THE *MUQARNAS* CEILING OF THE PALATINA CHAPEL IN PALERMO

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Keywords: wooden structures, *muqarnas,* ceiling

1. Introduction

Roger II, the first Norman king of Sicily, decided to build the *Basilica of St.Peter*, better-known as the *Palatina Chapel,* at the centre of the Royal Palace in Palermo, Italy, between the Greek and the Pisan Towers on the remains of an earlier church of Greek rite. The chapel was consecrated in 1140 [1], but was actually completed well before that date, given that in 1132, it had already been raised to the level of parish church (during the Norman dominion, the second in the city after the Cathedral as regards date of foundation). In 1143 the construction site was still operative, as evidenced by a mosaic inscription on the drum of the cupola. The Chapel has a Basilica lay-out and is characterized by mosaic decoration which entirely cover its walls, cupola and apse; the floor has marble inlays in geometrical patterns, as have the bases of the wall surfaces. The interior is divided into three naves, with two different arrangements of decorated wooden ceilings over the corresponding spaces beneath: a slightly inclined one, with little vaults orthogonal to the longitudinal axis on the two lateral naves (also called *navatine* [1] or *navatelle* [2]), and a *muqarnas* ceiling, a type of decoration commonly found in Islamic-period architecture, with a compact arrangement of niches, convexities, concavities and stalactites. This ceiling, above the Chapel's central nave, has a plan measuring approximately 18.84 x 5.60 meters and is richly decorated with about 750 well-defined small-scale painted figures and scenes, on a variety of themes ranging from splendid palaces to gardens with palm-trees, from lions to birds, from human figures to court-life, from beverages to musical instruments and everyday objects. Leaving aside the exceptional intrinsic artistic value, it is an extraordinary testimony to what is commonly considered the only known example of a *muqarnas* decorative structure made entirely of wood.

In previous centuries historians and scholars devoted their attention principally to the extensive mosaics covering the entire walls and the painted ceilings, but much less so to its construction from the point of view of the carpentry used in assembling the wooden parts; our aim is to study both the load-bearing structures and other non-structural parts in order to discover their peculiarities and possible correlations with coeval architecture. However, the objective difficulty encountered when studying these

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artefacts has so far limited technical knowledge to a reductive examination of the visible parts.

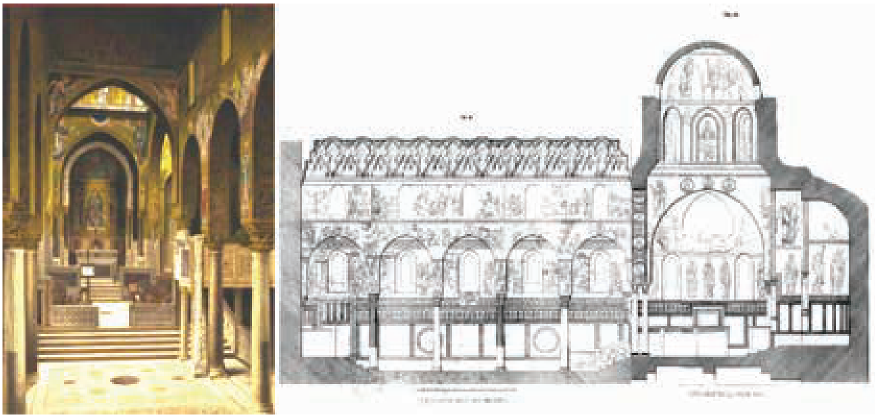

Figure 1. Internal view and longitudinal cross-section of the Chapel [1].

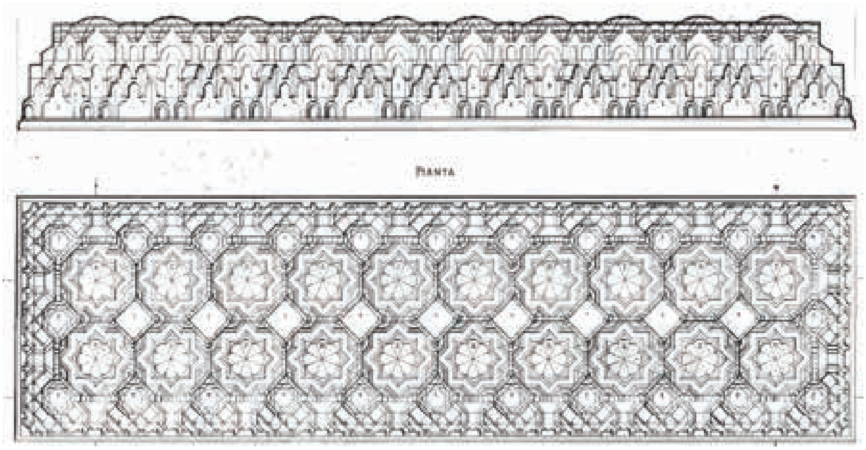

Figure 2. 19th century survey showing longitudinal section and intrados plan of the ceiling.

2. Past interventions on the ceiling

Due to the complexity of their structure, the wooden ceilings in the Palatina Chapel (central nave and *navatelle*) have been subject to periodic damage and disfigurement and have subsequently needed countless restoration interventions, the first dating back to the early centuries of its long existence. In 1348, a document [1] described the above-mentioned restoration work as supervised by the engineer Ughetto from Milan (the successor to a certain Tommaso di Bonaccorso) on the *Sala Verde*[1] and the actual Chapel, following damage caused by a fire started by the Catalana faction in the Palazzo Reale, during a revolt in the same year.

The first reading and interpretation of the Arabic inscriptions on various parts of the ceiling, from the springer cornice to the decorative thumbs, seem to have been facilitated by access to the scaffolding used during on-going restoration in 1798 [2]. These inscriptions bear witness to a series of consolidation and restoration interventions carried out in 1478, 1482, 1499 and 1553.

The emergence of institutions responsible for safety measures prompted the requisite inspections and repairs to the monument, which marked a long period of interventions with particular attention paid to the wooden structures. The first documented 19th century conservational activity, handled by Francesco Saverio Cavallari, director of *Antiquities of Sicily* in 1867, revealed damage to the wooden structures in the central nave and to the stonework structures beneath.

