The Muqarnas Wooden Ceiling and the Nave Roofing in the Palatina Chapel of Palermo: Geometries, Failures and Restorations

Mario Li Castri, Tiziana Campisi
Dipartimento di Progetto e Costruzione Edilizia - University of Palermo

Relationships between basic geometry, mechanical and damage behaviours in muqarnas wooden ceiling of the Palatina Chapel in Palermo

Complex wooden carpentries, as that of muqarnas ceiling in the Palatina Chapel of Palermo induce technicians and scientists to have a relationship with interesting study-cases, in which the aspect connected merely to basic geometries and volumes (particularly - for the examined case - the intrados and extrados surfaces, strongly plastic, corrugated and modelled), indissolubly integrate themselves with the adopted materials (above all, wood and iron), with constructive elements on a vast scale (we thought to the realization of principal and secondary bearing structure, of finishing and completing parts, useful to the intrados continuity), as they integrate themselves with detailed aspects (we cited the little wooden rods, joists, tablets and slats used to model now the muqarnas alveoluses, now the barrel vaults, the segmental domes or the vaults having a mixtilinear profile, etc.), and also with specific constructive technologies (particularly we refer to connection systems through nails and strips, permeation of structural elements, ..., resulting very important and resolutive for a wooden carpentry so articulated, and that have to be extremely accurate and reliable, because of they constitute “sensible” points of efficacy and/or structural frailty, besides a punctual constraints).

A such “scenic machine”, spectacular for its pictorial impact and planned for result “self-carried”, is above all a structural system at risk (for its staggers of planes, projecting and re-entrant parts,...) and also “heavy”, for its overhanging and “suspended” elements, like the pyramidal stalactites in correspondence of central portion: the complex volumetry of each single part makes significative the study of the whole carpentry, not only in the survey analysis (direct and instrumental) of the same constitutive geometries, repeated to constitute modular unities, but - above all - if collected data will be related and read in parallel to the mechanical behaviour of structure in time: disconnections and disarrangements happened during the centuries induct –in fact –to the introduction of carrying and protection systems, suggesting to the scrupulous and respectful project of restoration and structural rehabilitation the better verify of correct functioning of related structural systems (ceiling/support structure); moreover, we don’t underestimate as often the overhanging structures could reflect the effects of their failures on the underlying ones, and from these conditions derives the useful verify of deformations and decay of nave attic roofing (relationships among ceiling/support structure/attic floor).
Figures 1, 2. Little wooden rods, joists, tablets and slats used to model the muqarnas alveoluses, the barrel vaults, the segmental domes or the vaults having a mixtilinear profile.

Figures 3, 4. Verify of disconnections and lost of elements in correspondence of pyramidal stalactites and unthreading of nails.

For the Palatina Chapel, and as we better would examine in the next paragraph, the connection of wooden ceiling to an apposite and autonomous support structure (realized in 1939) results useful but introduces possible risks correlated to prospective deformations and failures of the same support structure; besides, the continuity solutions offered by the numerous pieces and elements composing the structural unities of ceiling, often also minute, presumably induct in time to interventions that would limit warpings, slippages and translations of parts, dangerous for the structure and also for the precious pictorial surfaces at intrados: starting from these premises - et not only during its construction – further joints and maintenance interventions were realized, orientated to the monitoring of deformation mechanisms and possible failures in act. These two aspects, interface with deformations and disarrangements caused not only by vetusty, but also by erroneous maintenances, or by restorations effected during the time, by external conditions (earthquakes, or as we said damages inducted by overhanging structures, ...), that constrain the Norman ceiling to suffer loads and failure (wreckages that are located above all inside the cave portions).
The ceiling, object of great attentions for the valuable pictorial decorations of the intrados surface has been inspected punctually to the extrados, noticing as the central stalactites, that initially we presumed were realized as solid wooden elements, really they were hollow inverted pyramids that in time were saturated with various materials coming from the demolitions of the overhanging attic, pieces of ashlars, mortar, guano and dusts; this condition determines a serious increase of loads, contributing so to disarrangements and disconnections of parts.

Figures 5a-b-c, 6, 7. Extraneous materials coming from the demolitions of the overhanging attic, that determines a serious increase of loads, contributing so to disarrangements and disconnections of parts in correspondence of stalactites and hollow parts at extrados.
This material, besides incoherent and therefore mobile to horizontal actions has been drawn out manually through aspirators, also thanks to the passing hole of wooden pendants put down in the stalactites, carved like a drop. Besides the removal of these elevated loads, extraneous for the structure, the intervention proceeds to a cortical consolidation and to the revision of all bearing systems with a direct investigation on wooden and metallic junctions. The fireproofing treatment of extrados surface completes then the intervention. The completion of the analysis on the real geometry of ceiling, supported by minute operations of instrumental survey, effected with laser scanner, and from the studies about the constructive systems of assemblage of every single parts, allows to read in parallel the examination of disarrangements and failures, and a structural modelling allows also to understand the mechanical behaviour and to analyze the necessity of further vertical and horizontal bearing elements of support, that will be inserted in the restoration phases.

