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TRADITION AND MODERNITY OF CATALAN VAULTS:

HISTORICAL AND STRUCTURAL ANALYSIS

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Abstract The paper analyzes from different points of view a particular type of vaulted structure known as bóveda tabicada (Catalan vaults) and the related construction technique. Catalan vaults are thin vaults made with alternate layers of bricks and mortar characterized by a very low thickness. The first step performed has been to investigate the historical aspect in order to frame the Catalan vaults and its construction technique all along the history of architecture and to understand the reasons of its great success. Later, a campaign of experimental tests on samples of Catalan masonry, taken from existing structures, has been performed. This campaign completes a foregoing one allowing to characterize the structural behavior. The paper confirms the peculiar features of such vaults opening an important way in the structural aspects of the ancient structures restoration as well as in the design of new ones.

Sommario Il lavoro analizza da diversi punti di vista un particolare tipo di strutture voltate noto come volte catalane *(bóveda tabicada)* e la tecnica costruttiva correlata. Le volte catalane sono volte realizzate da strati alterni di mattoni e malta, caratterizzate da un esiguo spessore in relazione alle altre dimensioni. Il primo passo presentato nel lavoro è quello di investigare tutti gli aspetti storici al fine di inquadrare sia la tipologia che la tecnica costruttiva correlata all'interno della storia dell'architettura e di individuare le ragioni di un così grande successo lungo i secoli. Successivamente, è stata effettuata una campagna di indagini sperimentali, che completa una precedente, su campioni di muratura prelevati da una struttura esistente, finalizzata alla caratterizzazione del comportamento strutturale. Il lavoro conferma le peculiari caratteristiche strutturali di tali volte ed apre nuovi orizzonti nell'ambito del restauro strutturale di volte antiche e in quello della progettazione di nuove.

1. – INTRODUCTION

In the framework of history of architecture three main different construction typologies characterized the architectural evolution: the massive, the frame and the shell (plane or curved

elements) one. This subdivision can be immediately discovered in nature where wonderful applications – such spider's web or flower glass – can be found. In particular it is important to emphasize that natural shell constructions such eggshell, beehive, seashell or bug dermal skeleton always excite human astonishment and constitute a fundamental model to be copied in human constructions. The human ability of fulfilling such models has kept step with the theoretical and experimental knowledge of the materials together with the technological one able to realize new materials and the design one which synthesizes all the information. Another important aspect of the (plane or curved) shell constructions is the aesthetical one which plays a fundamental role in architecture (e.g. the domes of Santa Maria del Fiore in Florence and that of Santa Sofia in Istanbul). Nowadays the designer, besides all above described knowledge, has at disposal also hardware and software able to correctly analyze, with reasonable time consumption but with affordable results, even very elaborate situations allowing their analysis and design. On the other hand in last decades in modern society the role played by the folk memory together with that of the ability of cultural-architectural heritage conservation have increased. As a consequence in the same time a large amount of both national and international standards have been approved in order to avoid indiscriminate actions on such heritage. The proposed paper places itself in the above described framework focusing the attention on the structural aspects of elements realized with the *tabicada* technique which, as it will be deeply explained later in the paper, combines the tradition (since its origin starts in ancient age) together with the modernity (since it has been widely adopted by many of the most important architects of the XXth century). Mainly this technique has been used for building a particular type of vaulted structures also known as *bóveda tabicada*, Catalan vaults or timbrel vaults. This technique rests on realizing thin thickness (in comparison with the other two dimensions) by laying bricks lengthwise alternated with layer of mortar mainly based on gypsum. Due to the characteristic low overall thickness and to the fact that the ratio between the brick and mortar layer thickness is no more than two, the overall material can be regarded as a first type of composite material adopted in the history of construction. In literature Catalan vaults are very important and many studies (see e.g. [1], [2]) have been performed mainly from historical and technological points of view.

The study presented in the paper is divided in two main sections: the first one faces the *tabicada* technique and the Catalan vaults from the historical point of view; the second one faces the identification of the mechanical features of the structural elements realized with this technique defining an appropriate constitutive model. The results confirmed the peculiar features of such vaults opening an important way in the structural aspects of the restoration of ancient structures as well as in the design of new ones.

2. – Historical background

As mentioned in the Introduction, the first step is a deep investigation the historical background of the Catalan vaults. As it will be explained in the following sections the *tabicada* technique founds its origin very far in the history while it has been adopted with different peculiarities until the first decades of the second half of the XXth century.

