Vaults with guiding arches. Sant Cristòfol in Culla.

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Bricked vaults of the 18th century Valencian hall churches: graphical representation, constructive and pathological analysis

Beatriz Sáez Riquelme[1]

[1] *Departamento Ennginyeria de Sistemes Industrials i Dissey, Universitat Jaume I*

ABSTRACT

The efficient recovery of historic buildings is only possible through a deep knowledge of traditional construction systems.
This article focuses on the study and analysis of the vaults of a group of temples located in the Spanish Levante region, the Valencian hall churches, inspired by the European architectural model known as "Hallenkirche". Erected during the second half of the 18th century, to the north of the Valencian Community, they make up a constructive group limited in space and time, likely to constitute an ideal entity for investigation.
The peculiarity of this type of churches lies in its vaults, which spring from a common height. The main contribution of this research is its graphically schematized constructive classification, as well as the unveiling of their composition and the verification of the use of various counterfort systems.
This study concludes with the analysis of the aforementioned vaults pathologies, derived from possible structural movements and expressed in the form of fissures, providing the classification thereof based on their location, and quantifying and assessing them.
In order to achieve the stated objectives, it has been necessary to carry out technical inspections of the vaults, both from their intrados and extrados, obtaining data through its direct intake and through deduction methods.

KEYWORDS
brick-vault, hall-church, graphical-representation, construction, pathology

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Figure 1.

Vaults of the archpriestal church of Vila-real

1. INTRODUCTION

1.1 HISTORICAL CONTEXT

The hallenkirche model is etymologically German, and spread from the Teutonic country to the rest of Europe, especially during the 14th century. The first Spanish hall church with naves at the same height is the Colegiata de Berlanga de Duero (1526), (Martínez 1980: 358-371), which was then followed by a large number of cathedrals and minor temples, some of which should be specifically pointed out, due to their influence on the Valencian ones, like those built in the city of Zaragoza, and more specifically, the Cathedral-Basilica of Our Lady of the Pillar.

The master builders of the neighbouring Kingdom of Aragon, who in the mid-eighteenth century embarked on a migratory exodus to the north of the Kingdom of Valencia, fostered the dissemination of the model and its construction techniques in this area. Unlike the previous ones, which were Gothic, these churches fall within a style of transition, influenced by the lines of the late Baroque and early Neoclassicism.

Between 1742 and 1799, seventeen temples were built in the Kingdom of Valencia (Bautista 2002: 31-41). Although this model is characterized by real spatial grandeur, it was applied to different types of temples, and thus adapted to very different sizes.

From the latter on, these type of churches continued to be internationally influenced. Firstly, at the beginning of the 19th century, master builders and construction friars began to find it difficult to continue working as

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Figure 2.

Mapped dispersion

code	Town / Village Temple's noum	Date
BG	Benifairó de les Valls *Church San Gil (parish)*	*1773-1790*
CC	Culla *Hermitage San Cristóbal*	*¿?-1781*
CP	Cinctorres *Church San Pedro Apóstol (parish)*	*1763-1782*
CS	Càlig *Sanctuary Madre de Dios del Socorro*	*¿1776?-1785*
LA	Les Coves de Vinromá *Church Asunción de Nuestra Señora (parish)*	*1774?-1793(+)*
MA	Montán *Curch Santa Ana* *(Ex-Monastery servita la Madre de Dios de los Dolores)*	*1781- 1787*
PA	Portell de Morella *Church Asunción de Nuestra Señora (parish)*	*1742-1750*
QM	Quart de les Valls *Church San Miguel (parish)* *(Ex-Monastery servita del Pie de la Cruz y del Santo Sepulcro*	*1776-1780*
RC	Ribesalbes *Church San Cristóbal (parish)*	*1766-1777/81*
SA	Suera *Church Asunción de Nuestra Señora (parish)*	*1773-1797?*
VB	*Vilafranca del Maestrat* *Hermitage Santa Bárbara*	*1773-1794*
VE	Vallat *Church San Juan Evangelista (parish)*	*(-) 1763-¿?*
VG	Vinaròs *Hermitage San Gregorio*	*1780-1799*
VJ	Vila-real *Archpriestal church San Jaime Apóstol (parish)*	*(Planos 1752)* *1752-1779*
VL	Vilar de Canes *Church San Lorenzo Mártir (parish)*	*1781?-1786*
VV	San Vicente de Pedrahita *Church San Vicente Ferrer (parish)* *(Ex-Monastery Dominico)*	*1770-1781*

Table 1.

