of the port gathered [1]. Two tertiary beams have been identified with the typical tapering of the masts of sailing boats, even if we cannot say for sure in the absence of official documents. The tertiary beams in question are: the one of the first order in the West pitch, which is composed of two elements of naval carpentry, joined together through two metal riveted straps, in correspondence with the tapered part of the two elements, suitably roughened for the union, and the terzera of the second order, also in the West pitch; this type of connection is a half-timber joint. We can equally suppose the use of chestnut for what concerns the secondary truss that rests directly on the purlins, to which the plank of the mantle is then supported, which can also be made of chestnut. The joints in place, which have been observed directly, are mainly "four-shot" [1] head iron nails and metal strapping, which are also nailed.

Roof structures are often poorly studied and poorly monitored due to the difficulty of accessibility and visibility. The research carried out for the Vico Malatti salt warehouse shows how it is possible to obtain reliable information even in situations that are difficult to access.

In this case, for example, it was possible to obtain precise indications regarding the chronological sequence of the interventions on the roof, analyzing the perimeter walls on which the roof rests with a stratigraphy approach. Studying an almost intact trestle roof structure made it possible to add a precious element to understanding this historical local construction technique, which is very common but little studied. All these elements also made it possible to develop direct observation sheets of the individual elements and to carry out their monitoring, a prerequisite for their good conservation.

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Authors contribution

Paragraphs 2, 4, 5 and 6 are attributed to both G. Calvi and D. Pittaluga, paragraphs 1, 3 and 7 to D. Pittaluga, and all photos and drawings are by G. Calvi (except those for which specific attribution has been provided). Conceptualization, methodology: D. Pittaluga, Investigation: G. Calvi, Funding acquisition, resources: D. Pittaluga, Supervision: D. Pittaluga, Writing original draft: G. Calvi, D. Pittaluga, Writing-review&editing: D. Pittaluga.

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A REVIEW OF SCANDINAVIAN RESEARCH ON MEDIEVAL CHURCH ROOFS

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Abstract

The remarkable clusters of preserved high medieval church roofs in Scandinavia have been known since the early 20th century, but surveys aimed at mapping and documenting these structures began around 2000. The author reviews the State of Scandinavian research and presents recent and ongoing survey projects in Swedish dioceses. These cross-disciplinary projects have enhanced the value of historic timber structures as archaeological source material. A reading of craft techniques and tool marks provides insight into the work of the medieval carpenters. The presented example shows how a structured survey followed by moderate cleaning shaped a basis for maintenance and restoration in compliance with international principles.

Keywords

Medieval roofs, Medieval church buildings, Medieval carpentry, Survey methods.

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1. INTRODUCTION

This article deals with research on medieval roof constructions of churches in the Scandinavian countries (Denmark, Norway, and Sweden) (Fig. 1). The scarce economies of Scandinavian parishes after the 16th century Lutheran Reformation have often been mentioned as an explanation for the high authenticity of their medieval churches. This is not all true since many churches were modernized in the 17th and 18th centuries, not to speak of the large-scale demolitions of the 19th. However, a remarkable number of medieval churches still retain their original roof structures, several from the High Middle Ages, when the first stone churches got erected in this northern outskirt of Christian Europe. Clusters of preserved 12th century roof structures, such as the ones in western Sweden, are rare in Europe. Since these roofs are part of a European tradition of trussed tiebeam roofs, they are interesting material for comparison with structures in other countries [1].

This text aims to summarise the State of Scandinavian research. The focus, though, will be put on the last eleven years of structured surveys in the current Swedish dioceses (thus incorporating formerly Danish and Norwegian provinces), their methods, and outcome, also concerning the question of maintenance and conservation. The author has participated in several of these projects and recently published a report on the State of Swedish research in relation to European literature [2]. This is the basis for the present review.

2. HISTORY OF RESEARCH IN SCANDINAVIA

The interest in medieval carpentry was evoked among European architects in the wake of the 19th century Gothic revival with names such as Eugène Viollet-le-Duc in France and the Brandon brothers in Britain. Soon the ar-

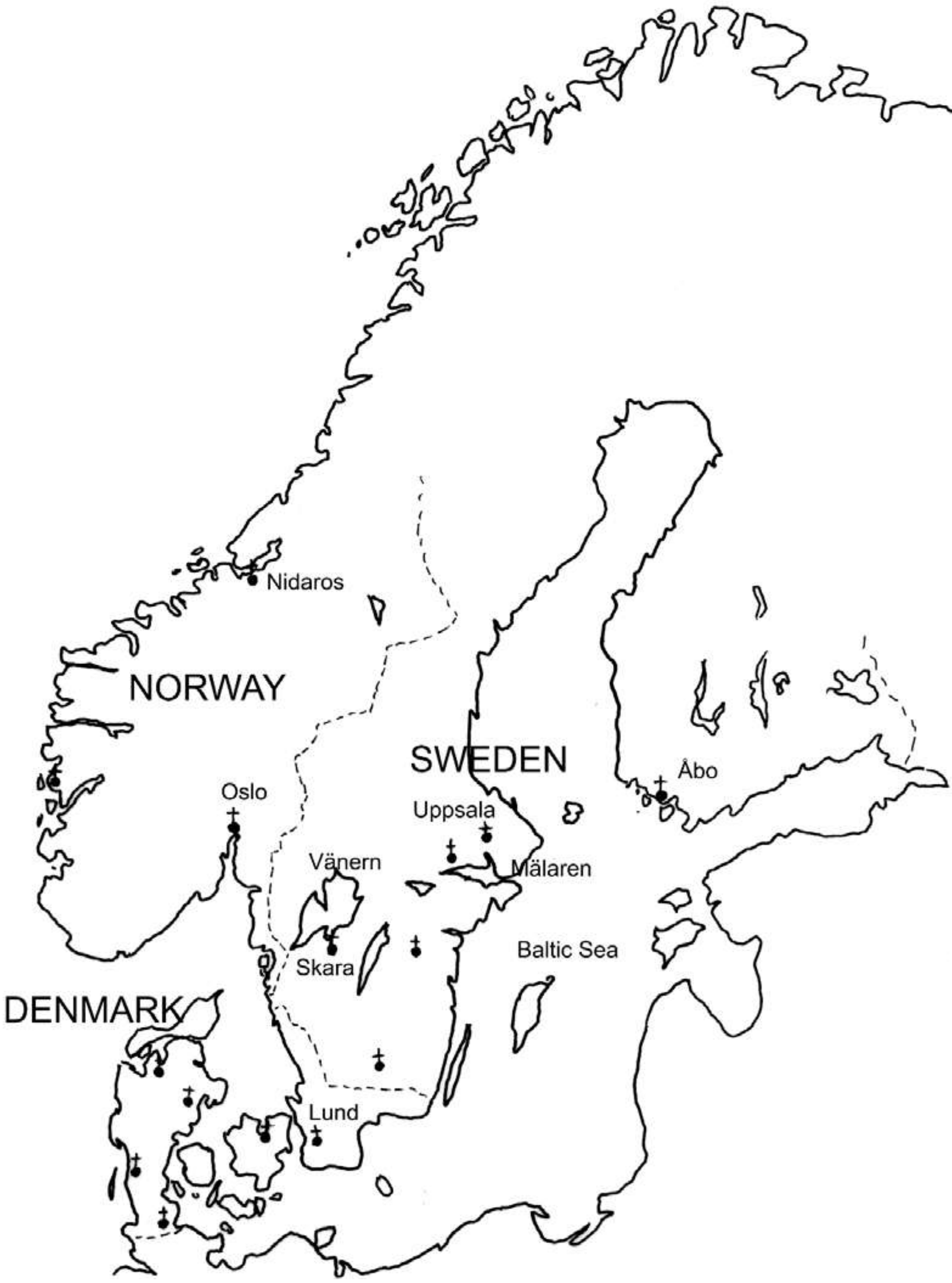


Fig. 1. *Map showing Scandinavia, including Finland with the medieval state borders and the diocesan towns. (Map by the Author).*

chitects got joined by scholars from the new discipline of art history. Nevertheless, before the birth of modern buildings' archaeology in the mid-20th century, very few regarded the timber structures covering the monuments as worthy of any deeper study. First, in the 1980s and 90s buildings' archaeologists raised the importance of studying the roof structures to fully interpret the buildings. Since then, the historic roofs have received a steadily increasing interest. In large, the history of research in Scandinavia follows this European pattern.

2.1. ART HISTORICAL BEGINNINGS – C. 1900-1970

The open roof structures – that is, open to the interior and without tiebeams – of Norwegian stave churches were the first Scandinavian church roofs to get studied in the mid-19th century and attained interest even outside Scandinavia. The likewise open roof of the large church in Værnes, Trøndelag, was long considered the sole surviving medieval roof among the Norwegian stone churches and was used to reconstruct lost roofs in some monuments. This fits the image of an interest connected to contemporary architectural trends and the quest to discover and partly reconstruct a national heritage in several countries. The question of the open roof as an integrated part of the original church interior was debated among Danish archaeologists of the late 19th century, who started to investigate and interpret small-scale Romanesque parish churches. This reflects a general shift in focus from the significant monuments to a broader field of study around 1900, which went hand in hand with the emergence of national "art histories" and a centralized organization of heritage care in the Scandinavian countries. A result of this was the ambitious national survey projects of historical church buildings, still ongoing in Denmark and Norway but in the case of Sweden, very far from finished and, since c. 2000, put to a halt [3, 4]. In the Swedish publications, the roofs are often treated very briefly and from a pure art historical perspective, naturally since the project was "an art historical inventory" and one of the means of creating a Swedish art history.

In the early years of the 20th century, some Swedish art historians and archaeologists made minor studies of a handful of well-preserved 12th century tiebeam roofs, newly discovered, which due to their decorate features, were interpreted as once visible parts of the church interior. The later head of the National Board of Antiquities, Sigurd Curman, regarded these roofs as the meeting between surviving prehistoric Scandinavian carpentry traditions and the European novelty of masonry building [5]. The awareness of high medieval roofs and their inherent values led to astrengthened protection. However, the slow rate of surveys in "Churches of Sweden" left the majority of medieval church attics unexplored and many medieval church roofs have, up until today, been the object of interventions not paying regard to the historical values.

The Norwegian stave churches and their structures have been studied by mainly Norwegian researchers throughout the 20th century [6], but roofs of other medieval churches in Scandinavia have to a much lesser degree, found its ways into publications. Two architects, though, put effort into approaching and trying to read these structures, the swede Erik Lundberg and the dane Elna Møller, whose studies were made possible by the large-scale church surveys. Møller, with a background as a trained carpenter, found that medieval church roof structures were more common in Danish churches than formerly assumed. She could be regarded as one of the key persons in shaping the Danish church archaeology and developed survey methods for roof structures with "truss cards" inside the project "Churches of Denmark" (ongoing since 1933 at the National Museum) and made a typology for "Romanesque" and "Gothic" truss types, (the former with tiebeam), long referred to in Danish research. Møller was also the first to pay respect to tool marks [7, 18, 19]. The focus of Lundberg was structure and shape, marked by a diffusionist art historical perspective, putting the constructions in a European context and questioning their "national" character. He claimed the importance of influences from Carolingian Europe and played down any pure Scandinavian character in the Swedish High Medieval roofs [8].

2.2. THE ARCHAEOLOGICAL PERSPECTIVE – C. 1970-2000

The development of buildings' archaeology and the advent of dendrochronology in the 1970s and 1980s got a foothold also in Scandinavia, giving birth to new methods and raising new questions in the research on medieval churches, often revising earlier stylistic datings. In the 1980s, Nordic researchers on medieval churches started a group focusing on roof structures, which presented their view on the state of research in a seminar on church archaeology held in Viborg in 1993, which showed the need for intensified documentation. Mainly motivated by the increasing archaeological excavations of cultural layers in medieval towns, but also as a part of "Churches of Sweden" and its sub-project "Medieval timber churches", dendrochronological samplings started to be taken and reference curves being built. In Denmark, dendrochronology got incorporated in the surveys of "Churches of Denmark". An interest in questions of building techniques and building organization manifested itself in the 1980s, marking a shift from the macro-perspective of earlier art historians to a micro-perspective examining the building materials, their tool traces, and the local preconditions. Parallel to this, village and settlement archaeology evolved, and several aristocratic and royal manor sites from the Viking Age got excavated, giving a backdrop to understand the transition of Scandinavian countries into Christian kingdoms.

Architect Peter Sjömar's thesis from 1988 on medieval timber buildings emphasized the study of the crafts in historic timber structures [9]. In two subsequent articles, Sjömar called out for structured surveys of preserved medieval roofs in Sweden [10, 11]. Together with his Norwegian colleague Ola Storsletten he made the first in-depth documentation of Swedish church roofs and sketched an outline for a national project on behalf of the National Board of Antiquities, but it never got started. In Norway, such a project came about through the work of Storsletten, published in his 2002 thesis, which showed the presence of several original roofs in Norwegian stone churches that also got dated [12]. Both Sjömar and Storsletten stressed the importance of a solid Scandinavian carpentry tradition and the local resources for the character of the roofs studied. In both Norway and Sweden, institutions for the education in, and research on, traditional crafts got established (Norwegian Craft Institute and The Craft Laboratory at the University of Gothenburg), paving the way for a new reading of historical constructions, the craft's perspective.

2.3. CROSS-DISCIPLINARY NETWORKING – AFTER 2000

Even though the research on medieval churches in Scandinavia remained a small world with a limited amount of researchers, the research proceeded very much along parallel lines, the art historical, the archaeological, and the architectural/technical, connected to different universities and seldom traversing the disciplinary limits. Triggers for a widened networking concerning research on historic roofs were the European programs "Wooden culture" and "Roofs of Europe" in the first decade of the 21st century, making practitioners and researchers in crafts meet with art historians, archaeologists, and architects in enhancing the timber structures as a valuable cultural heritage. This cross-disciplinary approach took physical shape in the Norwegian projects aiming at properly maintaining the stave churches around 2000 [13]. The reconstruction of the burnt 14th century timber church of Södra Råda in Sweden acted as a catalyst for "practice-led" craft research connected to medieval churches, providing a full-scale archaeological experiment finished in 2021 [14]. This project renewed the interest in making reality of a national survey. Architect Kristina Linscott put on behalf of the Church of Sweden forth a report on the state of research in 2007, including a database of known structures and a typology [15]. A structural investigation into medieval roofs as load-carrying structures was made by engineer Carl Thelin in his thesis 2006 [16].

In Denmark, the well-preserved church roofs of southern Jutland have been thoroughly documented and dated. They have been interpreted and published by medieval archaeologist and art historian Per Kristian Madsen, The National Museum, in 2007 [17, 18]. He points at the remnants of a highly developed domestic carpentry tradition open to new ideas from abroad. In an article on the Arrild church roof, he also combines historical and archaeological sources to put the construction in a socio-political context [19]. Inger Laigaard, in 2018 evaluated and dated the tools and techniques encountered in danish church roofs [20]. It should also be mentioned that extensive research on Viking Age carpentry finds in Denmark and Norway has been done in relation to settlement archaeology and the finds of Viking ships. This provides a domestic context to some of the techniques found in Scandinavia's high medieval church roofs.

Fig. 2. *Survey of trusses in the chancel of Knätte, Västergötland, Sweden. (Photo by the Author).*

3. RECENT AND ONGOING SURVEYS IN SWEDEN

The altered relations between the Swedish State and the Church of Sweden in 2000 led to a mutual agreement on the future preservation of the churches as cultural heritage, while the other Scandinavian countries have maintained their state churches. The Swedish dioceses became crucial in administering the new state funding and creating an up-to-date knowledge base for managing the church buildings and their complex historical values. In 2010 the author headed a small pilot project aiming to map the extent and character of medieval church roofs in a part of the province Småland, Linköping diocese [21]. Seven dioceses have run similar survey projects in the following ten years, some still ongoing [21–28]. The primary objective was to grasp and evaluate what remains of medieval timber constructions in attics and bell towers; in short, a rapid inventory becoming a prerequisite for correct maintenance and a starting point for further research (Fig. 2).

3.1. METHOD

Although the composition of the survey projects has varied somewhat from diocese to diocese, since they were all individually run, they share common points of departure and aims. Central has been the collaborative work of conservators, archaeologists, dendrochronologists, and, not least, craft researchers and traditional carpenters with experience from the Södra Råda project. Whereas the preserved structures are the primary source material, complementary dates have been searched for in the archives (although these mainly concern early modern times).

The projects have been run as hermeneutical processes with stages zooming in from a macro- to a micro-perspective. Limited archive studies were used to sort out churches that could have preserved structures and would be the object of survey. This meant spending half a day in each church to map if any timber structures were preserved, if so, their extent and general character, using a standardized checklist resulting in a protocol, sketch drawings, and photos. Questions were formulated based on the results of the survey, and a selection of objects was chosen for continued in-depth field and archive study, forming the following case studies.

The investigations in selected structures focused on identifying original parts and later alterations, their relation to the masonry, traces of use, and the understanding of the system, tools, and techniques applied by the original carpenters. For the latter part, reading and interpreting the tool marks and other traces of the production and erection processes was vital. The astoundingly well-preserved surfaces of many timbers in Scandinavian church attics give good possibilities for what has been labeled as “traceology” or “forensic perspective”. The experiences of craft researchers and carpenters in recreating these traces with replicas of historic tools were necessary to fully understand and value these “fingerprints” of the medieval craftspeople, which earlier often had been passed by. Such traces contain information vital to understanding the craft.

Analyzing these roofs in detail resulted in hypotheses that were tested by dendrochronological samplings in selected promising timbers. Exact dating is, nonetheless, tricky in the high medieval structures since the carpenters seldom left any vaney edge or sapwood. Thus, the sample timbers must be sought out and examined carefully to determine the presence of vaney edge or sapwood, top or bottom, and the number of year rings. The most common species used in medieval Norway and Sweden were pine, to a lesser extent oak, and spruce, whereas oak was all present in the churches of medieval Denmark. Pine and oak have good reference curves while spruce poses a much greater challenge. Much of the dendrochronological analyses have been made at the Department of Geology, University of Lund, the central archive for Swedish samples. The extensive comparison material from different regions also allows for suggesting provenance. The samples also give information on the growth circumstances for the actual timber, giving an image of how the forests once looked and were used. Such questions have been highlighted in the diocese projects, and dendrochronological methods have been further developed in a project run by the Craft Laboratory and the University of Lund [29].

3.2. A SHORT SUMMARY OF RESULTS FOR SWEDEN

The diocese projects have enlarged and deepened the knowledge of medieval roof structures and timbered bell towers in contemporary Sweden. The amount of known structures has doubled since the report of 2007, from 268 churches to well over 500, and still much remains to be surveyed. Circa 160 constructions, to a large extent preserved in situ, can be regarded as pre-dating 1250, a unique European corpus. The dendrochronologically dated structures have also doubled from circa 100 to more than 200. To summarise the material is consequently not possible in this article. Now the work is to process this extensive empirical material scientifically and put it into context, regionally and in relation to Europe. The author is treating the West Swedish material in an ongoing PhD-project; another PhD-project concerning the material from the Danish period in the diocese of Lund in southern Sweden is run by carpenter and archaeologist Karl-Magnus Melin. A minor part of the earliest dated west Swedish roofs were the objects of a dissertation by Kristina Linscott in 2017, focusing on the relation between the inner space and the roof and its possible perception [30]. The regular contacts with colleagues in other countries through the network of "Arbeitskreis Dachwerke" and the "Construction History Society" seminars have given valuable input for the research on roofs in current Sweden. Summarizing articles on Swedish and Danish material will be included in the upcoming publication "Dachwerke vor 1230", headed by the "Arbeitskreis".