In 1884, the *Restorations Director*, Giuseppe Patricolo, carried out an inspection of the condition of the structures and discovered that the ceiling of the central nave was weighed down by a quantity of rubble deriving from the previous building works; he had it promptly removed and proposed demolishing several odd additions. He added (1887) that *[…] we were able to ascertain that on this side rainwater falls freely on the brick paving immediately above the ancient ceiling, damaging not just, and in an irreparable way, the magnificent tempera paintings* [4]. The works planned by Patricolo and others were urgently carried out in 1891, since they had to be completed *[...] before the arrival in Palermo of the Royal Family on the occasion of the National Exhibition* (held in Palermo in 1891-92)*, because it would be exceedingly inopportune, during this happy event, to present shored up walls […]*. In spite of the work carried out, in a report compiled by the Royal Family's engineer Nicolò Mineo, damage to the decorated ceiling of the left *navatina* was detected, caused by the infiltration of rainwater from the roof *[…]*; apart from this, the entire roofing *had aged and was deemed to be in poor static condition and […] because of the construction system which was unsuitable for protecting treasures of such importance and rarity.* In 1893 the old roofing was repaired and refurbished; iron structures were added together with skylights made with a *galvanized iron* framework, at the level of the southern *navatina.*

Figure 3. Global view of the wooden muqarnas ceiling.

We need to leap forward to the 1920s to find further information regarding interventions on the roof. Francesco Valenti, in 1925, consolidated the structures which had to support the ceiling of the main nave from above, inserting squared pitch pine beams as additional purlins; restoration work was also carried out on the decorative paintings on the intrados together with the consolidation of small wooden parts of the ceiling.

In 1948, the *Istituto Centrale del Restauro*, with its director Cesare Brandi, opened a building-site employing the Institute's students. Work was protracted until 1953 and aimed to tackle all the problems of the ceiling in the Palatina, with particular attention given to the decorated surfaces and gaps in the painted parts. We know that several interventions were carried out on the wooden structure.

Photographic evidence preceding the restoration reveals the disastrous condition of the surfaces with widespread gaps, flaking, cracks and blistering of the pictorial film. The broken-up surfaces were restored and the gaps touched up using water-colouring applied with the technique of "colour breakdown" (*rigatino*), fine-tuned by Brandi and subsequently widely used in many interventions of pictorial restoration.

After the disasters of the Second World War, the Palatina Chapel, according to Brandi, was *[…] saved by a miracle, in spite of the devastating bombardment of Palermo […] the ceiling required minimal restoration […]: then one could see the understated diligence and frail simplicity with which all those cupolettas had been fixed to the ceiling* […]. According to Brandi, the complex wooden scaffolding supporting the ceiling, seen from above, looked like a *puppet theatre* [10].

There was another long wait until the end of the1980s in order to resolve problems deriving from the infiltration of water. This was accomplished by the Superintendency of Palermo which had all the roofing structures removed and a new roof installed using classic truss-beams of glulam with overlapping translucent polycarbonate sheets; at the time this was considered a provisional measure.

The 2002 earthquake caused extensive damage to the Royal Palace and the Palatina Chapel; working in synergy, technicians from the Superintendency for Cultural and Environmental Heritage and the Regional Centre for Design and Restoration were forced to make the first urgent interventions. The willingness of the German industrialist/sponsor Reinhold Würth,[2] founder of the homonymous multinational tool-making enterprise, to finance large-scale restoration work on the Chapel proved providential. A restoration project was financed with a specific convention stipulated in June 2003 and developed by the two Regional institutions. The building-site was opened in March 2005 and the completed work was represented to the city in July 2008.[3] The work-site consented the utilization of a large, stable working-platform reaching up to the level of the ceiling intrados. In the first stages this proved extremely useful for acquiring first-hand knowledge and analysing the plastic and pictorial decorative elements, together with sporadic information about the original construction techniques and the stratification of the interventions over the years. Without the need to remove the precious painted panels, we were provided with the opportunity to accede to the supporting structures, to the lofts and interspaces, in order to inspect and examine the extradoses and the actual wooden structures. The straightforward climb to the platform also allowed numerous scholars and tourists to gain access, providing them, for any number of reasons, with the possibility of inspecting both the decorated intrados of the wooden structure and the spectacular wall-mosaic decoration at close quarters.

These fortunate circumstances enable us today to have access to wide-ranging documentation regarding the original and complex carpentry work and the interventions it has undergone [3].

An opening in the northern wall allows access to the interspace between the roof slab and the monumental ceiling[4] [4]. This circumstance enabled us to carry out extensive, direct scrutiny of the extrados of this ceiling and to understand the rationale behind its construction and structure.

3. The structural/static system of the wooden *muqarnas* ceiling

In the final years of the 19th century F. S. Cavallari stated that *the ceiling was self-supporting* [1], an unshakable conviction which is confirmed by literature in our possession, according to which the complex system of the ceiling had borne its weight for about seven centuries. This was evidently before the wooden tie-beams, which transferred most of the weight to the overlying beams above, had been constructed. It is widely believed that, this profound modification in the static condition was probably the result of having raised the perimeter walls of the central nave at the end of the 19th century. Resting on these walls, the afore-mentioned beams had vertical boards nailed to them and were connected to elements projecting from the ceiling structure. However, due to their particular design, we think that some of these boards and connecting rivets might be ascribable to much older consolidation operations which only analytical studies of the materials and/or archival research might eventually confirm.

Through close observation of the constituent elements visible on the bare jagged extrados, when compared with the highly elaborate shape of the painted intrados (recently subjected to an instrumental survey), we hypothesized what might have been the ceiling's original static system, with the exception of the two opposite extremities. In spite of great inaccuracies, the detailed surveys carried out during previous restoration work (from the mid-19th century onwards), together with the technical-static considerations, proved rather useful, enabling us to formulate sufficiently plausible hypotheses as regards the parts of the wooden structure that remain hidden from view and are impossible to analyse.

Taking into account any possible misinterpretation on our part, several rather unstable parts were identified. It is probably these parts which led to the addition of the afore-mentioned nailed wooden suspending boards This might have been due to the appearance of deforming phenomena, if not actual structural failure, of which we have not found any evidence in the specific literature.

