The Eighteenth Century Brickwork Domes in Valencia

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INTRODUCTION

This paper is based on documentation produced during recent conservation works. However, there is no reference to the operations carried out to preserve the authenticity of the construction systems. This paper is a synthesis aimed at defining the characteristics of the construction as accurately and detailed as possible, by means of test pits and surveying. In addition, it is also an attempt to define the cultural environment in which these works are produced. The purpose is to provide data to the scientific community to further expand the design of models, in order to achieve a balance between practice and theory **(fig.1)**.

Figure 1. Vicente Tomás Tosca, San Felipe Neri Church, Valencia.

The construction of the communion chapel of San Roc in Oliva, illustrates in architecture the ideals of the Valencian innovators "novatores", who were not unaware of the figure of Gregori Mayans. With a classical inspiration, following the grammar of orders, its early date of 1729 should be noted, which in Spain was some decades ahead of the appearance of the Academies of Fine Arts. It is necessary to understand it as a part of the same movement that promotes the contemporary construction of the church of the Oratorianos of San Felipe Neri, fostered by Tomas V. Tosca, or the communion chapel of San Andrés, or many other Valencian classicist works that culminate in the rotunda of the Escola Pía with 24.5 m of interior diameter, in the last third of the seventeenth century.

The hermitage of San Marcos in Olocau del Rey is a work carried out by master builders, Joseph Dols and Fernando Molinos, both native of neighbouring Aragonese regions, with recognized prestige, main figures of the last moments of the professional association of construction masters, who are the managers of the process of material execution, and will be gradually replaced by other creators that will be imposed by the new order established by the academies.

The archpriest's church of Vila-real, in the second half of the century, means to historians the "farewell to cosmopolitan baroque and the acceptance of classicism”. The creators come from the world of the established academies. Fray Josep Albert Pina, degree academician from the Academy of San Carlos and of recognized mastery, was responsible for the design of some plans. The final project is due to Juan José Nadal, with a long professional career recognized by his appointment as academician by the Academy of San Fernando. The checking of the dome was carried out by Antonio Gilabert, Director of the Academy of San Carlos and author of the extraordinary dome of the Escola Pía and until the completion of the archpriest's church distinguished architects with academic background also take part.

THE DOME OF THE COMMUNION CHAPEL OF SANT ROC. OLIVA

Figure 2. Communion Chapel of San Roc. Oliva Church. Exterior View.

II.a Brief outline of the monument.

The parochial Church of Sant Roc is located in the area previously occupied by the old Muslim quarter of Oliva, it is located in the same place as a previous mosque. The chapel has a Greek cross plan, although the side of the chancel is circular. The central area is covered with a dome that is lifted on a low drum; the chancel is covered with a cul-de-four, on which a lantern is placed, and the arms by means of a barrel vault with lunettes. The access side has been mutilated, absorbed by the side aisle of the church, which was built after the demolition of a previous one, and establishes its syntax, aside from the preceding architecture.

The retrochoir has a central plan, with three lobular chapels covered with a half-domed vault; the central area is finished off with a dome with lantern **(fig.2)**.

The chapel as well as the retrochoir are profusely ornamented. The pictorial decoration is the work of the famous master Lorenzo Chafrion who applied an elaborated iconologist programme, within a framework of false architectures **(fig.3)**.

Figure 3. Communion Chapel of San Roc. Oliva Church. Cupola Interior View.

Built in the first third of the 1700s, the architect who carried out the plans is not known, but unquestionably influenced by the postulates of Tomas V. Tosca, in his famous treatise.

Description of construction of the dome.

The assembly of the communion chapel reveals the volumes of the upper body with an interesting play of coverings of its dome, lantern and cupola of the retrochoir. The coverings are arranged as a roof, with field tiles whose upper board - the support of the curved roofing tiles - rests in small partitions that are lifted and back the vaults. The covering of the dome with blue glazed roofing tiles and white hips should be noted here.

The outside of the dome was topped with a wrought iron cross built in a base of ornamental stone. It is the lower piece of the decorative pinnacle, the only one preserved from the original stone top. The metal bar crosses the resistant shell of the brick vault and enters the inside. A pendant was hanging from the lower end, some sort of false keyblock or drop, a large construction of wood, beautifully decorated with stuccos and gilts with a side table missing, that was swinging, due to its lack of anchoring, a short metal pin perpendicular to the iron bar.

In the upper top, the piece that was preserved from the original stone pinnacle was cracked due to its incompatibility with the iron bar that crossed it. The lantern and cupola of the retrochoir were also topped off with pinnacles of similar characteristics and several smaller pathologies.

For the definition of the resistant vault, a detailed measurement of its geometry was carried out, since it had scaffolds, based on continual approaches, comparing the sections of different meridians by its extrados.