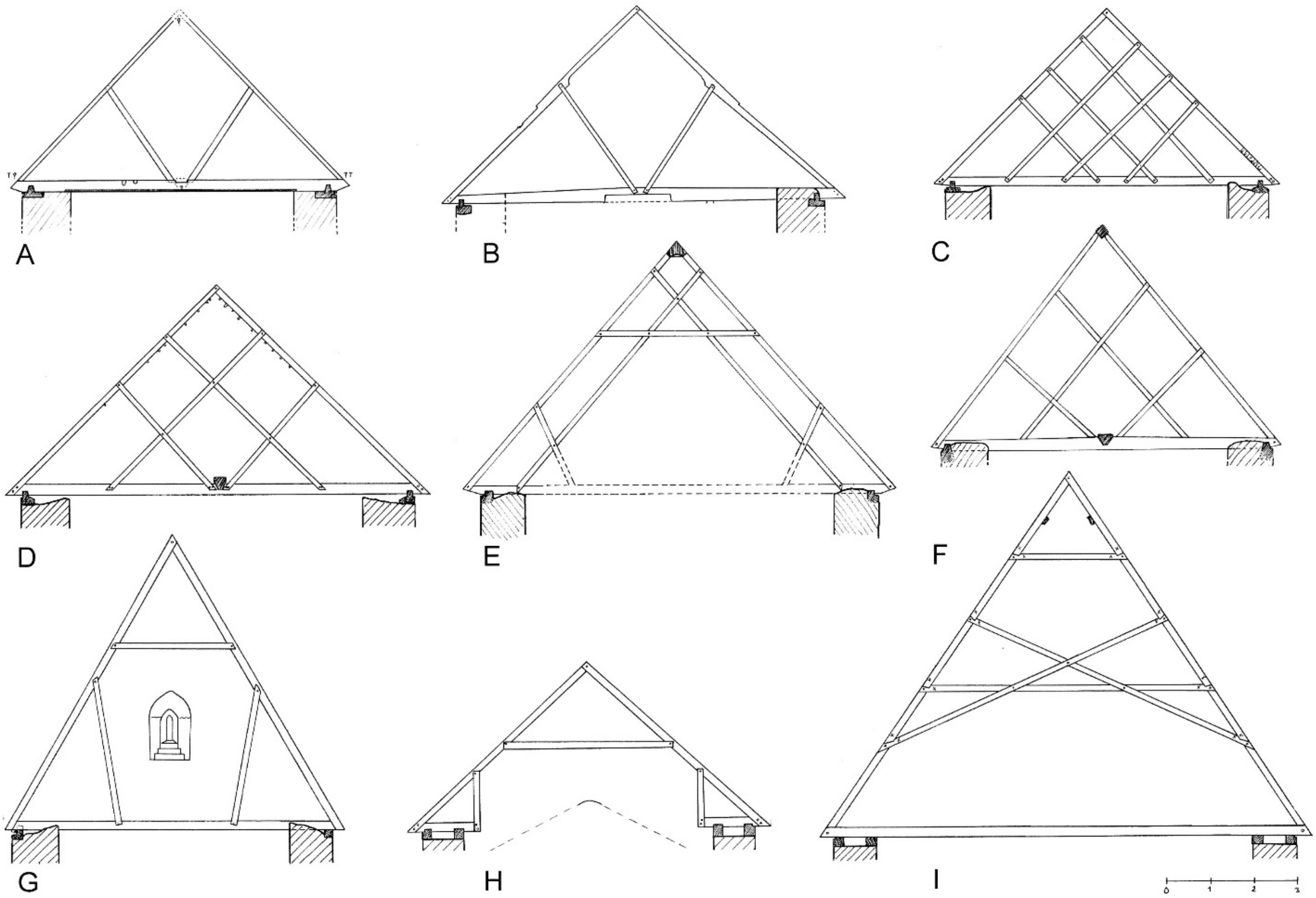
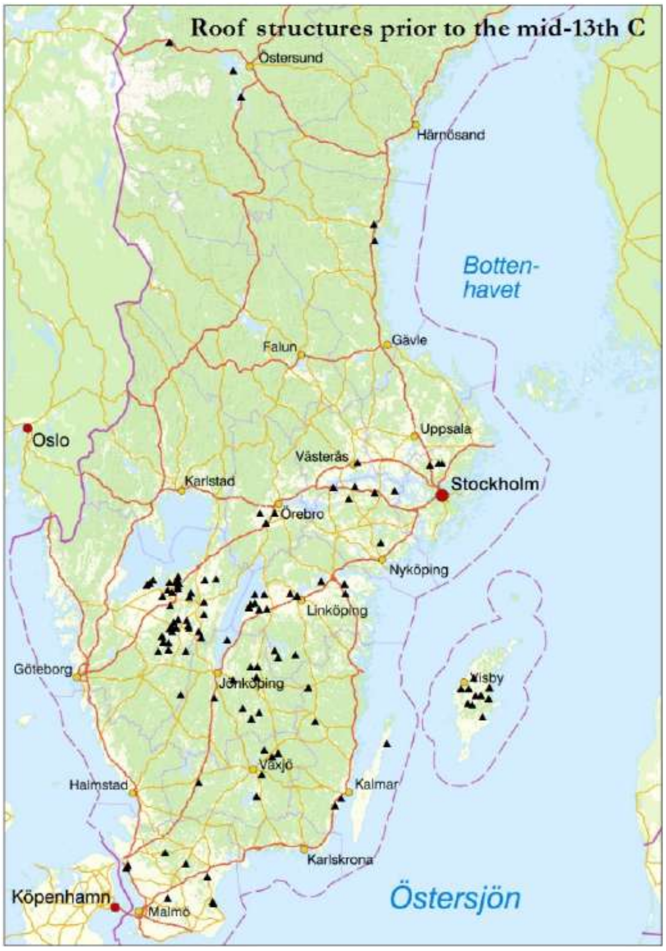
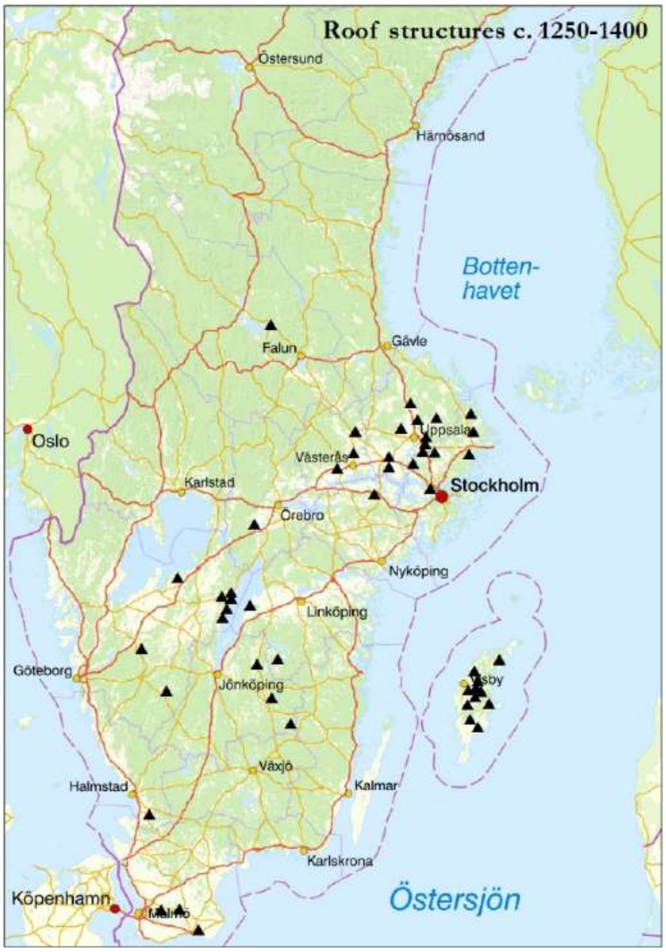


Fig. 3. *Examples of church roofs in West Sweden from 1100-1400. A. Truss with canted struts inserted in mortises without dowel, the 1120s (d), Västerplana church, nave roof. B. Truss with canted struts and lap joints, 1135-1137 (d), Forshem church, nave. C. "Lattice" truss with crossing struts, together with the D variant, the most common type from the 12th and 13th centuries, 1138-1149 (d), Marum church, nave. D. "Lattice" truss with a steering beam on the tiebeams, undated, Sveneby church, nave. E. Truss of the South Norwegian Østland type, here with a steering beam on the ridge, 1205-1207 (d), Ljungsarp church, nave. F. Truss with rafters inserted into a ridge purlin, 1200-1204 (d), Valtorp church, nave. G. Steep pitched truss with canted struts and collar beam, probably late 13th or early 14th century, Knätte, chancel. H. Truss adapted for vault with ashlar and sole pieces, standing on double wallplates, 1269 (d), Forshem, chancel. I. Truss with scissor beams and dovetail lap joints with carpenter marks, 1378/79 (d), Mölltorp hall church. (Drawings by the Author).*

I will here try to sketch some more general conclusions apart from the simple mentioning of numbers, names, types, and dates. The Middle Ages is a long period, and carpentry shows some radical changes from the oldest remains of the late 11th century to the structures before the Lutheran reformation shortly before the mid-16th century. Nevertheless, these changes occur in different regions at different times and paces (Figs. 3 and 5).

The oldest dated remains belong to the second half of the 11th century but are only preserved as reused timbers in younger constructions. Still, these few traces of tiebeams, wall plates, and steering beams found in early stone churches in Scania (until 1658 part of Denmark) and remnants of stave churches in Östergötland and on Gotland testify to the use of tiebeam trusses. To determine when and where this new way of roof construction got introduced in Scandinavia is difficult due to the scarcity of remains, but it seems that domestic carpenters were at work already in the early examples and had a high level of skill. Up until the mid-14th century, most structures show the same set of tools and techniques, most characteristic the hewing with knife grinded felling axe in the direction of the wood fibers, shaping a fishbone pattern (Fig. 7). The oldest preserved trusses date from the first half of the 12th century and are found in Scania, Väster- and Östergötland, Södermanland and Gotland, early centers of Christianity and worldly power. These trusses with high tiebeams and slender rafters supported by canted struts, all nicely square hewn, are closely related to the oldest preserved examples in Western Germany. In total, 21 structures could be regarded as preserved. Dominating the corpus of high medieval roof structures are the tiebeam trusses with a lattice of crossing struts, which seems to have developed into a normative type from the mid-12th century, enduring for more than a century in newbuilt stone churches but also timbered ones. In total, some 90 are known, of which





Figs. 4 and 5. *Distribution of preserved church roofs from the period 1100-1250 respectively 1250-1400 in current Sweden, stand 2020. (Maps by the Author).*

69 can be regarded as preserved structures, mainly in Västergötland, but also in other provinces (Fig. 6). 12 roofs are rare hybrids between the trussed roofs and the older post-and-purlin roofs, featuring rafters inserted into a ridge purlin. A characteristic feature of 12th and 13th century church roof trusses in medieval Sweden is their tight and, in effect, over-dimensioned spacing around one ell (Fig. 7c, 10). In contrast, the spacing in the rest of Scandinavia and northwestern Europe has a standard measure of the double (only the earliest dated structures up until the 1120s show a more European spacing). Decorative elements on tiebeams and steering plates, as well as plastered surfaces between the tiebeams and traces of fixation for small bells, imply that the roof structures originally were visible from below, to become hidden by flat wooden ceilings first in the 13th and 14th centuries and subsequently resulting in less refinement in the following roofs. Also, the use of seasoned timbers, evident in the still very accurate and tight joineries, marks a difference against continental roofs. The dendrochronological samplings indicate the use of local timber resources during most of the Middle Ages [31].

The carpentry innovations brought forward by Gothic architecture on the continent reached the Scandinavian regions very unevenly. The first dated applications of a hierarchical roof structure adapted for vaults (with primary tiebeam trusses and secondary ones with ashlar and sole piece) are on the island of Gotland from the early 13th century. In Västergötland it is stated first from c. 1270 and in very few examples since few Gothic refurbishments were made. Instead, the regions around lake Mälaren and the north thereof advanced as centers for large-scale church projects, including the insertion of wooden trefoil and barrel vaults, which are known from 28 churches, though none of these vaults today is preserved in situ. From the mid-and late 14th century, the few dated structures might reflect a decline in building activities in the wake of the Late Medieval Agrarian Crisis and the Black Death. Whereas some parts of medieval Sweden retained the Romanesque roof solutions, the carpentry in general adopted the techniques of continental truss and timber frame building such as working on templates, use of carpenter marks, increased spacing, bracing with scissor beams, hewing mainly with the broad axe across the fibers and the use of more developed lap joints or doweled tenon and a mortise (Fig. 8).

Fig. 6. *Lattice roof trusses in the nave of Jät church, Småland, Sweden, 1225-1226 (d). Note the hewing marks going along the fibers ("sprätthuggning") and the sharp edges without vaney. (Photo by the Author).*

The Late Medieval roof structures are closely related to the continental ones, even though the old-fashioned tiebeam roof held on, especially in Western Sweden due to the lover rate of vaultings. Most preserved 15th and 16th century roofs are found in the regions around Mälaren and in the North. Medieval Sweden has few examples of Gothic double-framed roofs. The earliest known example was erected on the bridgetine convent church of Vadstena in 1418, followed by the roofs some large city churches, maybe under the influence of German merchants and craftsmen.

Ten Romanesque masonry towers still preserve their original roof structures, but these remain to be studied closer and dated. A handful of timber-framed campani-

Fig. 7. *Different 12th century surface treatments. A. Slender rafters in Jäla church, Västergötland, 1124-1142 d, of cleaved pine and oak, hewn with a felling axe in the direction of the fibers, the Scandinavian technique of "sprätthuggning". B. Tiebeams and ornate steering plate in the nave of Hagebyhöga church, Östergötland, 1119/20 d; the surfaces worked with a plane, and the edges enhanced with a profile plane; note the traces of a later inserted ceiling on the bottom of the beam. C. Tiebeams in the nave of Mularp church, Västergötland, 12th century, the beams are full timbers hewn to a conical shape in the technique of "sprätthuggning", the sides finally flattened with a broad axe working cross the fibers, leaving a stroke of "sprätthuggning" along the edges. Note the flush and tight strut lap joint and the embedding of the beams in the masonry, originally plastered. (Photos by the Author).*

les have also survived, belonging to the High and Late Middle Ages, related to preserved ones on the Danish islands.

3.3. STATUS IN THE OTHER NORDIC COUNTRIES

In Denmark, there are few known remains of roofs older than 1200, though traces have been found in some 50 churches in Zealand [32]. Twenty-three medieval roofs on southern Jutland have been more closely investigated and dated from the 13th century until the 16th, most interpreted as younger than the church itself [17, 18]. Inside the project "Churches of Denmark", documentation of medieval churches is ongoing in eastern Jutland and on Funen, including studies and dendrochronological sampling of roof structures [3]. The overall picture is similar to the former Danish provinces of Scania and Halland, where Late Medieval structures dominate, and High Medieval remains are few compared to medieval Norway and Sweden. The Danish roofs have been structured into four types by Møller: the Roager type with tiebeam, canted struts, and often a collar beam, the Arrild type where two or four of the struts cross each other; the Scissor braced type with or without tie or collar beam, the Collar beam type with small ashlar pieces and sometimes sole pieces. The preserved tiebeam types have mainly datings from the 13th and 14th centuries, the ones adapted for vaults are mainly dated from c. 1400 onwards. Some types have been applied throughout the Middle Ages, showing lasting carpentry traditions. The roofs of medieval Denmark have many similarities with roofs in Northern Germany from the same time and also share features such as pit-sawn quarter timbers in rafters and bracing.

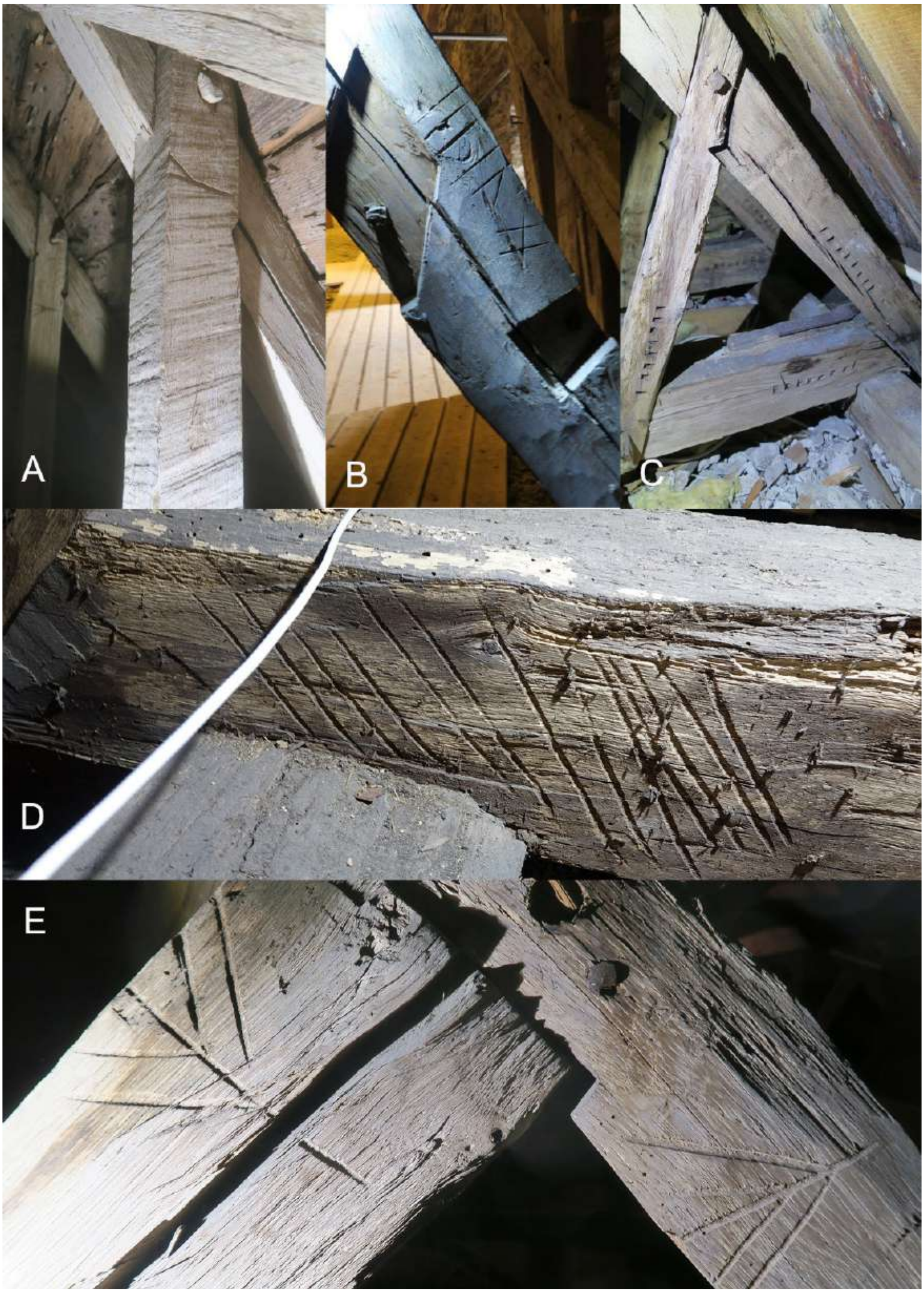


Fig. 8. *Examples of high and late medieval carpenter marks in Sweden. A. Symbolic runic mark made with race knife on ashlar piece, pit-sawn quarter timber, in the chancel of Ysby church, Halland, 1275-1287 d. B. Cut Roman marks on reused broadaxed beam from the original double-framed roof of the convent church in Vadstena, Östergötland, from the 15th century. C. Square cut marks ("Macken") on oak rafter foot in Torslanda church, Bohuslän, 1470-1472 d. D. Race knife lines on tiebeam in the hallchurch of Sällstorp, Halland, 1460s d. E. Race knife marks on the double-framed nave roof of Veinge church, Halland, 1517 d. (Photos by the Author).*

Fig. 9. *Carpenter Mattias Hallgren hewing a new wall plate of oak to the church of Gökhem, Västergötland, Sweden, in 2019 using the same tools and techniques that could be read on the original. The church in the background still has 20th century roof tiles. (Photo by the Author).*

Since the research of Storsletten, the complete corpus of high medieval church roofs in Norway is today known, comprising 53 preserved structures from circa 1100-1350, of which 28 are found in stave churches (with a span of datings from the mid-12th century up until the first half of the 14th). Storsletten has created a typology consisting of six types, of which three are solely connected to the open structures of the stave churches. The advanced internal bracing of the trusses is highly characteristic, such as the doubled rafters of the Østlandtype, also found in a few Swedish examples, and the elaborate fan-shaped lattice bracing of the open trusses of the Trøndelag type, which, as the stave church roofs, applies trusses without tiebeams long before the innovations of Gothic carpentry reached Scandinavia. These imposing roofs have also been found in the current Swedish provinces of Jämtland and Hälsingland, showing strong influence from neighboring Trøndelag and the Norwegian archdiocese of Nidaros. The craft techniques and tools used in the Norwegian roofs are more or less identical to those found in most of the high medieval Swedish material, stating the existence of an overarching Scandinavian carpentry tradition.

In 2020 a Finnish survey project started, conducting cross-disciplinary in-depth field studies of the 20 known late medieval church roofs preserved. Since Finland, from the 12th until the early 19th century, was part of the Swedish kingdom, several comparisons can be made. Of high medieval structures, only some reused fragments seem to remain, mainly due to the relatively late start in constructing the still-standing stone churches.

3.4. SURVEYS AS A PRECONDITION FOR MAINTENANCE AND CONSERVATION

People can properly maintain and preserve only what they know. The surveys have been motivated by the need for better knowledge to preserve this significant part of the oldest surviving Scandinavian carpentry in situ. The lack of knowledge is evident in several attics and con-

Fig. 10. *Restoring severely damaged tiebeams (1140/41 d) in the nave roof of Gökhem church, 2019. Carpenter Bengt Bygdén making a recess for a lap joint. Note the hewing of the tiebeams, made accordingly to the technique used on the scarfed piece. The log was cut square with a felling axe working in the direction of the wood fibers; finally, the somewhat protruding sides got flattened with a broad axe working across the fibers, a treatment connected to the original visibility of the beams in the church interior. (Photo by the Author).*

structions, which had not been recognized as historical structures with their own values. Even recently, values have been lost forever or damaged due to random alterations, exchanges, and technical installations. Creating awareness among local trustees, decision-makers, and entrepreneurs is a great task, the surveys are the necessary starting point.