In order to find the original static design we deemed it useful, first of all, to separate the ceiling structure into two clearly distinct parts: A) the central part which is more or less horizontal and B) the steeply sloping lateral strips which transfer the vertical load to the perimetral walls.

The central part of the ceiling is wide and flat with nine parallel "ribs" approximately 2.5 linear metres long, with a distance of about 1.6 linear metres between the axes, made up of square beams about 20 cm high and about 8 cm thick. There is a distance between the rib ends and the longitudinal walls of about 1.6 linear metres. These are the main load-bearing beams, since their ends are connected to the perimetric system B by two horizontally extradosed wooden panels, lying in a direction deviating by 45°

from the axis of the ribs and connected to the latter by nailed boards. The whole, composed of the beams and the extradoses of the afore-mentioned panels, forms the flat sub-horizontal part of the ceiling of the main nave.

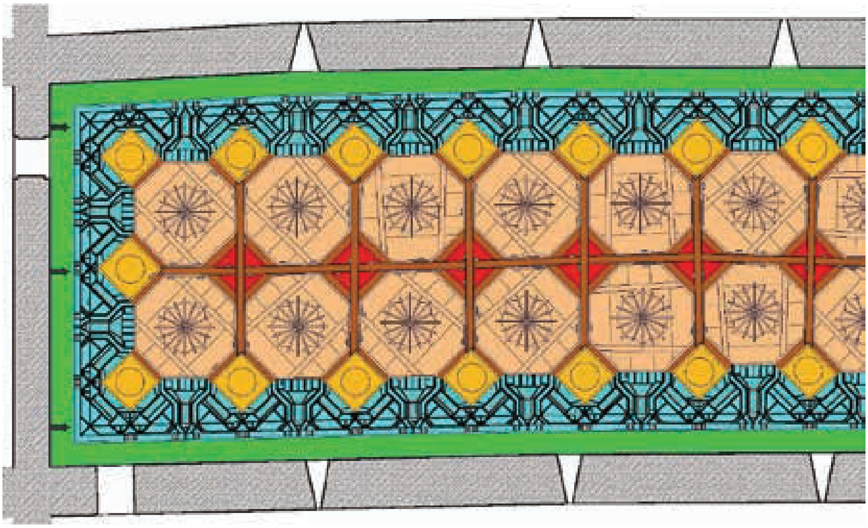

Figure 4. A detailed view (from above) of part of the extrados ceiling: central ribs and diagonal beams positioned at 45° for reinforcement (brown); central squares aligned symmetrically along the axis (red); removable (covering) octagonal cupolas with multilobed star pattern (pink); cupolettas on square support (yellow); steeply inclined perimetral strips, with niches, stalactites, fan shaped vaults (light blue); perimetral masonry (green).

B) Interpretation of the static system of the perimetral parts of the ceiling is much more complex. On average the sections are between 65 cm and 90 cm wide in a horizontal projection, but are actually almost 2.3 m high, bearing in mind the difference in height between the central plane and the wide strip linking it to the outer wall. The tortuous structural lay-out seems to follow a line that forks out and breaks up in at least three points in order to enable the creation of decorative areas in accordance with complex and original outlines, and to form the three-dimensional shape of the cupolas, niches, projections and stalactites. In our interpretation therefore, the load-bearing structure of each "module" in these lateral B areas, extends in the three directions, determining geometric figures able to transfer, at several points in an outward spreading direction, the load on to a complex and atypical supporting structure which rests on the lateral walls. This part is not visible since it is covered by a perimetral boardwalk; it is clear however, that the wide band running alongside the springer of the whole ceiling does not have the function of load-bearing as might seem evident at first glance; it is a simple cove composed of long thin wooden boards, decorated externally, their position and shape maintained by means of wooden frames hidden at the back [5].

As we have seen, whilst it was possible to utilize straight square beams for the ribs and some of the connections between them, they could not be used for the steeply-inclined lateral bands in a broken-up axis; here, the load-bearing structure itself is made up of flat box-shaped panels formed by pairs of planks arranged in a vertical position, connected by systems of fillets, wedges and joist-spacers at variable levels, nailed into the space between the planks, their total thickness varying between 7 cm and 10 cm. The structure is very light but at the same time stiff, the lower edges of the boards shaped in such a way as to follow the complex shape of the decorated intrados. On the extrados these original structures have been left unfinished and are visible from above.

We believe that this undoubtedly bold and original construction system was chosen following a series of considerations that offered more advantages than other solutions:

a) taking into account the spaces between the two layers of boards, one can estimate that the total weight was reduced by over 70% compared to any structure made entirely of solid wood;

b) over the course of time solid wood is subject to permanent deformation to a much greater extent than a system composed of fillets and boards;

c) making connections along the edges between diversely-oriented planes was made easier by the use of vertical fillets of variable shape.

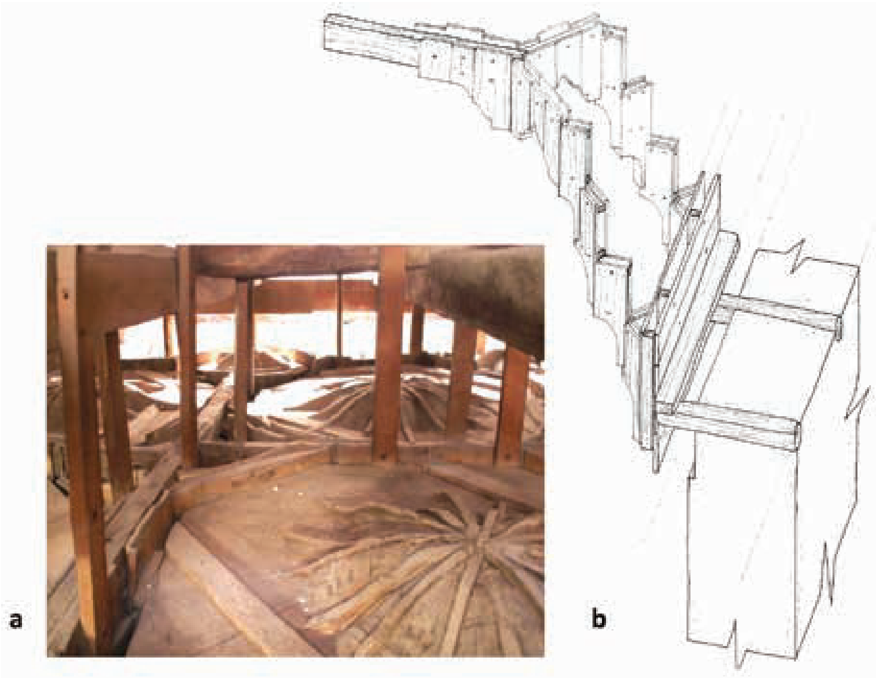

Figure 5. a) Detail of "B" construction system, consisting of wooden planks forming slim box-shaped panels joined to the central rib; b) extradosal view showing the ribs, diagonal beams, octagonal cupolas with multilobed star pattern and wooden suspending boards.