2.1 – *The Catalan vaults in the history of architecture: from its origins to the nineteenth century*

The research of the origins of Catalan vaults can be conducted thanks to some considerations on the three peculiarities of *tabicada* construction: brick, mortar made of gypsum and the absence of ribs during construction. It is necessary to refer to those geographical areas where use of gypsum, brick and construction technique without ribs were known [3]. The civilization that, most of all, showed a conscious and controlled use of gypsum was the Arab-Islamic one; brick was a widespread technology, common to distant geographical realities and different historical periods. The use of bricks placed flat orients the

research within a broader environment of constructive experiences: the Assyrians, the Sumerians, the Egyptian civilization, the Roman buildings [4]. From the other hand, the construction technique without ribs restricts the repertoire of historical examples of reference. This practice was born in Mesopotamia, where the first examples were found in the works of the Assyrians and the Sumerians (twenty-first century b. C.); it was then transmitted through Byzantium first and Spain after [4]. Actually the Mesopotamians discovered that, in an arch, it wasn't necessary to place bricks with radial joints because the more horizontal they arranged, the better they held up during the execution, being not necessary any auxiliary support element. As regards Italy, timbrel vaults were adopted since the medieval period and widely used from the Renaissance throughout the nineteenth century [4]. The most relevant text about construction and mechanic of *bóveda tabicada* is the treaty of architecture by Fray Lorenzo de San Nicolás, published in Madrid in 1639 [5]. By reading this treaty it is evident that *tabicada* building tradition was already consolidated. In chapter 51 the *bóvedas tabicadas* are classified according to geometry and materials. Finally, the author was well aware of the fundamental property of Catalan vaults: due to weight reduction the thrust exerted on the walls is reduced with respect to that of stone vaults and of those with bricks arranged sidewise. Consequently, by adopting Catalan vaults it is possible to produce smaller piers.

In eighteenth century it is worth noting the book by the Comte d'Espie (*Manière de rendre toutes sorte d'édifices incombustibles*, published in 1754 [6]. He was probably the first author who focused the fire invulnerability of the *tabicada* technique. An entire chapter has been devoted to the vaults comparison and it is affirmed that Catalan vaults don't thrust against the walls. The reason of a such particular behavior is attributed to the monolithic character of the structure. Espie's ideas were generally accepted without criticism by later authors, as the absence of thrusts and fire resistance met with interest and success not only in France but also elsewhere in Europe. Major French and European treatise authors were attracted by this new construction system. This is the case of Laugier [7] and Rieger [8], and the extensive discussion devoted to Catalan vaults in the treaty of Blondel and Patte (1771-1777) [6]. Joaquin de Sotomayor translated Espie's book into Spanish in 1776. By combining this text with his own comments inserted in square brackets gave birth to his book, *Modo de hacer incombustibles los edificios sin aumentar el coste de la construcción* [9]. From the other hand, Ventura Rodriguez, the principal architect of Madrid and one of the most important Spanish architects of the eighteenth century, harshly criticized the ideas supported by Sotomayor and by Espie. Ventura, mentioning several examples of cracks and collapses in buildings, did not agree with Espie and Sotomayor and considered Catalan vaults even dangerous. In the nineteenth century in Spain, Espie's influence was felt in other two treaties that addressed the issue of Catalan vaults, that of Benito Bails (1796) [3] and that of Manuel y Gurrea Fornes (1841-46) [3]. Rondelet [10] summarized the state of the art on Catalan vaults in a book, numerous editions of which were printed as well as translated into Italian and German. Therefore, some of the most imaginative common ideas about this technique, such as the monolithism and the absence of thrusts, originate from this treaty.

2.2 – *Tradition and innovation: the use of Catalan vaults in the twentieth century*

