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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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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.

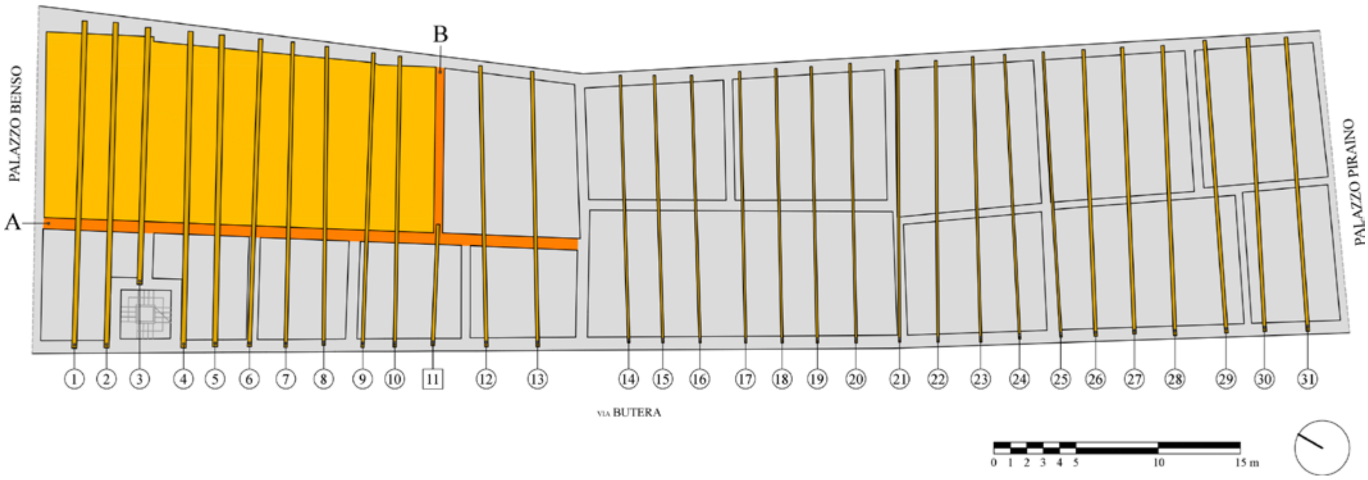

Fig. 1. *Scheme of the location of trusses in the roof structure of palazzo Butera. Yellow identifies the part of the building this study focuses on.*

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.

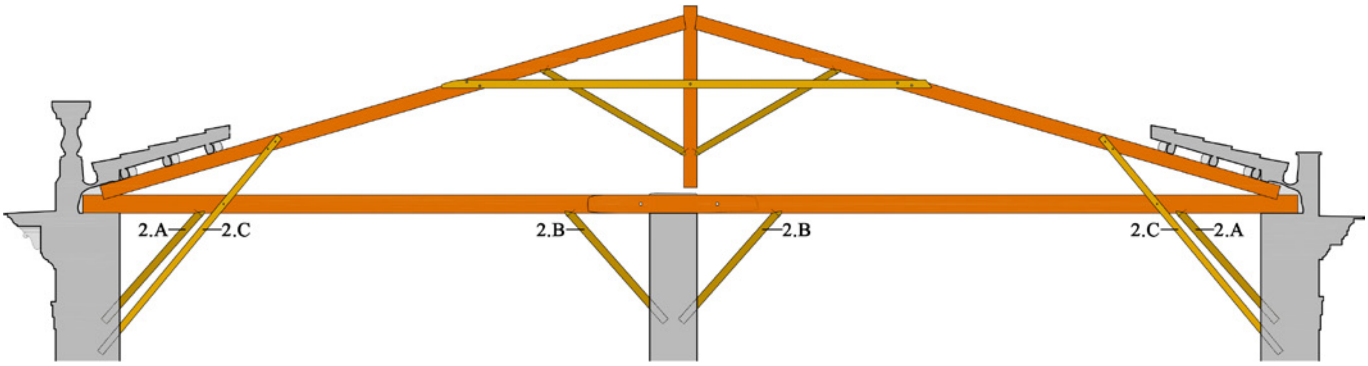

Fig. 2. *Basic scheme, common to all trusses inside the roof of palazzo Butera. The position of the intermediate load-bearing wall, which is almost central for trusses 14 to 31 (Fig. 1), does not influence the scheme. Frequent size of cross sections (width x height in cm): tie-beam 16-22 x 19-25; rafter 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

