Transactions on the Built Environment vol 39 © 1999 WIT Press, www.witpress.com, ISSN 1743-3509

Vaulted brick masonry constructions in Venice in the eighteenth century in the architectural and constructive context of the time

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Abstract

Ever since the Renaissance, experimentation in vaulted masonry systems in Venice has been characterised by alternate phases in which practical contributions (Sansovino) and theoretical ones (Poleni) have marked the progress of scientific research, the perfecting of the construction techniques and the choice of materials. The widespread use of stone for building heavy vaulted systems, resting on uneven terrains with poor reliability such as those in Venice, has produced various constructive results. This work particularly investigates an unusual constructive episode in the eighteenth century, a period which saw the maturing, in the Veneto region as elsewhere, of that process of rationalisation and coding of rules and instruments, which was to lead to the formalisation of an organised scientific corpus. The rediscovery of antiquity and of Vitruvius, together with these coded construction rules, conditioned architectural production in the Veneto during the second half of the eighteenth century. With reference to these themes, the authors studied the church of the Maddalena by Temanza, a construction inspired by the Pantheon as a formalisation of the constructive knowledge gleaned from Roman architecture. They then analysed the vaulted structure of the dome and the rules of composition and construction of the building, highlighting the variations with respect to the original model imposed by the particular situation of the Venetian context.

1 Introduction

In the direct reading of the structure, the built on a round plan church of S.Maria Maddalena by Tommaso Temanza (1705 - 1789) in Venice, - seen as a real manual of construction technique .- but in the light of authoritative specialised studies carried out by its designer, the authors aim to find original static and constructive intuitions and real anticipations of the modern criteria of design and management of constructive reliability. There is a dual aim, both cognitive and operative, as the authors share the conviction, which is now quite widespread, that the refinement of instruments for analysis on site and the possibility of correlating the results of investigations in quite varied disciplines - history, technology, statics, etc. - always supply instruments with a considerable practical range for the rationalisation of procedures for the maintenance of cultural assets over a period of time and, more specifically, for limiting these procedures.

The building a vaulted structure with a dome of bearing masonry without buttresses by structures, that can absorb the thrust, with the not indifferent span of about 14.6 m, on a difficult terrain such as that of the lagoon, is an unprecedented exception in Venice, with the exception of the case of the Emiliana Chapel on the Island of San Michele with a stone dome which is only about half the size of the one on the Maddalena. It was certainly made possible thanks to Temanza's well-founded cultural training and to the influences of the school of experimental thought of the Galilean tradition, which had recently been formed in Padua at the time when the church was built. The figurative choice of the maximum "transparency" and "recognisability" of the structural system even from the outside makes the operation a modern work and a break away from Venetian architecture.

The eighteenth-century example of the church of S. Simeon Piccolo by Giovanni Scalfurotto (c. 1700 - 1764)), also built on a round plan with a similar span, a short time prior (1718 - 1723) to the church of the Maddalena, still suggested the more tested and less problematic use of wood and of the specialised craftsmen at work in the town to make the whole dome, a reticular structure marked off, both outside and inside, by curved wooden boards. Temanza's unconventional choice and his renewed faith in the exclusive use of bearing masonry to realise the dome, with a structural behaviour of which he perfectly understood the mechanisms, are probably the most original elements of his work, justifying our interest in further investigation.

Yet at the same time the work fits into the mainstream of centuries of Venetian building tradition, of which it represents an element of continuity in the use of rules of the craft that had been long tested and adjusted on the experience of mistakes made in past.

2. The cultural environment in Venice and the role of Temanza

The construction of the arches in vaults and domes was to be the field of application in which the major clash occurred, in the years between the eighteenth and the nineteenth century, between two cultures: the one that saw architecture as

a derivation of humanistic studies and the one that welcomed the "new science" as a tool for the control of structural safety. Throughout the eighteenth century, the culture originating from medieval and Renaissance still survived in Venice, where the "*proti*" or curators of the *Serenissima* were the best representatives of this tradition. The construction of arched stone bridges in the town falls within this tradition and is based on a practice which has always done without operative manuals, being perfected by experience, entrusting a good reserve of static safety and durability to the high thicknesses of the vaults and the small dimensions of the structures [(1) (2).]