18th Valencian Hall Churches

architects so they were forced to move towards the Principality of Catalonia and the New World (South America). It was at the end of the century that this model broke into North America, reaching again its zenith at the beginning of the 20th century, thanks to the civil work of Guastavino, descendant of one of those Aragonese master builders who, in the 18th century, helped spread the model in Valencian lands (Vegas 2012: 133-156).

1.2 FORMAL CONFIGURATION OF THE TEMPLES

These are temples with three naves, where the central one is wider than the lateral ones or aisles, and the transept of which is flush with the lateral façade walls, constituting rectangular floor plans consisting on various numbers of bays.
The key feature of this model, its diaphaneity, is the result, on the one hand, of the use of pillars as backbone elements of the space, guiding each of the sections and, on the other hand, of the use of a unified height level, with vaults springing at the same height, which is defined by the plinths located on the running knot cornice (Sáez 2017: 38-47).

2. MORPHOLOGICAL ANALYSIS OF THE VAULTS

2.1 METHODOLOGY

The strategy of the research conducted was based on graphic data acquisition by means of the combination of manual and mechanical methods (Sáez and Pitarch 2015: 12-19). We used a total station for the measurement of xyz coordinates, which were then verified by an electronic distance measurement (EDM) instrument, in order to obtain general dimensions, and flexometers in some specific circumstances.
The analysis of their constructive composition was carried out through their organoleptic inspection, paying special attention to aspects like thicknesses, breaks, fissures and flaking, and then engaging in deduction and generalization methods.
In addition, we also resorted to performing a bibliographical research in scientific publications, architectural execution projects and original plans.

2.2 TYPES OF VAULTS

Types of vaults according to their location in the temples

In the central nave, the most commonly used vaults were found to be barrel vaults with straight lunettes (70.6%), which were also sometimes curved (17.6%), and, to a lesser extent, sail vaults (11.8%).
As for the lateral naves, these spaces were generally covered by groined vaults (76.5%), although it is also worth pointing out the use of barrel vaults with straight (5.85%) and curved (5.85%) lunettes, as well as sail vaults (11.8%).
In the aligned transept, the type of vaults used was generally the same as in the central nave, that is, barrel vaults with straight (58.9%) and curved (17.6%) lunettes and sail vaults (5.85%). There were only three cases in which the vaults of the transept differed from those of the naves, using unique vaults such as the five-panel lunette vault (11.8%) and the double groined vault (5.85%).
On their part, the crossings enjoyed a great variety of cupola. They could be classified in inner and outer cupola, where 41% were hidden under the roof and featured the following characteristics. First of all, it was noted that 65% of these vaults lacked a drum or tambour, resorting to sail vaults (29.4%), semicircular domes (29.4%), and a segmental domes (5.85%). For their part, 35% of these vaults did rest on a tambour, using in this case stilted domes (23.55%), and semicircular domes, both on an octagonal tambour (11.8%).
Most of them projected outwards (59%). The most commonly used domes were the stilted ones (29.4%), followed by semicircular domes (17.6%), both resting on octagonal tambours. Being the segmental dome on octagonal tower
tambour (5.85%), and the segmental dome on octagonal tambour with blind lantern (5.85%) unique cases.

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CODE	CN	LN	AT	P	CR (inner)	CR (outer)
Completion decade 50-60 – Influence King of Aragon						
PA	*BL*	*A*	*BL*	*QS with L+R*	*G*	-
CL	*G*	*A*	*BL*	*BL*	*G*	-
VE	*BL*	*A*	*BL*	*B*	*SC over OT*	*SC over OT*
Completion decade 70-80						
CC	*BL*	*A*	*AA*	*AA*	*G*	-
RC	*BL*	*A*	*BL*	*QS*	*ST over OT*	*ST over OT*
VV	*BL*	*A*	*BL*	*BL*	*SC*	-
CP	*BL*	*A*	*L*	*L*	*SG over OTl*	*SG over OD*
CS	*BL*	*A*	*BL*	*BL + QS*	*SC*	*ST over OT*
VB	*BL*	*A*	*BL*	*BL*	*G*	-
VL	*BL*	*A*	*BL*	*QS*	*G*	-
Completion decade 90 – Influence of Academy						
BG	*BL*	*G*	*BL*	*L*	*SC*	*SG over OTL*
MA	*BL*	*A / BL*	*BL*	*BL*	*SC*	-
QM	*BCL*	*BCL*	*BCL*	*QS*	*SC*	*SC over CT*
LA	*BCL*	*G*	*BCL*	*BCL*	*SC over OT*	*SC over OT*
SA	*BCL*	*A*	*BCL*	*B*	*ST over OT*	*ST over OTL*
VJ	*BL*	*A*	*L*	*L*	*ST over OT*	*ST over OT*
VG	*G*	*A*	*G*	*QS over S*	*SG*	*ST over OT*
LEGEND						