The afore-mentioned perimetric walkway provided by the planking, less than 30 cm wide, (probably) separate from the lower structure, was built at the end of the 20th century in the interspace between the extrados and the lateral walls. Although this walkway, on the one hand, made it easier to gain access to the hidden parts, on the other, it constituted an obstacle to examination of the extrados in the portion beneath the planking. Therefore, our hypothesis regarding the connection between the load-bearing structures of the ceiling and the outer walls had to be based on an analysis of the overlying structural parts that were still visible and the evidence found along the painted intrados surface.

In our opinion, assumptions previously put forward by other scholars [5] with regard to the original support system for the ceiling and connection with the lateral walls found partial corroboration during the frequent site inspections in those points where they were discovered to be compatible with the geometry of the lower registers of the ceiling's decorative system. Approximately at the height of the first decorative register and thus, well above the cornice at the base, there are wooden brackets crossing over the perimetric walls, the rear ends of which are occasionally visible on the exterior of the walls themselves. These brackets are no longer visible throughout their length, but certain considerations and bibliographical documentation [5] [13] seem to make it clear that they jut out from the interior by about 30 cm - 35 cm and support a line of beams parallel to the wall, thus forming the main structural support system for the whole wooden ceiling. During restoration work in 1928, Francesco Valenti reported that there were 11 brackets on each of the long sides (and probably 2 on the short sides), with a cross-section of 0.08 x 0.10 meters, resting on a dividing system represented by "wooden girders" (with an average cross-section of 0.12 x 0.20 meters) deeply embedded in the walls. Over a period of time these beams rotted, leading to partial structural failure in the support of part of the ceiling, which made it necessary to fill the gaps with masonry [13].

A box-shaped panel is nailed to the vertical plane which is marked by the external ends of the beams and brackets; the panel is made up of vertical double planking connected and separated by large spacers measuring 80cm/90 cm in height and runs along the entire perimeter. This internally hollow panel with a total thickness of about 12 cm constitutes the terminal wall of the whole ceiling structure. It receives all the loads through pairs of box-shaped vertical panels, rotated through 45°; the latter constitute the "ramified" extremity of the afore-mentioned B system, making the whole a light-weight structure of great stiffness. This "terminal" panel is joined to the bracket-beam system at an intermediate position along its height, continuing downward in such a way as to form the first underlying decorative register and linking up to the base cornice which, as already mentioned, consists of a hollow wooden cove.

This series of lateral structures (B), with only their lower ends resting on the cornice which juts out about 30 cm from the wall, is unstable if seen separately from the rest of the structure. On the contrary, these lateral structures are to be considered fully able to support themselves and any working loads tightly connected to the horizontal beams (the afore-mentioned "ribs"), by positioning pairs of the same nailed planks, that constitute a fundamental part of the structure, along the greater part of the lateral surfaces.

The sequence of the 9 main transversal trusses described above (A + B), is integrated with longitudinal and diagonal linking elements, with a random and variable use of wooden beams, joists, simple/coupled/multiple planks, fillets and various types of connecting elements. The result is a three-dimensional structural whole that is sufficiently stiff with hardly any thrusting force. At the same time the empty areas are delineated using geometry suited to receiving and supporting the typical decorative elements of the *muqarnas*: from the star-shaped octagons, to the squares with *cupolettas*, from the niches to the stalactites or other built-in or protruding components (Figure 6).