It can be interpreted as a 7 m revolution ellipsoid of horizontal axis, approximately 30 Valencian handspans, and a 10 m vertical axis, that corresponds with 45 Valencian handspans. Thus, the horizontal axis is lifted with respect to the inside impost of the pendentives, at the level defined by the upper line of the openings of the drum **(fig.4)**.

In order to define the composition of the construction, as the intrados was decorated with valuable paintings, the indispensable test pits were carried out to find fundamental aspects that allowed the study of the construction.

A partitioned vault of double common brick with plaster is placed at a line of approximately 60 cms, lifted with respect to the level of the outside cornice, on a ring of half ft brick of circular plan, that is fitted internally to the brickwork of the drum,. On this inside plane, perpendicularly at each side of the drum, the stiffbacks are arranged formed by only one brick on edge, following the meridians.

These ribs are used as bearing to the upper board formed by brick and backed with plaster, thus creating the bearing of the covering of ceramic roofing tile.

We can consider it as a dome with two planes, taken to the limit. The outside follows the same geometry, only separated by the edge of the brick.

It is not necessary to draw attention to the great slenderness of the dome. If we consider only the thickness of the partitioned vault, the diameter is one hundred times its thickness. The box structure created with the stiffbacks is very indicative, not only from the structural point of view, but mainly from the point of view of its hygrothermal behavior, due to the formation of the chamber (Soler, Rafael, Soler, Alba and Llopis, Cardona 2002).

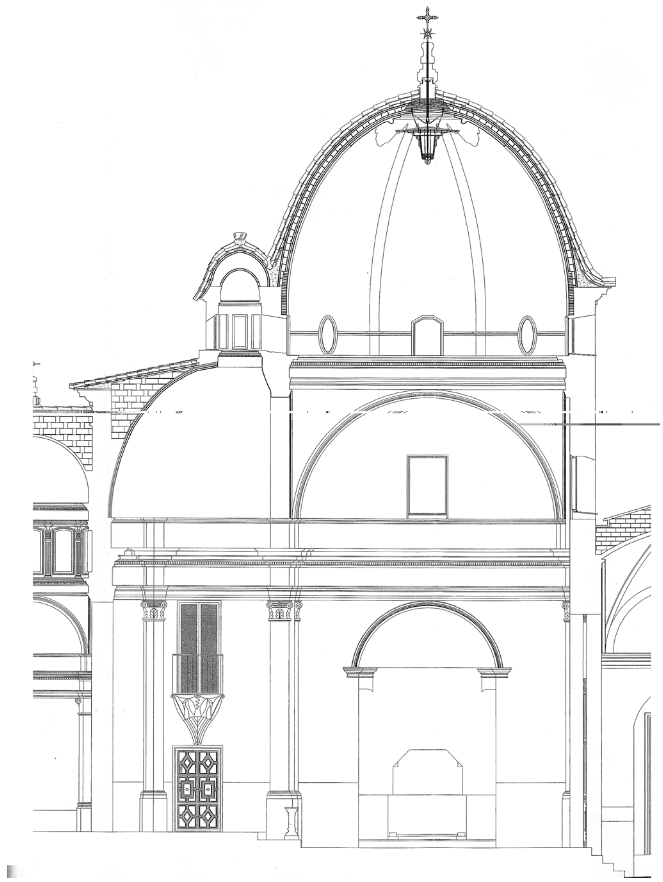

Figure 4. Communion Chapel of San Roc. Oliva Church. Constructional section.

THE DOME OF THE HERMITAGE OF SAN MARCOS. OLOCAU DEL REY

III.a Brief outline of the monument.

The current configuration of the assembly of the hermitage is due to the works carried out during the eighteenth century, around a primitive construction, of which only a gothic chapel with star vault is preserved, at the moment included in the building of the inn.

The church prevails in the assembly, emphasizing a slender facing brick drum with Mudejar influences, from which the dome that crowns the set rises **(fig.5)**.

Figure 5. San Marcos Chapel. Olocau del Rey. General Exterior View.

The plans by master Joseph Dols, follow a Greek cross plan, to which a section is abutted to lodge the chancel. In the spaces left by the arms of the cross, four smaller domes are lifted, only with inside plane, with an elaborated geometry, flanking the central dome that arises on the space of transept **(fig.6)**.

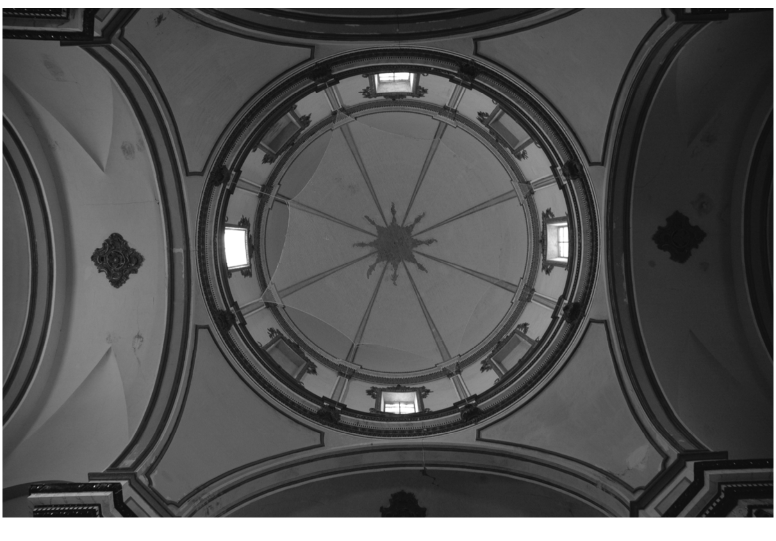

Figure 6. San Marcos Chapel. Olocau del Rey. Cupola Interior View.