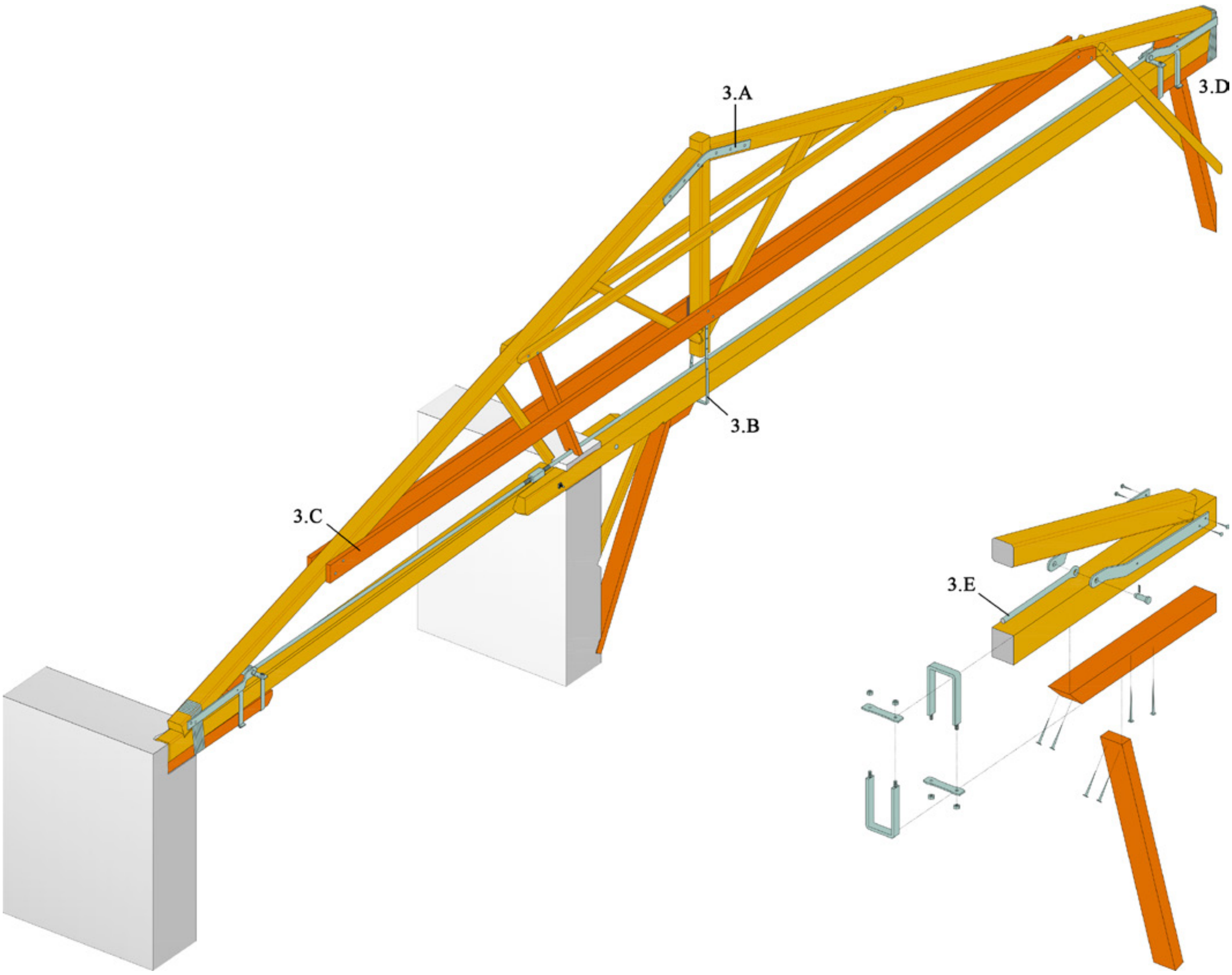

Fig. 3. *Scheme of trusses 1-10 (Fig. 1) with wrought iron and timber reinforcements. The joint between tie-beam and rafter was reinforced by a timber bracket, connected to the tie-beam by nails and a couple of iron fasteners. A thin iron strip was used to wrap together bracket and rafter.*