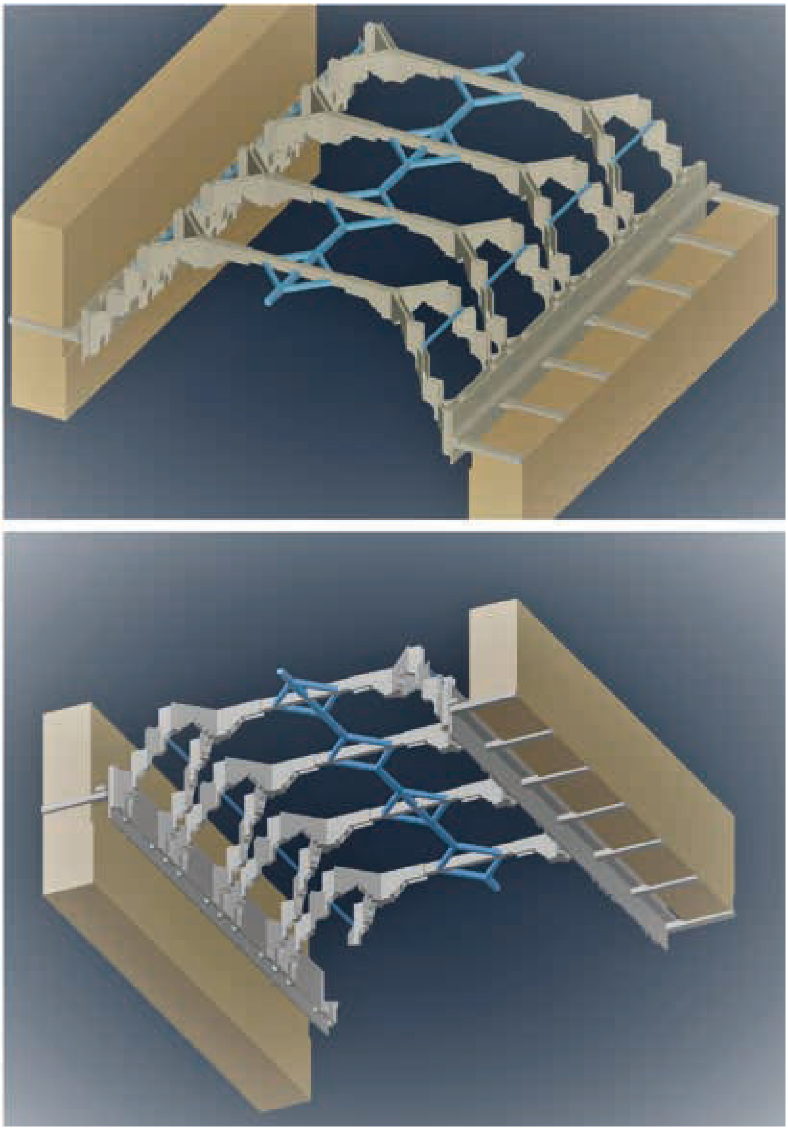

Figure 6. View of structural/static system of the wooden muqarnas ceiling - extrados and intrados view.

As regards the type of wood used in building the ceiling, specific analysis carried out by a team coordinated by researchers from the University of Tuscia identified the widespread presence of fir and pine in both the structural elements and the larger-sized panels, and birch, poplar and beech in the thinner slats. Literature regarding the technical-analytical study of vegetation existing in 12th century Sicily is limited and there was, therefore, an objective difficulty in distinguishing between the various species of fir used in the construction of the ceiling. Nevertheless, owing to certain peculiar aspects, an interesting hypothesis was put forward suggesting that 35 of the 150 samples of wood analysed could be attributed to the species Nebrodi fir (*Abies Nebrodensis*), of which only a few examples still exist in the mountains around Palermo; these are acknowledged as descending from an ancient group that survived the last Ice Age.

In its present state, in many areas, the central ceiling hangs from the beams above by means of small, variously shaped wooden boards that have been nailed in position over the years/centuries using rustic wood, thick square planks and metal section bars. These have contributed to this unique work being handed down to us in almost perfect condition, the lower surface maintaining the extraordinary decorative quality that the Medieval artists succeeded in creating. The simple addition of wooden hanging units also enables us to perceive, in the extradosal details, the original construction techniques used in the Middle Ages to support and shape the various parts of a ceiling of great complexity and execution, as well as artistic quality.

4. The ceiling's decorative modules

Observing the ceiling from the rustic and bare extrados, a complex frame is visible which, on analysis, immediately reveals the skill used in creating the extraordinary tableau of the intrados with simple raw materials; its execution and static reliability were the result of construction know-how that was well-known to categories of specialized craftsmen, from the choice of materials in the various applications to the way the structural elements were linked to each other, in other words the work involved in the finishing and completion stages.

The previously mentioned Saverio Cavallari was able to examine the extrados and tried to provide an analytical description: […] *the vault is made up of pieces of wood, whose thickness is no more than about a centimetre and a half, with the ribs and the largest sectors skilfully connected to each other and reinforced with bronze pins. However, independently of these pins, since the vault is generated from a mixtilinear curve, it supports itself by means of the wedge arrangement, in which the ribs are arranged between the joints in such a way as to increase the contact surfaces to achieve greater solidity. At the point the curve begins there is a series of niches one upon another, thrusting upward in order to support the central part where the octagonal lacunars are found. The upturned pyramids like so many stalactites also serve as just as many wedges …* […] [1].

As a connection and an integral part of the main load-bearing structure, there is a framework that completes the whole by connecting and integrating it into the main load-bearing structure, thus giving shape to the lacunars and providing a space for the other decorative elements. The framework is made by means of juxtaposing and nailing planks and slats to give shape to the different surfaces of the wooden *muqarnas* decoration. Planks of wood are linked to small wooden boards and thin wooden fillets, varying in width, length and section, ranging in shape from rectangle to wedge, useful for shaping the mixtilinear profiles, i.e. for determining the appropriate curvature to be used in the concave and convex parts, in the small-scaled barrel vaults or the truncated-cone and/or fan-shaped portions.

The wooden elements in the ceiling of the Palatina Chapel have been surveyed many times over the centuries[5] [6], with results that have not always been consistent. Thanks to the raised work-platform and the site scaffolding it was possible to carry out a detailed operation of measuring and examination of the ceiling, with the additional aid of laser-scanner technology, both during and following the restoration work [7].

The first evaluation phases were geared towards individuating the dimensions of the ceiling and any possible warping phenomena (with regard to both the supporting wall structures and the actual ceiling); investigations were carried out on the vertical sections utilizing the cross sections for the axes of longitudinal and transversal symmetry. After close examination of the plan, it emerged that the central part of the wall on the north side is affected by noticeable warping, whilst the east and west walls maintain an almost straight profile. The south wall presents a planimetric curve on the west side and a concavity on the east side [7].

The geometric areas defined by the elements of the ceiling structure provide the seat for the decorative modules, their succession and juxtaposition creating the volumetric shape of the entire ceiling.

In the flat part of the ceiling it is possible to distinguish the following primary ornamental components of the intrados:

a) 9 squares along the axis of longitudinal symmetry;

b) 20 star-shaped, multi-lobed octagonal cupolas, arranged symmetrically with regard to the longitudinal axis in two rows, each of ten stars;

c) 24 circular, low-profile *cupolettas* along the four sides of the ceiling perimeter;

d) 56 whole “stalactites”, of which 36 are arranged in groups of four around the decorative modules of the 9 central squares; the other 20 are distributed along the internal edges of the modules containing the multi-lobed octagonal stars. In addition, 48 other stalactites, incomplete as regards volume, are arranged along the perimeter of the flat part of the ceiling.