PARTS OF A CHURCH// AT: Aligned Transept, CN: Central Nave, CR: Crossing, LN: Lateral Nave, P: Presbytery
VAULTS// A: Arris, AA: double Arris, B: Burrel, BL: Burrel with Straight Lunettes, BCL: Burrel with Curved Lunnettes, G: Groined, L: of Lunettes, QS: Quarter Sphere
CUPOLA/DOME// G: Goined, SC:Semicircular, SG: Segmental, ST: Stilted
S: over Scallops, L: over Lunnettes, R: Ribs
TAMBOUR/DRUM// CT: Cylindrical, OD: Octogonal Dome, OT: Octogonal, OTL: Octogonal Tambour with Lantern

Table 2.

Type of vaults

Influences and y periods

The analysis of the formal configuration of the vaults allowed us to define clear periods, directly linked to the influences received.

Aragonese influence (17.6%). The greatest impact of the Aragonese model concerning the vaults occurred during the first stage of dissemination of the model in Valencian lands, which ended between the 1750s and 1760s. The Aragonese stereotype was inspired by the church of Santa María la Mayor de Alcañiz (Thomson : 2006), which featured barrel vaults with straight lunettes in the central nave and in the aligned transept, groined vaults on the lateral naves, and a face brick lantern tower dome in the crossing.

Influence of the Saint Charles Royal Academy of Fine Arts of Valencia (41%). It was especially significant in the late eighteenth century, taking control of the architectural production and its dissemination, both through the drawings of the Academy (Bérchez-Correl 1981), and the construction works, especially by Vicente Gascó and Antonio Gilabert, directors thereof during the reporting period (Bérchez 1987: 7).

The academic architecture distinguished itself by the influence of the classical architecture. Its drawings were marked by the use of semicircular domes, which, together with segmental domes projecting outwards, were Gascó's favourite models, as confirmed by the semicircular dome of the Communion chapel in the Archpriestal church of Vila-real or by the dome on drum of the church of Our Lady of the Nativity, in Villahermosa del Río (Pitarch and Sáez: 2009: 1071-1080).

On the contrary, Gilabert, who also used to draw those same idealized domes, already in his first academic work, culminated the crossing of the Church of the Nativity of Turís (Valencia), with a two-third-diameter stilted dome, following the indications of Fornés and Gurrea (1841: 36-37, 40), on an octagonal drum with lantern. He also introduced the use of curved lunettes in the parish churches of Gastalgar (1780), Callosa de En Sarriá (1765-1786) and in the project of the church for Paterna (1782) (Bérchez 1987: 133-134, 192), to which Gascó also resorted for the renovation of the Cathedral of Segorbe (1791-1795).

Transition period (41%). It was also possible for us to establish an eclectic period between the Aragonese and the academic influence stages. This period was characterised by its adherence to some of the guidelines of the previous period, such as the use of barrel vaults with straight lunettes in the central nave and groined vaults in the lateral ones. But, above all, by experimenting with new types of vaults: double groined vaults and lunette vaults in the aligned transepts and the presbytery; quarter sphere and lunette vaults in the presbytery; and segmented and stilted domes on the crossing.

3. CONSTRUCTIVE ANALYSIS OF THE VAULTS

Vaults being the nerve centre of this article, this section focuses purely on them but, because they should be understood within a complete constructive context, at the end of this section there is a brief summary on the constructive-structural elements linked to them through their loads.

3.1 MATERIALS

The data collection and its comparison allowed us to generalize that these were bricked vaults, which featured large format bricks, usually on both sides, and mortars of slightly variable thickness. Although the aforementioned format of the bricks used is not standard, it can be established, with little margin of deviation, that they used bricks of about 30x15.5cm and around 3 and 5cm thick.

The number of brick rowlocks on them was also variable. For example, the vaults of Vilar de Canes (3cm) and Castell de Cabres (5, 7cm) featured just one rowlock; those of Castell de Cabres and Suera (9cm), San Vicente de Piedrahita, Benifairó de les Valls and Quart de les Valls (10cm), as well as the dome on the crossing of Vila-real (Soler and Soler 2012) featured two rowlocks; and the vaults of Culla (11, 12cm) featured 3.

