Timbrel vaults in Sicily.
Constructive techniques and intervention methodologies

Giovanni Fatta*, Tiziana Campisi, Calogero Vinci

Highlights

The spread in Western Sicily of tiled vaults (“realine”) took extensively place from the second half of the XVIII century to the first decades of the XX century. The encouraging results of the load tests on the intact vaults and on example-vaults support the choice of re-construction and demonstrate how the instruction of workers to the competence of obsolete techniques involves a limited financial and temporal commitment, taking a quality of the intervention and the respect of history. The constructive knowledge instils confidence in the performance of tiled vaults.

Abstract

Almost totally ignored by the official historical and current technical culture, both locally and in the Italian ambit, thin brick vaults actually are mostly demolished or transformed in decorative ceilings. The detailed and comparative knowledge of many cases, encouraged also by building continuity in other countries, but also the partial and total reconstructions that have occurred in recent years, allow to properly assess potentialities and limitations, the real possibility or opportunity for their maintenance, rehabilitation or re-proposal, even preserving the structural function.

Keywords

Western Sicily, Tiled vault, Constructive technique, Recovery, Reconstruction

1. INTRODUCTION

Among the many types of vaults found in Sicily, aiming to combine economy and lightness without sacrificing safety, we analyse Sicilian vaulted floorings consisting in three or four overlapping layers of thin tiles woven together with plaster (realine vaults, according to local definition). There is no reliable information of origins of these vaults, this type of vaulting was likely to be introduced in Sicily in mid eighteenth century, and reinterpreted in light of local building culture. It has repeatedly given original solutions, given also the peculiar environmental and geographical conditions and the high seismicity of the area. Not casually, a large use of these vaults in Western Sicily, especially in Palermo, date back to the period immediately following XVIII century earthquakes (1726 and 1751): these vaults were in fact considered good solutions if applied for earthquakes prevention, because of their lightness and
a presumed monolithic structure, which could reduce the thrust on perimeter walls. Paradoxically, the collapse of some of these structures during seismic events in the nineteenth century discouraged their re-proposal for many decades [1].

Currently, many findings during restoration works have made necessary a close study and an accurate assessment of the whole constructive system, in this paper we analyse the peculiarities of technical solutions and the original elements of the Sicilian structures. Almost totally ignored by the official technical culture, thin brick vaults actually are mostly demolished or transformed in decorative ceilings. Therefore, we intend to document the possibility to maintain and reconstruct these vaults even with their structural function, instead of tearing them down. The detailed and comparative knowledge of many cases encouraged also by building continuity in other Mediterranean countries and in the Americas, but also the partial and total reconstructions that have occurred in recent years, allow to properly assessing potentialities and limitations, the real possibility or opportunity for their maintenance, rehabilitation or re-proposal, even preserving the structural function.

2. STATE OF ART. A LITTLE KNOWN CONSTRUCTION TECHNIQUE

There is an ongoing trend started a few decades ago, which is the rediscovery of obsolete construction systems that had been discarded for a long time, as they were considered old and risky. However, if we set aside any prejudice and investigate the technological features and the constructive rationale, even with respect to the surprising good current use conditions, despite the lack of care and maintenance, we are forced not to judge them, but rather to deepen our knowledge.

The vaults made of multi-layers of thin tiles represent a significant example. New light has been shed on them following the studies of many scholars who described the most important steps [2, 3, 4, 5, 6], the reference texts dating back to the construction time, the monumental structures being realised and their dissemination in the western world. To confirm and update what already published, we deem it useful to get to know how these construction systems spread locally, with variants and/or adjustments made to meet specific needs. It was a poor and skilful technique at the same time: intended to be economical, it also confirmed the ability to foresee and interpret the behaviour of unconventional structures.