More specifically:

a) At the intersection between the aforesaid nine ribs and the connecting beams along the axis of longitudinal symmetry, the nine squares with a flat intrados reappear once again. From above, only the structural elements, at the edges of the square which define the perimetric framework are visible; the two surfaces of the framework itself are covered by nailed-down planks. At the centre of the intrados surface, richly decorated with geometrical motifs, there is a metallic ring connected to a pin provided with an eye which was presumably used as a hook for a lighting holder and anchored deeply to the rib structure. The vertical surfaces of the stalactites converge at a point corresponding to the vertices of the square.

b) The star-shaped, multi-lobed octagonal module on the extrados is a rustic structure, created and decorated separately and easily removable whenever inspection of the interspace is required. The posthumous construction of the “hanging units” in most cases prevents their removal. Each side of the octagons measures about 60 cm, with slightly variable measurements however, from one lacunar to another; the “star-shaped” cupola has a rise of about 25 cm.

The flat part along the perimeter, which is itself octagonal in shape, consists of boards placed side by side and nailed to at least two other boards positioned in a transversal direction. To ensure the sealing and consolidation of the joins between the boards, wood-fibre bast was pasted on in a longitudinal and transversal direction.

The structure of the poly-lobed star adheres to the building strategy of wooden ceilings, with centrings of curved ribs opportunely shaped to follow the curvature of the intrados. These curved ribs are arranged radially and fixed with large nails to the planks on the edges of the cover-panel.

The "petal" structure is made with curved veneers (probably either using steam or through repeated soaking) and lint wood with glue nailed to the intrados of each of the afore-mentioned centrings. The cover-panel rests on the fillets or the planks at the edge which are nailed to the "ribs" and the secondary connecting structural elements. On the intrados, the cover-panel bears pictorial decoration only on the part that is visible (mostly geometric motifs and human figures). The line of discontinuity between the fixed and the mobile parts is partially hidden by small protruding cornices that form a continuous cordon, whilst the spaces between the planks and veneers and between the supporting structures and petals are hidden by layers of gypsum plaster and stucco.

c) The little *cupolettas*, with pictorial decoration of a mainly geometric and non-figurative type, are set in the middle of a flat cover-panel on a square base; this too was made with planks placed side by side and nailed on to other transversal planks. The *cupolettas* have a base measuring about 50 cm per side and a rise of about 20 cm. At the vertices of the quadrangular hole, on which the cover-panel with the *cupoletta* rests, there are diagonal fillets hidden on the intrados that provide a triangular support for the vertices of the cover. Only the central part of this decorative module, corresponding to the *cupoletta* and to the perimetric 8-pointed decorative band, was built off-site. After being completed and finished, it was placed on the fixed part of the perimeter characterized by a star-shaped hole. The *cupoletta* structure presents several construction variables: some have ribs jutting out from the extrados and the dome shape, produced using steam and/or wet curved veneers nailed to the actual ribs of the intrados, then stiffened with strips of pasted-on lint wood. Others include a structure with wooden strips positioned in different directions or a structure with a device consisting of small veneer rectangles applied in several layers with staggered joints, which perhaps made it easier to obtain the desired curvature. Along the edges of the lacunars, created to accommodate the mobile ornamental modules, the rustic planks were left to jut out from the extrados so as to keep the cover-panels firmly in place, preventing the lateral portions with no decoration from remaining exposed (Figure 7).

d) The "stalactites" in the central area of the ceiling placed at irregular heights, ranging between 40cm - 55 cm, are hollow wooden structures, most probably formed by a fillet frame to which the small lateral wooden boards are nailed. They have the shape of an asymmetrical triangular section so as to render the surfaces congruent with the adjacent decorative panels. They stand upright, in a position corresponding to the central square panels and are inclined and mixtilinear in the other directions. As with the *cupolettas* they were constructed separately and then nailed to the structure above with appropriate boards and fillets which emerge from the extrados of the stalactite itself (Figure 8). Each stalactite has a removable *pendentif* inserted into a predisposed clearance hole on the lower end. In addition to these are other partially completed stalactites which enhance the perimetric *muqarnas* decoration in such a way that they create *[…] powerful shapes which form a significant interplay of masses and thus, of shadow and light, a succession of planes of varying levels that give a strong sense of moulding* [2].

Figure 7. Top: intrados views of multi-lobed star on octagonal support and star-shaped module of a cupoletta. Bottom: different construction systems used for the cupolettas.

Above the ornamental shell-cornice running along the four walls in the area of the central nave there is a wide decorative strip with a succession of registers, with niches, deep recesses and highly protruding elements, that reaches an overall height of about two linear metres. This is the part of the wooden ceiling that slopes very steeply and described in the previous section as “system B”. It is made up of structural elements consisting of vertical double planks that go off in various directions, with interposed spacing/stiffening joists. The finishing structure to complete the *muqarnas* was then arranged on top of these, with variegated forms and modules making up the four overlapping horizontal decorative registers. Operations to finalise and complete the work were steadily carried out drawing on geometric Muslim matrices [7] shaped in accordance with the diverse types of niches and the outwardly jutting parts of the *muqarnas*.

The result is cavities of different sizes that overlap with each other in the various registers, such as the one with a superior mixtilinear profile (just as an example) made with flat slats for the bottom and small fillets, about 5 mm thick, for the surface. Its solidity was ensured using nails and pasted-on lint wood. Niches of a truncated-conical shape, made from a series of small trapezoid shaped veneers, are laid out radially and are also connected to the small wooden boards at the end with nails and strips of wood-fibre and glue. In similar fashion, the elongated niches were given a barrel roof shape and those that constituted the brackets, a "*cavetto*" profile, useful for linking up the honeycomb decoration with the central portion of the ceiling, creating the characteristic steep progression of the projections (Figure 9).

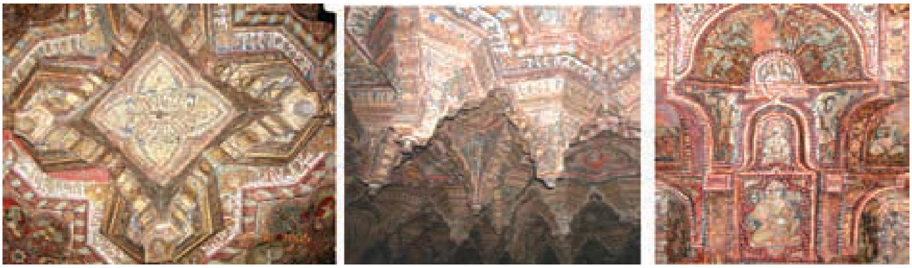

Figure 8. Intrados view of square central modules and stalactites. Decorative muqarnas registers, steeply inclined, in proximity of masonry.