The works began in 1769 following the plans of Joseph Dols, who directed the works until 1771, when Fernando Molinos took over, and had to conclude them within the next four years. In fact, in 1783 the dome was not yet lifted, "about to cover its cimborio". After this date, the problems seemed to be overcome, since the date of 1784 appears in the metal rod on the top of the outside crown of the dome. Once these main difficulties were overcome, and the church was already inaugurated, the works of decoration on the inside continued in the following decades.

Description of the construction of the dome.

In spite of all the existing documentation and several historical studies carried out, accurate data were not available with respect to the dome, neither of its geometry, nor of its constructional characteristics. The definition of the dimensional and constructional characteristics are based on the measurements and test pits carried out.

The dome with a stilted outside profile, without lantern, white glazed roofing tiles in the hips and with ornamental motifs of blue glazed roofing field tiles, raises on a slender drum, of outside octagonal plan, made with large format brickwork, with special pieces in its cantons and the upper cornice. The elevation of the drum corresponds to a classic composition of pilasters, bolsters and entablature, interpreted with a certain degree of freedom by means of the use of brickwork. In the axis of each case there is a trabeated opening, filling the stretch to the cornice with a brick bond in diamond point that gives it a certain relevance.

The design of the dome is 9.20 m in diameter, which corresponds to the preferred measurement of design of 40 Valencian handspans. The inside plane corresponds to the geometry of a hemisphere, which is elevated with a base moulding of approximately 90 cm in height. On that line is located the plane on which is a partitioned vault with one brick covered with plaster on both faces, with an average thickness of 6 cm. It shows ornamental ribs on its intrados whose width decreases when approaching the keystone, decorated with stucco mouldings with a floral motif. From its extrados it receives a supplement of eight arches of variable widths, in double brick, covered with plaster, that meet and form a central crown **(fig.7)**.

The outside plane follows an elevated geometry with a relation of two thirds between radius and arrow. It is also a partitioned vault, in this case with two bricks, covered with plaster on the external side, with an average thickness of 9 cm. In the lower area, from the springing to approximately 2 m in height, both planes, outside and inside, are juxtaposed, and from this section they separate with the characteristics described above, forming an attic between them, without connection.

From the inside of the attic, created between the two planes, to which we have had access during the intervention of the anchoring of the upper top, we have seen the first layer of the outside plane, in this section without covering that allows one to define the dimensions of the bricks and their bond, and also its geometric deviations. They are joined as a brick on edge partition, with plaster with emphasized joints, which are lowered, without developing in spiral form, but by successive horizontal lines.

The drum of octagonal plan in its outside, locates its high cornice approximately 1 m on the base plane of the dome and its brickwork acts as a rigid ring of containment, complementing in the upper part with a filling of light stones and mortar that are fitted to the circular plan of the extrados (Soler, Rafael, Soler, Alba and Martinez, Pedro G 2004).

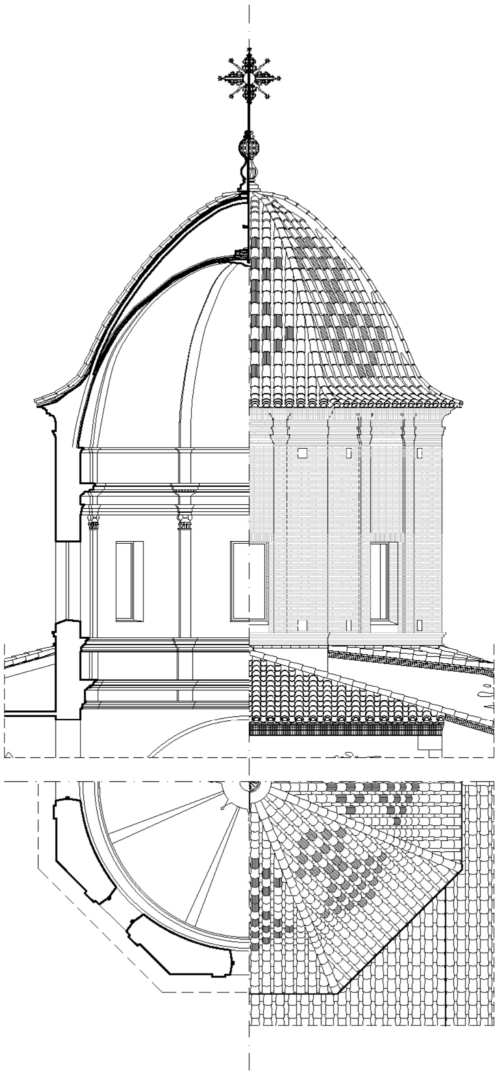

Figure 7. San Marcos Chapel. Olocau del Rey. Constructional section.