A few high medieval timber structures have recently been the object of well-planned restorations and conservations. A good example is the works concerning the unique 1140s nave roof of Gökhem church, Västergötland, 2017-2021 (Figs. 9 and 10). Before a planned renewal of the 20th century roof covering of tiles, a study was made of the structure in the attic, which partly was covered in birds nests and waste material, making an evaluation of damages difficult. An archaeological cleaning of the attic was made by the author and craft researcher Mattias Hallgren, followed by a buildings archaeological investigation and thorough inventory of damages, the latter showing severe inner damages of fungi in several tiebeams, aggravated by their embedment in the masonry [33].

Such a cleaning and detailed investigation could be considered a third stage following the surveys and case studies. This shaped the basis for a restoration plan in which engineer Carl Thelin also ensured the level of necessary structural function. The aim was to minimize the interventions to preserve the maximum of the original substance, but also to respect the original working methods, materials, and techniques, and not least, to maintain the authentic visual impression of the attic, whose trusses were once visible parts of the church interior. This meant that each truss was treated as a unique case with regard to the degree of damage and information on the original surfaces. Luckily the roof is typically over-dimensioned in its spacing of the trusses, meaning that it would be enough if only every second truss were fully functioning. Thus a lot of work and original substance could be spared. The worst damaged tiebeams had to be scarfed with new material of corresponding quality, hewn in the same techniques and with the same type of axes as the original, a process which in itself meant a deepened knowledge of the original techniques [34] (Fig. 11). In other cases the damaged tiebeams with intact surfaces underwent surgical reparations getting new form shaped infills. The tiebeams cut for vaults in the late 15th century were reconnected with iron anchors, preventing further deformation. The destroyed southern wall plate was reconstructed in oak (Fig. 10). The archaeological building investigation showed that the present embedding of the tiebeams in masonry was not original; thus, it was decided not to reconstruct it on the fungus-infected southern side, leaving the tiebeams free. 20th century random additions could be removed. To lessen the weight put on the trusses, the decision was made to change the roof covering from tiles to lighter shingles, which could be historically stated both through the archives and through findings in the cleaning. Throughout the process, public demonstrations of the project were made as well as a temporary exhibition, which met with great interest from locals, tourists and visiting experts. In upcoming years the aim is to make part of the roof accessible for smaller groups and create a minor exhibition. Thus the surveys shape a foundation for better-planned maintenance and restorations in line with the principles stated in the Mexico charter of 1999 and letting the timber structures speak for themselves.

4. CONCLUSION

Since the turn of the Millenium, significant efforts have been made in all Scandinavian countries to better understand the extent and character of preserved medieval carpentry in the churches. This has highlighted the roof structures as unjustly neglected sources of knowledge concerning crafts and building in the Middle Ages. The cooperation between scientists and craftsmen has given new insights and readings of the well-preserved material, valuable for both the research and the challenges of preservation and conservation.

Acknowledgment

Per Kristian Madsen, The National Museum, Copenhagen, for reading and giving valuable comments, especially concerning the Danish material.

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LOST ROOFS – CASE STUDIES FROM MUNICH

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Abstract

The article presents the results of the author's research on *lost* roofs in Munich. The importance of Munich rose continuously over the centuries. Talented master builders met demanding clients. This resulted in prestigious buildings with ambitious constructions. Today, most of them are lost due to the destructions of the Second World War. The aim of this study was to reconstruct the most important roofs on the basis of archival sources and building archaeological research on the remains. The results show a great variety, always reflecting the current developments in roof construction. Among them, there are also quite experimental solutions. The results are presented as detailed scale models.
The models allow getting a lasting impression of the lost structures. They serve to illustrate this essay. Finally, special attention is given to some constructions that have a link to Italianate designs.

Keywords

Roof constructions, Reconstruction, Scale models, Timber construction, Knowledge transfer.

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1. INTRODUCTION

This paper gives a short overview of a study on roof constructions that were destroyed during the Second World War in Munich. The whole research was published in 2019 [1].

There have been systematic studies on roofs within cities (e.g., Bamberg, Basel) [2–4] or regions (e.g., Thuringia and Lower Saxony) [5]. They brought valuable results, especially concerning the development of constructions in a comparable setting. A study on lost roofs is, apart from single objects (e.g., Vienna cathedral) [3], a new approach in this field. Due to the preconditions, the study had to focus on the most prominent objects.

The old town of Munich was widely destroyed in the air raids of 1944 and 1945. The important architectural monuments, such as the Residence of the Bavarian Dukes and Kings, the medieval *Frauenkirche*, and many of the other large churches and secular buildings, were mostly destroyed. In any case, they lost their roofs.

Munich was first mentioned in 1158. In that year, the Bavarian Duke Heinrich built a bridge over the river Isar. The city finally became the capital of the Wittelsbach duchy of Upper Bavaria in the second half of the 13th century. The growing importance of Munich was reflected by the rise of prestigious and large-scale architecture. Thus, also ambitious roof constructions were built. However, there is no more evidence of roofs from the 13th century. The oldest traceable example dates back to the 14th century [6]. From then on, a manifold development set in.

A glance at a historical veduta or model reveals how much the city was shaped by its roofs. The model of Munich from 1570 shows a roofscape as it exists nowadays

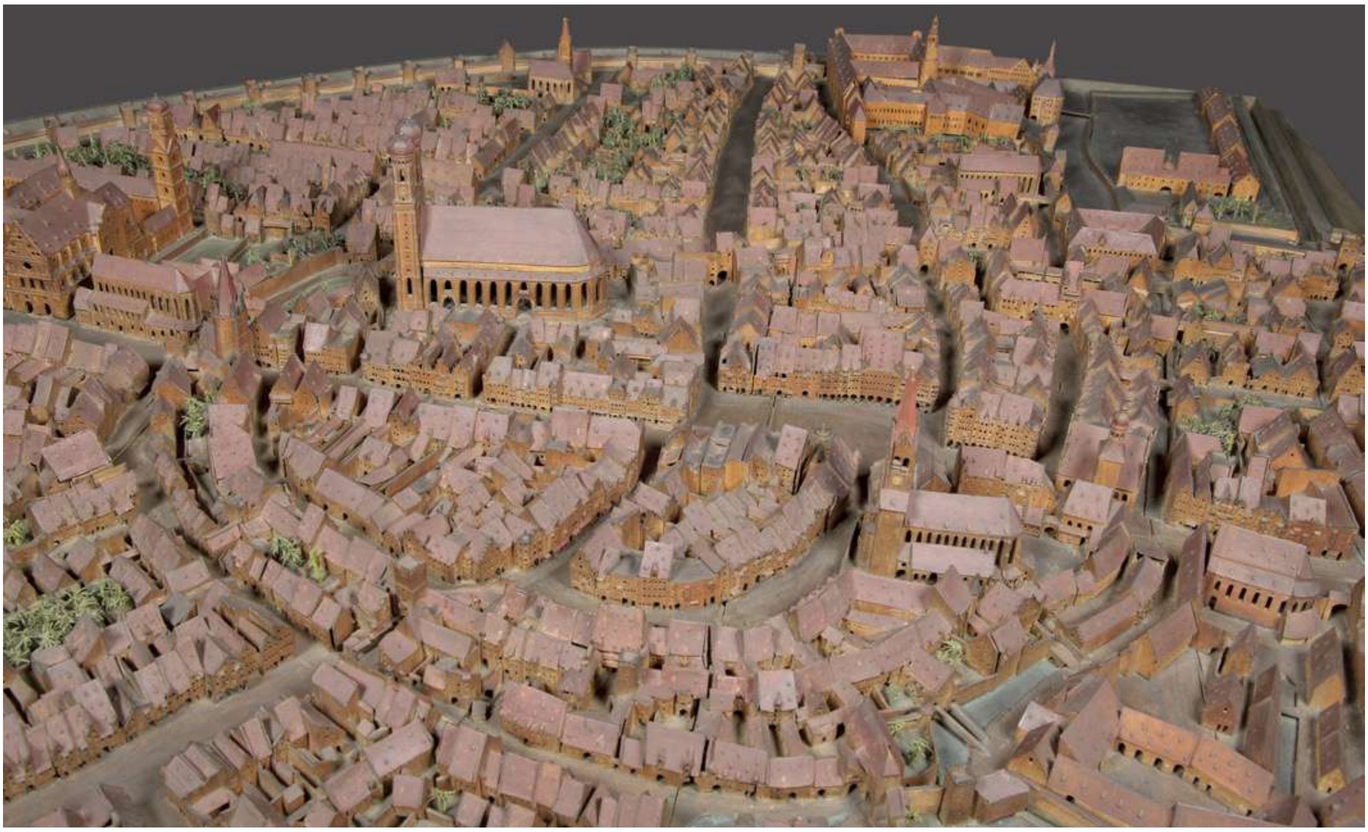

Fig. 1. *Model of Munich, built by Jakob Sandtner in 1570. (Picture: I. Mühlhaus).*

only in a few historic places. The variety of constructions is considerable. Besides the prevailing steep rafter roofs, there are also purlin roofs, which are typical for the rural architecture around Munich. In many cases, the roofs take up more than half of the building cubature. This also implies that roofs were considered to be a representative part of the house [2], like a "fifth façade".

Especially the large roofs of the southern German hall churches dominate the city silhouettes and thus also the distant view of a city. In many places, even in Munich, this is still evident today. When the cities were still sharply defined from the countryside by walls, this effect must have been even more striking.

In emerging cities like Munich, experienced master builders always faced ambitious clients. Thus here was an ideal breeding ground for innovative achievements in architecture and construction. This also affected roof structures: only what could be roofed could be built.

2. METHODOLOGY

All reconstructions of this study are based on archival sources. In a second step, the buildings were inspected to look for traces and relics of the former roof structures by means of building archaeology (all roofs were rebuilt with modern structures after the war – none of the lost roofs was reconstructed in their original state). Further references, e.g., roof structures related to the objects studied, could contribute to the answering of open questions [1].

The reconstruction as a model or drawing was only done if sufficient sources could be found. Further selection criteria were if the roofs represent a challenge in terms of span and construction. In addition, the objects (the real, now destroyed roofs) should illustrate an important stage in the evolution of roof constructions, e.g., representative examples from the Middle Ages with vertical struts (*Stehender Stuhl*) or raking struts (*Liegender Stuhl*), examples from the early modern period, the 19th century, etc.

The result is the documentation and reconstruction of 14 roofs on churches and secular buildings. Ten of these were destroyed during World War II, while two others (the *Turnierhaus am Hofgarten* and the wooden vault in the pilgrimage church of *Maria Ramersdorf*) were lost much earlier. Two roofs from the survey (*Salvatorkirche* and *Ludwigskirche*) were never destroyed but are considered to be important for the overall context. This is why they were nevertheless included in the study [1]. However, they are not discussed in this article.

Eleven roofs were built as wooden scale models in 1:20, some of which include two different constructions (*St. Peter*, *Marstall*). An additional model was built for the large roof of the hall church of St. Martin in Landshut. It demonstrates great similarities to the roof of the *Frauenkirche* in Munich – a very interesting aspect of the development of late medieval hall churches in southern Germany.

The requirements for the model building were set high – every single component of a roof structure was to be represented in the model. The timber joints had to be reproduced realistically. So the models can be assembled, disassembled, and reassembled again. This means that the data in the archival sources had to be sufficient enough to reconstruct the lost roof structures down to the last detail. During the research, two historic scale models of St. Michael and Welsche Hauben of the Frauenkirche were also found. In those two cases, no new models were built.

Models allow the large and sometimes very complex constructions to be experienced in a three-dimensional and haptic way, at least on a small scale. The reconstruction models were presented to the public in a highly acclaimed exhibition at the Munich City Museum in 2018.

In the following, the results of the reconstructions are briefly presented in chronological order.

3. RESULTS OF THE RECONSTRUCTION OF LOST ROOFS

Church of St. Peter

The roof of the nave of the Basilica of St. Peter, built after 1327, consists of identical trusses stiffened by scissor braces. There is no longitudinal bracing except the roof

Fig. 2a. *Church of St. Peter*

Fig. 2b. *Roof constructions of St. Peter – the medieval roof of the nave (left) and early modern roof of the presbytery (right). (Model: C. Knobling, Picture: I. Mühlhaus).*

covering. Only for the erection process, diagonal timbers were nailed to the inner sides of the rafters to hold the spacing between them. Thus, it represents a common case in medieval roof construction [7, 8].

Scissor-braced roof trusses are quite typical for this time and region. The former Augustinian church, built around 1340 (choir) and 1440 (nave) [6], had an almost identical roof and illustrates the prevalence of this construction for basilical churches.

Subsequently, a reinforcement was installed in every fifth roof truss of *St. Peter*. An iron bar, attached to a truss, carried a girder providing additional support for the existing tie beams. The reinforcement cannot be dated exactly but was apparently built in the 19th or early 20th century.

The presbytery of St. Peter's Church was rebuilt in 1630-36 as a baroque triconchos [6]. Its roof construction with raking struts (*liegender Stuhl*) and king post is quite common in the early modern period [2, 7]. The joint at the intersection of the king post, collar beam, and straining beam is very complex since the king post cannot be interrupted. The will to bring all elements together in one layer caused such difficulties, which can also be seen in other early modern roofs (e.g., *Michaelskirche*, see below). Unlike the medieval roof of the nave, the presbytery roof is braced lengthwise by St. Andrew's crosses. To align it with the medieval roof of the nave, it has an unusually steep slope of 61°. The reconstruction is based on sources from the parish archive of St. Peter, i.a. detailed photographs from the destroyed church with the roof partly still in place.

Church of the Assumption of Mary (*Mariae Himmelfahrt*) in Ramersdorf

The roof of the pilgrimage church *Mariae Himmelfahrt* in Ramersdorf was built around 1360 [9]. A wooden vault was once integrated into the roof structure. It had the form of a half quatrefoil, i.e., it consisted of a central barrel vault and lateral half-barrel vaults. The vault was resting on longitudinal beams, two on consoles at the side walls and two fixed with tenons at the interrupted tie-beams of the roof. The interrupted tie-beams are supported by king posts. Bent ribs, made of interlocking pieces of wood, supported the cladding. They were fixed on the longitudinal beams with tenons. Scissor braces stiffened the trusses and transferred the tensile forces above the vault.

The construction of the vault was not based on Nordic models, where such forms were shaped primarily by the addition of short beams bevelling the lower angles [5] – the Ramersdorf vault was an independent structural unit

Fig. 3a. *Pilgrimage church St. Mariae Himmelfahrt in Munich-Ramersdorf.*

Fig. 3b. *Roof and timber vault of St. Maria Ramersdorf. (Model: C. Knobling, Picture: I. Mühlhaus).*

(but firmly connected to the roof). This refers more to the wooden vaults of the Veneto (e.g., San Zeno in Verona, see below) [10, 11]. As early as 1445, the timber vault was dismantled and replaced by the still-existing solid vault [12].

The reconstruction is based on the results of building archaeology. Traces of the lost vault were found on the still-existing roof and walls, e.g., mortices, former wooden joints or imprints of the planks of the vault in the mortar of the side walls and gable walls and on the beams of the roof. In this way, it was possible to find out not only the geometry but also the dimensions of the single components of the construction.

The Old Town Hall

The roof of the Old Town Hall (*Altes Rathaus*) was built in the years between 1470-75 [6]. It covers the large assembly hall of the town, spanning over 18.40 meters without supports. The roof construction contains a timber vault, which was supposed to be the prestigious ceiling for this most important room of the municipality. Since the view of the wooden vault was not to be disturbed, the construction also had to work without a continuous tie beam. The vault is made of wooden ribs, forming a segmental arch. It sets on below the eaves and extends to the lowest collar beam of the roof construction.

The structure above is formed like a conventional roof with struts, diagonal bracing, and king post. The lower part, which had to contain the vault, needed a specific solution: master builder Heinrich von Straubing [13] placed half-timbered walls alongside the vault, which had to stand inclined due to the limited space. The vault was connected to the roof structure with short beams and punctually supported by the king post.

Fig. 4a. *Old town hall (Altes Rathaus) in Munich, exterior (left) and great hall with wooden vault (right).*

Fig. 4b. *Roof and timber vault of the Altes Rathaus. (Model: C. Knobling, Picture: I. Mühlhaus).*

The construction survived for more than 400 years. Unfortunately, the roof was destroyed in 1944 before it could be repaired. The reconstruction model still illustrates the builder's eagerness to experiment, which led to such an unconventional and unique construction.

The reconstruction is mainly based on archival sources from the public works service of the city of Munich – among them drawings made for a renovation that did not take place due to the war. The vault was also discussed in the "*Bürgerliche Baukunde*" by Carl Friedrich von Wiebeking (1826). A drawing of the roof was published by Friedrich Ostendorf [10], but incorrect in some details.

Municipal Stables and Armoury

The roofs of the Municipal Stables and the Municipal Armoury were built around the middle of the 15th century (Stables) and 1491-93 (Armory) [6]. They are good examples of prestigious buildings of late medieval citizenship. The constructions had large base widths (Stables: 20.30 m; Armoury: 16.30 m). Since the roofs could be supported by intermediate walls, the spans were nevertheless small. Both the stables and the armory used a combination of vertical struts (*stehender Stuhl*) and raking struts (*liegender Stuhl*), which is common for roofs of this period and size. The elaborate construction of both roof structures indicates that the attics were used as storage floors and were, accordingly, heavily loaded.

The reconstruction is based on archival sources from plans from the 18th century, which could be found in the collection of the City Museum. Further sources like schematic drawings and historic photographs could be found in the municipal archive of Munich.

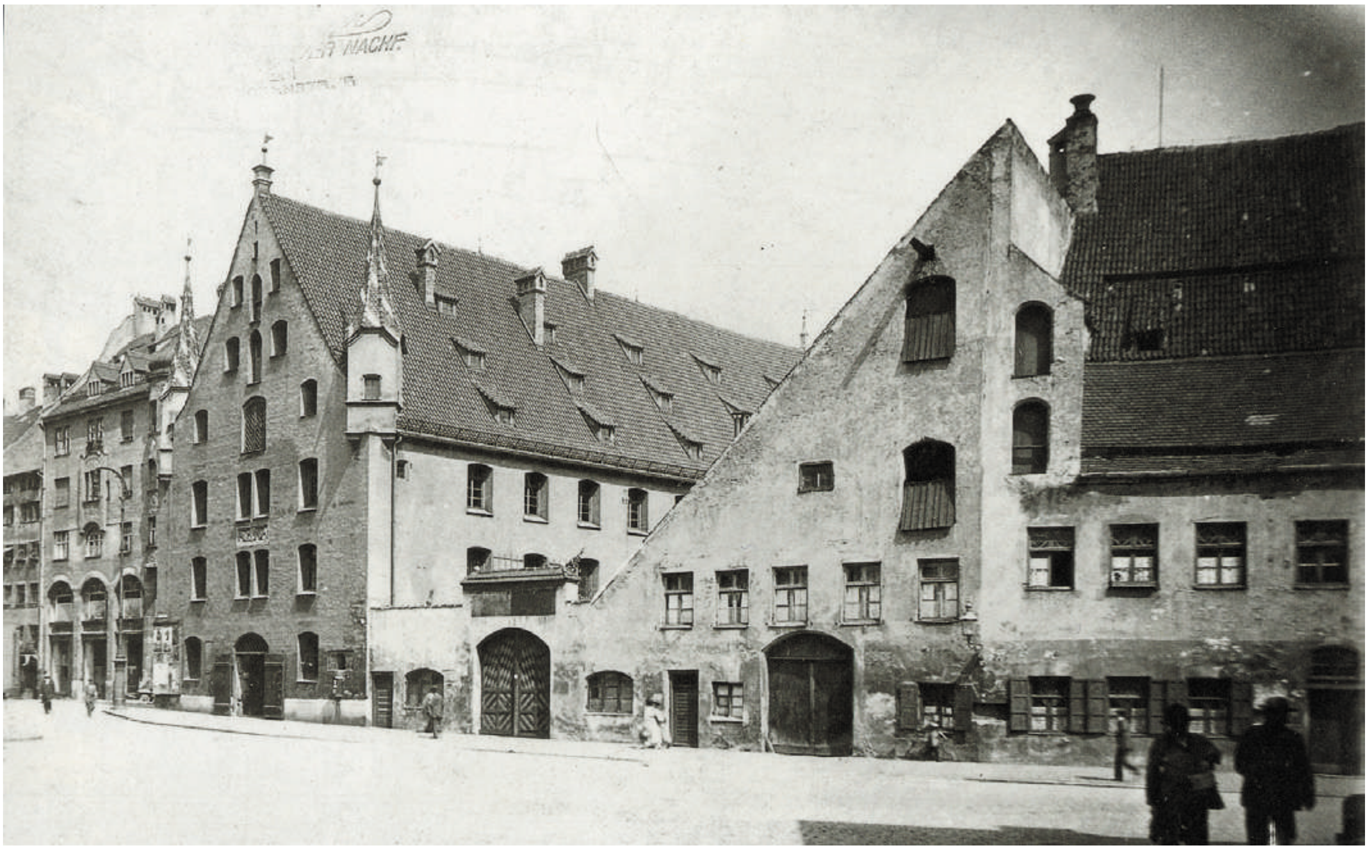

Fig. 5a. *Historical image of the municipal armory (left) and stables (right), G. Pettendorfer (R. Bauer / E. Graf, Der Stadtfotograf, Munich 1989); the building in the middle represents a typical half-gabled house.*

Fig. 5b. *Municipal stables (left) and armory (right). (Model: C. Knobling, Picture: I. Mühlhaus).*

Church of Our Lady (*Frauenkirche*)

The roof of the *Frauenkirche* (1468-88/94), built between 1473 and 1475 [6], represents one of the highlights of late medieval carpentry. The 31.60 m wide construction was one of the largest roof structures of the Middle Ages [3]. The 22 m high construction is supported on the side walls and the partition walls of the aisles. There are 12.80 m high vertical struts (*stehender Stuhl*) placed in the axes of the partition walls. On those, a collar beam divides the roof into an upper and a lower section. The careful bracing with St. Andrew's crosses in the lower section is particularly striking. The high struts are thus a rigid central structure to which the lateral struts could be easily connected. The central strut is partially suspended by St. Andrew's crosses in order to get the middle part of the tie beam free from heavy loads. The approx. 10 m high upper part of the roof represents a conventional construction with struts stiffened by raking braces [10].