Figure 9. Construction details of decorative elements in the muqarnas registers.

Here, we shall limit ourselves to pointing out the rich imagination demonstrated in creating the areas that give rise to the honeycombs of various shapes and sizes, the differences linked to their position with regard to the structural fields, to the disposition of the portion of the ceiling and to their proximity to the corners [7]. The systems for connecting the wooden elements vary primarily according to the structural role or finish of the parts to be linked. There is widespread use of nailing to join the different elements and varies depending on the material employed: from the bronze pins mentioned by Cavallari to the iron elements which vary in length and nail-head section, often with curved ends in order to prevent extraction. The preparatory layers for the pictorial decoration consented many of these nail-heads to be concealed but became visible once more in those areas most affected by deterioration. As already suggested, the system of veneering the thinnest and most fragile wooden elements is widespread, involving binding with wood-fibre and animal glue to ensure adhesion between the flat elements placed side by side along the slender edges and possibly substituted and/or reinforced at a later date with extra binding in flax and hemp gauze [5].

There are also reinforcing and connecting elements made from small wedges and chocks, used to strengthen the structural parts that tend to become detached.

5. Overhead structures and support beams for the ceiling

In the large space above the *muqarnas* ceiling, there is a system of wooden and metallic beams which, as previously noted, today constitutes an appropriate support structure from which the monumental wooden ceiling is suspended. This is evidently a posthumous addition, but it has proved most useful in containing the warping, shifting and deformation of the parts, which might have caused considerable damage to the structure and, in a worst-case scenario, the precious pictorial surfaces on the intrados.

The afore-mentioned perimetric walkway on the extrados of the ceiling, allows access to the entire interspace and facilitates inspection of the various orders of beams supporting the *muqarnas* ceiling.

A first order, made up of four NP-160-type iron beams, was set in place by Francesco Valenti in 1939 in the direction of the short side of the nave. Apart from supporting the ceiling, the two opposite walls were connected by using longitudinal contrast sections (with a UPN 140) and tightening bolts.

A second order comprises two pitch-pine purlins, each made up of two pairs of beams (with a 5.5 x 211 cm section), set in place in 1894; a subsequent third order is made up of 22 semi-square beams (of sections varying between 10 cm x155 cm and 13 cm x18 cm) dating back to the period of the late 19th century when work was carried out to raise the central nave. Due to the absence of ventilation holes, some of these beams had visibly deteriorated heads, causing a reduction of the section, surface whitening and loss of material compactness. Between the ordinary beams and the purlins there is often a contrast wedge for "structural activation", i.e. a steel corner fixed to the beams with self-threading screws. The stringers resting simply on the beams beneath might be considered a fourth order, with a variable length of 77cm - 290 cm and a section of 5 cm x 55 cm to 8 cm x 16 cm.

The wooden hanging units are connected to the stringers and the beams; they are simple laths with an average section of about 3 cm x 8 cm and a variable length of between 70 cm -160 cm. In all there are 174, of which 114 are nailed to the system of semi-square beams and 60 to the longitudinal stringers. The connection is made on the long side of the section of the "hanging unit" as well as on the short side. In the latter case the lath often has a cavity which reduces the section. It has a regular and sub-vertical shape in the flat part of the ceiling and is slightly inclined when it lies along the perimetral strip of the ceiling [8, 9] (Figure 10).

In the central nave, the whole structure of the Chapel is covered by a flat floor, consisting of a simple framework of beams placed along the smaller span; the planking on top was exposed for a long time to the inclemency of the weather and only in the 1980s was it provided with a temporary covering which, however, caused a microclimate that was most unsuitable for wooden structures. The removal of several parts of the 17th century floor brought to light ancient flooring in *cocciopesto,* about 4 cm thick; the exposed surface is beaten and smoothed over and has an underlying screed containing significant pieces of *cocciopesto* of a more refined texture. Elevation of the outer walls is clearly visible, with an increase in the height of the springing line of the floor covering the central nave of about 1.10 m, compared to the original, presumably dating back to the Norman era. This stonework is different in both bond and thickness, consisting of perfectly square ashlars of bio-calcarenite up to a certain height. On top of this lies disorderly masonry made of rubble from demolition- waste, the wall spaces being filled with the bones of fowls, cloth remnants and even a shoe and spoon clearly of 17th century production.

Figure 10. Wooden plank hanging supports connected to overlying structures and support beams for the ceiling, made of iron and wooden beams.

6. Conclusions

In addition to the evident aesthetic quality and skilfully depicted scenes from life at that time, the wooden ceiling of the central nave of the Palatina Chapel also displays its uniqueness and exceptional qualities in the conception of its structural system and building design together with the techniques involved in producing the different component parts. It seems that the numerous interventions for maintenance, restoration and consolidation over the years have not greatly modified the original structure, except in several structural joins /connections or marginal architectural elements.

Accurate analysis enabled us to understand how different types of wood came to be employed; although the wood probably came from Sicilian forests, only a number of the species used still exist on the island. The variety in its workability and mechanical resistance indicate it was used in different parts of the ceiling, from the long, straight "ribs" to the connecting planks, from the fillets to the extremely thin slats used in shaping the niches, honeycombs and the more complex reliefs.

The investigation was facilitated by recently-executed cleaning operations which vacuum-cleaned the damaging quantity of dust and other deposits from the surface of the ceiling's extrados. In many areas, these substances made it difficult to identify the various elements involved in its construction. Furthermore, the utilization of brushes and scalpels consented removal of the encrustations and the more firmly attached elements. The same operation was necessary for the hollow interiors of the stalactites, which were full of rubble resulting from the demolition of the floor above, pigeon-droppings and dust. The consequent increase in load, in several cases, might well have contributed to some of the parts becoming detached. This material, which is loose and consequently unstable in the case of horizontal forces, was also extracted manually, thanks to the presence of the mounting hole of the wooden pendant-drops at the tip of each stalactite.