With the strength of well-grounded experience, which he had absorbed from the craftsmen of the Arsenale through the teaching of Scalfurotto, and with a profound knowledge of treatises, Temanza felt the innovative influence exerted, from Padua, by the strong personality of the experimenter and scientific scholar, Giovanni Poleni (1685 - 1761). Occupying the university chair *Ad mathesim et ad Philosophiam sperimentalem*, founded in 1739, Poleni had given an impulse to experimental studies of international renown on the mechanical behaviour of structures, which were to lead to the definition of a method for checking the efficiency of vaulted structures, coded in his *Memorie istoriche della gran cupola del Tempio Vaticano* in 1748 [(3)]

With reference to these questions and to the debate that arose surrounding them in the Venetian area, Temanza has a dual commitment, on the one hand to theory and on the other to application. His young work *Degli archi e delle volte e regole generali di architettura civile, opera e studio dello Architetto ed ingegnere Tommaso Temanza* [(4)], written in 1733, but published posthumously only in 1811 - based on the static principles of the vaulted constructiones - did not make an original contribution, capable of making innovations in the development of the strength of materials, with respect to which Temanza's work remained substantially extraneous (Mascheroni [(5)], Di Pasquale [(6)]). But it was in the church of the Maddalena (1763-1790), the first neo-classical building in Venice, that he succeeded in expressing the originality of his thought and her constructive knowledge. In the church he proposes a synthesis which reconciles the reasons of science, left in the background, with those of art, filtered through the reappropriation of the classical rules of building, which are substantially confirmed as valid since, in his view, they are able to sum up the criteria of structural reliability, functionality and durability (*firmitas* and *utilitas*) in the synthesis of beauty (*venustas*). In this sense his work is among the most significant on the European scene of the time.

3. The project for the church of the Maddalena

The eighteenth-century project for the church of the Maddalena in Venice is one of the simplest operations, in its neo-classical evidence, but at the same time one of the most intellectually complex of the period.

It is a church with a circular plan, defined by a masonry cylinder topped by a dome and preceded by an advanced pronaos. The plan is obtained by superimposing a

circle and a hexagon, while its dimensions are defined by precise rules of proportion. The building, lying in a north-south direction, is situated on the *ultra* or outer island of the city, in the district of Cannaregio, in an irregularly shaped *campo*, bordered on the west by the rio della Maddalena, to the east and north by buildings.

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The return to the study of ancient monuments, the continuity restored width Palladio's (1508 - 1580) works and the use of the classical language mark the transformations in Venice's urban layout and buildings in the eighteenth century, both in the city itself and in the territory. In the city these transformations took the form, as in the case of the Maddalena, of the replacement if public architecture with a strong symbolic value, even creating urban spaces outside the building, so that these are noticeable for their spatial role.

The problem of proportions in architecture is tackled, for the first time in the eighteenth century, by considering the proportioning of buildings in scientific and relativistic terms, depending on the needs that may be found during composition.

Temanza is perhaps the most important representative of classical purism, which is being developed at that time in Europe. The project of the church of the Maddalena is almost an in-vitro experiment of a procedure.

The blatant indifference to the environment is indicated by the interest in a solution that would be valid for all times and places, such as is represented by the type with a round plan.

3.1. The model, the rules of proportion and the context

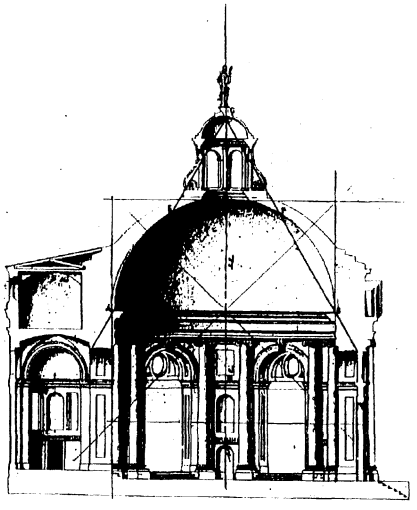
The architect's autograph letters and notes [7] [8] allow us to know and "interpret" much more deeply the process that generated the work.

With his architectural production, Temanza always did large-scale theoretical research, which finds some of its greatest expression in his best known literary work, the *Vite* [9].