THE DOME OF THE CROSSING OF THE ARCHPRIEST'S CHURCH OF SAN JAIME. VILA-REAL .

Brief outline

The archpriest's church of Vila-real is located very close to the main square, historical centre of the town. Its head, formed by the apse and the transepts, opens to a columnar space of three naves separated by eight pilasters from which start the arches that lower the barrel vaults with lunettes of the central section and the cross vaults of the side naves, which are flanked by chapels, lodged between the abutments **(fig.8)**.

Figure 8. San Jaime Archpriestal of Vila-Real. Exterior view before restoration.

In the centre of the crossing, at a height of 33 m the dome rises on a drum lowered by the pendentives and transverse arches. Externally covered with glazed blue roofing tiles they form the elevated profile of the dome **(fig.9)**.

Initiated in 1752, Juan Josep Nadal was responsible for the plans and the management of the first stage of the works, until his death in 1763. The works were continued by his disciple and collaborator Cristóbal Ayora. The church was inaugurated in 1779. Around 1775, a check of the dome was requested of Antonio Gilabert and Lorenzo Lahoz who gave a favourable opinion. The excellent paintings on the pendentives by the famous painter Josep Vergara in 1777 should be noted.

Description of the construction of the dome.

In terms of layout and construction details, the dome of the archpriest's church of San Jaime follows many of the guidelines gathered in the famous manual by architect Fornés and Gurrea.

The dome is placed by means of the technique of partitioned vaults, which in the Valencian context reaches a mastery difficult to reach. In spite of all the existing documentation and several historical studies carried out, accurate data were not available with respect to its geometry, or its constructional characteristics. Lowered by the transverse arches of the crossing, and partially hidden by the field tiles over the naves, the drum, or body of lights arises. It has an octagonal plan on its outside, and circular in its inside. Built with brickwork, of large format, that uses special pieces in jambs and breast beams of the large windows located in the axis of each face.

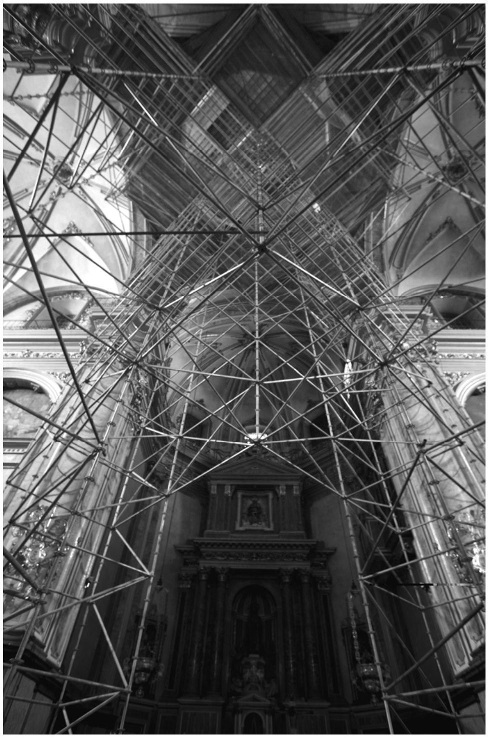

Figure 9. San Jaime Archpriestal of Vila-Real. Cupola Interior view.

Its cornice, approximately located at 3.5 m high on the base plane of the dome defines an octagonal perimeter and is executed using moulded brick on edge, cantilevered in relation to the face.

During the restoration works it was discovered, on the side of the fallen cornice, an iron chain, witness of the technology of the braces and chains described in the manuals and historical treatises. It is a finding with a high documentary value. They are wrought iron links, alternately connected and horizontally and vertically arranged. In the corner, a ring vertically anchored in the brickwork connects the different sides. It is located at the level of the cornice and is set back one ft from the outside alignment. The detailed drawing shows their characteristics more accurately.

The design of the dome has an inside diameter of 12 m, equivalent to 54 Valencian handspans. The inside plane is located from a slightly higher plane, 1.40 m, to the circular cornice that connects from above, the transverse arches and the pendentives of the crossing.

Taking an ellipse as reference, with semiaxes of 6 m coinciding with the radius and an arrow of 9 m, 40 Valencian handspans, a surface of revolution is created, which is partially emptied by means of eight lunettes that define conical surfaces, in correspondence with the large windows of the drum and whose vertex is located at one quarter of the diameter. The strongly edged inside plane described reproduces a solution away from the orthodoxy of the hemisphere, in a certain way Gothic **(fig.10)**.