1. INTRODUZIONE

Tra le tante tipologie di volte riutilizzate sul territorio siciliano finalizzate a congiungere economia e leggerezza senza perdere in sicurezza, vengono in questo studio analizzate quelle costituite da due, tre o quattro fogli di mattoni sottili uniti con gesso (volte realizzate secondo la definitione locale). Non si hanno notizie certe sull’origine di queste volte che, probabilmente introdotte dall’area iberica in Sicilia nella prima metà del XVIII secolo, evidenziano come un sistema costruttivo importato da aree geografiche spesso molto distanti possa essere reinterpretato in funzione dei materiali disponibili e della cultura costruttiva dei luoghi. Ciò ha in più occasioni determinato soluzioni originali ed ingegnosse, essendo del confronto costruttivo, geografico e ambientalmente peculiari, non ultima la considerazione della sismicità dei luoghi. Non a caso le prime realizzazioni nel XVII secolo, a Palermo, di volte realizzate risaliverebbero al periodo immediatamente successivo ai terremoti del 1725 e del 1731, queste strutture erano infatti considerate per la leggerezza e per la presenza monolitica, che avrebbe dovuto ridurre le spinte sulla muratura perimetrale - soluzioni ideali (rispetto alle volte “reali”) in caso di terremoti. Paradossalmente, fu probabilmente il crollo di alcune di queste volte sottili durante gli eventi sismici che si verificarono nel XIX secolo, ne scoraggiò la riproposizione decretandone la scomparsa per alcuni decenni [1]. Attualmente, i sorprendenti e numerosi ritrovamenti avuti in occasione di lavori di indagine e di restauro in edifici storici siciliani hanno reso indispensabile uno studio approfondito, di cui questo report costituisce un breve resoconto, ed una valutazione del sistema costruttivo che hanno evidenziato alcuni elementi di originalità nelle realizzazioni dell’isola, quasi del tutto ignorate dalla cultura tecnica ufficiale storica ed attuale, sia in ambito locale che italiano, in molti casi le volte sottili in mattoni sono state demolite o trasformate in soffitti decorativi prescindendo dalla loro originaria funzione portante. La conoscenza puntuale e comparativa dei tanti casi ritrovati, confermata anche dalla continuità costruttiva in altri Paesi mediterranei e nelle Americhe, ma anche le ricostruzioni parziali e totali già avanzate in questi anni, sono tutti fatti che consentono di valorizzare correttamente le potenzialità ed i limiti, l’effettiva possibilità e l’opportunità del mantenimento, della riabilitazione o della riproposizione, anche con funzione strutturale.

2. LO STATO DELL’ARTE. UNA TECNICA COSTRUTTIVA POCO CONOSCIUTA

Da alcuni decenni, si assiste alla riscoperta di sistemi costruttivi obsoleti, per lungo tempo abbandonati, perché considerati non più attuali ed a forte rischio. Analizzandone senza pregiudizi i caratteri tecnologici e la stessa ratio costruttiva, anche in relazione alle sorprendenti condizioni d’uso attuali multigenerazionali, l’assenza di cura e...
Our research shows that ‘realine’ vaults were much more present in western Sicily, and they could indeed bear considerable loads. However, it also emerged that they are completely neglected by current technical regulations, and this legal vacuum makes it impossible to perform calculations and static controls. Rather than demolishing and replacing them with safer structures, any curious researcher would go into more of it, asking colleagues and technical operators for information and conﬁrmations and analysing and checking directly the works and the existing documents.

We would look for descriptions and recent in-depth works about other areas, and from them we would go back to the extensive literature: only to mention the most known, we would list the Treaty published in 1639 by Fray Lorenzo de San Nicolas, those ones of Félix-François d’Espie (1754) [7], Blondel (1770) [8] and Rondelet [9]. (Figure 1) the Italian nineteenth century manuals, the construction documents of important buildings, until we arrive to the early twentieth century price lists of Palermo. In the same period the American experiences of Guastavino, supported by analytical studies and laboratory tests have allowed the diffusion and transfer of this construction system, also in combination with the steel structures, from residential buildings types to the most demanding industrial complexes [10, 11].

In this vast bibliographical and documentary acknowledgment, also a wide geographical spread correspond, which is conﬁrmed by the curious and terminology cross-references: Blondel wrote about the Italian origin of the best tiled vaults builders; the French architect L. Dufourny and G.V. Marvuglia, a well-known Sicilian architect of the eighteenth century, referring to the tiled vaults realized in Palermo, called them as “French”, while in Naples the same vaults were called as “Sicilian”; referring to other Panormitan examples the vaults are deﬁned as “realine” or sometimes “Catalan”. Certainly, the Sicilian realizations have a credible historical and temporal reference in the bóvedas tabicadas of Catalonia, where they will assume with their free and organic forms an extremely important role for the whole modernist movement. In the works of Domenech y Montaner and Gaudi, the sinuous forms of tabicadas shells will create an unprecedented and amazing integration between material, structure and shape. In conﬁrmation of this, recent studies have shown that Catalans “vaulted masters” were operating certainly in the ﬁrst half of the eighteenth century in the Palermo area.

In the light of what is already known and has been written on the same topic for other geographical areas [12, 13, 14, 15] – and that we intend to refer to, especially with respect to the guidelines that clarify in detail the problems, solutions, technical and economic reasons, risks and advantages – this short
essay is aimed at adding information and reflections on findings, peculiarities, construction experiences and methods of intervention.