Failed maintenances and interventions, disarrangements and decay during the centuries of wooden structures of nave

The painting wooden ceiling of the Palatina Chapel, erected by King Roger II immediately after his crowning (1131), is the only pictorial monumental wooden structure of the Fatimite period integrally survived in the whole Mediterranean Basin. About materials, constructive techniques and recent restorations an article published on the Proceedings of the past 15th IIWC International Conference and Symposium has already deepened these themes, as a poster introduced to this 16th IIWC International Conference and Symposium deepens instead the complex geometries of ceiling, useful to delineate the correlated phenomena of disarrangement and decay, and the actual restorations.

The wooden roofing system of the Chapel is still less known than the wooden carpentry of muqarnas ceiling, tightly connected to the same underlying ceiling, resulting a fundamental technological element of completion for the Norman monument. The Palatina Chapel has a basilical plant with three aisles and presents in its central portion an horizontal roofing, unlike other coeval architectures having the same typology, that present roofings with span-roof. The roofing structure of the three aisles,

---

1 Look at Li Castri M., Campisi T., Fatta G., Timbered coverings and ceilings of the Palatina Chapel in Palermo. Materials, constructive techniques, restorations, published on the 15th IIWC International Conference and Symposium Proceedings. Look also at Agnello F., Campisi T., Li Castri M., A complex scenic machine: geometry, structure and mechanical behaviour in the muqarnas wooden ceiling of the Palatina Chapel in Palermo, poster presented at these same Symposium.

2 We quoted, as significative examples, the Cathedrals of Monreale and Cefalù.
particularly that of nave, more interesting for our study, is constituted by a simple roof framework of wooden beams put along the smaller span with overhanging boarding. The recent restorations allow to investigate the constitutive materials and the constructive systems, also through the partial and limited demolition of the strata composing the technological roofing system. The restorations of XIX century and of the first halves of XX century, through the demolition of a big part of the superfetation structures (in the optic of a liberation intervention), returned a function to structures that for centuries had been losing their volumetric identity; particularly, the protection from rain and its disposal system are submitted to the original structures, deprived however of their efficiency, producing meteoric infiltrations that characterized the degradations manifested in the whole second postwar period. Only in the eighty years of last century the Superintendence has meritoriously performed a provisional coverage, avoiding to the ancient wooden structures a dangerous contact with atmospheric agents.

Figures 10, 11. Provisional coverage that protects the roofing attic of nave, having covering mantle with alveolar and poli-carbonate plates.

This roofing results today partially in efficiency for the obsolescence of alveolar and poli-carbonate plates constituting the covering mantle; although it had protected the structures of the ancient roofing from rain and from wind, it has determined and determines micro-climatic conditions that certainly aren’t suitable for wooden structures. The removal of some portions of the XVII century tile floor, has shown as there is, very well preserved, a pavement with tile powder as filler (cocciopesto) having a thickness of around 4cm, with a well smooth and beaten surface and with constant and uniform inclination toward the original systems of water draining points. The necessity to intervene on the heads of the wooden attic beams of attic, whereas the preliminary diagnostic analysis denounced meaningful reductions of sections, has brought to the removal of cocciopesto flooring through the detaching technique (stacco), because of

---

3 This intervention was effected by the Superintendence of Cultural Heritage of Palermo, using funds of a private sponsorship (Würth Italia s.r.l.), beginning from March 2005. Complex restorations were effected on decorated surfaces and on architectures of the Palatina Chapel inside the Royal Palace of Palermo. The building works are directed by the architects G. Meli e L. Bellanca of Panormitan Superintendence and are executed by an association of corporation composed by M. Solito, C. Tomasi, C.B. Art, C.R.C., S. Salvati e M. Furci technically directed by the architect M. Li Castri. The architect M. Scognamiglio (architect in charge of the Cultural Heritage service of Panormitan Superintendence, directed by the doct. A. Mormino) is the R.U.P. of this restorations building yard.

4 It’s necessary to premise as the transformations that have interested the monument during the centuries - and particularly the building events connected to the Baroque reform of monument, beginning from the second halves of the XVI century, transferring in the Royal Palace the vice-royal function - has determined raisings and alterations of the native building volumes and consequently a change of completion elements as floorings and attic masonries.