As regards the other conservation and restoration interventions on the ceiling's extrados, mention should be made of the cortical consolidation of certain parts, and the revision of the wooden and metallic joints, with accurate re-bonding and substitution of small, deteriorated parts. The intervention was completed by treating the extrados surfaces with a fire-proofing spray.

The study has confirmed the extraordinary nature of this great structure with regard to both the originality of its technical and decorative solutions and the executive quality. This is the only example of wooden carpentry from the Islamic era still surviving in Europe; it is also priceless in that it has remained almost totally immune to change when compared to its original structure.

The neat, modular sequence that is recognizable on the decorated intrados loses a great part of its geometrical rigour in the apparent disorder of the extrados; its rustic wood box-panels linked to each other in complex shapes and horizontal dispositions, the increasingly thinner slats, nailing, the pivoting and gauze bandaging, fibre and glue, all bear testimony to the incredible artisanal and artistic skills.

Most surprising is the multi-branched, three-dimensional static model which relies on very few precise elements for its support on the walls: with no risk of instability, 26 brackets manage to keep the precious ceiling safe from damaging external sources of moisture. The large cornice at the base is also rich in decoration and inscriptions and leads us to believe that it constitutes the perimetric supporting base for the ceiling, whereas, in reality, it is internally hollow. The behaviour of the whole structure and the decorative finishing elements is thus revealed, the understanding of which seems essential to evaluate the Chapel's state of health and to plan possible future maintenance and consolidation interventions.

Acknowledgements

The author would like to especially thank Calogero Vinci (engineer) for his cooperation in the CAD drawings of the structural model of the ceiling.

Notes

[1] The traveller Ibn Gyubair, in 1184, described the Palazzo Reale in Palermo and, in particular, what one presumes was its "green room": *"[…]We went through squares, gates, royal courtyards and saw splendid palaces, well-laid out exedras, gardens and rooms for public officials, things to dazzle one's eyes and astonish one's mind… apart from other things we noticed a hall in a large courtyard surrounded by a garden and flanked by porticoes. The hall takes up the whole of the courtyard, to the extent that we marvelled at its size, the height of the belvederes. We discovered that this was the place where the king usually dined with his retinue. Opposite were the afore-*

mentioned porticoes and the offices where the magistrates, public officials and the finance agents sat […]".

[2] The authors wish to thank *Würth srl* most heartily for their cooperation in consenting the use of images taken from the site archives, as well as the restoration-site operations management and the sole project manager.

[3] A temporary entrepreneurial association (ATI) was set up between the firms "Martino Solito restauratore s.r.l." (group chief), "Consorzio C.B. ART" of Marina Furci, "Studio C.R.C. S.r.l." of Paolo Pastorello, Carla Tomasi and Sergio Salvati.

[4] This opening was attributed to transformations undergone by the northern nave between 1786 and 1795, for the construction of an access stairway to the Astronomical Observatory; see [4].

[5] In 1891, on the occasion of the *Esposizione Nazionale* held in Palermo, the pavilions designed by Ernesto Basile housed three wooden models of the ceiling, today conserved at the Accademia di Belle Arti in Palermo. In 1893 Alexis Pavlosklij published the first thorough and precise analysis of the stylistic features of the ceiling, as well as an Islamic attribution for the pictorial cycle.

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Biographical notes

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Summary

St. Peter's Basilica inside the Royal Palace of Palermo, known as the *Palatina Chapel*, is one of the most popular medieval monuments in Sicily. Built between 1130 and 1163, it contains interesting wooden framings that represent both bearing and finishing structures.

Studies on the Arab-Norman church have often concentrated on the very rich and suggestive decorative mosaic apparatus of walls and floorings, as well as the pictorial cycle of wooden ceilings. Knowledge about the constructive techniques adopted and in particular, about the realization of the coverings, is very limited: there are wooden floors built at different levels, vaults and wooden ceilings and among these is the portion that covers the main nave, housing the *muqarnas* decorations.

The fortunate coincidence of the restoration building yard made it possible to gain precious knowledge of this extraordinary wooden structure, also through a laser scanning survey of a significant area of the wooden ceiling, performed with a low range device. The collected data adequately represent the geometry and the state of conservation of the ceiling and have been used to develop a spatial and geometrical analysis of the *muqarnas* and relate it to the structural layout.

The survey of the internal and external sides of the covering enabled us to investigate further the materials and constructive techniques employed in this ancient wooden ceiling. At the same time, we were also able to document the original structural system and the completion parts, its conservation status and the interventions and modifications it has undergone through many centuries.

Riassunto

La Basilica di San Pietro, all'interno del Palazzo Reale di Palermo, nota anche come Cappella Palatina, è uno dei monumenti medievali più conosciuti in Sicilia. Costruita tra gli anni 1130 e 1163, contiene opere di carpenteria lignea di grande interesse, sia dal punto di vista strutturale che per quanto attiene gli aspetti decorativi.

Gli studi sulla chiesa arabo-normanna si sono il più delle volte concentrati sul ricco e suggestivo apparato musivo, sia sulle pareti che nelle pavimentazioni, così come sul ciclo pittorico dei soffitti in legno. La conoscenza delle tecniche costruttive adottate e, in particolare, dei sistemi di impalcato della copertura, è molto limitata: si ritrovano solai di copertura impostati a quote differenti, ma anche volte e soffitti in legno e, fra tutti, particolare qualità ha il soffitto decorato a muqarnas che copre la navata principale.

La fortunata coincidenza del cantiere di restauro ha permesso di acquisire preziosi elementi di conoscenza di questa straordinaria struttura in legno, anche attraverso un

rilievo a mezzo di scansione laser di un’importante area del soffitto a muqarnas eseguita con un dispositivo a bassa portata. I dati raccolti rappresentano adeguatamente la geometria e lo stato di conservazione del soffitto e sono stati utilizzati per sviluppare un’analisi spaziale e geometrica del soffitto stesso di correlarla allo schema statico-strutturale.

L’indagine sia all’estradosso che all’intradosso ha permesso di approfondire i materiali e le tecniche costruttive impiegate per la realizzazione di questo soffitto in legno. Allo stesso tempo, si sono potuti documentare sia l’originale sistema strutturale che le parti di completamento, lo stato di conservazione e gli interventi e le modifiche subiti nel corso dei secoli.