Bóvedas tabicadas were admired and manufactured out of Spanish territory thanks to the work performed in America by the Catalan architect and builder Rafael Guastavino Moreno and by his son Rafael Guastavino Espósito. Guastavino in 1881 emigrated to America where, working with both renovations and new constructions, gave birth to about two thousand buildings, especially in the eastern United States. Here he thought to find a more stimulating and propitious atmosphere to develop his ideas [11]. The *Guastavino Fireproof Construction Company*, founded in 1889, was specialized in the execution of vaulted roofs of large areas, especially industrial buildings, where fire resistance was an indispensable requirement. The fire resistance of this kind of vaults accorded great importance

and, simultaneously, ensured the company reputation, especially in those years in which serious fires destroyed entire cities. Guastavino patented various aspects of his construction system. At the end, among him and his son, they held about two dozen patents, some for stratified laminar vaults and others for more sophisticated uses, such as acoustic bricks and sanitary uses (Figure 1a). Guastavino received some assignments as an architect, including the one for the Boston Public Library (Figure 1b) that assured him great fame. Guastavino decided to work as a builder at the service of the most important contemporary architects, considering it the only possible way to realize his ideas, building, until his death in 1908, hundreds of roofing of all types. Guastavino father and son's work, in fact, includes more than one thousand vaults in churches, cathedrals, chapels, and public buildings in nearly 70 years of working with an intensity of 30-60 buildings a year.
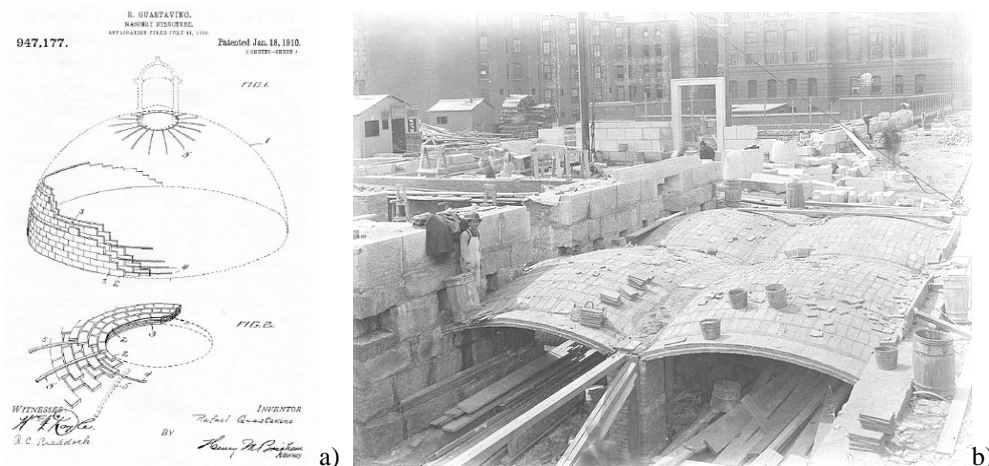

Figure 1: a) Patent of reinforced bóveda tabicada of Guastavino's son (1910); b) Construction of Catalan vaults of the Boston Public Library

The construction system proposed by Guastavino was initially looked upon with reticence. In order to convince American architects and engineers of the strength and the high quality of this system Guastavino needed a historical as well as a technical theory, which could give academic soundness to his impeccable building practice [11]. His research represented, therefore, the first major theoretical contribution that explains the structural behavior of Catalan vaults scientifically. His studies of *bóvedas tabicadas* were published in the *Essay on the Theory and History of Cohesive Construction, Especially applied to the timbrel vaults* in 1893 in Boston [12]. Guastavino divided masonry construction in two groups: the «*mechanic construction*» or construction by gravity, and the «*cohesive construction*» or construction by assimilation. The *tabicada* construction is cohesive but it isn't the only one that can be considered as well. In the history of this technique, Guastavino recognizes as cohesive the Roman technique of concrete structures, the Byzantine and Islamic brick constructions and mentions the Middle Age as the period in which this system really developed. Therefore, according to Guastavino, the main structural characteristic of timbrel vaults is the «cohesiveness», that is the structural monolithism, the cohesive force established between the various layers of bricks and mortar. Guastavino developed the concept of «cohesiveness» for supporting his thesis about the ability of these structures to bear considerable traction tensile states. If this theory could be useful to understand the global behaviour of the *tabicada* structure, in literature [13] it didn't seem so convincing but, on the contrary, approximate. The reason lies on the proposed mathematical model of calculation emphasizing that the «cohesive» nature is not relevant by the structural point of view, but only by the constructive one. But according to the Catalan builder, *bóvedas tabicadas* provide high structural performances due to the layered arrangement of brick interposed to the mortar. In the cohesive system, in fact, the presence of the hydraulic binder, working in an active