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

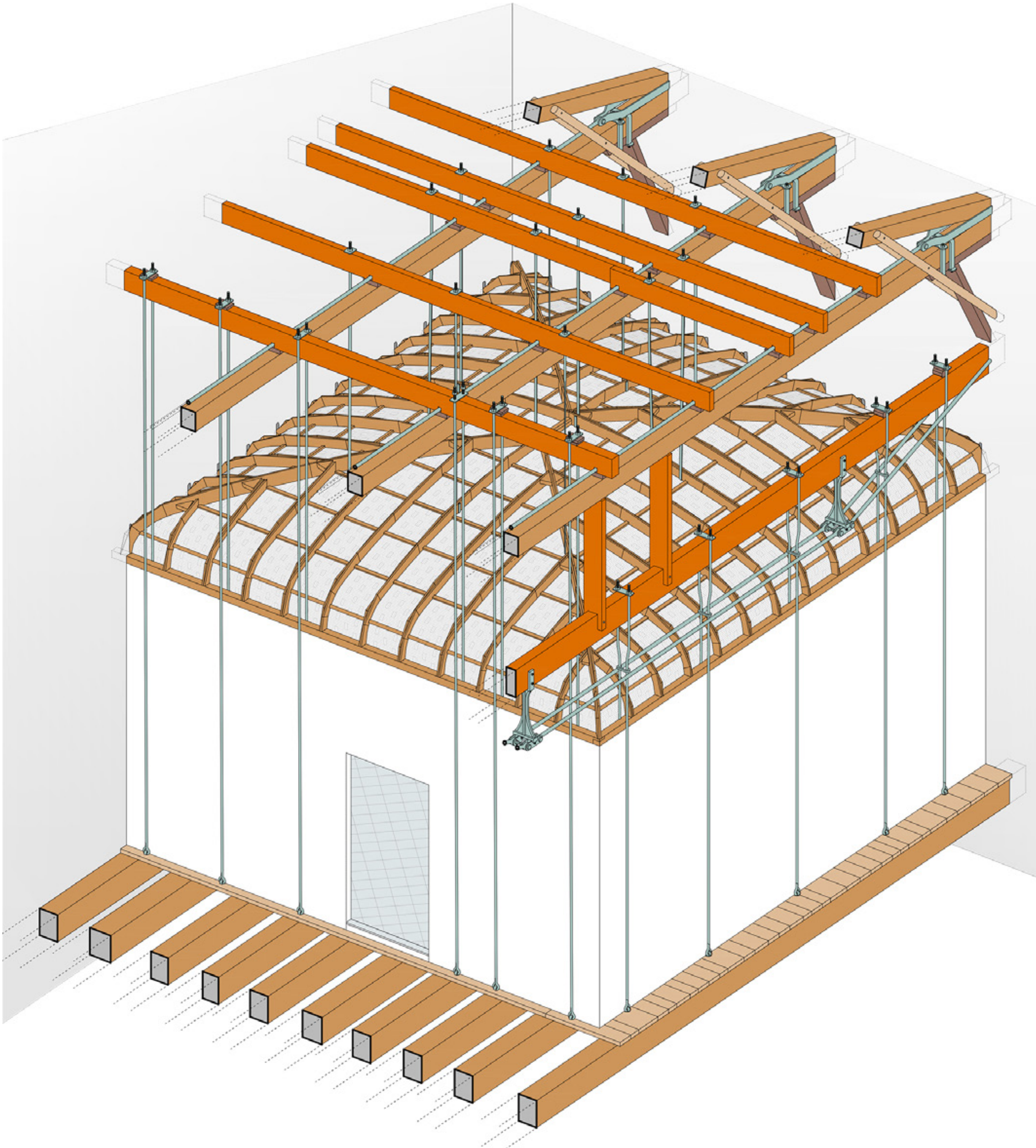

Fig. 6. *Construction scheme of thin-tile brick partitions, corresponding timber vaulted ceiling, and connections to the roof timber trusses on the second storey of palazzo Butera. The average cross dimensions of floor beams are 0.25 m x 0.35 m, while the distance between beam axes is 0.70 m.*