Figure 1. (at the top) Comte D’Espie’s “fireproof roof”: flat vault made with three layers of tiles, close-range tiled buttresses supporting the roof structure, also made with multi-layer tiles. (at the bottom) Thin tiled multi-layer vaults (Blondel-Patte).
3. “REALINE” VAULTS RESTORATION.  
FROM KNOWLEDGE TO INTERVENTION

Until the recent past, the limited confidence towards the potential and structural adequacy of many little-known construction solutions, has led to less respectful and infrequently damaging actions. In some cases, the lucky ones, already the maintaining of the historical building element, even if surrogate in its structural function, has been considered as a good compromise, compared to a more simple demolition. However, in the recent years, we are comforted by a new performance-regulatory approach, that directs the interventions on historic buildings. It is oriented towards the safeguard and the respect not only of image and material characters, but also of the structural design and building concept; the technical culture has begun to operate preserving the original static system and, where necessary, also structurally supplementing and improving it. This is an approach, which obviously presupposes a thorough knowledge of the traditional building and its construction history, along with a mechanical characterization, often timely, scientifically and economically demanding. In this optic, tiled vaults are an emblematic example, spread in Western Sicily more than we might expect; this kind of vaulted system is currently neglected by both treatises and specific rules and legislations, compared to a wide literature produced as early as the seventeenth century. Looking at a so relevant history, only recently and essentially basing on an academic aspect, specific studies have developed, contributing to the spread of knowledge and to the understanding of the static-constructive ratio. Therefore, it was possible that designers and operators, comforted by concrete experiences, they have chosen to maintain, retrieve, integrate - where this approach seems appropriate - or consolidate tiled vaults and, in some cases, completely rebuild these structures [16, 17, 18, 19].

In the Western Sicily, for almost two centuries and on an alternate luck, tiled vaults have been considered as an efficient technical alternative to stony real vaults of monumental architecture, as well as economic solutions for the most common realizations. Although the memory of this building technique has been lost, the numerous findings in restoration building yards testify its use until the second decade of the twentieth century, both in new construction and in the re-arrangement of existing buildings. A detailed research was the basis of our study, arrived in its final phase, which helped to identify in Western Sicily a typological and temporally significant record. An invariant aspect is the size of the basic constructive elements, the overlapping-layers thin tiles, used for partition walls as well as for the
construction of vaults, presenting variable overlapping-layers, in relation to the function that vaults has to be (only 2 layers for ceilings, 3-4 layers for the bearing vaults), linked exclusively with gypsum mortar until the end of the nineteenth century.

The geometrical variations were often related to the mutability of the architectural language or practical requirements (as the rise of vault, the size of rooms, the number and morphology of supporting structures), while finishing elements (abutments, fill materials, transversal and diagonal ribs, stiffening arches, thin buttresses, longitudinal or lunette counter-vaults), placed at the extrados of vault and therefore not visible and inspected (if not subsequently a partial demolition), represent a rich catalogue, able to represent both the consolidated constructive practices, which variants and the structural interpretations, but generally also the confidence given by the coeval builders.

As a result of the unexpected and widespread diffusion, both from the temporal point of view and the variety of building types in which we found these tiled vaults (noble palaces as well as basic buildings, churches or agricultural warehouses) a structural and typological analysis has been effected, concerning what until now had seemed only a sporadic presence in the history of the Sicilian construction, wrongly limited above all to the self-supporting ceilings.

The study has been conducted primarily through a typological classification of construction solutions, continuing with the analysis of the studies, tests, diagnosis, structural modelling and experiences carried out both locally and nationally. In parallel, an evaluation of degradation and recurrent instability has been carrying out on the structures that we have analysed, supplemented by information derived from technical reports of past damages, occurring during earthquakes or other causes.

The realized methods of intervention are finally analysed, relating them to different functions or construction characteristics.

As regards the classification of constructive solutions, we have considered that the interventions of consolidation/structural improvement and recovery cannot of course exclude the restrictions imposed by the presence of eventual decorations at the intrados and of possible and structural elements at the extrados (Figure 2). We would examine as an example the unload counter-vaults making not directly accessible the extrados of the main tiled vault, on which usually the intervention is made. In this phase, the research has been also conducted on literature, bibliographic sources and archival documents, which often led to a correct interpretation of study-cases, by chance discovered during restoration building yards.
In order to evaluate the structural behaviour and also mechanically characterize the materials, we have referred to the recent literature, reporting the results of load tests, laboratory analysis of samples derived from collapses or specially reproduced, visual or endoscopic inspections. The results of the load tests effected in situ often have shown that the not damaged tiled vaults resist adequately to ordinary loads.