5 This technique is very diffused for wall fresco paintings and constitutes a good intervention for our study case.
the presence of diffused crackings in the flooring stratum determined by deformation of attic principal structure; these crackings are used as solutions of continuity between the removed parts and the preserved ones in situ. This flooring, attributed by some scientists to the original Norman building, is put on a thick layer of not cemented footing (tercisato), constituted by rests of demolished plasters, sands and calcareous grit of various size. Inside this footing, besides the material already described, meaningful parts of demolished cocciopesto strata have been recovered, more refined in comparison to this one existing in the superior stratum.

Figures 12, 13, 14. Uncovering of wooden heading beams, through the removal of cocciopesto strata and boarding of attic floor; we could notice the decrease of section and the caries decay.

The stripping away technique, conducted by renovators, has been preceded by consolidation in situ of the preserved parts through cotton gauze and acrylic resin in watery emulsion. The detached surfaces have been consolidated through imbibition of ethyl silicate, subsequently adhered to crossed layers of cotton gauze and - after their numeration, graphic and photographic representation - stripped through the use of steel swords, special long blades with which the experienced hand of operator effects the separation of the plaster from the base layer of flooring.
The boarding underlying the footing is spiked to the wooden beams of attic through small pyramidal nails having a squares head, hand-forged with a length of around 7cm and side to the head of around 6mm. The boarding presents conditions of varying maintenance, moving from support toward centre. In correspondence of supports, the degradation of caries makes consistent diminutions of structural sections with the classical conic course of residual sections having structural assignments. The semi-square wooden beams of squared section - varying among the 25-30cm of side - have a length of 6,56mt and an interaxis particularly close of around 36cm. The dismantlement of wooden boarding and the superior inspection allow to notice as the structural system was incomprehensibly confused and realized in evident scorn to the ordinary art rules, atypical in historical buildings of quality and more incomprehensible in a monumental building like this, where the building workers had expressed the best of Sicilian material and artistic culture of the XII century. The wooden beams of the carrying roofing framework had been put on a masonry of shapeless stones, edged and incorporated in a chaotic masonry, scarce of incoherent mortar and different for geologic nature. The emptying of this material, that from the quota of boarding extended constantly under itself for 46cm and that - further to englobe the wooden beams characterizes around 20cm of perimetral masonry - underlines the evident existence of
From Material to Structure - Mechanical Behaviour and Failures of the Timber Structures


an original offset of masonry, in which the wall suffered a reduction of around 40cm; the incoherent material that filled this offset was besides composed by rests of bird bones, cloths and even a shoe and a spoon of clear XVII century epoch.

The constructive and mechanical relationship of the nave bearing structures: degradations and failures, actual restorations

The examination of intrados confirmed the external observation, with further elements deducing from the masonry typology and from the geologic nature of stone ashlar (calcarenite) used for the perimetral masonry. The presence of a wooden element, a large table having the thickness of 3,5cm, the depth of 40cm and the length of about 1,06mt - separating so these two perimetral masonries - manifest the clear function of dormant-tree for a roofing floor that in a past epoch had been planned in correspondence of its altitude.

Figures 18, 19. Punctual support for the principal and secondary frameworks, that in time really would results pejorative because of the transfer to ceiling of deformations and disarrangements of the overhanging structures.

Some squared beams having an equal section of 13cmx18cm are present with a regular interaxis of 88cm in the portion of masonry set between the dormant-tree and the actual position of the wooden roofing beams, whose function is that to support through special wooden joists the muqarnas ceiling (called in the Sicilian constructive jargon like appenditori); these elements indissolubly joint in neuralgic points the carpentry of plain roofing to that of the completion and finishing structure, transferring failures and deformations of the first one to the other one.

This articulated system of reinforcement and support for technique and used materials immediately declare his posthumous realization in comparison to the construction of muqarnas ceiling; this practice, common to many other interventions realized on wooden ceilings to guarantee best punctual support to the principal and secondary frameworks, confirms also a consolidated constructive practice that often during its construction is

---

6 This one, in fact manifest as we say before the chaotic masonry in the last 50cm, put in evidence also the different nature, dimension of ashlar and typology; the ulterior 40cm look down on this masonry are constituted by ashlar in an evident overlapping to the original one.
animated by good intentions, but that in time results pejorative really because of the transfer to ceiling of deformations and disarrangements of the overhanging structures, as the study case attests.\(^7\)

The hypothesis of an attic raising of the Palatina nave seems possible, from the first altitude indicated by the dormant tree and the masonry of the Norman construction (*isodoma*) to a more elevated position that allowed the insertion between the two structures (ceiling/attic floor) of a third structure supporting the ceiling, that originally was a self-carried structure. The raising of attic roofing determined the formation of a narrow volume that makes susceptible of examination the extrados of ceiling and the intrados of attic floor.\(^8\)

If the structural conditions of muqarnas ceiling can be considered acceptable, exclusively allowing a first phase of restorations interventions of technological rehabilitation, these approach can’t be operate for the attic roofing, strongly interested by mechanisms of decay and failures. The evident disarrangements manifested in correspondence of attic and perimetric masonry after the recent earthquake happening in Palermo on the September of 2002, underlined as some improvement in the mechanical behaviour of building organism to horizontal actions were very urgent, for guarantee a structural safety to the monument and its users.