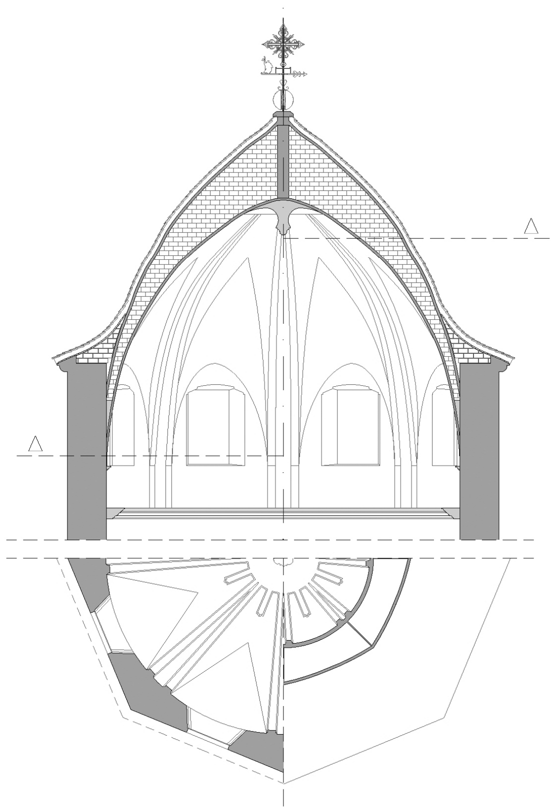

Figure 10. San Jaime Archpriestal of Vila-Real. Constructional section.

The intrados is lowered by eight twin ribs whose width decreases when approaching the upper crown in which they meet, and from which eight ribs run, but do not reach the lunette. Fine decorative details of plaster, stucco, gilts, with floral motifs, decorate the ribs and the upper crown, as well as the large windows of the drum.

The composition of the inside plane consists of a partitioned vault, of "double brick" covered on the inside with a plaster layer. There is a first layer of solid brick with plaster, a fine layer of plaster in its extrados, a second layer of solid brick with plaster, with a *llafardat per dalt"*.

The brick bonds or possible connections or joints with the inside plane of the ribs are not known accurately. It is only possible to hypothesize. However, the outside geometry of the covered brickwork has been determined, with dressings and mouldings, that in addition are variable, according to the height, which confers a remarkable complexity.

The outside plane follows an elevated geometry, reaching a 12 m arrow matching the dimension of the diameter. It is formed by eight vaults with edges matching the diagonals of the drum and in whose intersection are located eight stiffbacks, brick on edge partition, that start from the inside plane, and meet in a pillar of brickwork, with a square plan with 1.5 ft sides.

Its constructional composition is, also a partitioned vault, "of double brick", similar to that described for the inside plane, but without plaster layer in its inner side. The visual inspection carried out from the interior of the attic allows one to see the disposition of the brick on edge bond, with plaster, with the largest dimension of the brick being vertical, alternating with some lines arranged horizontally, and whose guidelines are increasingly curved. It displays one peculiarity, in the lower area from the base, up to an approximate level of 1.60 m above the cornice of the cover, it is backed by *"uns carrerons"* of solid brick, as small partitions, separated approximately by 30 cm. that overlap with the drum.

The attic created between the outside and the inside plane, lends excellent characteristics with respect to its hygrothermal behavior, giving great importance its degree of ventilation. The connection between both planes also allows to elaborate different models of mechanical behavior (Lizandra, Joaquim, Soler, Rafael, Soler, Alba and Rodriguez, Amparo 2005).

STRUCTURAL ANALYSIS OF THIS TYPE OF DOME

As described above, all these domes have the common characteristic of being domes of double partitioned plane with very little thickness, barely 10 cms, and a great slenderness. In spite of not showing any considerable structural pathology, it has been considered appropriate to analyze its stability, as complementary research to the process of restoration, which allows the achievement, at the diagnostic stage, of accurate models on its structural behaviour.

On the basis of a precise graphical elevation of the geometry of the domes, of their constructional characteristics, as well as of the estimation of the gravitational loads that act on them, the methodology of analysis followed to evaluate the structural behaviour, which serves as criterion for an effective approach to restoration, is the following:

1. A first analysis of the global stability of the dome through the classic procedure of graphical statics, and the application of the theorems of the limit analysis, with the purpose of verifying if the line of thrusts runs through the interior of the thickness of one of the meridians of the dome. Also seeing if the result of the horizontal component that balances with the contiguous arch stones of each parallel does not produce tension or that their value is negligible. In the absence of clear fissures, it would not be necessary to verify that the fictitious arches produced between two meridian fissures, are stable (Heyman 1995).