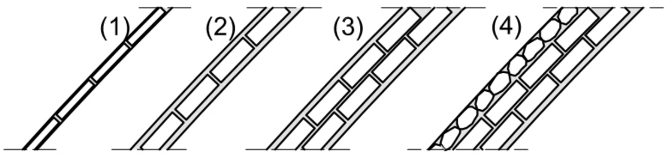

Figure 3.

Rowlock
1- The vaults of Vilar de Canes
2- The vaults of Castell de Cabres
3- The vaults of Vila-real
4- the vaults of Culla

However, our research revealed some exceptions regarding the materials used, such as the use of a final layer of slab covering in Culla, or the simple hollow bricks in the reconstructed vaults of Vilar de Canes (Más 2008: 152).
As for the rest of the elements with a direct or semi-direct structural relationship with the vaults, the following constructive aspects should be pointed out:
The arches on which they rest were formed by bricks or slabs of stone arranged in rowlocks and bound together with mortar.
Most walls were made of ordinary masonry, which, in some cases, was chained in the corners by ashlars and, to a lesser extent, of horizontally coursed masonry, reinforced by small pilasters, and ashlar masonry.
There is less data on the composition of the pillars, although we found that there were bases formed by large-scale ashlars, as well as masonry and solid brick reinforced pillars. Likewise, the constructive knowledge of other contemporary hall temples built in the neighbouring kingdoms, such as the Servite Convent of Cuevas de Cañart or the Church of Corbera d'Ebre allowed us to guess they were made of both brick and masonry (Sáez-Pitarch 2012).

3.2 CONSTRUCTIVE PROCESS

Previous works
At the moment of erecting the vaults, their perimeter (walls/arches) had to be perfectly delimited, since the order of the constructive sequence in this type of temples was continuous in horizontal levels. The thickness of the perimeter walls varied between 0.55 and 1.34m. On their part, the square/starred-section pillars oscillated between 60cm and 1m, except in Vila-real that was twice that size.
For the execution of the bricked vaults, they had to use work platforms allowing both their layout and the placement of the bricks, as shown by the putlog holes found at the base of the domes of San Vicente de Piedrahita and San Francisco de Alcañiz, which are also hall temples.
Whilst, for the execution of the arches the use of wooden centres was highly necessary, it was not needed for the erection of the bricked vaults, which, in turn, resorted to ingenious and simple contraptions that allowed to secure their geometry. The simplest one of these contraptions consisted on a string or line, which was fixed at one end, the other end being the one that indicated the exact position of each of the rowlocks (Ricci 2004: 101-118). This system greatly simplified and cheapened the construction of vaults.
The methods that used both strings and construction levels were already known and commonly used, as stated in the treaty of Friar Lorenzo de San Nicolás (1663).
It is highly probable that, in order to secure the geometry of the vaults in Vilar de Canes and Cinctorres in the 1940s, they resorted to the use of metal or wood elements, that is, more modern tools, to define the geometry of these bricked vaults.

Bricking of the vaults
The bricking of the vaults began by making chases all around their perimeter, the depth of which could be established around 16cm (Thunnissen 2012: 236), as shown by the space located in the first floor of the Gospel side in Quart de les Valls.
Once the cleaning of the chases in which the vaults were to be embedded was completed, the bricks were moisten and then put in place. They were arranged flat, so that their bed could be seen from inside the temple. For its part, and as suggested by treatise writers and experience, the binder used had to be plaster, prepared in small quantities in order to allow its application, at least for the first rowlock. This is was spread on the header and stretcher faces of

the bricks, which were then quickly fixed and pressed in their position for a few seconds, in order for the plaster to set.

3.3 VAULT BRICKING SCHEMES

The careful and direct observation of the intrados and/or extrados of some of the vaults of the studied temples, allowed us to determine their schematic graphic definition, being even able, in some cases, to establish their rowlocks' sequences.

Sail vault
Sail vaults were bricked starting from the vertex of the spaces that delimited them and following concentric rowlocks until reaching the crown.

False groined vault
This vault's formal appearance from its intrados was that of a double groined vault. However, the careful analysis of its extrados revealed that its execution corresponded to that of a sail vault, bricked by concentric rowlocks arranged from its perimeter to the crown. This led to change its initial morphological definition and call it false groined vault, since the edges or groins that can be seen in their underside, which lent them their name, were the result of an ingenious work of plastering.