The high *stehender Stuhl* in the middle allowed the huge dimensions to be handled. It was both a rigid core and an aid for the erection of the roof structure. Similar constructions can be found, among others, in Wasserburg, *St. Jakob* (1417), in Laufen an der Salzach, *Stiftskirche* (1436), in Amberg, *St. Martin* (before 1442), in Wasserburg, *St. Jakob* (1417) and Landshut in the churches of *St. Martin* (after 1475) and *St. Nikola* (1481). Especially the similarity to the roof of *St. Martin* in Landshut indicates a close relation between the builders [13].

The reconstruction of the roof of the *Frauenkirche* is mainly based on sketches from students from the 1930s from the archive of the *Architekturmuseum* of the Technical University of Munich and drawings and photographs of the ruined roof from the archive of the diocese and the archive of the Bavarian state office for heritage conservation. The roof was also published in the books of Gottgetreu [24] and Ostendorf [10], albeit with minor inaccuracies.

Fig. 6a. *Frauenkirche, roof and tower roofs ("Welsche Hauben").*

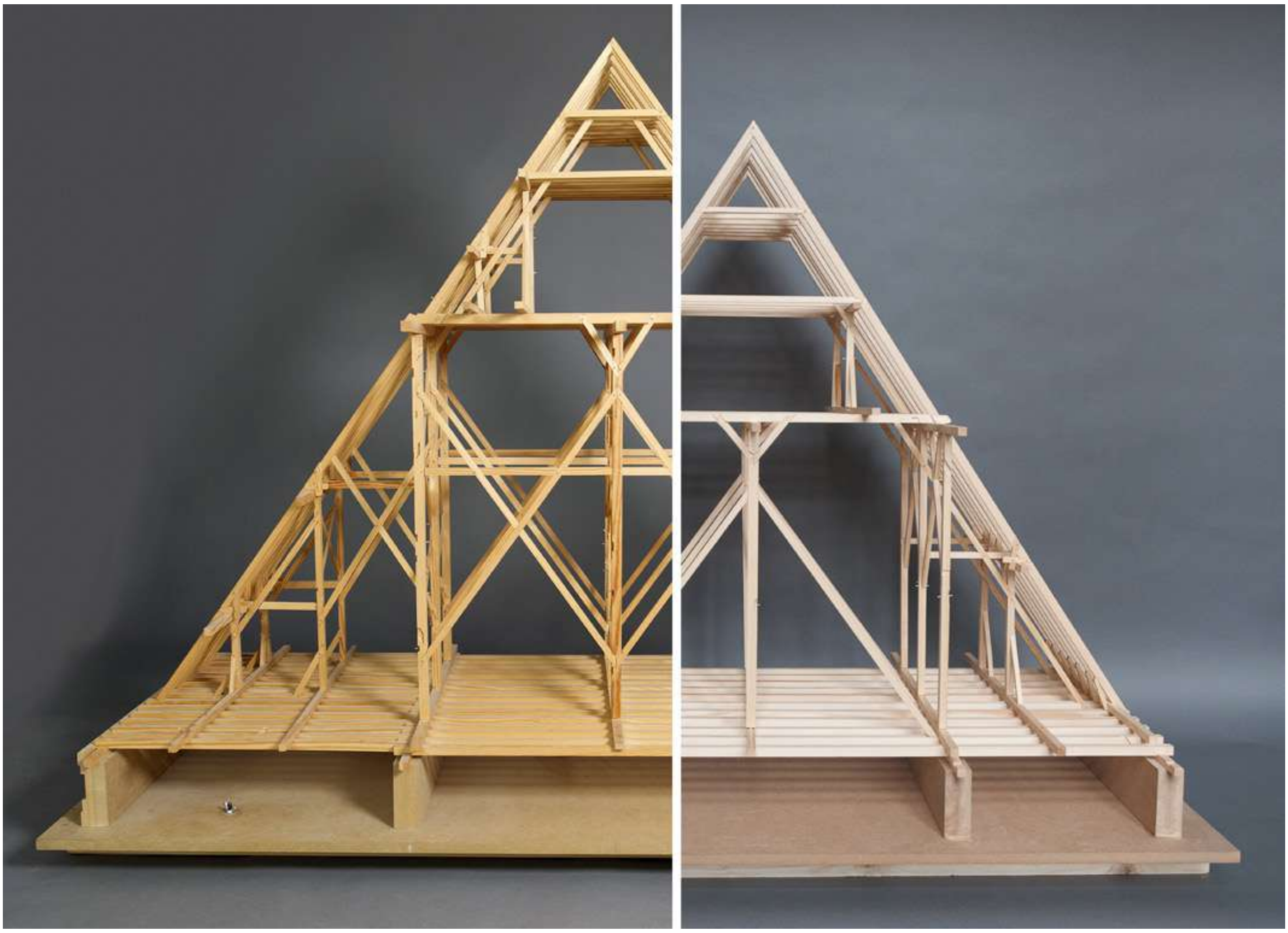

Fig. 6b. *Roof constructions of the Frauenkirche (left) and St. Martin in Landshut (right). (Model: C. Knobling, Picture: I. Mühlhaus).*

The tower roofs (*Welsche Hauben*) of the Church of Our Lady

The roofs of the towers of the Frauenkirche have become Munich's landmarks. The "Welsche Hauben" built in 1524-25 [6] even indicate by their name (*Welsch* means "foreign", especially from the South) a close relation to Italian models. However, this refers mainly to the form, less to the construction, which is based on an element from "ordinary" longitudinal roofs: struts (*stehender Stuhl*) with collar plates. Those were arranged octagonally in three storeys. Thus, they provided three intermediate supports for the radially arranged girders, which were made of planks assembled in two layers.

The form of the *Welsche Hauben* was new in Bavaria, apart from some forerunners in Augsburg [14], and was to become a landmark element in the whole country, especially in the Baroque period.

The sources for the reconstruction were sketches by students from the 1930s from the archive of the *Architekturmuseum* of the Technical University of Munich

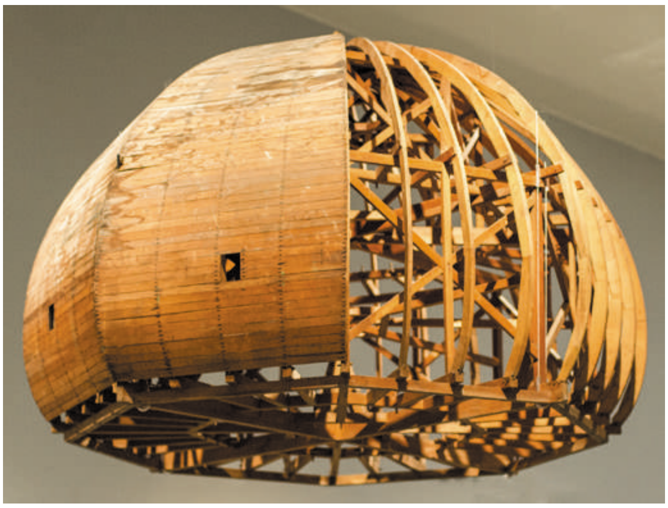

Fig. 7. *Model of the helmed roof (Welsche Hauben) of the towers of the Frauenkirche. (Model: Architekturmuseum TUM, Picture: I. Mühlhaus).*

and historical photographs from the archive of the Brannekämper company, which rebuilt the destroyed Frauenkirche after the war. There are also two models of the construction, one in the *Architekturmuseum* of the Technical University of Munich and one in the *Deutsches Museum*. Today´s *Welsche Hauben* are thin concrete shells.

The Jesuit Church of St. Michael

The roof of the Jesuit Church of St. Michael, built in 1583-97 [6], set new standards in Munich. The task was to span the single nave with its 20-meter-wide barrel vault without supports. Although free spans of up to 20 m had already been achieved in some isolated cases (e.g., in Stuttgart, *Lusthaus*), this construction should become exemplary for many roof structures of the 17th and 18th centuries.

With high effort, the master carpenter combined all elements of the truss in one layer. The resulting intersections of the beams caused large losses of load-bearing capacity in some elements of the construction (at the intersections with the collar plate and collar beam, the king post is reduced to one-third of its actual thickness). This was obviously not considered a problem – neither here nor in many other roof structures of the 17th and 18th centuries.

The raking struts (*liegender Stuhl*), which extended over two levels in the lower part, were the basic element of the structure. King and queen posts bore the loads of the tie-beam and the lower collar beams.

A special feature was the “vault stamps” – beams lying on the vault and connected to the roof structure by v-shaped struts. These were intended to counteract deformations of the barrel vault by means of the load of the roof [15]. This kind of construction is also used in other Jesuit churches (e.g., in Landshut).

The reconstruction is based on sketches by students from the 1930s from the archive of the *Architekturmuseum* of the Technical University of Munich and historical photographs from the archive of the Bavarian State Office for the Preservation of Monuments. A model of the construction is preserved in the Deutsches Museum, but its details are inaccurate.

Fig. 8a. *Jesuit Church of St. Michael (Michaelskirche).*

Fig. 8b. *Roof construction of the Michaelskirche (left) and of the Antiquarium (right). (Model and drawing: C. Knobling, Picture: I. Mühlhaus).*

The *Antiquarium* of the Munich Residence

A smaller, quite an ordinary roof of the early modern period was once located above the Antiquarium of the Munich Residence. Built around 1600 [6], the structure with raking struts (*liegender Stuhl*) and king post had a span of 13 meters. Here again, it was intended to arrange all structural elements flush in the same layer. As in *St. Michael*, this also weakened the cross-section of the king post considerably.

The archival sources (State Archive of Bavaria) suggest that the Antiquarium, built already in 1570-71, once had a much flatter roof of Italianate design, which, however, was removed in the course of the reconstruction of the entire Residence around 1600 [16]. Next to this source, there were also drawings from 1932 and photographs of the destroyed roof from the archive of the Bavarian Administration of State Palaces, Gardens, and Lakes.

The Tournament House

The roof of the Tournament House at the ducal gardens was perhaps the most unusual of all Munich roof constructions. The building was erected in 1660-61 as an indoor riding arena and venue for tournaments on horseback [6, 17, 18]. Accordingly, the width of 25.70 m had to be spanned without supports. Although just this being already a challenge, it was also intended to integrate a platform for spectators into the roof structure. This resulted in an "open" construction, i.e., a roof without continuous tie-beams to not obstruct the view from the ranks onto the arena. The spectator platform could then be placed on the interrupted tie-beams. In order to redirect the loads across the central void, the carpenter arranged inclined doubled braces. These connected the interrupted tie-beams with the collar beams and thus with the queen posts.

The elements of this unconventional design are, once again, taken from the traditional repertoire of roof construction: struts, raking struts, king and queen posts. After all, this roof lasted until at least 1720. A painting from the 19th century (Domenico Quaglio: *Der Abbruch des alten Turnierhauses*, around 1822, *Neue Pinaktohek*, Munich) shows the demolition of the whole building.

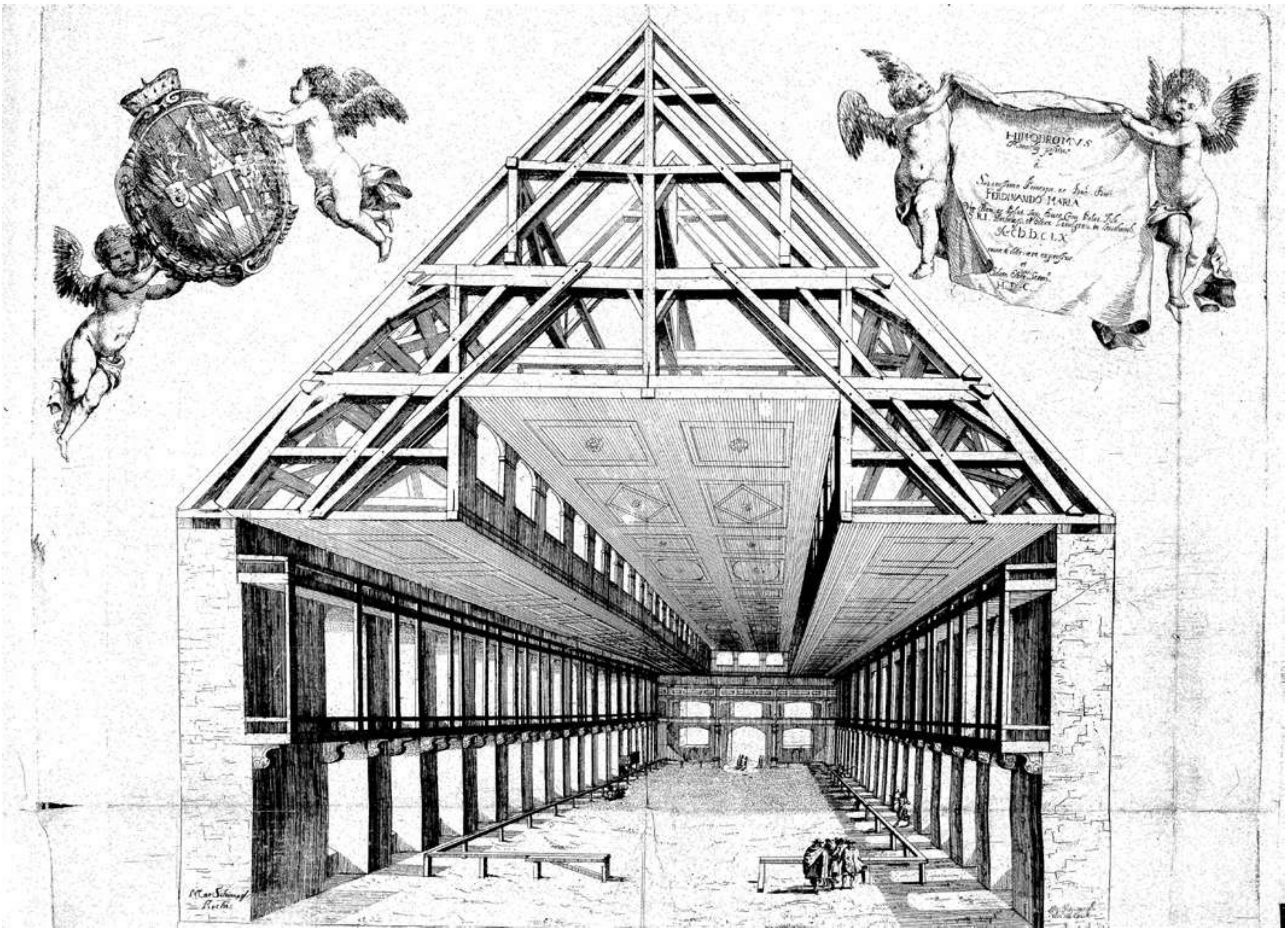

Fig. 9a. *Tournament house, plan drawn by master builder M. Schinnagl, 1660. (Bayerische Staatsbibliothek München).*

Fig. 9b. *Roof construction of the Tournament House at the ducal gardens. (Model: C. Knobling, Picture: I. Mühlhaus).*

There, a different roof structure is shown. It had continuous tie-beams and was most likely erected due to the conversion of the building into a grain store. However, this new roof showed striking similarities to the construction of 1660-61 and maybe was just a restructuring of the existing roof. The building was finally replaced due to the neoclassical redesign of the area around 1825 [6].

There were just a few sources available for the reconstruction: a drawing from master builder M. Schinnagl from 1660 (published in 1662; Bavarian State Library) and a not dated plan from the State Archive, which was obviously drawn in the 18th century. A further drawing from 1720 (Jeremias Wolf) shows the interior of the building and the shape of the ceiling.

Theatine Church (*Theatinerkirche*) of St. Kajetan

The Italianate roof of the *Theatinerkirche St. Kajetan*, built in 1668 (the whole church was built 1663-88), was still “exotic” north of the Alps in the 17th century. The later Electress Henrietta Adelaide of Savoy wanted a thoroughly Italianate architecture for the church [6], including also a flat-pitched roof. The master builder, Agostino Barelli from Bologna, accordingly made designs that foresaw a “Palladiana”. Probably this was never realized. Sources from the Bavarian State Archives show a modified construction – a structure consisting of a central king post and two laterally queen posts, each with raking braces. The archival sources indicate that this was the construction of the 17th century. Similar schemes have already been handed down from earlier times, e.g., by Serlio and Bernardino Baldi [19]. It can be assumed, however, that the construction was substantially strengthened in the 19th century, at least at the base points. When it was built, an “Italian” purlin roof was still highly unusual in Bavaria [20]. While carpentry was mastered, sheet metal roofing still caused problems. The reason for the design of a flat-pitched roof was not only the incompatibility of a steep roof and the Italianate facade (which was not completed until the 18th century).

Fig. 10a. *Theatinerkirche.*

Fig. 10b. *Italianate roof of the Theatinerkirche. (Model: C. Knobling, Picture: I. Mühlhaus).*

Also, the dome should stay visible, and thus its tambour not be impaired by a roof [6].

The reconstruction is mainly based on drawings from the State Archive from 1944 and a drawing from A. von Voit from the 19th century, preserved in the archive of the *Architekturmuseum* of the Technical University of Munich. There are also drawings from Agostino Barelli from 1663 and 1667, preserved in the Bavarian State Archive. These plans show the original design, which differs from the construction preserved until the war.

National Theatre

In the 19th century, Italianate purlin roofs became part of the repertoire of southern German master builders. A neoclassical influence played a role, as well as technical and constructional aspects did [7]. Purlin roofs with trusses could bear heavy loads and be adapted for large spans. These aspects were the requirements for the design of the roof of the National Theatre. The building was re-erected by Leo von Klenze after a fire in 1823-25 [6]. He was also responsible for the 31 m wide (span 29.10 m) roof construction. In order to create the necessary construction height and flat pitch of 23° at the same time, Klenze used a trick: the actual base of the roof construction was located behind a flap-tile. So the outer segments of the assembled principle rafters could be inclined somewhat steeper at 29° while the common rafters continued to the eaves at the same inclination (23°). This was also applied in other buildings of Klenze [21]. Four king posts were placed in each truss. A rod polygon transferred the loads from the king posts to the supports. The king posts were assembled of two parts each. Thus, they could embrace both the rafters and the rod polygon. The tie beams were assembled of five individual parts, which were connected with dowels [22–24].

Underneath the roof, there were further trusses to carry the floor of the painters' hall as well as the vaulted ceiling of the auditorium below. Since the trusses rested on the circular enclosure of the auditorium, each had a different free span. Thus, Klenze constructed different types of constructions for each span. A ring, which held the girders of the plafond of the auditorium, was fixed in the middle of the two central trusses. The vaulted plafond

Fig. 11a. *Nationaltheater (State Opera House).*

Fig. 11b. *Roof construction and trusses of the ceiling of the auditorium of the Nationaltheater. (Model: C. Knobling, Picture: I. Mühlhaus).*

was constructed according to the system of Philibert de l`Orme, a model dating back to the 16th century. The roof and ceilings of the National Theatre were a remarkable example of the variety of timber constructions in the 19th century, some of which also make use of historical models.

At the end of World War II, the National Theatre was also destroyed. However, the nearby *Gärtnerplatztheater* survived. Its roof construction is a smaller replica of the larger but lost one from the National Theatre [21].

The reconstruction is based on several sources – among others, on building surveys from 1929, preserved in the archive of the *Architekturmuseum* of the Technical University of Munich, on the original plans by Leo von Klenze, and additional drawings preserved in the Bavarian State Archive. The roof construction was also published by Gierth (1840) [22], Romberg (1833 and 1847) [23], and Gottgetreu (1882) [24].

4. CONCLUSION

The study shows that the Munich roofs were among the most innovative constructions of their kind. The huge roof of the *Frauenkirche* was one of the largest structures of its time. Unusual buildings such as the *Turnierhaus* could probably only be erected in an up-and-coming ducal (and later royal) residential city that had a need for large representative buildings. Also, a building like the *Nationaltheater* could only be realized in such an environment. The court also attracted other institutions to settle in Munich and build prestigious and thus also constructively demanding buildings like the Jesuit Church of St. Michael.