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,

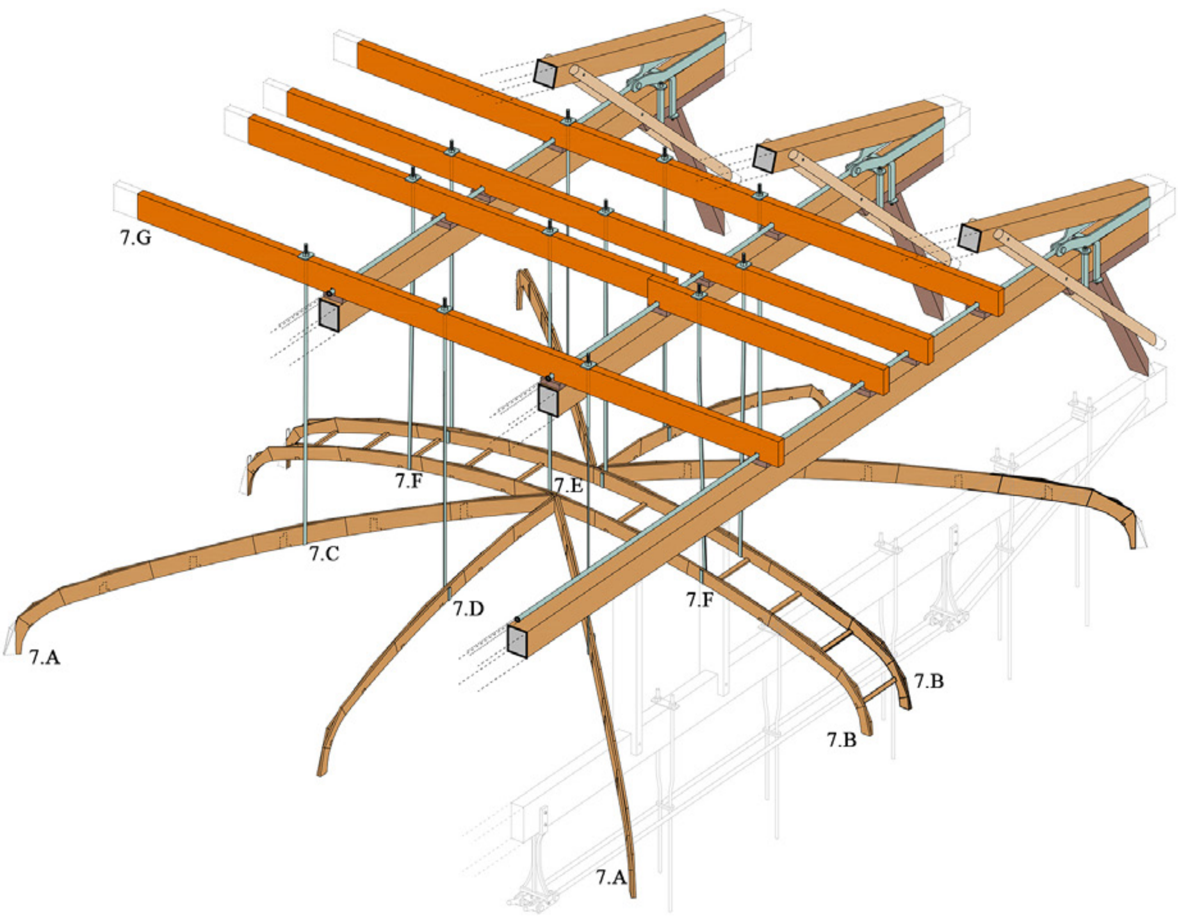

Fig. 7. *Scheme of tie rods and suspended ribs of the vaulted ceiling, together with the bearing joists placed on the tie-beams of trusses. One of the joists is made of two shorter elements with the same cross section as the others. The average distance between the three trusses is 1.6 m.*

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.