way, introduces an additional force which is the peculiarity of the system; in the mechanical or gravity system the force of cohesion is determined only by the force of gravity keeping bricks in position by the compression exerted on the exclusively vertical joints. Moreover these ones are not protected by the presence of horizontal layers, so that a reduction of their thickness would affect the setting of concrete, that only exercises a *pillow action* and doesn't increase the inherent strength of the arch; the mortar doesn't provide an important static contribution to the overall balance of the system but simply makes possible the curvature of the vault, by varying the angle between the joints. In the first system the component materials are so cohesive that they cannot be separated without destroying the entire structure, in the second one the structural mechanism is determined by the reciprocal actions that act between bricks without a primary static function of the interposed material [14]. Guastavino recognizes to the timbrel vaults many other advantages: a better resistance to bending; the protection of the vertical joints from erosion due to the presence of the horizontal ones; the decrease in the number of the joints themselves that represent structural discontinuity elements of greater weakness. Guastavino focused on experimental tests to validate his theories. Since 1887, he started laboratory tests with the aim of determining the compressive, tensile, bending strengths and also fire resistance of Catalan vaults (Figure 3) [15].

Figure 3: Load test on a vault performed by Guastavino, New York City, 1901.

Rafael Guastavino Expósito worked in the father's company from the age of fifteen. His work is important for many reasons: he systematically applied the membrane theory for the calculation of internal stresses with particular reference to domes; on the basis of the membrane theory, he devised a system for domes design preventing the traction appearance; he anticipated by fifty years Eladio Dieste realizing one of the first patents on the reinforced brick vaults; he created a pioneer survey on acoustic materials working with Wallace Clement Sabine, the inventor of architectural acoustics. Nowadays, at Massachusetts Institute of Technology a project for documenting and preserving the works of the Guastavino Company is active and the interest on his work is very high in Spain (e.g. [16]) and in Italy (e.g. [17]).

In Spain, between nineteenth and twentieth century, the *tabicada technique* found large diffusion thanks to the work of Antoni Gaudi. This ancient constructive tradition was renovated achieving innovative outcomes and showing its unexplored potentiality. The research carried out by Gaudi found his most significant manifesto in the *Provisional Schools of the Sagrada Familia* (1909), entirely manufactured according to the design criteria of *tabicada technique*. This technique has been adopted both in the walls and in the roofing, to meet the demands of simplicity, speed and construction economy (Figures 4). Gaudi explored the theme of *bóveda tabicada* from the geometrical and spatial point of view and drew a new and unusual form for roofing and walls. This form, called conoid, is obtained with a double layer of bricks making up a continuous and thin layer. The brick (*rasillas*) dimensions are

15×150×300 mm and they are linked with gypsum paste and with lime mortar and cement in the first and second layer, respectively. In the *Provisional schools of Sagrada Familia* there is no distinction between supporting elements and supported ones, between the roof and walls; everything responds to a single geometric rule, the sinusoidal profile of the conoid, and the *tabicada* construction technique. The exceptional nature of this work lies in the ability to mould a modular and rigid element such as brick reaching formal results never seen before with an impression of lightness, fluidity and elegance [4].

Figures 4: A. Gaudi. Provisional Schools of the Sagrada Familia (1909): a) outside; b) roof.

The meeting of Le Corbusier with the *bóveda tabicada* goes back to 1928 when he had the opportunity to directly know the Gaudi's work. On his travel book the mechanism used by Gaudi for building the Provisional Schools of Sagrada Familia is noted (Figure 5a). Le Corbusier didn't seem to be indifferent to this construction typology which has nourished the reflections contained in his preparatory drawings, sketches or even in his writings. However these were often simple considerations and were not translated into realized architecture [4]. The architect of the Modern Movement reinterpreted the *tabicada technique* bending it to personal will, taking away its unique construction essence and leaving just the image that it returns (Figure 5b). The system designed by Le Corbusier is between the concretion one used by the Romans and that of Catalan vault. As shown by his drawings, the two layers making up the vault are independent of each other: the first layer, called «*casing*» cannot be considered collaborating with the second, consisting of «*large format bricks*». The rules imposed by Guastavino, as the joints staggered disposition, the relationship quantity binder-size brick and the concept of the structural cohesiveness, aren't respected. Filling the first layer extrados with lightweight concrete mixed with a mesh of iron rods the structural behavior of the vault is modified; the resistant section includes the area of the abutment filled with porous material, and finally in the structural checks the contribution by the resistant brick is not considered. The conventional Catalan vault becomes a casing with reduced resistance [4].
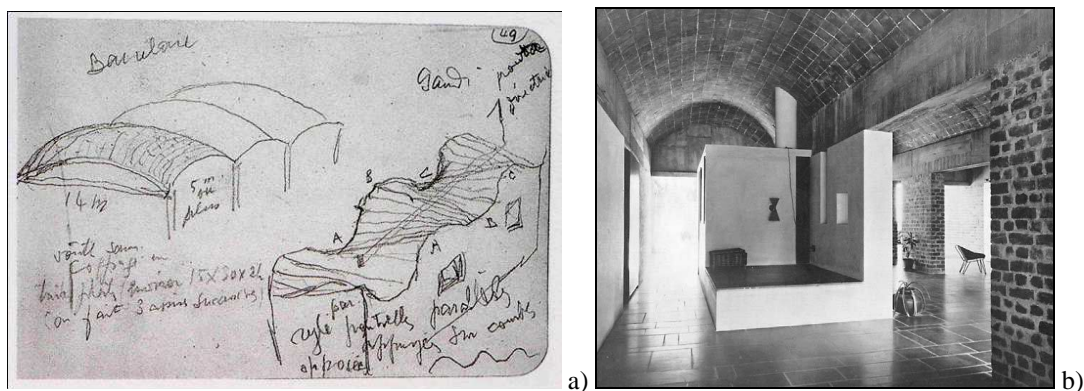