The importance of the city and the international relations of the court are also reflected in the architecture of the city and even in the roof constructions. Italian influences are particularly evident. This already began in the 14th century with the vault in *Maria Ramersdorf* (around 1360). Its construction is not based on the numerous wooden vaults in northern France and northern Germany, which are mostly just formed by cladding the trusses, which were shaped by some additional beams. Rather, it follows a different path by having its own supporting structure. Similar solutions can also be found in some wooden vaults of the Veneto, especially in San Zeno in Verona.

The Italian references then become obvious with the tower roofs (*Welsche Hauben*) of the *Frauenkirche* (1524-25). The inspiration for these constructions came from the Veneto – or directly from Venice – via Augsburg [25]. A glance at the veduta of Venice by Jacopo de Barbari from 1500 reveals numerous helmed roofs of this type. Nevertheless, the construction of the Munich roofs was still geared towards local techniques.

A veritable copy of an Italian roof was then erected on the *Theatinerkirche St. Kajetan* (1668). The master

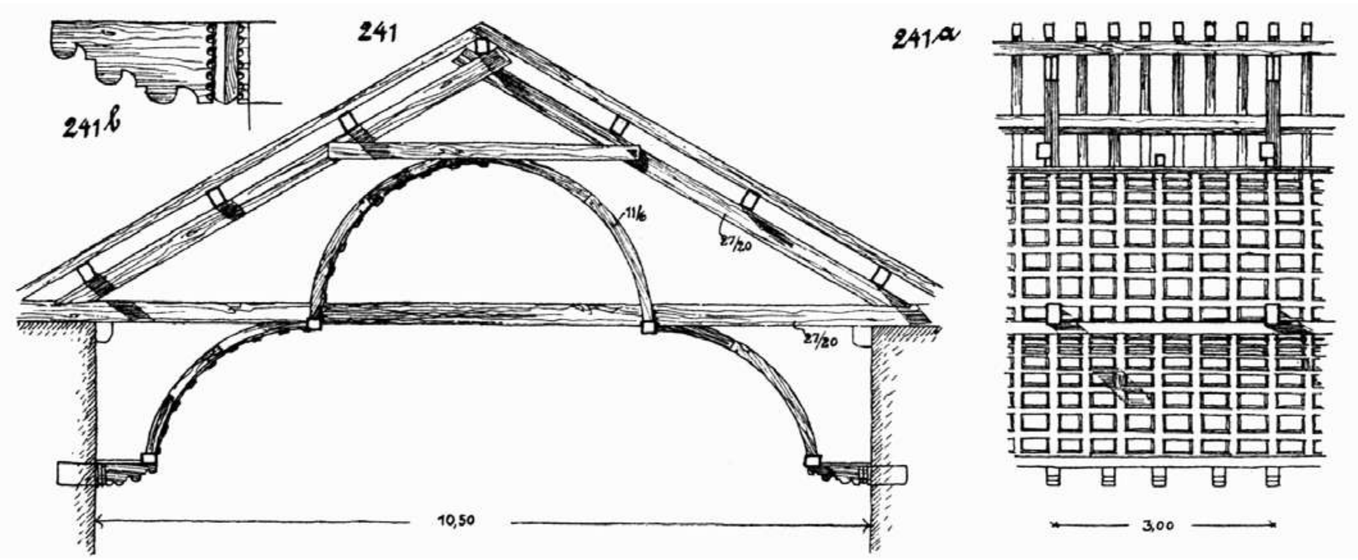

Fig. 12. *Roof and vaulted ceiling of San Zeno in Verona, drawn by F. Ostendorf, 1908.*

builder, Agostino Barelli from Bologna, provided an Italianate design for the entire church. The roof was built by German carpenters, who were apparently trained in Italian carpentry. With the single-shell dome, the *Theatinerkirche* enriched Munich's skyline with another specifically Italian element.

The roof of the *Theatinerkirche* was still a prototype. Although flat-pitched purlin roofs have always been the predominant type in the Alpine and Pre-Alpine region, their occurrence was mainly limited to residential buildings and, thus, to smaller spans. For churches, the rafter roof has always been employed. Thus, the need to develop wide-span purlin trusses was just not given for a long time. As soon as the need arose (due to stylistic and constructional demands) – especially in the 19th century – people often fell back on the Italian models that had been matured for centuries [7]. The National Theater and the *Gärtnerplatztheater* in Munich are good examples of this.

Many roof structures were lost in the Second World War before the rise of interest in this hidden heritage and before any comprehensive documentation. Thus, many blank areas remain in research on historic roofs, especially in heavily destroyed city centers. Yet this is exactly where some of the most important buildings and the largest spans were to be found. Therefore, this first in-depth study on "lost roofs" is an incentive to address this significant lacuna and investigate missing roofs in other urban centers.

Acknowledgments

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A list of the catalog signatures can be found in the printed version of the dissertation [1].

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COFFERED CEILINGS IN THE CHURCHES OF ROME, FROM THE 15TH TO THE 20TH CENTURY

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Abstract

The contribution concerns the coffered ceilings in Roman churches, which were built between the mid 15th and the mid 20th century and still represent ornamental components of great value. The coffered ceilings still visible today are approximately sixty; many others have been demolished or destroyed by calamities through time.
The attention on the subject revived after the collapse inside the church of San Giuseppe dei Falegnami occurred in August 2018; the event highlighted the vulnerability of the coffered ceilings and a lack of historical and technological knowledge regarding individual cases.
By referring to the architectural treatises on the subject, this article focuses on the early 19th century texts by Jean-Baptiste Rondelet and Giuseppe Valadier, illustrating two different criteria for creating coffered ceilings.
In the first one, the coffered ceilings are directly connected to the roof trusses, providing for the lining of the tie beams.
In the second one, the coffered panels are nailed to wooden frames hanging from joists placed over the tie beams. Both construction methods can be found in the coffered ceilings of Rome, but most cases refer to the second system. Thus, the contribution delves into the construction process in detail and focuses on the arrangement of the elements, reporting the analysis of some study cases based on direct checks and surveys. In this regard, knowledge of the extrados of the ceilings is crucial for foreseeing possible conservation works, allowing to avoid the risk of inappropriate restoration or replacement of original elements.

Keywords

Ceiling, Lacunar, Coffered ceiling, Wooden structures.

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1. INTRODUCTION

On August 30, 2018, two of the four trusses of the Roman church roof of San Giuseppe dei Falegnami collapsed, and consequently, two-thirds of the carved wooden ceiling, dating back to 1612, suddenly fell off [1]. When the construction site for the restoration of the lost ceiling was set up, a lack of technical knowledge about the coffered ceilings of ecclesiastical buildings in Rome was revealed [2].

As many coffered ceilings were inserted during the Modern Age in former, ancient spaces (exceptions are some 19th-20th century churches newly designed with coffered ceilings), studies in the historical-artistic field are predominant; nonetheless, the construction criteria and structural functioning are scarcely investigated. In this regard, one key factor is the structural peculiar-

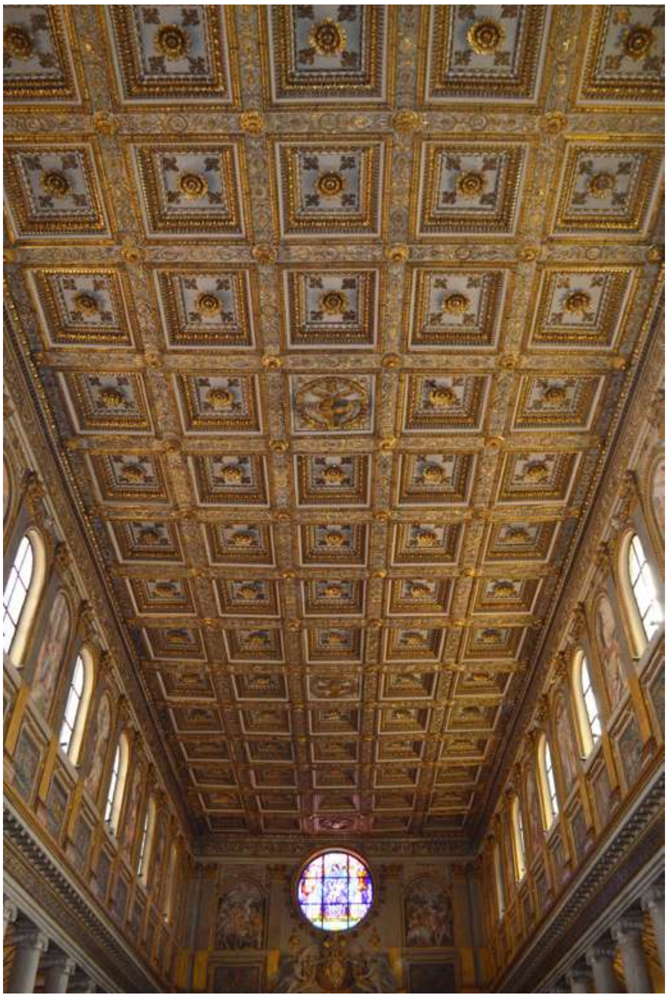

Fig. 1. *Rome, Santa Maria Maggiore all'Esquilino; the coffered ceiling of the basilica (1492-99).*

ity: coffered ceilings of Rome are wooden decorated decks hanging from above structures in different ways. Therefore, specific knowledge of both the construction technique and the structural behavior is necessary, considering their conservation and restoration status. The mentioned characteristics are strictly related to the design development, namely their artistic outcomes over time. This contribution moves in this direction and represents the first anticipation of the contents of broader research currently underway.

2. COFFERED CEILINGS SPREAD IN RELIGIOUS ARCHITECTURE AND RELATED CONSTRUCTION CRITERIA ILLUSTRATED BY TREATISES

The addition of coffered ceilings in Roman basilicas dates back to the mid 15th century. The first two churches to include such structures were San Marco in Piazza Venezia (1467) and Santa Maria Maggiore all'Esquilino (1492-99) [3] (Fig. 1). Both works were commissioned by the Pope, probably inspired by the Classical Florentine carved ceilings (a well-known example is the basilica of San Lorenzo, in Florence). Similar additions were realized between the 15th and 16th centuries.

However, the coffered ceilings had the most diffusion in Rome after the Council of Trent (1545-1563), as the consequent Reformation was calling the Catholic Church to refer to its origins, and the coffered ceiling was assumed as a reference looking to the Constantinian basilicas.

In addition to the iconographic value of that architectural solution, there was also a functional acoustic improvement coming from the coffered ceilings, which created an excellent "sound box" for listening and preaching, a crucial element of the Tridentine Reform, clarified by the *Instructiones fabricae et supellectilis ecclesiasticae* by Carlo Borromeo (1577).

Moreover, the ceiling can also be intended as a communicative religious "tabula", exhibiting elements of indoctrination by images, statues, and canvases: the ceilings changed from representing starry skies to acquiring a mystical Christian dimension [4]. The purpose of inserting statues and various elements required a more versatile composition, encouraging the spread of this kind of ceiling, characterized by coffers of various shapes, compared to the simple checkerboard configuration [5].

This evolution was followed by a new structural system, allowing the creation of more varied and complex shapes. The ceilings realized in the Roman basilicas between the second half of the 15th century and the middle of the 17th century are approximately thirty [6]. This development was interrupted for about two centuries and had a revival under the pontificate of Pope Pius IX Mastai Ferretti (1846-1878): about a dozen of new ceilings were built, and many others were restored. This trend continued during the mid 20th century: in 1939, the last newly designed coffered ceiling was built for Santa Giovanna Antida Thouret Basilica; in 1940, the former coffered ceiling destroyed by fire was replaced in San Lorenzo in Damaso.

The treatises, as well as the contemporary specialist literature, offer a wide range of knowledge on the topic, including suspended ceilings from the slab [7–9]. While investigating this kind of structure, suspended coffered ceilings must be included, considering their peculiar formal and technical characteristics and construction solutions. Regarding coffered ceilings, Renaissance sources – as most of the following ones – are focused mainly on artistic qualities. Among the first writings mentioning the coffered ceilings, there is *De re aedificatoria*, first printed ed. 1485 by Leon Battista Alberti [10], and also *Sette libri di Architettura* (1537) by Sebastiano Serlio [11]. Serlio illustrates a catalog of the figurations used in simple and complex compositions and makes some considerations on the advantages and limits of such coverings.

Similarly, 18th and 19th centuries writings deal with the theme of describing shapes, not going into their technical characteristics in more depth. Among these, *Trattato elementare di Architettura civile* by Francesco De Cesare (1827) describes four characteristics: shape (square, rectangular or rhomboid); placement of the full and empty forming the coffers related to the inner architecture of the nave; proportion, (the proportion between width and length of the coffer); decoration, inspired to ancient buildings [12]. Therefore, architectural treatises mainly refer to coffered ceilings describing their figurative characteristics and focusing on the shape that the scheme can assume in accordance with the space to be covered [13, 14]. Only two books from the early 19th century deal with the technical issue regarding coffered ceilings, describing them as false ceilings connected to trusses: *Trattato teorico e pratico dell'arte* by Jean-Baptiste Rondelet (originally French edition 1802-1817; Italian edition 1833) [15] and *L'architettura pratica* by Giuseppe Valadier (1828) [16].

Both authors refer to the existing ceiling of the Basilica of Santa Maria Maggiore, built during the pontificate of Pope Alexander VI Borgia (1492-1503). The ceiling

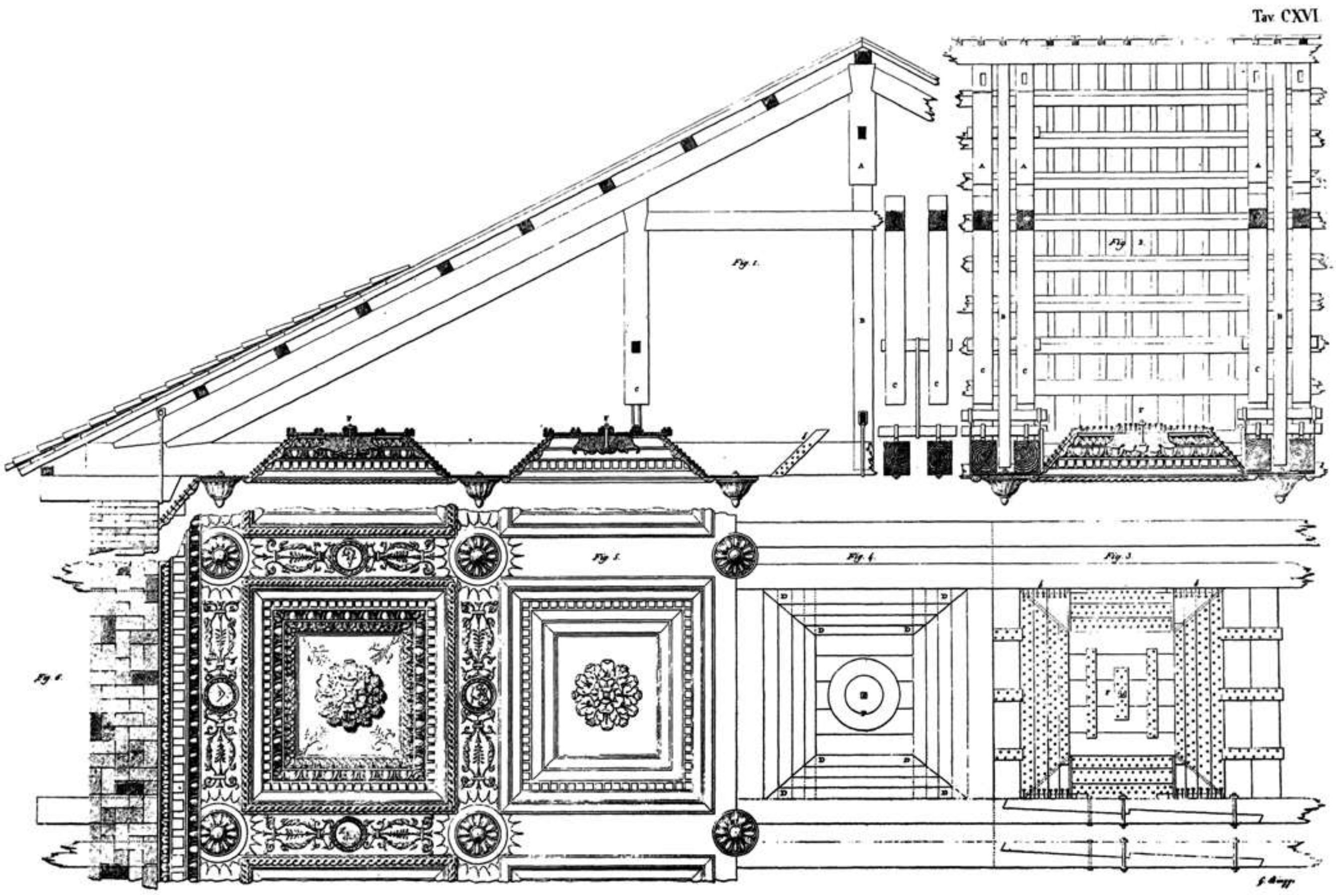

Fig. 2. *Jean-Baptiste Rondelet, Trattato teorico e pratico dell'arte di edificare, p. CXVI (first French edition 1802-1817; Italian edition 1833).*

is described through technical drawings (a plan and a detailed section) and text. However, the two authors illustrate different procedures for the construction. The drawing by Rondelet shows the tie beam of the trusses encased by the boards forming the coffers. The spacing between the trusses determines the general ceiling scheme. Moldings are then applied on the boards, supported by oblique wooden plugs nailed to the tie beam, with a span of about 15 m. The bottom of each coffer is covered by a board to which the carved rosette is fixed using a "cavicchia" (a metal connecting element used instead of a nail) (Fig. 2). Differently, the drawing by Valadier represents the section of the ceiling of Santa Maria Maggiore separated: «dalle corde delle incavallature sostenenti il tetto o il pavimento di una sala superiore perché, primo non si dà alle corde, o travi maestri un doppio peso da sostenere, e poi siccome facilissimo è il caso di rinnovare una qualche incavallatura […] Sarà dunque prudenza di un architetto di tessere sotto le incavallature […] un'altra armatura di grosse travi sostenuta [da] saettoni […] ed a quelli con legni del tutto separati affidare il soffitto» (From the tie beams of the trusses supporting the roof or the floor of an upper room because, first, the ropes or master beams are not given a double weight to support, and then, since it is very easy to renew some trusses […] Therefore, the architect will be cautious in fabricating under the trusses […] another framework of large beams supported [by] struts […] and entrust the ceiling with those with completely separated woods).

The drawing reveals that the structure illustrated by Valadier was not allowed to load the trusses but a system of horizontal beams placed parallel to the trusses on a lower level. The described structure would be able to achieve renewal operations of the roof without touching the underlying ceiling. Once the load-bearing system of beams is placed, "arcarecci" (purlins, namely minor square section beams) have to be placed; on the purlins, U-shaped frames (formed by laths) are fixed supporting the boards composing the lacunar ceiling (Fig. 3).

This scheme does not correspond to the structure of Santa Maria Maggiore, where the ceiling is made according to the criterion reported by Rondelet. Observing the extrados made it possible to certify that the existing system of the boards composing the lacunars connected to the twin trusses supporting the roof was feasible. As reported by the author, the composition boards of the coffers are nailed to the tie beams of the trusses using wooden wedges, which correspond to the transversal wooden ribs in the intrados drawing. However, according to Valadier's description, the system composed of frames hanging from a secondary truss was the most widespread procedure in the realization of the wooden ceilings of Roman churches. So, possibly Valadier was trying to illustrate a standard method, considered the best option; yet, hanging the frames on an independent system of beams – instead of trusses – does not correspond to the most common practice in Rome. Regarding the construction, two methods emerge: in the first one, the coffered ceiling is made starting from the covering of the floor beams or trusses, and in the second one, connection elements hang the beam of the trusses and coffered ceiling.