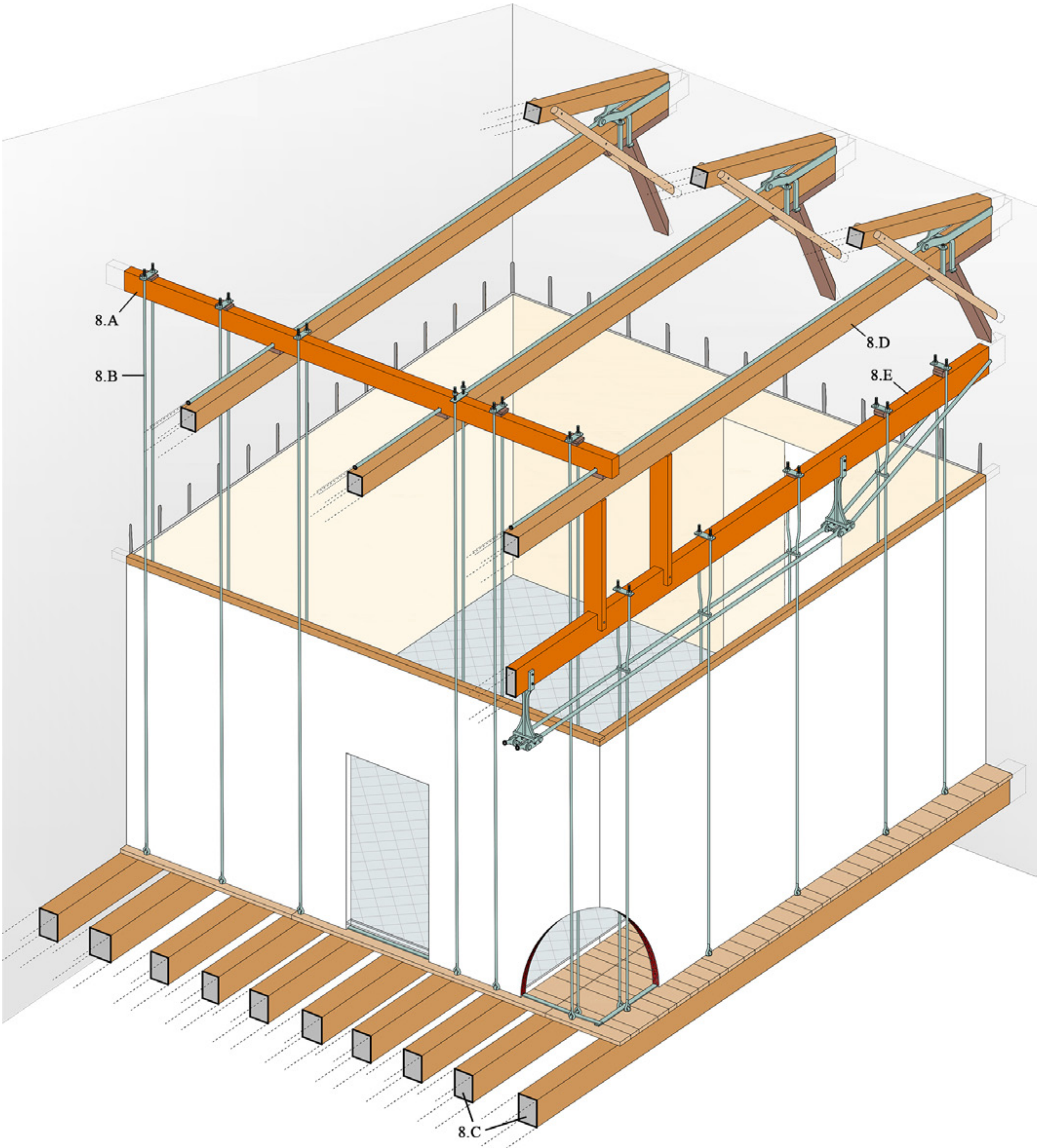

Fig. 8. *Scheme of the system used to suspend the thin-tile brick walls from the roof trusses.*