   Nevertheless, the study of the stability has been performed under three assumptions:

   a) Behaviour as arch on the hypothesis of a width of arch stones resulting from a "segment" in a plan of 18 degrees in width.
   b) Behaviour as dome, with the same width of a "segment" in plan as the previous case, but considering the horizontal efforts that are transmitted to the contiguous arch stones in their same parallel, more in accordance with the membrane behaviour of the dome.
   c) A third combined assumption, which consists in considering behaviour as arch in the lower two thirds of the dome where based on experience the damage usually takes place, and behaviour of dome in the upper third generally compressed.

2. Verification of the membrane tensions and shell flexion by means of the modeling of the dome by surface finite elements, with the hypothesis of gravitational loads.

3. Analysis of a model of damage, nonlinear, and on the basis of the previous hypotheses with a rank of resistance of the brickwork of the dome of 4 N/mm^2 in compression and 0.2 N/mm^2 in tension, equivalent to values between 5% and 10% of the compression (Leon et al n.d.).

The conclusion of the results of this analysis in these domes is as follows:

For the dome of the church of Sant Roc in Oliva (Valencia)

1. For these dimensions, form and loads it is confirmed that the dome is stable according to the position of the line of thrust in the analysis of graphical statics performed with the dome model **(fig.11)**.

2. In the simulation of the arch model, the line of thrust runs by the outside of the thickness of the dome; thus, for domes of this slenderness, this model is not suitable for the mechanical analysis of the monument **(fig.12)**.

3. The membrane tensions in the direction of the meridians are of compression and far away from the values that could be considered as critical of the material.

4. The membrane tensions in the direction of the parallels show tension values in the lower third of the dome, matching the static analysis, although their values are very far from those which could justify damages in the brickwork **(fig.13)**.

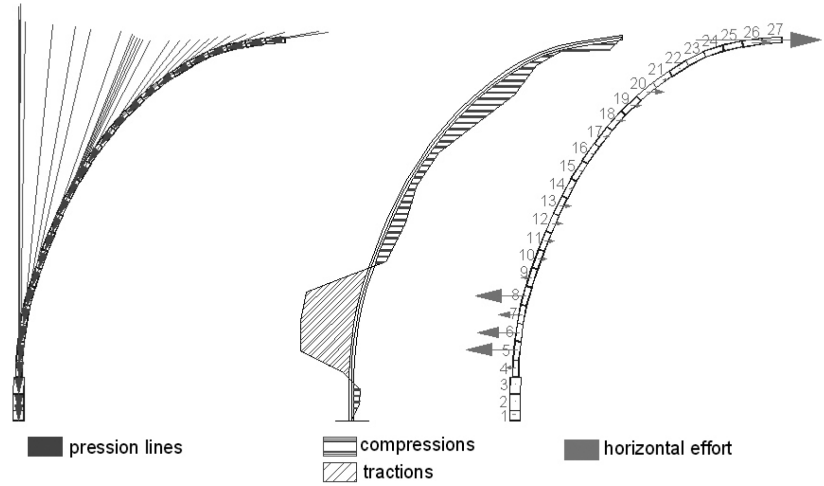

Figure 11. Communion Chapel of San Roc. Oliva Church. Graphic Estatic: Cupola Model.

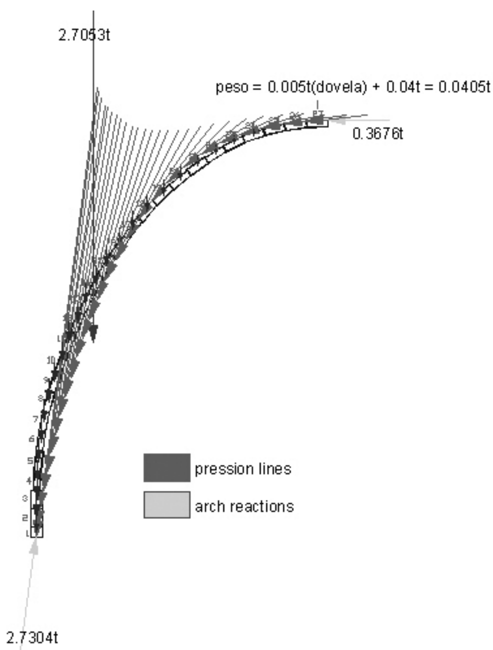

Figure12. Communion Chapel of San Roc. Oliva Church. Graphic Estatic: Arch Model.