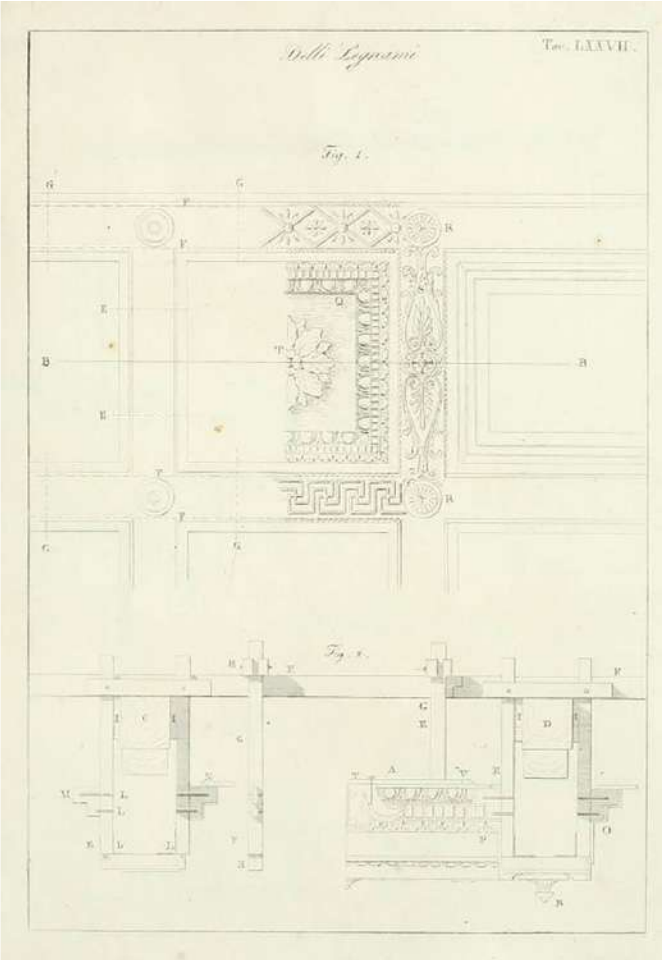

Fig. 3. *Giuseppe Valadier, L'architettura pratica (1828), p. LXXVII.*

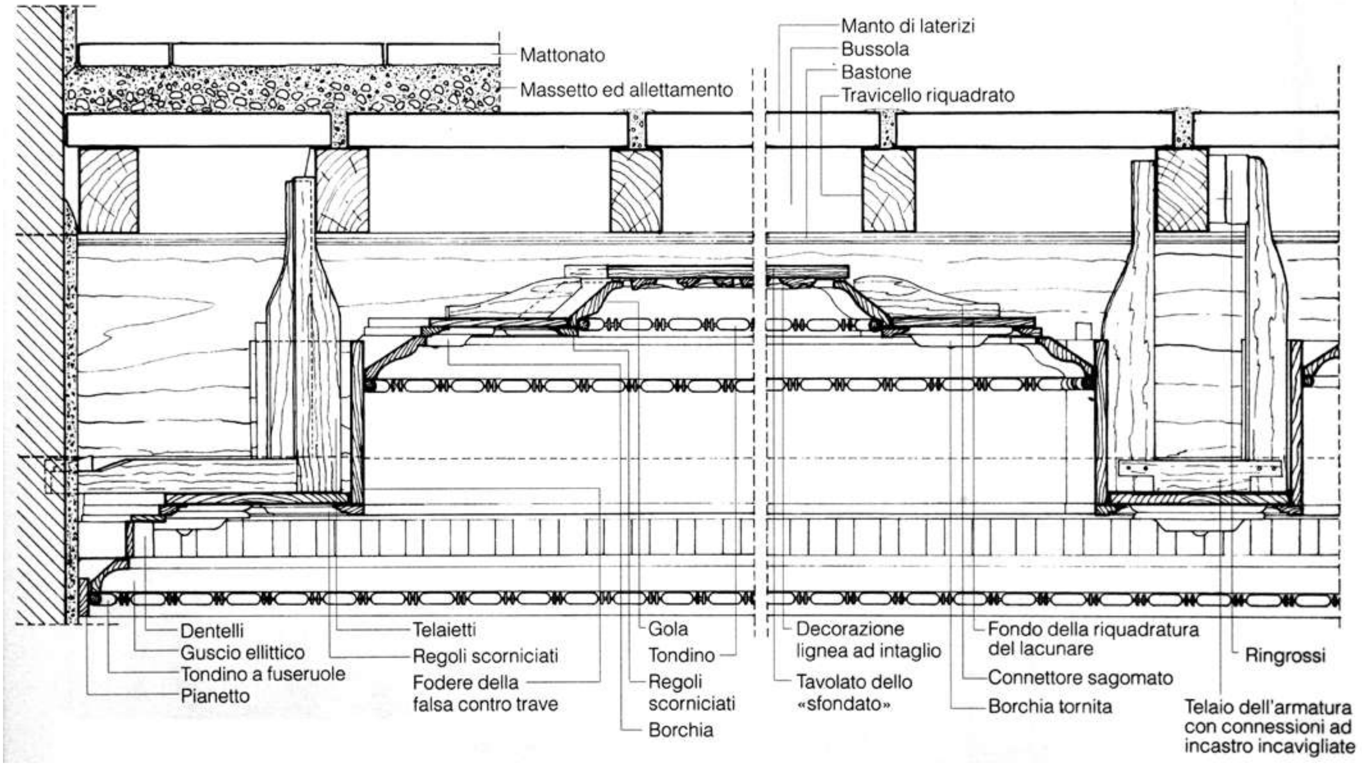

Fig. 4. *Detail of a lacunar false ceiling in Palazzo Altemps. (Image source: Manuale del Recupero del Comune di Roma, 2000, p. 193).*

The first method was realized during the 15th century in San Marco and Santa Maria Maggiore – a technique used until the second half of the 16th century when a more free design of the coffers led to hanging them from frames. This system – as Valadier claimed – made it possible to repair and maintain the roof without dismantling the coffered ceiling. The book *Manuale del Recupero del Comune di Roma* (2000) provides a technical analysis of the construction methods of the wooden ceiling, based on the examples of the second half of the 17th century existing in Palazzo Altemps [17]. The volume illustrates a coffered ceiling attached to the beam, as described by Rondelet (a regular coffered shape following the spacing between beams of the above floor), and a suspended ceiling with lacunars, inserted below a wooden floor and partially similar to the one reported by Valadier. For the latter one, detailed drawings highlight the set of elements necessary for its hanging; the coffers are supported by "panconcelli", namely small wooden uprights, allowing the total adaptability to the shapes of the suspended ceiling (Fig. 4). These elements are slimmer at the top, allowing the insertion of anchoring nails to the joists of the floor above. The represented frames are U-shaped to fix the boards forming the coffer to the beams above and L-shaped on the perimeter, inserted in the walls. Nails and half-lap joints guarantee connection stiffness among the elements. The construction process of the ceiling includes positioning the frames first, then the covering fixing forming the false beams. Then, frames and decorative elements are positioned through nailing (small elements can be glued). The description in the *Manuale* is detailed and precise; however, to further understand the construction methods of the coffered ceilings in Roman churches, it is crucial to examine the wide range of cases, looking at their state of conservation and envisioning the potential restoration works.

3. ANALYSIS OF CONSTRUCTION CRITERIA

The ceilings considered by the research are approximately sixty (including the coffer ceilings covering naves and transepts and some chapels of churches in Rome, from the 15th to 17th century and from the 19 to 20th century). Dimensions vary significantly: from modestly sized ceilings – such as San Giuseppe dei Falegnami (11.00 m x

16.00 m) to imposing ceilings – such as the one covering the central nave of San Paolo fuori le mura (24.30 m x 90.50 m).

The research is based on inspections of both internal and external elements of the ceiling, which are commonly not considered. It aims to understand their reciprocal position to identify how the compositional and ornamental aspect of the wooden coffers is related to the supporting elements.

Once the various elements were identified, a comparative analysis of the various cases was carried out, allowing a better understanding of the building procedures and verifying the presence or absence of systematic methods [18, 19].

Considering that the coffered ceilings examined were inserted in existing buildings, we can assume that the trusses supporting the roof were already present; consequently, the workers were forced to work in a given situation. So, after the architect designed the ceiling, in its general lines describing the coffers, the *faber lignarius* considered the number and spacing of the existing trusses to achieve the assembly, covering the trusses directly or hanging the ceiling from them. The covering system, commonly used in 15th century Roman churches, is also used in the ceiling of San Vitale in via Nazionale, which was built in 1934; all other coffer ceilings, whose external structures were explored, are made following the hanging system. The decoration scheme of the ceiling in San Vitale shows three longitudinal bands – the central one is the largest – in a checked pattern of rectangular coffers. In this scheme, false transverse trusses are positioned according to the spacing between the upper trusses. The boards forming the false trusses are nailed to the beams, and the bottom boards of the coffers are nailed to them, also by shims (Fig. 5).

The direct anchoring criterion, therefore, limits the design of the ceiling: uniformity and rigidity of the scheme are the direct consequence of the need to relate to the distribution of the trusses. More complex compositions, in free shapes, are realized by a system not related to the trusses' position, fixed using frames nailed to the joists placed above the beam. By positioning the joists freely, the frames can retain the "shaped skin" of the ceiling, therefore representing a somewhat flexi-

Fig. 5. *Rome, San Vitale in via Nazionale; extrados of the coffered ceilings (1933-1934).*

Fig. 6. *U-shaped frame detail. On the left, frame with a crossbar (Rome, San Bartolomeo all'Isola, 1623-24); on the right frame with two crosspieces (Ss. Cosma and Damiano, 1632).*

Fig. 7. *U frame with a crosspiece made up of several elements connected to each other in a staggered form. The picture shows the reinforcement work carried out about ten years ago, proving the insertion of a little reinforcing steel with double screw clamps for the anchorage of the bottom. In fact, the ceiling presented a marked transversal viscous deformation accompanied by localized subsidence (Rome, San Silvestro al Quirinale, 1573).*

ble system, offering more freedom in constructing the wooden roofs. On the other hand, by adding sleepers above the joists, hanging frames not in vertical correspondence with them is possible. The frames analyzed can be grouped into three classes: the first one including U-shaped devices, consisting of two uprights and one or more cross beams (Fig. 6); the second also concerning U-shaped elements, whose cross beams are made up of several jagged elements, able to hook an articulated shape of the lacunar (e. g. San Silvestro al Quirinale, Fig. 7); the third one relates to L-shaped devices, used to be clamped to the masonry, if the frames, instead of being supported by joists, are anchored to the perimeter walls (Figs. 8 and 9).

Fig. 8. *L-shaped perimeter frame anchoring the ceiling to the perimeter walls (Rome, Santa Maria in Trastevere, 1617).*

Moreover, individual panels or iron hangers can be found (see ceilings built from the second half of the 19th century or replacing wooden hangers damaged). Finally, the use of iron pins to hook modest size decorations in the interior of the ceiling is revealed (as heraldic coats of arms and reliefs). The comparison among the study cases allowed understanding some standard construction criteria. Regular seriality arranging the frames along the edge of the ceilings was constantly observed; it is based on the continuity of the perimeter frame and the constant weight to be supported along the extension.

The center-to-center distance of the frames generally does not exceed one meter. The position of the frame upright (double in the case of larger frames) determines the position of the first purlin, constant in each span. The internal part of the ceiling is differently organized, showing an uneven and varied arrangement of the frames, derived from the complex and diversified forms of the lacunars requiring a continuous change of position of the posts. Nonetheless, comparing the symmetry of lacunar frames along the longitudinal axis, an asymmetrical dislocation of the frames emerges, demonstrating that the frames are placed not following a pre-established, gen-

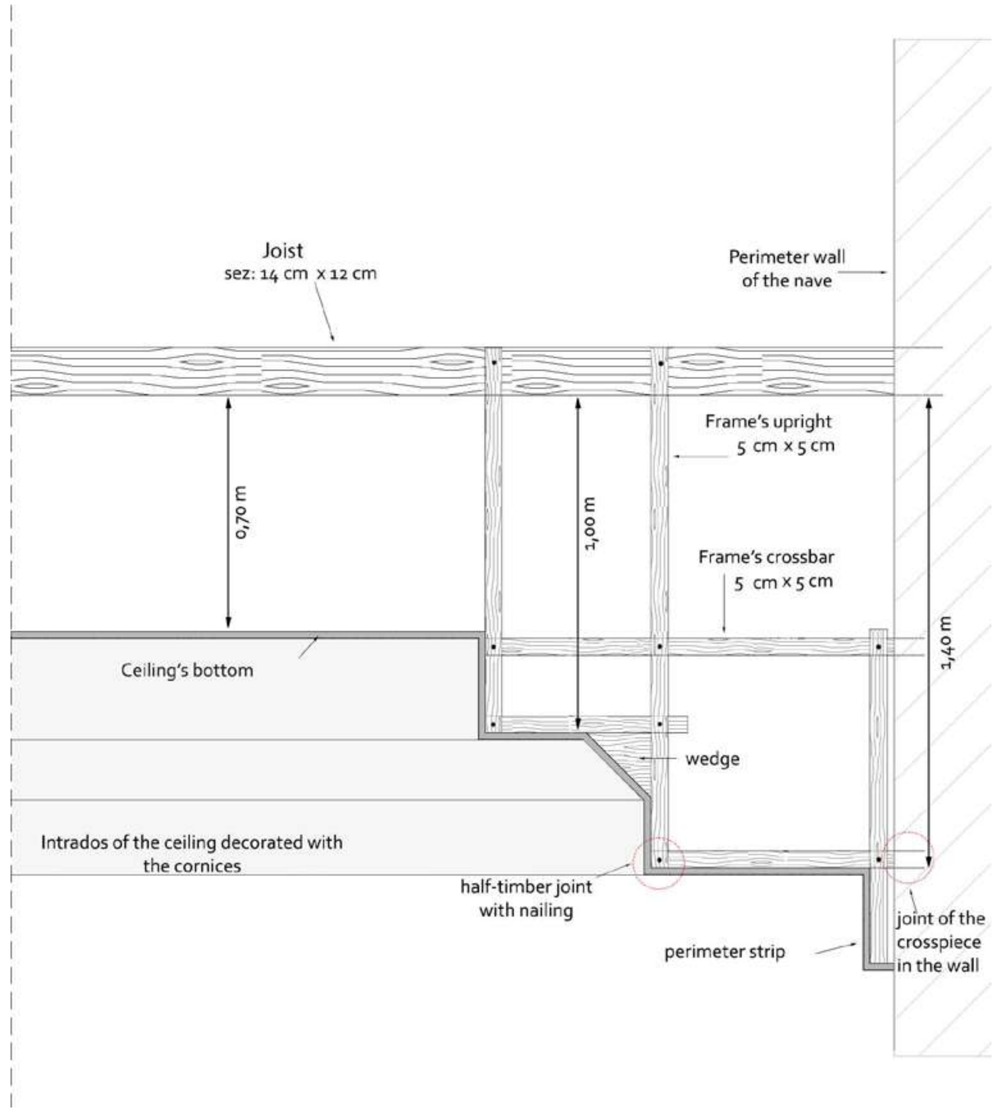

Fig. 9. *Basilica of Saints Cosmas and Damian. Detail of an L-shaped perimeter frame of the ceiling (1632).*

eral, and rigidly adopted criterion but following flexible rules, according to the organization of the construction site and workers skills. For example, the parallel sides of the same lacunar are often hung by frames placed in different positions, even if they are in the same number. Regarding their spacing, the archival research documentation proved the existence of reference parameters. The contract for the construction of Sant'Eligio dei Ferrari ceiling, arranged on May 24, 1602, between the archconfraternity of the church of Sant'Eligio and the carpenter Francesco Nicolini, reports: «Che detta soffitta sia fatta di legname d'abeto conforme al dissegno, e profilo sottoscritto da noi a tutta spesa del mastro con alcune cornice di albuccio, et intaglio di legname stagionato ben polito, e bene inchiodato con chiodi novi, e ben congiunto. Item, che le squadre che andaranno per reggere detto soffitto siano fatte di ligname di castagno bene inchiodati, e che ogni longhezza di tavola d'abeto debbia pigliare quattro squadre e non meno. Che gli alcarecci dove si devano attaccar dette squadre siano di buona grossezza al paro di travi» (That the aforesaid ceiling is made of fir wood conforming to the design, and profile signed by us at the expense of the master with some poplar frame, and carving of well polished seasoned wood, well nailed with new nails, and well joined. Item, that the teams that will go to support said ceiling are made of well-nailed chestnut wood and that each length of fir board must take four frames and no less. That the joists that these frames have to be attached to are of good thickness, like the beams).

The document clearly mentions the wood elements used (chestnut for the structural elements – joists and frames – fir for lacunar external boards, and "albuccio" or poplar for the decorative parts) and reveals that the frames (called *squadre*), are composed of at least by four boards per fir plank. The boards are vertical elements constituting the lacunar structure; the entire frame width derives from their width; the horizontal board of the frame is nailed at the crosspiece base.

In this scheme, the number of frames is adjusted to the length of the vertical boards, to be fixed to the uprights. Then, the assembly of the boards, completing the lacunar with nails or joints, and the decoration elements follow (including astragal, bead, and reel – or coats of arms and figures in relief). The frame can be made by more than one crosspiece (probably in relation to the number of "bussole" (squares constituting the height of the lacunar, defining the depth of the coffer). Together with the frames, the panels (single vertical axes) are used, often placed at the corners or supporting the boards of the coffer bottom, inserted where the double anchoring provided by the U-shaped frames is not necessary or possible. Considering the ribs of the coffers – both straight and curved – a regularity in the distribution of the frames emerges, and a center-to-center distance, also in this case, does not exceed one meter in length. However, the center-to-center distance varies with the weight that the uprights are supporting, according to the number of boards composing the lacunar and the decoration applied. Therefore, in the case of a richly decorated ceiling, the spacing is smaller; otherwise, it is larger without carved elements decorated with painted tables or canvases.

The frames, or the individual panels, determine the arrangement of the upper joists. When considering these elements, two factors are crucial, although they do not affect the quality of the ceiling: the spacing of the trusses and a walkable wooden surface above the joists. In case of a short distance between the trusses and the absence of a walkable surface, the joists have a small section (about 6 cm x 6 cm), rough in shape, not squared; moreover, their positioning is due to the need to hang the uprights below. The result is an irregular and uneven arrangement that, in some cases, is not perfectly orthogonal with respect to the tie beams of the trusses (as in Sant'Agnese fuori le mura, 1606) (Fig. 10). Moreover, a more regular arrangement of the joists emerges in trusses with a wide center-to-center distance. However, in both situations, the joists are not nailed to the beams, wrapping them, but just leaning on top. Differently, realizing a walkable surface requires a maximum distance between joists of 50 and 60 cm to nail the planks over them. Therefore, the frames for hanging the ceiling are not directly related to the joists and the insertion of crosspieces – below the beams or at the same height – is necessary to fix the hangers in the intermediate spaces (an example is the coffered ceiling of San Giuseppe dei falegnami (Fig. 11).

Fig. 10. *Ceiling without upper wooden deck with non-uniform arrangement of joists (Rome, Sant'Agnese fuori le mura, extrados of the coffered ceiling, 1606).*

Fig. 11. *Ceiling covered by a walkable floor, made by joists placed on regular distance, to which the U-shaped or L-shaped frames of the ceiling are hung by crossbeams (Rome, Extrados of the ceiling of San Giuseppe dei Falegnami, 1612).*

4. CONCLUSIONS

The study aimed to highlight the importance of the building technique of the coffered ceilings in the churches of Rome. So far, this topic has not been addressed specifically; there is a lack of a detailed illustration of the different structures built and a broad picture of the different construction typologies. Conversely, the studies of ceilings in the field of art are highly developed; studies focus mainly on diffusion – starting from the second half of the 15th century – and on the evolution of forms over time, up to the early 20th century. Furthermore, due to the particular historical and aesthetic value attributed to the coffered ceilings, special attention was paid to the state of conservation: preserving the structure of the coffered panels and the rich decorative and chromatic quality was repeatedly requiring interventions, even of considerable extension, to ensure tightness, prevent collapses (even minimal ones, and with serious risks for people), replace damaged parts, restore surfaces and reliefs [20]. However, during certain restorations, the lack of knowledge on the topic and the scarce consideration of the ancient wooden carpentry above the extrados of the ceilings led to inappropriate interventions, up to the complete replacement of the ancient technological system [21]. The complete replacement consisted of inserting a steel structure, independent from the roof trusses, namely a mesh of IPE beams with metal tie rods fixed to the coffer's wooden boards. An example is the case of the ceiling of the central nave of the Basilica of San Pancrazio where, during the restorations carried out at the beginning of the 2000s, the original hanging system was replaced by a steel one, supported by a framework of IPE beams. This substitution, useful to reinforce the structure, radically changed the overall behavior of the ceiling. In fact, wood – a hygroscopic material – is affected by environmental conditions, shrinking, and swelling due to changes in moisture content. The modification of the structural system – even if limited in size – brings new constraints, resulting in unwanted deformations. Moreover, metallic material leaning against the wood, if not treated or inserted in a way that does not allow proper ventilation of the area, could activate processes of localized biotic degradation [22, 23]. Therefore, a specific understanding of the construction methods of the lacunar ceilings in the churches of Rome, based on the importance attributed to their integral physical authenticity, both intrados, and extrados, emerges. In order to preserve the integral physical authenticity, the maximum effort – based on the historical value of the technique and on the ancient execution modality that could be valid for structural efficiency – should be made. This condition can only be verified by fully understanding the original construction features of the coffered ceilings, their requirements, their effectiveness degree, any constitutive defects, and the conditions of conservation of the materials. In this manner, works aiming at solving static and deterioration problems could be carried out in a controlled and targeted way rather than a radically innovative way.