Figure 5: Le Corbusier. a) Preliminary sketches depicting the construction device used by Gaudi in the Sagrada Familia Schools; b) Villa Sarabhai (India, 1951).

Probably nobody was able to mix building tradition with material innovation than the architect and engineer Eladio Dieste. He combined the traditional technique of *bóveda tabicada* with the realization on the extrados of a thin layer of reinforced concrete; although unlike the Catalan vault, the one designed by Dieste was reinforced with iron and built on the arch centers. The architecture of Eladio Dieste stems from a pragmatic observation of the context in which he operates, particularly in Latin America and Uruguay. Actually he worked in a country with few natural resources, where iron, as well as the timber, have to be imported and the only available resources are labour and clay. Consequently Dieste chose brick as the basic material for his buildings, bending it to take advantage of its resistance to compression, and reinforcing it with iron to allow crossing big spans getting extreme shapes [18]. He developed two types of structures: double curvature Gaussian vaults, with and without skylights, and self-supporting vaults. Among Dieste's works sheds for the manufacturing of wool, silos for wheat, supermarkets and bus stations can be mentioned. His most significant architecture is certainly the church of Atlantida (1958-60), in which walls and roofs have no flat surfaces. The walls follow two lines, one straight at the ground line and a sine curve at the top, showing a remarkable resemblance to the Provisional Schools of the Sagrada Familia of Gaudi. The roof is designed as a succession of Gaussian vaults (Figure 6).

Figure 6: E. Dieste. The church of Atlantida (1958-60).

3. – Experimental characterization of the structural behavior of Catalan masonry

In order to interpret the overall structural behavior, it is necessary to define a suitable mechanical model able to represent the material behavior. The identification of this model presents some difficulties related to the intrinsic characteristics of Catalan vaults and in particular to their being stratified, alternating layers of brick and mortar. These two materials are usually modeled as isotropic individually but, since their mechanical properties are different, the overall behavior cannot be regarded as isotropic. As a consequence, it is necessary to perform an experimental campaign in order to determine the main properties of both brick and mortar separately taken, as well as that of a representative portion of the layered material. Authors collected some samples taken from different buildings of the historic centre of Palermo, where some structural elements, mainly constituting walls and with two, three and four sheets of bricks, are made with the same technique of the *bòvedas tabicadas*. The widespread element is constituted by three or four layers of bricks with mean dimensions 240×120×18 mm connected by mortar of lime and plaster. In previous papers (e.g [19]) authors performed many experimental tests in order to characterize the structural behavior of the layered material. In the present paper the above referenced tests are completed with the analysis of compression behavior of samples with two, three and four sheets of bricks as well as with appropriate petrographic and chemical investigations on mortar samples. In particular one masonry unit constituted by two layers, four masonry units constituted by three layers and four masonry units constituted by four layers and (all units with mean dimension of 320×320×115 mm) have been derived. All the tests have been performed at the Laboratory of

the Department of Civil, Environmental, Aerospace, Materials Engineering of the University of Palermo. The experimental set-up is constituted by the Zwick & Röell Z600 universal testing machine controlled by the TestXpert 11.2 software, supplied by the same firm.