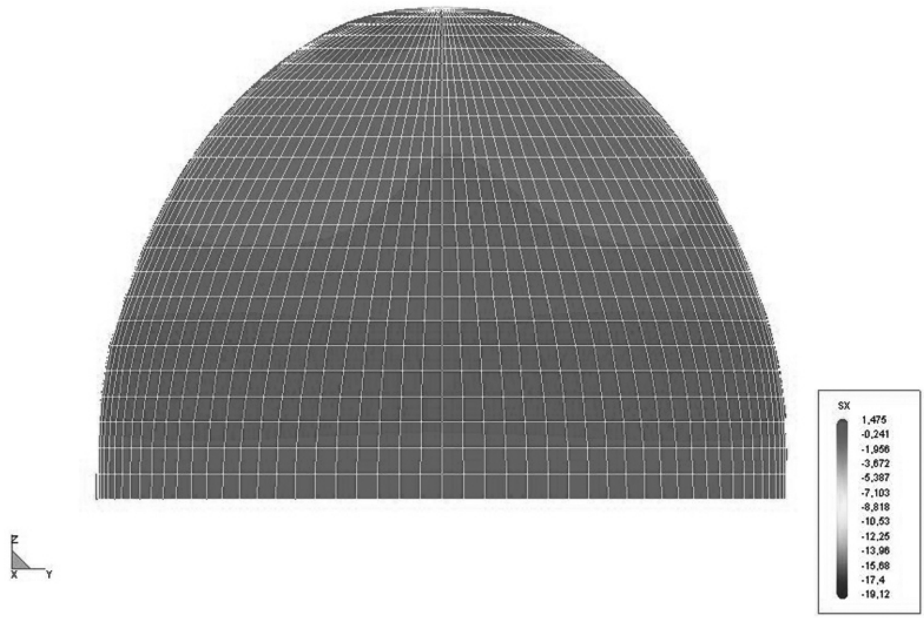

Figure13. Communion Chapel of San Roc. Oliva Church. Tensions on parallel bars.

For the dome of the hermitage of San Marcos. Olocau del Rey, Valencia.
In both the model of dome and arch and the model of dome, it is confirmed that the dome is stable according to the position of the polygon of forces in the analysis of graphical statics, even with the top of 400 kg, since at any moment the polygon runs by the interior of the thickness of the dome. By means of this model we can establish a value of the thrust of the dome on the drum of 1 Kn per linear m **(fig.14)**.

Also, the membrane tensions are acceptable and very far from the values that could be considered critical, in the hypothesis of load under consideration. The values of the membrane tensions obtained are the following:

Tension sx (in the direction of the parallels):

outside plane	+0.0186 N/mm^2	-0.0513 N/mm^2
inside plane	+0.0163 N/mm^2	-0.0287 N/mm^2

Tension sy (in the direction of the meridians):

outside plane	-0.0466 N/mm^2	-0.1277 N/mm^2
outside plane	-0.0260 N/mm^2	-0.0911 N/mm^2

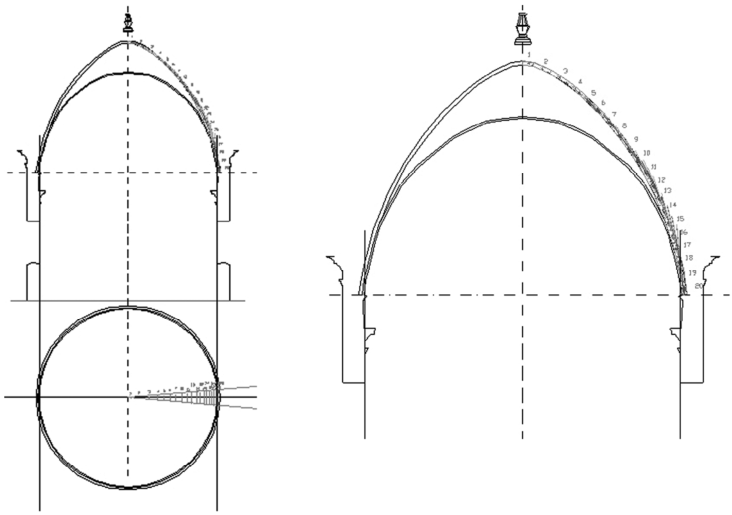

Figure 14. San Marcos Chapel. Olocau del Rey. Graphic Estatic: Cupola-Arch Model.

For the dome of the crossing of archpriest's church of San Jaime. Vila-real
The dome has been studied with two different models. A first model, that studies the global structural behaviour of the dome including the collaboration of the eight ribs between both; and a second model in which those ribs are eliminated to carry out the study of both domes separately, and thus being able to verify their influence on the stability of the assembly.

If we analyze the results of the modeling *with the ribs or "stiffbacks*", in a first overall vision, it can be seen that the most important tensions correspond to the inside plane of the dome, since the outside displays values between +0.082 (tension, T) /-0.2117(compression, C) in the direction of the parallels, and between +0.1030(T)/-0.2378(C) in the direction of the meridians, whereas, as mentioned before, the highest values appear in the inside plane, but these cannot be considered dangerous either. We find ranges between +0.372(T)/-0.213(C) for the direction of the parallels and between +0.087(T)/-0.83(C) for the direction of the meridians. But almost all the dome is compressed, an optimal situation, with only small tensions of traction in very localized points, in the joint of the drum with the lunette and the outside plane, and at approximately one third of the drum **(fig.15)**.