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TECHNIQUE AT THE SERVICE OF A NEW LITURGICAL MODEL: THE TIMBER ROOF OF THE CHURCH OF SAINTS MARCELLINO AND PIETRO IN CREMONA

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At the turn of the 17th century, the Jesuit order settled in the city of Cremona, where, thanks to the support of Bishop Speciano and some notable families, it started the construction of the church of Saints Marcellino and Pietro (1606-1620), the Schools and the College. The church model of the aisleless rectangular hall – large enough to accommodate a large number of faithful – forced the fathers to resort to unusual solutions for the area of Cremona, which, over the centuries, also led to instability and structural problems. The careful archival and bibliographic research made it possible to investigate the wooden roof with wide-span "Palladian" trusses (about 15.20 m), directing the diagnostic analyses, identifying the peculiarities of the technical solutions adopted, in a continuous comparison between indirect sources and *in situ* investigations. The construction events of the trusses and secondary framing were investigated over a long period of time, to include the succession of minute maintenance and repairs, also carried out in the last two centuries; the complexity and stratification of works carried out in phases and singular interventions, linked to the chronological succession of events, is the basis for the interpretation of the current state of the structure, therefore for a restoration intervention aimed at protecting the building palimpsest.

Keywords

Church of Saints Marcellino and Pietro in Cremona, Historical timber trusses, Palladian trusses, History of construction, Timber shipping.

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1. INTRODUCTION

At the turn of the 17th century, the signs of an economic and social crisis manifested in the city of Cremona, involving above all the merchant class and aristocratic families: following the plague of 1630, the city's population was reduced from about 46400 inhabitants in 1621 to only 13900 in 1660; therefore a long period of stagnation and cultural isolation begins, also as the result of the transition to an economy based mainly on agricultural income [1].

However, the harbinger of this crisis had already begun to appear in the 16th century; many noble families extinguished, and wealth flowed to a few individuals; Habsburg rule did not calm the political instability and, at the same time, numerous heretical communities settle and sprout, even among the noble class.

In this context, the reforms advocated by the Council of Trent, the influence of Cardinal Carlo Borromeo, and the appointment as bishop of Cremona of the Cremonese Cesare Speciano determined the conditions for the settlement of the Jesuits in the city of Cremona; a new religious congregation which was attributed the role of stemming heresy by preaching and educating the future ruling classes. As in other cities, the Jesuits settled in a central position of the city, where they initiated an impressive building program aimed at the construction of a capacious church, a school, and a college with dormitories and a library.

2. THE CONSTRUCTION OF THE CHURCH, GENERAL MODELS, AND LOCAL WORKERS

It is well known that the Council's "reform decrees" directly concerned the figurative arts but not architecture which, however, adapted itself to the radical change in liturgical functions and catechesis: the new buildings were conformed to re-evaluation of the salvific value of the sacraments (facilitating preaching and the centrality of the Eucharistic rite), the community of the faithful were gathered in aisleless churches, focused towards the main altar and the pulpit [2]. Even the newly built Jesuit churches found inspiration in architectural models – albeit not rigidly applied – identifiable in a rectangular hall with the altar at the end and shallow chapels communicating with each other on the sides of the nave [3, 4]. The Jesuit strategy in the architectural field – under the aegis of the *consiliarius aedificiorum* (and in particular of Father Giovanni Tristano, 1568 to 1575, and of Father Giovanni De Rosis, 1575 to 1610) – was also linked to the criteria of practicality, functionality, and economy, in accordance with the pauperism that characterized the first settlements.

From these architectural models also derived construction techniques that were new or derived from other existent building types: the first churches were often covered by articulated wooden ceilings, more rarely by brick vaults, the walls presented an austere architectural vocabulary, and the roofs had to cover the large span of the single nave. However, these recommendations were put into practice in different ways in the numerous provinces of the Order, where the materials available, the workers, and local building practices influenced the construction of churches and colleges.

In the ecclesiastical province of Milan – which includes the suffragan diocese of Cremona – the significant reforms implemented by Cardinal Carlo Borromeo also had a translation in the architectural field: the *Instructiones fabricae et suppellectilis ecclesiasticae* had great importance in initiating and orienting the restoration and construction of new religious complexes, defining stringent and highly detailed

Fig. 1. *On the left: orthophoto of the main façade. (Image source: courtesy of R.T.C. di Colturato&Pedrini). On the right: the interior of the church. (Photo by Angelo Giuseppe Landi).*

rules [5, 6]. Bishop Speciano was a trusted friend of Borromeo and a staunch – also economic – supporter of the Jesuit settlement; he was well acquainted with the *Instructiones fabricae*, and it is likely that he applied many indications in the project of the Jesuit complex, in which he played a pivotal role: in several documents the explicit will of the bishop to build a grandiose church is reported, a sign of the Counter-Reformation in the city. In fact, Speciano seeked to identify the site of the church and the college, necessarily located in a central, easily identifiable area, close to the places most frequented by the faithful. The studies conducted so far on the church have contextualized the settlement of the Jesuits in the city of Cremona and have documented, as far as possible, the construction of the church, with a specific interest in the early stages [7–10]: the building donated by Margherita Torri in January 1594, constituted the first step in a building program that affected the entire surrounding block, with the gradual acquisition of neighboring houses. Speciano also undertook to raise funds necessary for the purchase of the buildings, their demolition, and the construction of a new grandiose church, the schools, and a college: the hereditary bequests of the noble families (among which those of Margherita Torri Ferrari, of the Mainoldi, Fondulo and Fossa families) and a significant part of the inheritance of the bishop Speciano himself (who died in 1607) contributed to the costs for the construction of the church – dedicated to saints Marcellino and Pietro – which started between 1602 and 1603 [9]. The local aristocratic class worked to stem the spread of heretical movements and, at the same time, invested huge resources in a new religious order responsible for the education of future generations of the new ruling class.

The purchase of the houses located on the southern and eastern border of the church of San Michele Nuovo and the confirmation of the bequests allowed the Jesuits to start the demolition of the church and some adjoining buildings, as well as the start of the construction site, documented by the specifications of the works stipulated on October 30th, 1602 [10]: Francesco Laurenzi was commissioned by the Fathers to build the new church, in accordance with the project of the engineer Angelo Nani, following the best rules of art. The new building is structured on a single hall system (about 15 m x 37 m), a pseudo-Latin cross of imposing dimensions, with a pseudo-transept, side chapels, a large presbytery, and the slender bell tower. Originally the interior was probably austere, decorated, and punctuated by a succession of monumental pilasters surmounted by a plain entablature; the large windows above the entablature collect the light from protected loggias, guaranteeing filtered lighting in the interior space.

The church was built starting from the presbytery, demolishing all the pre-existing structures (whose materials were carefully stacked and, at least in part, reused) and building the new structures from the foundations: the construction from scratch of the building perhaps also implied a sign of symbolic value, of a Church to be re-founded on the austere solidity of the religious Order. The conditions agreed to in the specifications were quite precise; they required complex operations, the use of high-quality materials, mostly lime-based mortars instead of traditional earth ones, and «mature and well-experienced» workmanship for the most delicate processes (e.g., for lime processing).

The same principle is also reiterated for roofs, which had to have the correct slope of the pitches, trusses worked by competent carpenters, flat bricks under the monk and nun tiles (of adequate thickness), and the only requirement that «no beam rests on or touches the vault». Little or nothing is known about the materials used, in particular the woods that were supplied directly by the Jesuits to the construction site: the character of the commissioner, whose relationships and interests went beyond the confines of the Cremona area, today pose some critical issues in identifying the origin of the workers and materials used in the construction site.

The specifications predict a long and complex construction process, consisting of at least two building phases, the first involving the construction of the presbytery and the "transept", completed in 1607, whose project was still subject to revision by Father De Rosis, of the Roman *council aedificiorum*, in July 1603 [11]: in fact, the construction of a church of this size must have seemed excessive to the Jesuit fathers themselves if in March 1604 – when the foundations were already laid – they asked for permission to reduce the nave, denied by Father General Acquaviva. The construction continued briskly, also thanks to the inheritance of Bishop Speciano, who left most of his fortune to the Jesuit order [12]. The first portion was completed a year later, with a blessing by the

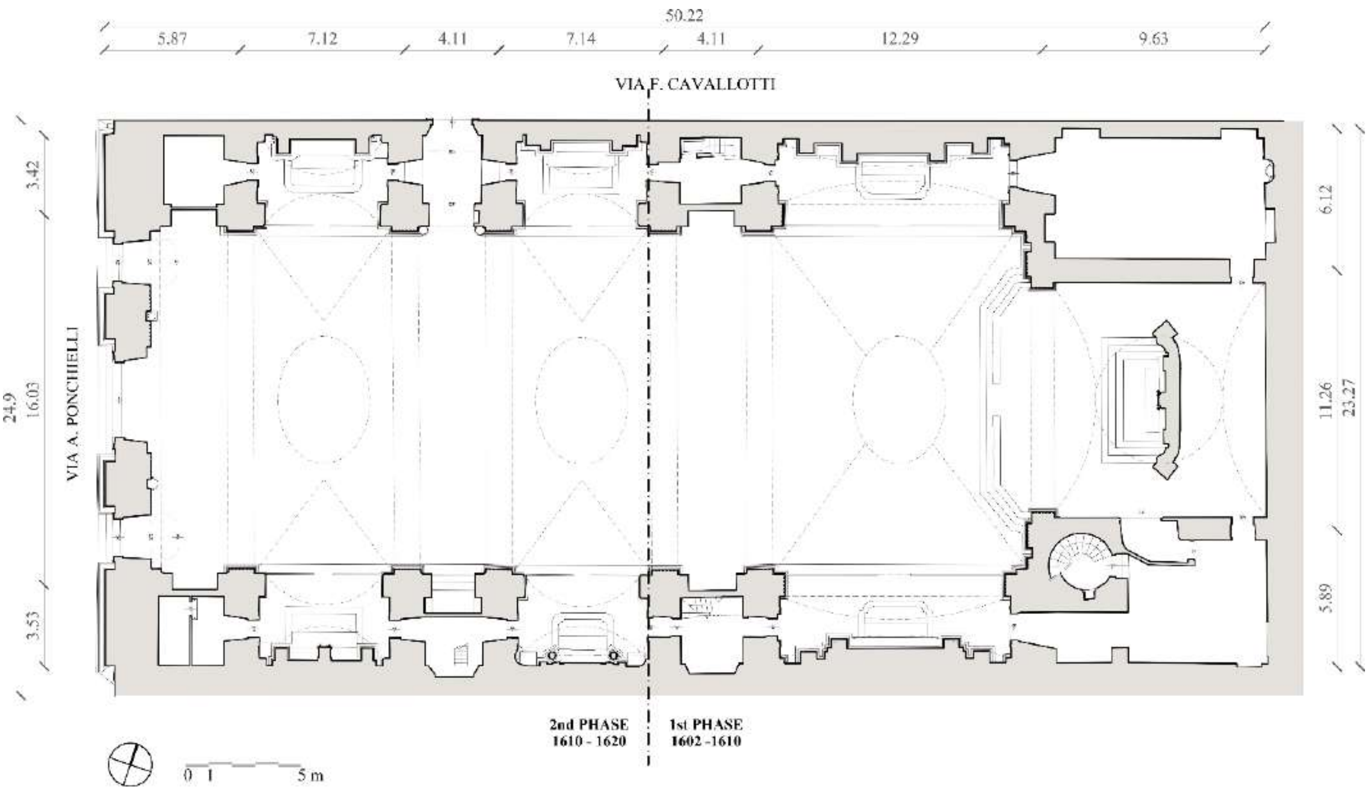

Fig. 2. *Plan of the church of the Saints Marcellino and Pietro with the projection of the vaults: a brick vault separates the large (about 15 m wide) Latin cross liturgical hall with a pseudo-transept from the attic space and the wooden roof. (Image source: geometrical survey, courtesy of R.T.C. di Colturato & Pedrini).*

bishop Paolo Sfondrati and although there is no description, it can be assumed that it was finished and suitable for placing the relics granted in 1611. Even today, the toothing on the vertical wall structures is clearly visible, while the large vault was certainly missing if, in December 1609, Father Acquaviva asked the local Jesuits for clarification on whether or not they intended to build it [13].

The analyses carried out in situ made it possible to establish that instead, the wooden Palladian or queen post trusses – a technological solution suitable for covering the wide span of the liturgical room, equal to about 15 meters (corresponding to about 31 Cremonese arms, being each arm equal to 0.483 m) – had already been placed on site. The vaults, however, were undoubtedly built before the start of the second building phase: the large cracks on the walls and the vaults themselves are compatible with the instability that occurred on an incomplete structure, in which the thrusts could not yet be fully countered.

After an interruption the duration of which is still unknown, the construction of the church resumed with the conclusion of the nave, without interrupting the use of the church, documented by expenses for the altars (in particular that of the Transfiguration) and the purchase of an organ. Margherita Torre expresses the will that her funeral be held at the church, while the bells of the nearby church of S. Nicolò «and that of the Jesuits» must ring, implicitly attesting to the presence at least of a bell, perhaps waiting to finish the bell tower [14]. The interruptions of such large-scale construction sites are well documented in the history of architecture; the unfinished aisles were closed with provisional wooden structures, mainly composed of boards, sometimes decorated with paintings.

On July 7th, 1620, the church was consecrated by Bishop Giovanni Battista Brivio [8]: it is very likely that this ceremony took place in a building still lacking in finishes, partially occupied by building works, but certainly sheltered by the entire wooden roof and probably also by the brick vault. The tympanum to be placed at the top of the main façade was never completed, while in 1622, Alessandro Macchi and Ippolito Tonsis financed the construction of the altars of two chapels and the related decorations in a church that still had a marked pauperistic character.

It was not possible to clarify whether the second phase of the construction site was completed by the same workers employed by Laurenzi and whether the procurement of materials is attributable to the same commercial channels: the investigation conducted on the roofs shows significant differences, not in the general structural system, but in some construction details.

Other finishes were progressively completed, always using the conspicuous bequests of Speciano and Margherita Torre. However, the economic resources converged towards the continuation of the building program, aimed at the erection of the Schools and the College, respectively on the southern and eastern sides of the church. In the period 1628-1629, the school project was discussed between the Roman *consiliarius* and the provincial father, opting for the entrance adjacent to that of the church, «as the founder [Bishop Speciano] liked» [15].

The appearance of the plague epidemic in 1630 determined the rapid decline of the city's economic system and a profound crisis for the following decades [16]. The city building activity was substantially canceled, and numerous construction sites were suspended or not started, resulting in a decline in real estate prices; however, raw materials prices dropped as they could be recovered from demolitions. Thus, the considerable economic resources of the Jesuits could guarantee the construction of the contiguous schools at sustainable costs and represented the opportunity to definitively finish the decorative arrangement of the interiors, with stucco moldings, between 1651 and 1652.

After the completion of the interiors, a long period of – discontinuous and poorly documented – maintenance begins and, from the 19th century, of abandonment. In 1777 a storm caused «serious damage» to the church of Saints Marcellino and Pietro [17]; after the suppression of religious orders, there was a risk of profane use (military riding hall). In 1817 the *Fabbriceria* of the parish church of S. Agostino – of which the church was a subsidiary – reported damage to the roof of the church of San Marcellino, in particular in the parts bordering the bell tower from which bricks fell; the following year, the parish vicar requested restoration work on the roof and the facade, whose marbles were by then in a very precarious condition [18]. However, the most significant intervention, albeit limited only to some parts of the roof, consisted of the strengthening that took place in 1841: three trusses needed to be reinforced with struts, modifications to some members, and insertion of metal straps, for a total amount of 700 Austrian lire [19].

Despite the directions in the specifications, the wooden tie-beams of the trusses are in contact with the extrados of the nave vault; a succession of longitudinal beams, placed on the tie-beams in a central position, seem to support the vault, to which they are connected by means of metal straps. The instability at the vault and the detachment of the plaster were also attributed to this system: in 1862, a restoration work designed by engineer Guarneri filled up the cracks, made the extrados buttresses up to a third of the height of the vault, and restored the detached plaster on the intrados [20].

The reconstruction of the eaves was attested in 1897, on both sides towards the road: the gutters and all the protruding parts of the wooden eaves were replaced [21]. Although with a certain discontinuity in the archival documentation, in the following years and up to the recent past, maintenance interventions and, more often, revision of the roof covering are attested.

3. METHODS

The historical-archival research conducted by the authors aims to develop further insights into the construction phase of the church, already partly outlined in the recent bibliography, and to integrate it with the history of uses and, above all, of the maintenance carried out up to the present. Even if incomplete and discontinuous due to the state of conservation of the archives (the Jesuit archive is quite incomplete, and that of the Fabbriceria di S. Agostino is discontinuous), this information constitutes a fundamental basis for supporting the interpretation of the data collected *in situ*, through direct observation of the building. However, historical knowledge also plays an essential role in drafting a restoration project that recognizes the value of the building as an architectural palimpsest, on which the numerous stories that have interested it have left their traces.

The analysis of the roof structures is, therefore, part of a continuous comparison process between written sources and material traces: a process of identification of construction phases, traces of woodworking, replacements, additions, strengthening, carried out giving diachronic restitution, based on absolute – when possible – or relative dating. This leads to the possibility of attributing materials and construction techniques to the different historical contexts that generated them, identifying the duration or intervals of deterioration manifestation in the structures and architectural finishes, of verifying the results of previous interventions.

4. THE CHURCH ROOF

From a constructional point of view, the church roof can be divided into four parts:

- the hip roof of the presbytery, with a truss, two half-principal rafters, hip rafters, and purlins supporting the joists;
- the gable roof of the nave (its span greater than that of the presbytery), with nine trusses that support the purlins on which the joists are placed;
- the roofs of the two bands on the sides of the nave – consisting of the side chapels and the pseudo-transept – with rafters, purlins, and joists.

Although – on a general level – the same structural organization was maintained in the two construction phases, differences can be identified both in the nave and lateral roofs. The peculiarities connected with the two construction phases of the church are accompanied by others due to the maintenance, renovation, and strengthening of the roof over the centuries.

4.1. THE ROOF OF THE PRESBYTERY

A single truss (T1) is on the roof of the presbytery; its span is significantly minor to that of the nave (about 11 m compared to about 15.15÷15.20 m in the nave). The truss support: on its west side, towards the nave, the ridge beam and four purlins (two for each pitch); on the east, two half-principal rafters, two hip rafters, and four purlins (also in this case, two per pitch). Transversely to the hip rafters, two diagonal, horizontal beams reinforced with struts are intended to support the rafters by vertical posts. Above this structure, there are the joists placed at a distance of about 60 cm, which support the laths on which the roof tiles are placed.

Fig. 3. *Closed joint king post truss in the attic above the presbytery of the church. (Photo by Emanuele Zamperini).*

The roof of the presbytery has been significantly reashed: it indeed underwent at least one significant maintenance intervention, of which, however, no documentary trace has been found; however, it can be dated to the period between the 1920s and 1950s, in which the parish archives show some gaps. The reinforcement works of the southern joint of the truss and the construction of the hip rafters certainly belong to this period; in both cases, thick boards connected with bolts and thin iron strips were used. The replacement of some purlins and joists probably dates back to this same period. These works most likely involved dismantling the entire roof frame and its repositioning with significant changes. The substitution of laths for flat bricks as the supporting element of the roof tiles has allowed a reduction in loads and the overcoming of the dimensional constraints imposed by the bricks; in the presbytery, in fact, the joists are placed at a distance of about 60 cm, unlike what happens in the nave in which the length of the "one arm long flat bricks" – used for the construction of the roof deck – is about 48 cm, equal to a Cremonese arm, as mentioned by Capra in his treatise written shortly after the construction of the church [22].

The truss is a king post closed joint truss [23] with struts; the joint between the king post and the tie-beam is a half dovetail tenon and mortice joint fixed with a wedge. The truss members are all made of oak timber; the boards used to reinforce the southern rafter/tie-beam joint are of spruce; part of the purlins are made of oak, part of spruce – and in this case, protected with the application of a tar-based paint – as one of the half principal rafters and some of the joists; the remaining joists – probably those preserved from the original construction – are some of oak and others of poplar. The laths – probably also made of spruce – are all treated with the same tar-based paint.

The two hip rafters deserve a separate discussion; they are not made of solid wood but with thick boards of painted spruce wood: two external boards are continuous along the entire length, and a third is present only in the middle part, where the bending stresses are greater; at the ends, to distance and connect the sideboards, there are laths inclined at 45° with respect to the axis of the beam, placed at 30÷50 cm from each other.

4.2. THE ROOF OF THE CHAPELS

The roof structure of the side chapels is simpler, consisting of rafters (generally placed in correspondence with the trusses of the nave, but some are probably added later

Fig. 4. *Roof of the band on the northern side of the nave; it is possible to see the extrados of the barrel vault of the pseudo transept. (Photo by Emanuele Zamperini).*

and placed between those) which support a single purlin placed in the middle of the pitch on which the joists rest. The rafters and the purlins are almost all made of oak timber, but some of them – probably even these still original – are made of larch, and others of spruce, which are probably recently replaced or added. The joists are mainly made of oak and discontinuous in correspondence with the purlin, but there are some made of poplar and some others of spruce which are recently added and usually continuous on the two spans. In this part of the roof, no significant differences are visible between the two construction phases of the church.

4.3. THE ROOF OF THE NAVE

The most remarkable part of the roof is, without a doubt, that of the nave; this applies both to the greater complexity of the structure – connected to the presence of trusses whose span is more than 15 m – and to the articulation of the construction events, and the presence of interesting traces related to timber transport and trade.