3.1 – Compression tests on masonry unit

First of all it has been necessary to realize masonry samples suitable for the compression tests from those collected from real buildings. To this end, after a first general look for identifying macroscopic problems (such embedded tubes, macro voids and so forth), the original samples have been cut by a water circular saw obtaining: four samples of four-layers, four samples of three-layers and two samples of two-layers. It is important to emphasize that only one two-layers sample has been tested since the other one broke during the test preparatory phase. It follows that the obtained results are reported only as indicative. It has been decided to verify the role played by the external plaster in the results. To this goal the external plaster, whose mean thickness was about 30 mm, has been removed on two of the four three-layers samples. Subsequently to the cut, the samples have been prepared filling the manifest gaps with gypsum paste. Finally, the two faces to be put in contact with the testing materials machine were spread with a thin layer of gypsum paste in order to straighten the loading surface. Once the preparatory phase was completed, the samples were numbered and their geometry was identified. Besides the overall geometric measurements, partial ones of the layers of mortar and bricks have been also performed. This allowed establishing that the mean amount of mortar is about 20-25% of the total thickness. In fact, each brick has a thickness ranging from 18 to 20 mm, while the layer of mortar varies from 6 to 8 mm, in a total thickness of about 105 mm for 4 layers, 75 mm for 3 layers and 45 mm for 2 layers. The tests were conducted under displacement control with a speed of the crossbar of 0.5 mm/min, except for the case of 2 layers sample in which the speed of the crossbar has been set to 0.15 mm/min. In Figures 7 some photos representing the different phases of the compression test for sample IV-1 are reported as representative of what happened during all the tests. An examination of these figures immediately reveals the particular behaviour of the layered material under examination. The obtained results in terms of stress and strain are reported in Figure 8 in which, for simplicity's sake the mean results for each typology (2, 3 and 4 layers) are reported. An examination of the reported results immediately reveals the role of plaster as stiffening the material behavior without increasing the ultimate stress. The behaviour of 2 layers sample shows how the intrinsic presence of irregularities in the material plays a fundamental role in the overall material behavior.

Generally speaking, the behavior exhibited during the compression tests shows a classical trend: after an initial phase in which the crossheads of the testing machine adapt to the surface specimen, the material presents a linear elastic behavior ending at about 2.5 MPa with a tangent modulus ranging from 0.33 GPa to 0.50 GPa; following the elastic phase a nonlinear strain hardening occurs until the ultimate stress is reached, after which a strain softening until the end of the test is present. It is worth noticing that the rupture of the material under investigation is not a brittle one but it mainly occurs (as reported in figures 7) as a separation between the layers and with an consequent instability of the bricks. The value of the ultimate stress reached during the tests is different: 1.7 MPa for 2 layers, 2.5 MPa for 3 layers, 2.9 MPa for 4 layers. The comparison between the results obtained for the sample with and without plaster allows to affirm that plaster influences only the material stiffness, which in the examined cases, leads to a Young modulus of about 1.7 GPa. The small irregularities in the graphs have to be ascribed to the internal fracture (local collapse) in the material and to subsequently stress redistribution. It has been observed that, in general, fractures start where the thickness of the mortar is reduced and on the interface between bricks and mortar. A further analysis evidences that the two-layers sample behaves in a stiffer way with respect to the mean of the four-layer samples but in a weaker way with respect to the mean of the three-

layer samples (without plaster). This result depends on the layered characteristic of the material. Clearly, the overall behaviour, besides the mechanical features of both bricks and mortar, is strictly related to technological way as well as to worker ability of correctly disposing the bricks and the mortar. The presence of geometric, technological and mechanical irregularities surely increases with the number of layers and strongly influences the results.