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,

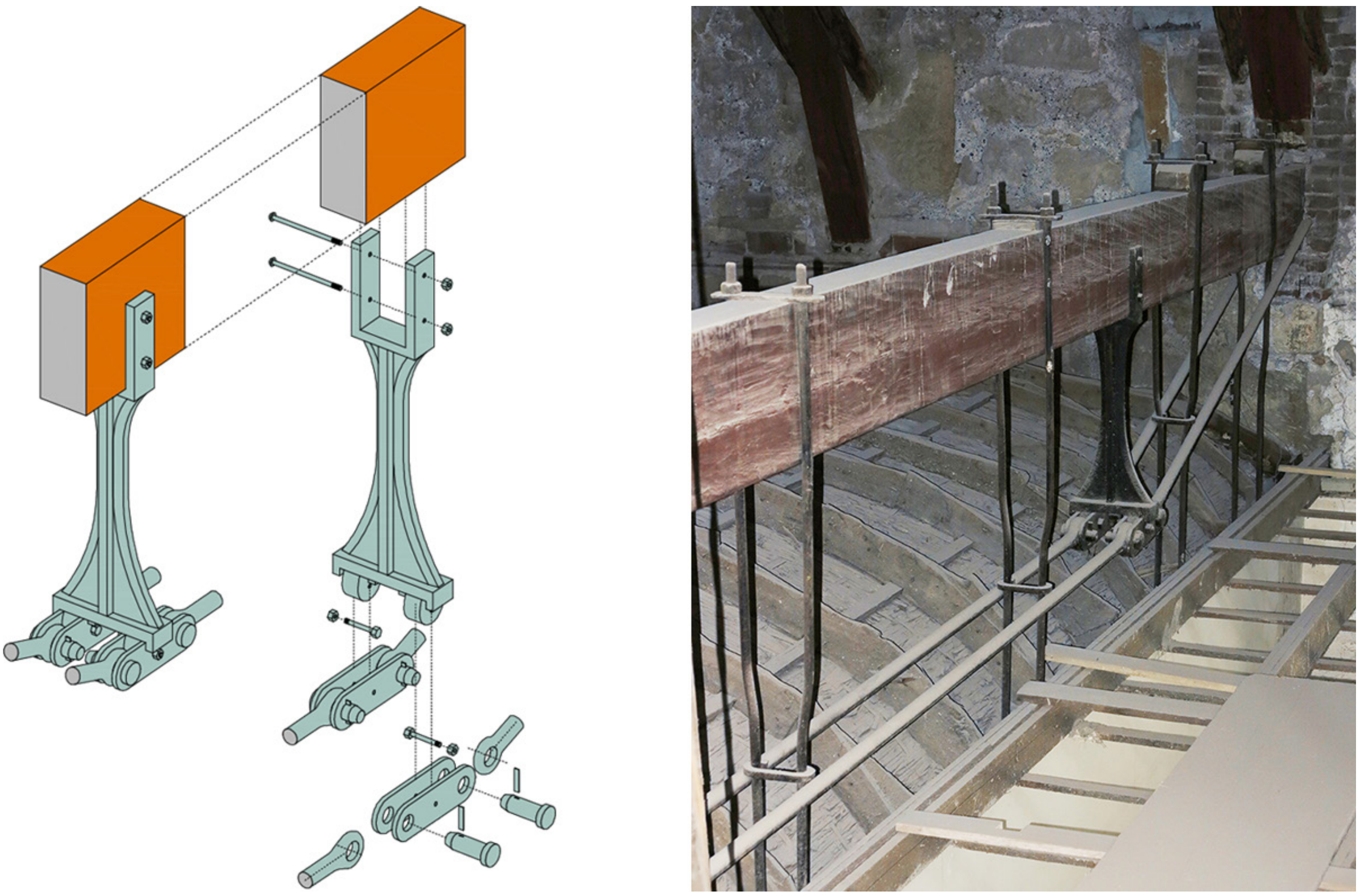

Fig. 9. *On the left: scheme of the metal struts of the trussed beam used to suspend a thin-tile brick partition. On the right: picture of one of the two struts.*

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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