Temanza's design for the construction of the dome gives us the rules for inserting the "*feral*" (the Venetian term indicating the skylight turret) [10] "to give light to the Temple...in proportion to the median AB, base of an equilateral triangle ABC.." from which may be obtained the width of the feral, which is the fifth part of the light of the whole dome [11] . But this design and its notes indicate the cultural references of the work, which agrees with what Sebastiano Serlio says in the second church that he designed, namely "that the feral forms the fifth part of the whole dome".

The same triangle, thirty-three feet high, may also be inscribed in the circular plan of the church and defines its division into twelve parts.

As the architect himself wrote in a letter to Francesco Maria Preti [12] , the church of the Maddalena is "simple and regular. The outside walls reply exactly to those on the inside, and the proportions are musical".



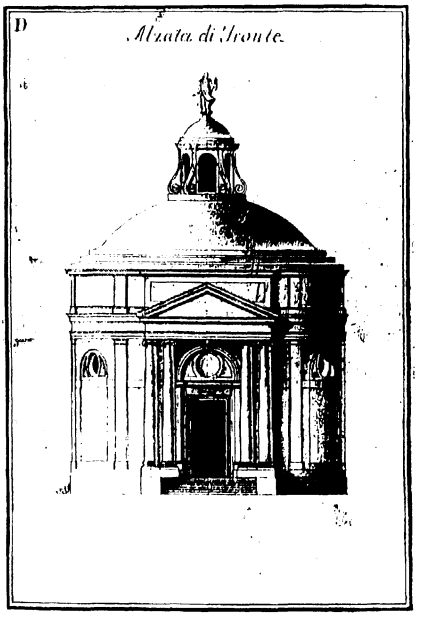


Figure 1 and 2: section and view of the church

Temanza expresses his regret in not having developed the details of the keystones of the arches he designed on a larger scale: "If I had had time I would have drawn some parts on a larger scale, in particular the keystones of the arches, in which there are some details of my own invention, but all based on Nature and the truth."
Here too he recalls antiquity through Vitruvius, "*ea probaverunt quorum expliciationes in disputationibus rationem possunt habere veritatis*" (we have accepted those explanations in discussions which can have a rational correspondence in reality) [13].
It is possible to interpret this sentence with respect to what is written in book seven of *De Architettura* [13] that is the need for a relationship between *veritas* and art, in which he notices that there is a strong coincidence between truth or reality and nature. In fact, Vitruvius poses the question that in representations there cannot be any things which do not have a rational correspondence in reality.
We may suppose that the details of invention of which Temanza speaks, failing proof to the contrary, are the connections of the wedges in the arches which, as in the arcades of the amphitheatre of Flavius, may have been achieved by means of pivoting or of reciprocal sockets. Confirmation of this hypothesis is also provided by Nicola Cavalieri San-Bertolo [14] : "The ancients too used the art of connecting the wedges by means of pivots, or of reciprocal sockets. In Arab buildings the wedges of the vaults had alternately toothed and hollowed edges, so that the many notches made the system hold firmly together, reducing the thrust on the piers."
The church may be read in its typological layout: it is a building with a central plan, for which precise formal references may be found in Serlio, Raphael and Palladio.