Figures 7: Sample IV-1: a) before the test; b) , c) during the test; d) at the end of the test.
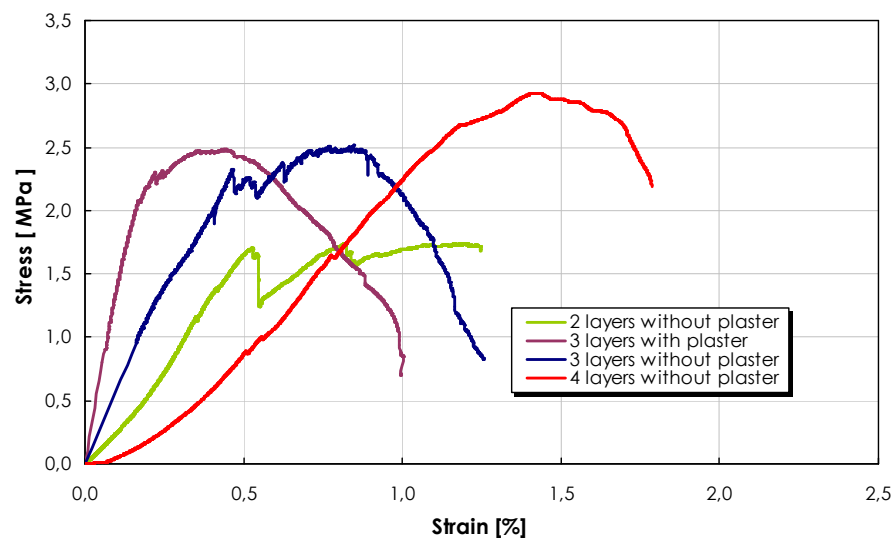

Figure 8: Stress-strain diagrams deduced by the compression tests.

3.2 – Petrographic and chemical analysis

In this section the results of both petrographic and chemical (XRD) analysis are reported in order to confirm the characteristics of the material under investigation. The petrographic analysis of the sample depicted in figure 9 is reported in the following table:

Level	Thickness [mm]	Aggregate/Binder/Pores ratio Temper/Matrix /Pores ratio	Description
A	10	(A/B/P): 65/25/10	Lime mortar: aggregates (0.1 ≤ d ≤ 2 mm) made mainly of quartz and in minor fraction of micrite and spar (d_{max} = 5 mm). High sphericity, roundness and sorting.
B	4	(A/B/P): 20/55/25	Mortar of gypsum: aggregates, poorly sorted (d ≈ 2 mm), made of microcrystalline gypsum (main fraction) and subordinately fine grained selenitic gypsum.
C	20	(T/M/P): 25/70/5	Fictile material characterised by a medium matrix birefringence. The inclusions are mainly of silt and rarely of monocrystalline quartz (d_{max} = 0.8 mm).
D	4	(A/B/P): 20/55/25	Mortar of gypsum: aggregates (0.5 ≤d ≤ 3 mm) made of gypsum both microcrystalline (main fraction) both selenitic. Macropores are frequent (d = 5 mm).
E	> 20	(T/M/P): 25/70/5	Fictile material characterised by a medium birefringence of the matrix. Inclusions are mainly of silt (d ≈ 0,02 mm), numerous

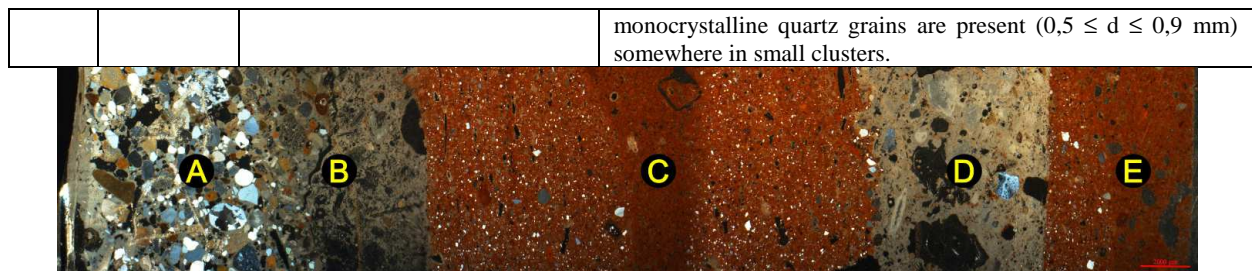|			monocrystalline quartz grains are present (0,5 ≤ d ≤ 0,9 mm) somewhere in small clusters.

Figure 9: Microscope image (7x) in reflected light of plaster – masonry – brick sample.