The structure is made of nine trusses (T2-T10), supported by masonry corbels or engaged pillars protruding from the longitudinal walls; the trusses – together with the wall above the arch that separates the nave from the presbytery and with that of the façade – support ten bays of purlins. All the bays have the same span, with the exception of the second from the presbytery (between T2 and T3), wider due to the greater height of the groin vault of the pseudo-transept, which would have interfered with the tie-beams of the trusses. There are three purlins per pitch plus the ridge beam, which are all discontinuous at the trusses; above each of the walls between the nave and the chapels, there are two other purlins. Almost all the purlins are made of oak wood, but some – even in this case obviously replaced in maintenance works or placed side by side with the pre-existing ones – are of spruce wood. In the organization of the joists (almost all of oak, except for a very few of poplar and some, recently made, of spruce), there is a clear difference between the first and second construction phase: in the bays of the first phase, the joists of the upper part of the pitches

Fig. 5. *Plan of the roof structure. (Geometrical survey: Courtesy of R.T.C. di Colturato & Pedrini). In purple the king post truss of the roof of the presbytery (T1); in red the Palladian trusses of the first phase in which the queen posts rest on the tie-beam (T3-T5); in orange the Palladian trusses of the second phase in which the queen posts are linked to the tie-beam with tenon-mortice joints (T6-T8); in pink the Palladian truss reworked probably in the first decades of the 19th century with queen posts detatched from the tie-beam (T9); in yellow the Palladian trusses reworked in 1841 with queen posts detatched from the tie-beam (T2 and T10).*

are continuous from the ridge beam to the second purlin of each pitch, while the other has a single span, from a purlin to the adjacent; instead, in the bays of the second phase, almost all the purlin have a single span. An exception to this general system occurs in the second bay of the first phase, in which the joists of the lower part of the north pitch are also continuous on three supports and are all made of spruce, like the underlying purlin; this – together with the traces of woodworking – suggests a recent replacement. Among the oak joists, there are some – perhaps coming from the houses demolished to build the church – that show evident signs of previous uses as floor joists due to the presence of notches intended to accommodate the laths covering the joints between the boards, and the *bussole*, thin inclined or concave boards placed between the joists to close the space above the girders.

As already stated, above the nave joists, there is a layer of flat bricks, whose dimensions determine the center distance between the joists, equal to about 48 cm. The only exception is the two bays adjacent to the penultimate truss (T9), probably rehashed in the early decades of the 19th century, as we will see later; in these bays, the joists are placed at a greater distance between centers – about 60 cm as in the presbytery – and support a recently made planking of machined spruce boards. The discrepancy between the period of intervention on the truss and the presumed date of construction of the planking leads to the hypothesis that when the truss was modified, the flat bricks were replaced with laths and that in a more recent intervention, the laths were replaced with the boards.

4.4. THE RELATIONSHIP BETWEEN THE ROOF AND THE MASONRY STRUCTURES

As already mentioned, contrary to what was prescribed by the specifications of the construction contract, all the tie-beams of the trusses (except the replaced one, which will be discussed later) are in contact with the crown of the vault, which, indeed, was shaped to house them. However, the interaction between trusses and vaults does not end in that contact; in fact, there are also some metal hangers that hang the ribs of the groin vault at the intersection between the nave and pseudo-transept, probably installed during the construction phase to prevent asymmetrical deformations in the vault when its centering was lowered. Another construction aspect already mentioned is the presence along the axis of the nave of a sequence of timber beams that rest on the tie-beams of the trusses and are bound to the vault by metal hangers; the dimensional variety of timber beams and metal hangers, and the fact that many of them show evident signs of previous use – contrary to what can be seen in the roof purlins, which are all rather regular – could lead one to believe that it is a consolidation system put in place later (perhaps even in emergency conditions) to limit the deformations of the vault. The lack of signs of the anchoring points of the metal elements to the intrados of the vault would, however, lead to place the realization of this intervention in the time lapse between the construction of the vault and its plastering. Alternatively, the irregularity of the timber used could be justified by the fact that the construction system was built at the same time as the vault but was initially considered just a temporary device, only necessary when lowering the centering and intended to be subsequently removed, but that this removal never took place, perhaps because the builders had noted the poor stability of the vault. The considerable thrust and lack of stability of the vaults are also manifested by the distancing of the longitudinal walls of the nave, evidenced by the vertical lesions present at the connection between them and the corbels or engaged pillars that support the trusses.

5. THE NAVE TRUSSES

The nine trusses of the nave roof are all "Palladian" or queen post trusses. Also in the case of the trusses, differences can be noted between the first and second phases, to which are added others connected to the reinforcement interventions carried out over the years. Observing the trusses that have not undergone significant alterations, it can be seen that: in those of the first phase (T3-T4-T5), the queen posts rest on the tie-beam, which in its midpoint is hung from the king post by means of a long metal bracket; in the unmodified trusses of the second phase (T6-T7-T8), instead, we see that the queen posts are joined to the tie-beam through tensile-resistant connections, made with a half dovetail tenon and mortise closed joint. In addition, the king post – always connected to the straining beam with a closed joint – has struts in the trusses of the first phase, while they are absent in those of the second phase.

The apparently modest different relationship between the queen posts and the tie-beam denounces a different structural conception. The quadrilateral formed by tie-beam, lower rafters, and straining beam inside the Palladian truss is a statically underdetermined structure, which – if loaded asymmetrically – undergoes large displacements. The role of the queen posts is, therefore, fundamental: they fix the distance between the lower rafter/straining beam joint and the underlying tie-beam; thus, they prevent the structure from becoming a mechanism by exploiting the flexural stiffness of the tie-beam.

However, from this point of view, the trusses of the two phases behave differently. In the trusses of the second phase, the queen posts are connected to the tie-beam with a joint capable of resisting both compression and traction; therefore, in case of asymmetrical loads, one of them will press against the tie-beam, and the other will lift it, subdividing the force necessary to stabilize the structure between two points, in one of which it would also reduce the bending of the tie-beam induced by its own weight and by the other loads applied to it. In the trusses of the first phase, instead, the queen posts simply rest on the tie-beam, and this ensures that in case of asymmetrical deformation, only one of them comes into action, pressing on the tie-beam and increasing the stresses induced in it by the other loads.

As already written, three of the trusses of the nave (T2, T9, and T10) underwent significant modifications and, therefore, now present a different structural configuration. As regards two of them (T2 and T10), it is possible to date the interventions with certainty, thanks to the archive documentation.

Fig. 6. *Unmodified truss of the first phase: T3 truss seen from the north-east. (Photo by Emanuele Zamperini).*

Fig. 7. *Unmodified truss of the second phase: T8 truss seen from the north-west. (Photo by Emanuele Zamperini).*

In January 1841, following a winter characterized by heavy snow, roof reinforcement works were started by the master builder Angelo Fontana; eng. Luigi Ghisolfi – a member of the *Fabbriceria* of the parish of S. Agostino – drafted a first report [19], in which he stated that the load imposed by the queen posts on the tie-beam would have caused the trusses to burden the vaults, causing them to crack. In his report, he also indicated the work to be carried out urgently and the other necessary – but postponable – improvements. A subsequent and more detailed appraisal is sent to the *Fabbriceria* by Eng. Benini on March 30th [24]: to eliminate the load of the trusses tie-beams on the vaults, in the T2 and T10 trusses, the queen posts are equipped with two struts each and are shortened so that they are no longer in contact with the tie-beam, but can support it by adding of metal straps; furthermore, the T4 and T10 trusses are equipped with struts that support the tie-beam, thrusting on the walls. In the T10 truss, some elements are also replaced (rafter, lower rafter, and king post), partially charred – such as some of the preserved elements and some purlins – having been struck by lightning; probably, this is the one that struck the church 64 years earlier – on August 19th, 1777 – right in that part of the roof, during a violent storm described in detail in a publication of the time [25]. Among the works described in the appraisal, there is also the shoring of the roof near the two trusses on which the most invasive interventions were planned, which therefore did not require the dismantling of the secondary framing and the roofing.

In describing the deferrable works, Benini instead stated that the insertion of the new struts and the cutting of the queen posts had to be performed on six more trusses [24]; this note is useful to define an *ante quem* term for the reinforcement of the T9 truss. There are nine trusses in the nave, and on two of them, the queen posts had just been shortened; the fact that the report provided that only six of them still needed to be modified suggests that at that time, the intervention on the T9 had already been carried out.

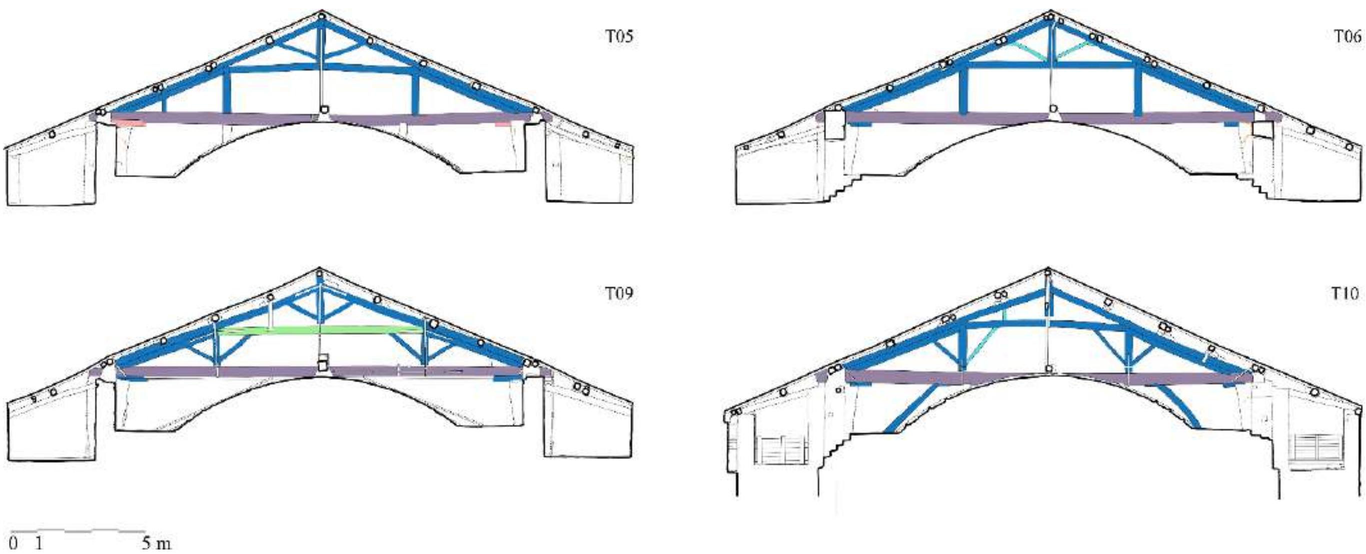

Fig. 8. *Survey of the trusses of the nave: on the top left, T5; on the top right, T6; on the bottom left, T9; on the bottom right, T10. (Geometrical survey: Courtesy of R.T.C. di Colturato & Pedrini). The colours represent the wood species of each truss member: purple for larch; blue for oak; light blue for poplar; green for ash; pink for chestnut.*

The T9 truss underwent the most radical modifications, perhaps after the breakage of heavy damage to its tie-beam, which has been, in fact, substituted. The new tie-beam is made of two pieces connected with a keyed and nibbed scarf joint, reinforced with lateral plates and through bolts, and it is placed at a slightly higher level than that of the other trusses in order to place the wrought iron horizontal tie-rod, to which other two in-

Fig. 9. *Modified truss of the first phase: T2 truss seen from the south-east. (Photo by Emanuele Zamperini).*

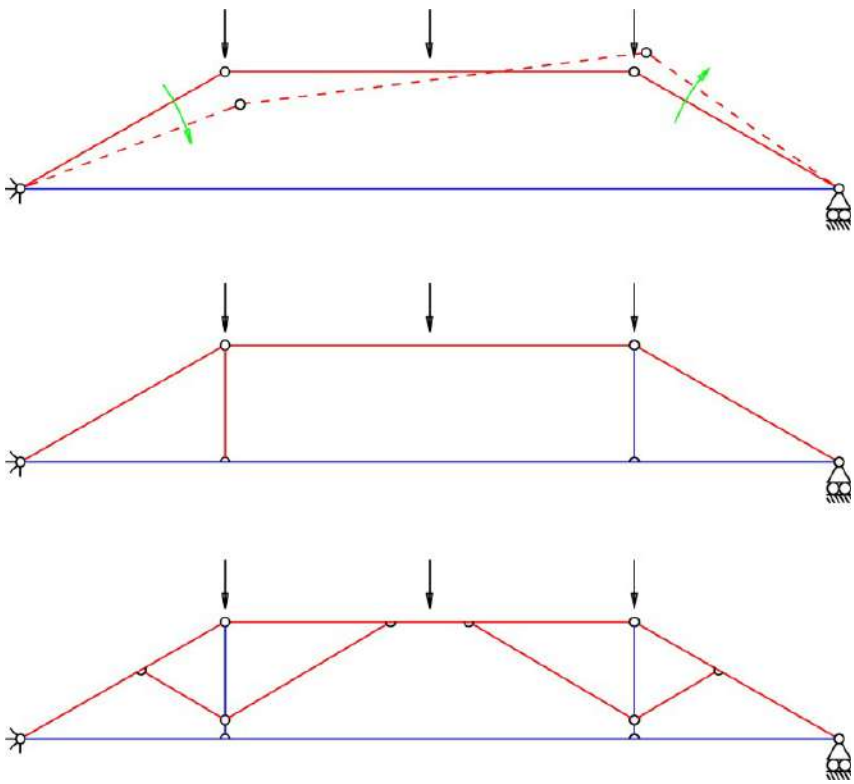

Fig. 10. *Schemes of the structural behavior of the trapezoidal structure inside the Palladian truss (in red, the compressed members; in blue the stretched ones): on the top, the structure without queen posts; in the middle, the structure with the queen posts; on the bottom, the structure with queen posts and two struts for each of them. (Drawing by Emanuele Zamperini).*

clined ties are fixed to reduce the thrust of the vault, but maybe also to lift and detach the truss from the vault. In this intervention, the truss was completely reconfigured, giving the rafters a lower slope (to have the ridge at the same height despite the tie-beam being at a higher level) and putting in place two struts to each of the three posts, which are detached from the tie-beam and straining-beam. The ironware used to reinforce the scarf joint, the tie-beam/rafter joints, and the straps that hang the tie-beam from the three posts seem to date back to the early decades of the 19th century [26] due to the coexistence of tightening systems with metal wedges and with screw bolts with square nuts, as well as for the fact that the straps are articulated with rings of the type that make up chains. In this case, the works were certainly carried out by dismantling the structure of the two spans adjacent to the truss, which are, in fact – as already described – made differently.

The interventions carried out on the three most rehashed trusses show a detailed understanding of their static behavior. The shortening of the queen posts and their detachment from the tie-beam makes the internal trapezoidal structure statically underdetermined; the simple addition of the straps would allow making the truss statically determined again; however, they only allow traction forces and therefore – like the simple supports of the queen posts in the trusses of the first phase – a unilateral constraint that concentrates in a single point all the actions intended to stabilize the trapezoidal structure. The addition of the struts to all the queen posts – blocking the amplitude of the angle between the lower rafters and the straining beam – instead constitutes a different system of stabilization of the structure, more effective, as it does not use the flexural stiffness of the truss tie-beam, which is rather poor given its remarkable span.

5.1. THE TIMBER USED FOR THE TRUSSES AND ITS ORIGIN

For the construction of the trusses, mainly oak and larch timber were used; however, there are some elements of other wood species. The tie-beams are all made of larch wood, both the original ones and that of the T9 truss, which has been replaced and is made of two elements.

The other elements are in the vast majority of oak, with some exceptions: the southern rafter of T2, the three posts and the two rafters of the T3, the two rafters of the T4, which are made of larch; the straining beam of the T6 and T9 which seem to be made of ash timber; the struts added to the king post of the T6, as well as various cleats and other secondary elements, which are made of poplar. The cantilevers placed under the supports of the trusses on the masonry deserve a different discourse: in the trusses from T2 to T5, these are reused chestnut elements, characterized by the presence of painted candelabra decorations, generally on the lower face; in all other cases, they are of oak wood.

Writing about the uses of wood from trees that grow in the Cremona area, Capra mainly mentions oak as a suitable wood for making beams and joists and poplar only for joists; with regard to chestnut – although he estimates its quality equal to that of oak – he mentions only the use for the construction of barrels and other containers, while for the ash he proposes the use only for work tools or weapon shafts [22]. As for the uses of wood obtained from trees that did not grow in the Cremona area but could be found on the market (such as all conifers), Capra instead refers to the treatise by Vincenzo Scamozzi, some decades prior to his work, and substantially coeval with the construction of the church. Writing about larch, Scamozzi affirms that «it is admirably suitable for making beams and roofing» [27].

In most cases, floors and roofs in the Cremona area – and more generally in the lower Lombard plain – contemporary to or earlier than the Church of San Marcellino confirm Capra's indications, as they are made almost entirely of oak or poplar wood; the presence of tie-beams made with larch wood is, therefore, an unusual fact, perhaps unique for the period. The reasons for this choice are to be linked to the remarkable span covered by the trusses, for which the woods of the Cremonese plain were probably no longer able to supply timber of a suitable size [28] due to the progressive exhaustion connected to excessive consumption, slow growth of oaks, and replacement of lowland forests with cultivated land.

Up to now, it has not been possible to find archival documentation relating to the origin of the wood used; however, the oak wood is probably of local origin; on the other hand, identifying the origin of the larch wood is more complex. Scamozzi cites the cities of the Po valley as a possible destination for larch wood coming both from the middle part of the Alps («these mountains of ours and [...] those of Grisons, and Switzerland») as well as from the eastern part that separates Italy from the Austrian regions. In the first case, timber could reach the cities directly from the mountains through the left tributaries of the Po (Ticino, Adda, Oglio, and Mincio) and then through the Po itself; instead, in the second case, it was transported through Adige, Brenta and Piave to Venice and from there led to the Lombard cities going up the Po. There is little information on the trade and transport of timber in the central part of the Alps [28, 29]. On the contrary, many studies have been carried out relating to the Veneto area, deepening technical, economic, and social aspects [30–38]. After a first phase practiced with very different techniques, depending on the specific orographic conditions of the forest, the transport of the timber started with the free-floating in the upper parts of the river courses, narrower and characterized by greater impetuosity and irregularity of the waters, to pass then to the transport in the form of rafts in the great Lombard lakes and the river sections in the plains, which are broader and more easily navigable; in Lombardy, however, transport by boat was often preferred to transport in the form of rafts [29]. These transport phases correspond to particular operations that leave traces that can also remain on the timber in place: to avoid confusion or theft of the free-floating timber; the logs were marked with special marks, different for each merchant [39]; the floating of the timber in the form of rafts, on the other hand, involved assembling them by making holes in the trunks and tying them by means of unstrung branches [40].

The original tie-beams of the church's trusses – and also some of the other elements of larch wood – keep both holes that testify to its transport in the form of a raft and transportation marks. The survey of these marks and their comparison with the repertories of marks relating to the eastern Dolomites [39], the only ones published so far with a certain systematicity, while showing strong similarities, did not allow for recognizing exact correspondences and therefore to identify with certainty the timbers provenance.

Fig. 11. *Trading mark on the west side of the tie-beam of the T7 truss. (Photo by Emanuele Zamperini).*

On the western face of the southern part of the tie-beam of the T9 truss – as already written probably dating back to an intervention of the early 19th century – it is possible to read the word "NOGAI" engraved with a scratch awl or a knife. A quick toponymic research has made it possible to identify a place with this name in the morainic amphitheater of Sebino in Franciacorta [41], a short distance from the Oglio river, which may have been used for the transport of timber up to a short distance from Cremona, also through its derivations of the Naviglio Civico and Naviglio Pallavicino.

6. CONCLUSIONS

The article summarizes the historical-constructional study of a remarkable example of a timber roof built in the Lombardy area in the 17th century, addressing it from the point of view of the history of the institutions that determined its construction and maintenance and of the construction history and technique. The singularity of the size of the covered space in the context of the city of Cremona makes it unique (not only for the time in which it was built), both in terms of the construction techniques used and for the need to procure non-local timber.

The constant comparison of the bibliographic and archival data with that of the real and present consistency of the artifact, its construction techniques, wood species, and decay has allowed the understanding and interpretation of the construction and maintenance acts, framing them in the more general social and economic context of the time and not only: the investigation made it possible to define a construction history that was not confined only to the construction site, albeit developed in two phases, but also to the numerous, and sometimes minute, maintenance works that involved the roof, over a period of four centuries.

The collection and interpretation of the data derived by the survey and knowledge of the building throughout its existence is an essential basis for further investigations (analytical checks on the state of conservation of the wood, analysis and assessment of the structures, definition of an overall structural model…) aimed at a coherent conservation project, for the purpose of the building protection and a controlled structural improvement.

Authors contribution

The bibliographic and documentary research, the direct study of the artifact, and the general conception of the article were made by the two authors jointly; the writing of paragraphs 1, 2, and 3 were carried out by Angelo Giuseppe Landi, of paragraphs 4 and 5 by Emanuele Zamperini; the conclusions were written jointly by the two authors. Emanuele Zamperini did the translation of the article.

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