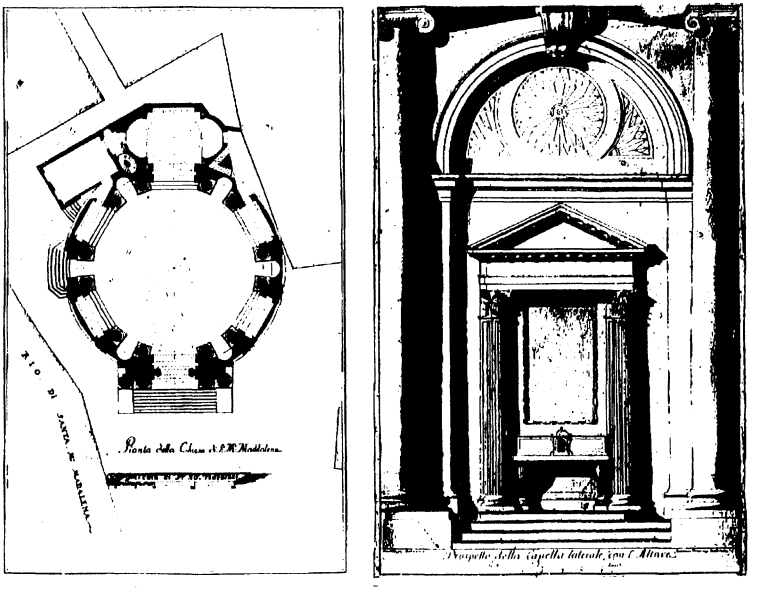


Figure 3 and 4: plan and detail of the arch with columns

In his Fourth Book, chapter, II [15] , Palladio indicates the round form as the most beautiful and regular: "... but the most beautiful and regular forms, from which the others receive their measurements, are the round ones...".
We should assess the exceptions involved in placing the type in the context of a difficult town setting such as Venice: in the chronicles of the building [16] we can see how this church was preferred rather than other projects like that of Massari on account of the less invasive perspective effect of the round form, but in Temanza's drawings we can see how the rules of proportion have been conditioned by other factors: "the three proportional means do not come from a real principle... there is one thing which, in my belief, can be firmly established, and it is that architecture has a number of its own, in the same way as music; and so I say that, just as the ear of the Speaker is judge and regulates the number of prose, so the exquisite eye of the Architect is judge and regulates the number of architecture." (letter to F.M. Preti in Bottari Ticozzi, Lettere) [12] . This letter shows us a subjective side of the writer, very often torn between the desire to abide by rules and rational principles laid down by the so-called "founder" texts, by the utopias from which the reproductions of the models derive, and by the need to solve problems concerning perspective or the inclusion of the model itself in the context.

3.2 The type of the classical round temple

The theme of the *monument* is a programmatic manifesto that takes up previous examples. Even in the Maddalena there were no static or constructive problems of exceptional importance, considering the church's small dimensions.

Temanza reconstructs the type of the classical round temple, based on the theory of Vitruvius and on history.
Like Bramante two hundred years before him in Rome, he seems to want to establish a model that can be proposed in Venice, a venture that is equally necessary from the historical point of view of the architect.
Here too the modular composition becomes the rule, combining the element and the whole in a formal "unit"; the basic module is the diameter of the column which forms a relationship with all the component parts; the proportional means - harmonic, geometrical or mathematical - can form the rules which alternatively form the harmonies, unity of composition and commensurable unity of the architecture.
The Tempietto Barbaro, built at Maser by Palladio in 1580, is considered by Temanza (1778) a quotation from the Pantheon, or rather a free interpretation.
The building combines two elementary forms: the cylinder and the hemispherical calotte. The author mentions it in the *Vite* [9] where he notes how the arches are placed against the masonry, while his choice in the "tempietto" before the church (oratory at Villa Contarini) had been to keep them in a straight line.
However, one of the figurative choices shared by the two projects by Palladio and Temanza seems to be the elimination of the tambour, at least on the outside. This compositive theme found a structural correspondence in the project of the arches of the temple.

4. Constructive criteria and structural conception

4.1. The constructive layout of the Church of the Maddalena

The construction is made of brick and Istria stone.. The Istria stone was used for the fundation, the basement, the inferior part of the columns, the circular entablature and the ring at the top of a dome, while the brick masonry for the others vertical elements and for the dome.
The vertical loads are transmitted uniformly from the dome to the entablature, from which they are transferred to the supports, which convey the horizontal thrust to the masonry piers. The supports are alternately composed of a pair of capitals and of the arches, which subtends the greatest span between the columns for a total number of twelve capitals and six arches. The stability of the arches is ensured by the fact that their springers rest on sturdy piers composed of the columns and of the pilasters behind them, which absorbs the stress, what are not cancelled by the effect of mutual contrast. The loads of the covering are thus transferred to the twelve piers, from which they are transferred to the bases and then to the plinth (*regolon*) which uniforms distribution on the foundation.
The elegant sequence of arches and columns, arranged alternately with an intercolumniation of one or two modules behind which the sturdy piers are concealed from view inside the church, is the way in which Temanza renders the rule of the transmission of stress with the greatest lightness. On the outside, the distribution of stress in the piers allows complete unloading of the four perimeter

walls which mark off the shell on the sides not affected by the openings and by the access to the sacristy.
Some signs of the age-old building tradition that remained almost unchanged in Venice were the accuracy in laying the foundations, on which relied the lasting reliability of the entire building structure and the wise precaution of preloading them to eliminate great deformations of the soil, referred to in the "*Register*"[16].
The care in distributing the stress transmitted by the building by constructing a kind of kerb around the base (the *regolon*) which had also the function of protecting the porous system of the brick masonry against the phenomenon of the capillary rising of damp from the soil completed all the roles traditionally used in the town.
Temanza's decision to rest the covering layer directly on the masonry calotte and to use copper for making it is, instead, an innovation with regard to the traditional constructive scene.