The XRD analysis has been performed on two samples: one obtained from the external layer (plaster) and the other one from the internal layer (mortar). The obtained results, reported in figures 10, confirm the use of a gypsum mortar for the internal layer as reported in literature.

a)

Quartz *SiO$_2$*   **Calcite** *CaCO$_3$*   **Dolomite** *CaMg(CO$_3$)$_2$*

b)

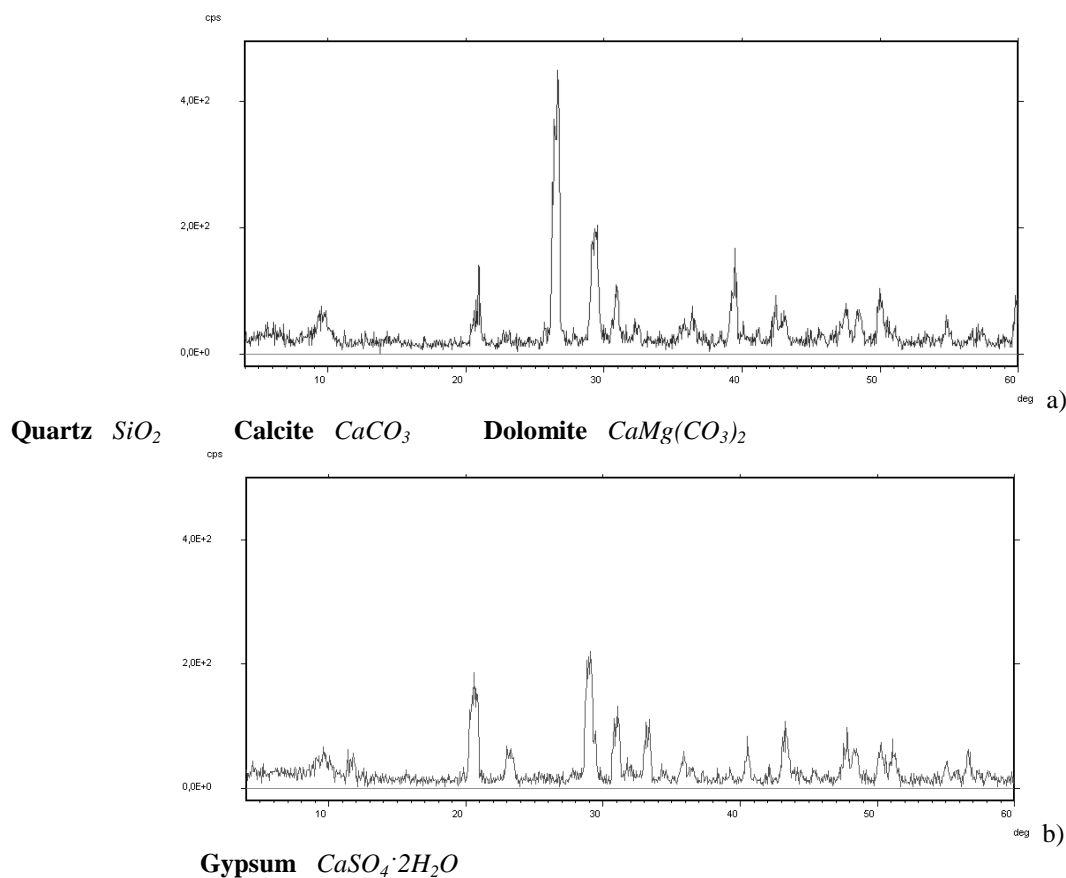**Gypsum** *CaSO$_4$·2H$_2$O*

Figure 10: XRD results: a) plaster; b) mortar.

6. – Conclusions

The work presented in the paper confirmed the role played by the *tabicada* technique, with particular reference to Catalan vaults, in the history of architecture showing how this ancient technique has been adopted and revised by the most important architects of the XXth century in many of their masterpieces. This analysis leads to other very important aspects of this technique related to its modernity and to the restoration of ancient architectural elements. In this framework it is fundamental to correctly characterize the mechanical behaviour of the structural elements in such a way to evaluate the real stress levels and, as a consequence, their safety factor when facing a restoration project; from the other hand a coherent mechanical characterization allows to correctly design new structures taking into account both the requirements of actual structural codes and the peculiar features of the *tabicada* technique. To the authors' opinion the results presented in the paper constitutes a first important step, even if

not definitive, being clearly affected by the low number of samples examined. The work presented in the paper also opens new perspectives in the reinforcing and maintenance of structures realized with the *tabicada* technique and in making up-to-date a technique of great historical tradition taking into account the recent technological and material developments which led to materials with high performance structural features. Future developments are to perform a deep analysis of the interaction between mortar and bricks from both experimental and numerical point of view and to analyze the structural behavior of the Catalan vaults also with reference to their use in constructions subjected to seismic actions.

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