As far as the models of damage and the index of damage for a scale between 0 (absence of damages) and 1 (collapse), we can see that there is only damage in the drum but very localised in a point, which we can consider almost negligible and in the inside plane in the junction between it, the lunette and the drum, which corresponds with those small tension mentioned before.

As far as the modeling *without the ribs*, we find that the tensions, without being dangerous, have all increased. The same situation of higher value in the inside plane repeats, but in this case ranging between +0.28(T)/-0.345(C) in the direction of the parallels, and as before, the main tensions take place in the inside plane, the junction of this one with the lunette and the drum; although in this case, considerable damage appears located in the connection of the drum with the inside plane and the lunette with value 0.74; as well as in the outside plane of value 0.49 in very specific points and also in the lunette of about 0.55 in the area where the ribs should be.

In the study of the behaviour through statics with model arch, it shows instability as also happened in the two previous domes.

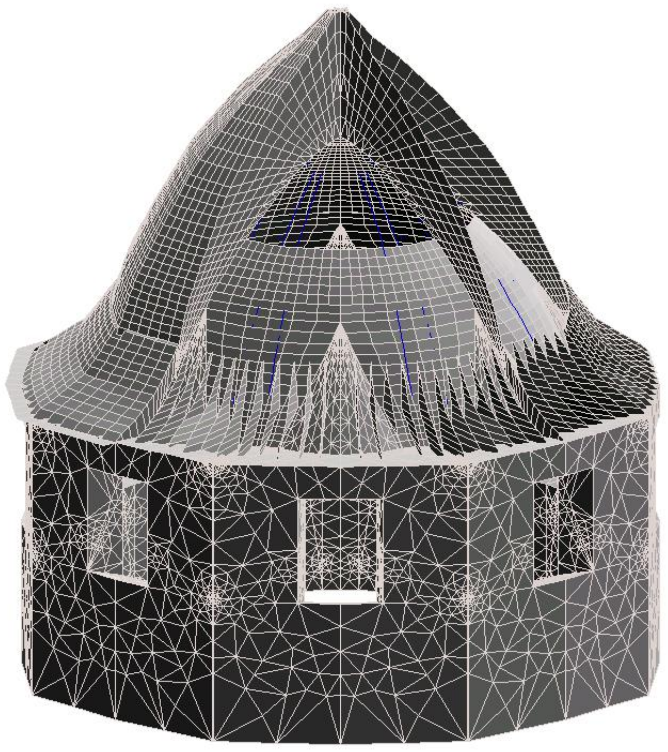

Figure 15. San Jaime Archpriestal of Vila-Real. Model for Finite Elements calculation.

CONCLUSIONS

The domes described in this paper, in terms of architectural plan as well as construction details follow many of the guidelines of "Observaciones sobre la práctica del arte de edificar (Observations on the practice of the art of building)" by architect Manuel Fornés and Gurrea, Director of the

Academy of Fine Arts of San Carlos of Valencia, and honorary member of the Economics Society of Valencia published in Valencia in 1857, are therefore representative enough, for the period and field studied.

The techniques based on brickwork prevail by their enormous advantages, lightness, lack of use of arch centres, economy of humble but excellent materials such as plaster, capable of creating spaces of geometry without restrictions. The partitioned vault, used to build the resistant vault, was however mastered in the Valencian context, since remote times (gothic partitioned ribbings in the fourteenth century and in the 1600s generalization of vaulted systems in numerous churches).

Builders to be recovered from their anonymity, who gather a long-evolved knowledge developed from practice, contribute decisively to the materialization of sophisticated devices, construction organisms that surpass in their behavior theoretical, abstract and universal schemes.

From the structural point of view they reach limits of lean use of materials, which can hardly be reached. If we take as reference the diameter and thicknesses previously defined, its relation or slenderness reach very high values. The studies of the stability have to be carried out by proposing the superimposition of different models that try to explain the behaviour of these constructions.

They are usually anonymous and little known works, in contrast to their famous successors, such as Rafael Guastavino, whose American works reproduce constructional sections, techniques, professions, several centuries later, inspired by similar solutions to those of his Valencia hometown.

Finally, I would like to note the condition of the covering of the domes. In the Valencia area they are solved by means of glazed roofing tiles that in order to solve the covering of spherical surfaces have to overcome considerable technical problems: covering from minimum, insufficient inclinations to infinite slopes. Also decomposing the non-developing surfaces into field tiles. The domes reach a high constructional complexity in some types. Functional requirements, such as the hygrothermal aspects, are also extremely difficult to be solved. Its structural condition is cancelled by the constructional condition. Even that one cannot be understood by reducing it to the gravitational world.

Historical construction treatises, aware of all this, give much importance to the construction issues, like mortars, bonds, anchorages, overlappings, layouts, auxiliary means, sequences and processes of execution. They devote more extension and detail to them than to the relatively simple resistant aspects.

Lovers of heritage feel admiration and are touched when they view the beauty of these constructions. And we wonder, what would they feel if they could understand it in all its complexity?

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