4.2. Constructive criteria of the hemispherical dome

In making the dome of the church of the Maddalena, Temanza applies the criteria that he himself expounded in his early work [4], which differ from the conventions of treatise writing based on geometrical formulae accepted a priori, rising then to the level of actual structural intuitions, expressing a unitary spatial conception of the designed structure. The inclusion of the structural conception of building in the discipline
of mechanics was to become successful in Venice, but only after the advent of the French school of engineering, brought by Napoleon in the early nineteenth century.
Below are summarised the constructive criteria adopted by Temanza for the structural set-up of the vaulted system of the dome:

1. Intuition of the mechanism of mutual action between wedges and the resistance by friction, which leads to the rule of directing towards "a common centre" the wedges that compose the vault (in his treatise [17], Scamozzi (1552 - 1616)had already highlighted the understanding of the friction-resistant mechanism); in the case of the brick calotte of the Maddalena, the direction towards the centre is that of the mortar beds of the rings.
2. The awareness of the possibility of "controlling" the "conveying" of the strain towards the piers in bearing masonry through the combined use of different constructive contrivances, all derived from classical building tradition and admittedly inspired by the lesson of the Pantheon: a) the adoption of the the less thrusting hemispherical section (following a long tradition), using brick rather than stone, as it is lighter and exerts less thrust; b) the adoption of a variable thickness that grows from the top to the springer ("*The greatest artifice in the Domes was making them in such a way that they were not so thick at the top as they were at the foot.*") (4); c) the concentration at the reins of a heavy weight, the terrace-shaped backing, in the zone where there is the greatest risk of tension breakage of the vaulted structure, to verticalise the resultant between loads and thrust; the masonry drum on which the hemispherical dome rests also contributes to this result. The joint application

of these measures probably led Temanza not to use "iron bars" to reinforce the entablature, as he feared they would have poor durability.

3. Mature understanding of the mechanism of the distribution of stress on all points of the surface of the curve of the dome (according to self-bearing parallels), which enabled Temanza to open the dome at the top and to load it with the weight of the skylight turret (establishing rules for the width of the hole).
4. Generalisation of the principle of the distribution of stress, entrusting it with the result of the stability of the entire system, considering in particular the treacherousness of the soil in Venice, generally lacking in homogeneity. All this leads to the greatest care in making the entablature of the dome and the arches which bear its weight, the base for distributing the strain on the foundation, and in the construction of the same foundations, resting on a wooden raft which in turn rests on pilings.
5. The profound knowledge of building materials, not only of their resistant and deforming characteristics, but also of their behaviour through time, which led Temanza to eliminate wood from the covering and probably not to use "*iron bars*" to contain the thrust, trusting instead in the quality of the brick masonry bond and in the meshing of the wedges in the stone bond. In the construction of the masonry he uses bricks and natural stone alternately framing the brick masonry with the stone to protect the bricks against attack by water and salt and, but above all to configure a structural system with the aim of optimising in strategic elements the bearing function of the stone system.

5. Conclusions

The authors propose a reading of this monumental example of Venetian architecture that aims to investigate the architectural static, constructive and technical reasons which, together, led to the configuration of the design and execution of the work. The work is analysed in relation to the traditional skills on which the building was based in a time of great cultural transformations, just a short time before the advent of building science.

The existence of a work written by the same architect suggested filtering the interpretation of the structure through the rules of art that he proposed there, the expression of refined technology and of a structural awareness that was mature, even though it had not yet been coded by the mechanics of building.

The coincidence between *firmitas* and *venustas*, relationship with *utilitas*, represent the true originality of the architectural Temanza's work, which is reading again in modern key.

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