Another investigated aspect was that regarding the identification of degradation and recurrent instabilities.

The earthquake and the deterioration of the gypsum mortar (basically due to contact with water) are always, even concurrently, the principal causes of collapse, as attested by the chronicles of the past. It is by now clear and it had been properly understood by the builders of the past, the poor earthquake-resistance due to less capacity of thin vault to constitute a rigid diaphragm in its plane.

Another recurrent cause of instability is constituted by variations of the geometry of supporting perimeter, even in small sizes, due to differential rotations or collapses to which the tiled vaults, being monolithic and thin elements, are not able to adapt themselves, unlike the traditional vaults realized using stone ashlars. Finally, as for the latter ones, it is demonstrated that the tiled vaults have a limited capacity of resistance, respect to concentrated or asymmetrical loads.

The results of investigation and the correct interpretation of collapse types are comforted by the structural modelling, conducted in academia or during the recovery interventions, confirming that the presence of extrados ribs, buttresses and counter-vaults greatly contribute to the stability of tiled vaults. Particularly, the extrados buttresses stiffen the shell, just in the areas where
the greatest traction stresses have manifested, ensuring a crushproof stability of geometry. Also the counter-vaults, being significantly diminished and particularly those longitudinal of the pavilion vaults, they were located close and with their axis parallel to the perimeter of the room; these counter vaults, besides alleviating the overlying portion of the vault, they have the important function to directly download on the perimeter walls the half of accidental load resting on them, and doing that the remaining part of the load will be more evenly distributed on a portion close to the axis of the main tiled vault.

This one will constitute a considerable advantage, if we have to consider the low resistance of tiled vaults to concentrated or asymmetrical loads.

Finally, we have considered the different cases of interventions on tiled vaults described in the literature and those recently made in the Sicilian area, in order to identify those, which can be considered as good practices, relating to local specificities. When excesses of carefulness do not prevail, that until the recent past have led to the demolition of these vaults, a frequent practice is the subrogation of their load-bearing function, leaving this function to a new technical element. The realization of a new floor unload the tiled vault that takes the simple ceiling function. According to the prevailing viewpoint, the eventual elimination of abutments, counter-vaults and filling materials, which they usually accompany this intervention, could destabilize the structure, occurring horizontal actions. A deeper knowledge and understanding of the construction system and its structural functioning has brought in recent years to the proposals and interventions that we believe can be considered as “good practices”.

For tiled vaults having a simple cap, therefore without extrados asperities, such thin buttresses and counter-vaults and presenting cracks without excessive dislocations, it’s enough the sealing of cracks with an expansive mortar: to ensure a continuity and the maintenance of a monolithic shell, often it’s better to proceed to encasing the extrados of vault using fibres, with bands or in a continuous way, and subsequently to fill the extrados with a lightweight concrete, to guarantee the foot traffic. In all those cases in which is a decorative apparatus, it’s generally preferred to intervene on the extrados in a discontinuous way, so as to ensure a greater permeability to vapour of vault and to prevent damage of moisture, occurring with a greater probability below a continuous cladding.

Relative to the same type of instability, recent studies have evaluated the convenience of a more compatible intervention from the point of view of the employed material, which even if significantly weighs the structure, however certainly appear simpler for a discontinuous extrados. After the filling of
cracks using a gypsum mortar, a double layer of thin bricks has put on the top, curing the perfect adhesion to the underlying layers. Tests carried out, after the intervention in a cross-tiled vault, attest an increase of strength and rigidity of the system. For partial collapses, the intervention can adequately reintegrate and rebuild on a wooden formwork, according to the criteria of material homogeneity and being careful to arrange the tiles correctly, following the original arrangement and starting from the lower layer (Figure 3).