The restoring intervention on wooden structure, contracted by the Superintendence of Cultural Heritage of the Panormitan Province, uses the funds of a private sponsorship offered by the German Reinhold Würth\(^9\) and has foreseen a systematic interventions of structural restoration for the wooden carpentries. On the roofing attic of nave structural interventions are immediately executed on the headings of wooden beams, for the reconstruction of that parts destroyed by caries. Together with this intervention, the restoration project would re-propose techniques of reinforcement and consolidation borrowed by the historical constructive practice and already currently present in the wooden carpentries, that well represent techniques of anti-seismic protection: particularly, it’s foreseen and already realized a wooden string-course that also assumed the functions of dormant-tree. Preliminarily, the just described chaotic masonry has been replaced with a masonry realized using solid bricks tied up by a mortar of slaked lime, *pozzolana* and calcareous sands; this masonry realized with two heads of bricks, is useful to reconstruct a regular and continuous impost for the roofing attic, and on this masonry the wooden string-course is located, mediating the relationship between the wooden beam heads and the same masonry. The wooden string-course guarantees also a diffusion of vertical load transmitted by each single beam to an area of masonry, ampler in comparison to the mark of beam, decreasing in such way the tension state of underlying masonry, with a diffusion of load on a greater masonry surface, as we well know.

The dormant-tree, realized in seasoned wood of broad-leaved species, soaking in autoclave with high pressure and *permetrina* in oil to prevent possible attacks of xylophagous, has the thickness of 5cm, the depth of 30cm and the middle length of 150-170cm. The following segments of dormant-tree - in order to guarantee a better wooden string-course behaviour - are shaped with rabbets and spiked through two wooden chocks having a diameter of 28mm. The wooden string-course at its two extremities will be connected to the orthogonal masonry through two metallic anchors. For the maintenance of wooden beams on the plan of work, for possible seismic actions, are realized with the same material two wooden wedges presenting the width of 5cm and the height of 5cm, determining a support platform that guarantees at structural constraint to operate in an axial way.

---

\(^7\) About the constructive characters of Sicilian wooden ceilings look at Campisi T., *I soffitti in legno e canne nella tradizione costruttiva palermitana del XVII e XVIII secolo*, published in the review *Recupero & Conservazione* nn.41 e 42/2001.

\(^8\) Further confirmation of our hypothesis, seems furnished by the presence of the precedent *cocciopesto* flooring, already cited, in the attic footing, whose demolition was necessary for the dismantlement of the original attic for its translation to a superior altitude. This hypothesis, verisimilar but on which it’s still necessary to investigate, influences the intervention of structural restoration of the ceiling and the attic roofing.

\(^9\) We would thanks the Würth srl for the availability to the publication of the images derived from the restoring building yard archive.
The reconstruction of the wooden beam headings has been effected through the well-known system of wood/wood prostheses, jointed through steel bars or composite with resin.10

The union of the prosthesis with wood is effected with metallic bars (common steel bars with an improved adherence) or in composite, glued through a thixotropic adhesive specific for wood, positioned into seats drawn in wood sections parallelly to wood fibre and covered by a wood fillet of suitable thickness. This condition allows to solicit the wood fibers in the direction “planned” by nature (in the tree they always works in a longitudinal sense, to traction or compression), and it guarantees a good holding of gluing during the time because a long line of wood fiber is glued, minimizing so the problem of compatibility: the wood, in fact, doesn't show an appreciable shrinkage in the longitudinal direction to the wood fibers, and also doesn't show evident swellings in occasion of the environmental thermal-hygrometric variations. Particular attention must be set to the choice of wood species used for prostheses: it's necessary, in fact that they have a particularly low hygrometric regime (< 18%).

A major attention was put to find seasoned wood structural elements, and in the study case we used beams and wood elements discarded from other historical buildings.

Figures 20, 21. Project drawing of the string-course with function of dormant-tree and photo of a detail of realized intervention.

Figure 22. Reconstruction of wooden heading, realized by a wood-wood prosthesis (LEGNO DOC).

Bibliographical References:

- LEGNO DOC- www.legnodoc.com