This practice is in fact feasible, in occasion of extended collapses, thanks to the possibility of recreating the continuity also at the extrados through the covering with GFRP (preferred to carbon fibres, if are not required high mechanical performances). The presence of counter-vaults not allow a coating of the main cap, so that it has been proposed a system which partly overcomes the problems caused by the already obsolete and dangerous interventions of reinforced-concrete covering, putting at risk the vault stability, especially for chemical and stiffness incompatibility. Through the interposition of a soft and deformable layer, the tiled vault indeed bears the permanent loads as the weight of the lightweight covering of steel reinforced concrete and also its own weight, while the accidental loads are transferred directly from this covering to the perimeter walls. The deformation of the covering, due to accidental loads, are -in fact- balanced by the deformation of the interposed layer, and only partially transferred to tiled vault. The intervention is particularly economical and easy to perform, if it is compared to the more expensive systems that use fibres. It has also overcome the perfect adherence of fibres to the extrados surface. Many and very interesting are the total reconstructions of realine vaults, effected both simply recovering the traditional system, and - in a precautionary manner, but much more expensive- interposing composite materials between the layers of thin tiles (generally a mesh of glass fibre, immersed in matrix of hydraulic mortar); this method can greatly improve the
traction strength of the most stressed portions. As regard the first system, two different constructive experiences, made o carried out in likewise restoration sites of monumental buildings in Palermo, allowed to experience how the reconstruction can be considered a practicable way, also when great collapses happen (Figure 4). During the works of transformation, occurred between 1894 and 1905, we can ascribe the reconstruction of some realine vaults inside a convent, in order to realize a vaulting system between the ground floor and the first floor. We talk about a double series of five tiled cross vaults having three layers of thin tiles, called pantofali (23*11.5*2.2cm), supported by four pillars of pantofaloni brick (26*13*6 cm). The lightening was made through four little tiled hemispherical domes, having only two layers of tiles, placed at junctions with the pillars. A filler of untied material, it determines the horizontality of the extrados, without overloading the structures. The stability of the same structure is guaranteed by the long-term use of the room over-leading the tiled vault, as a gym, and the absence of earthquake cracks. The restoration design has proposed the re-proposal of the tiled vaults, collapsed after the bombing of 1943, using the original technique. The reconstruction has started after a series of tests, done on some example of re-built tiled vaults, so that the workers could understand how verbal descriptions and technical drawings not explain. Wooden ribs, placed at the diagonals of the tiled cross vaults and at the intersection lines, had supported a continuous plank surface, on which the first layer of thin tiles was laid. Above the plank surface, a scaffolding system would allow the workers to operate from above, without adding its own weight on the wooden ribs, also preventing distortion and vibration that could compromise the construction result. The laying geometry was conducted according to literature descriptions and in agreement with the characteristics of existing adjacent tiled vaults. The bricks are placed with the longer side located along the generative line of the tiled vault, until the intersection where they are cut at 45°, allowing so the determination of the intersection, and the individual lines of thin tiles are offset by an half. The first layer of tiles was placed dry, and then it was covered with a mixture of gypsum and water, in order to saturate the joints between the same tiles. The next layer was placed with joints staggered of a half tile. Load testing confirmed the homogeneity of mechanical behaviour with existing structures already under analysis. Another example is that of the reconstruction of tiled vaults at the mezzanine floor, made in a noble palace with the realina technique in the fifties of the nineteenth century: in an existing building a vaulted system was inserted, not determining the need to change the oldest structures and involving an negligible loads increase due to an own weight. The tiled vaults were
collapsed because of water infiltration, coming from a battery of bathrooms connected to offices hosted for a long time into the building. The restoration, started in 2004, has provided the reconstruction of vault using a wooden frame completed by rods, and a wooden floor had to constitute the bearing structure. However, other tiled vaults were founded at the mezzanine floor, so that it was thought to rebuild the already collapsed one adopting the original construction system (fig. 5). The elimination of collapsed portion permit to rediscover the ancient trace made in the masonry to create the support of the new barrel vault: it is a neat cut, presenting a depth of about 9cm and a height of about 15cm, having triangular shape and made in the limestone ashlars of masonry. Along the two short sides, the vault, having a slightly lowered profile, presented no supports on masonry. The wooden ribs were placed every two meters, in order to support the continuous plank surface whose planks (4 meters long) were staggered with joints corresponding to the wooden ribs. The materials used for reconstruction were the already mentioned pantofali thin tiles, put in place on three layers using a gypsum mortar.

Figure 4, 5. Reconstruction of a partially broken down tiled vault. Philological reconstruction of a tiled barrel vault with lunettes.

4. CONCLUSIONS

Actually, the legislation evolution is oriented to discourage the demolition and to direct towards the maintenance; some unique example have demonstrate how the new construction of tiled vaults can be a viable and economical alternative to the creation of traditional stony vaults. An emblematic and original example is represented by the recent reconstruction, after the collapse of an original great stony vault in a fifteenth century building, located in the geographical area of Western Sicily (Figure 6).

Using the realina technique, realized with multi-layer thin tiles, combined with a hydraulic mortar, the pavilion-tiled vault with lunettes at the perimeter
has been recreated; this tiled vault has been subordinated to structural tests and bureaucracy verifies, useful to verifying its correct execution.

5. REFERENCES