Groined vaults with double guiding arches
It was the most sophisticated type of vault bricking, reminiscent of the Gothic vaulting, and based on the execution of the main nerves or ribs and the subsequent filling of the timbrel.
It consisted on the use of guiding arches that ran diagonally, as well as from the middle of the faces to the opposite ones, with rowlocks of bricks arranged parallel to their perimeters. Their construction started by bricking such guiding arches with a row of solid bricks joined by their stretcher faces, the diagonal arches first, and then those perpendicular to their perimeters. These last ones were bricked as from the crown of the discharging arches, which were made of solid bricks with stretcher bond. Then, the

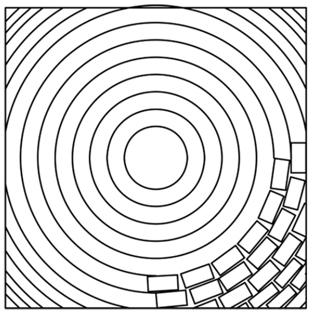

Figure 4.

Brick disposition on sail vaults: choir of Ribesalbes, organ room of Suera and dome of Vilar de Canes

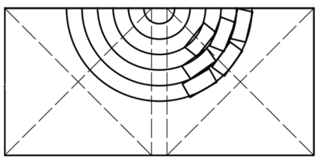

Figure 5.
Brick disposition on double groined vaults: presbytery of the hermitage of Culla

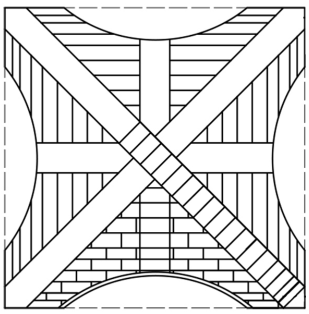

Figure 6.
Brick disposition on groined vaults with guiding arches and rowlocks parallel to their perimeter: roof of the Communion chapel of Vila-real

proper vault bricking started from the corners, over the guiding arches, allowing the latter to protrude on the underside. This type of vaults featured different panels joint by groins, the depth of which depended on the discharge arches.

Groined vaults with diagonal guiding arches
It was a more rudimentary type of construction, but still somehow reminiscent of Gothic structures.
The construction of this type of vaults began by bricking the guiding arches with solid bricks bound on their header face and arranged according to the diagonals of the surfaces to be covered. The vault was then completed by contiguous rowlocks of bricks arranged parallel to the guiding arches.

Groined vaults with guiding arches from face to face
Just as in the previous examples, the guiding arches were bricked first, with solid bricks bound on their header faces. However, in this case, they ran from one face to the opposite. The vault was then completed with parallel rowlocks of bricks, flush to the guiding arches, being especially circumspect that the joints of their header faces were not aligned.

Groined vault with rowlocks perpendicular to the sides and no guiding arches
These vaults consisted on solid brick rowlocks bound to each other on their header faces and arranged parallel to the sides that determined the area to be covered, meeting in the groins. This system, which might seem relatively simple, in practice, however, presented problems of precision, which ought to be dealt with by means of irregularly arranged pieces on the vaults' groins.

Rowlocks parallel to the sides and no guiding arches
This type of vaults were bricked with correlative rowlocks parallel to their perimeter.
The first rows to be bricked were those located next to the perimeter, then placing the following ones by means of hollow bricks perforated on their header

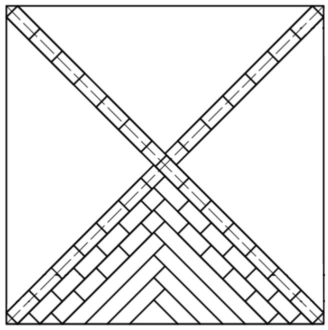

Figure 7.

Brick disposition on groined vaults with guiding arches and brick rowlocks parallel to them: vaults on the lateral naves of Culla

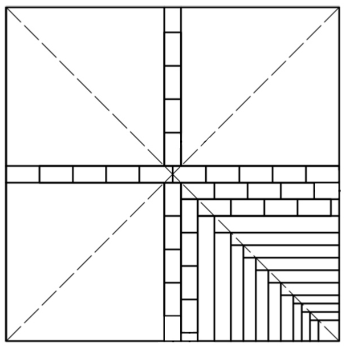

Figure 8.

Brick disposition on groined vaults with guiding arches and brick rowlocks perpendicular to the perimeter: lateral naves of Culla

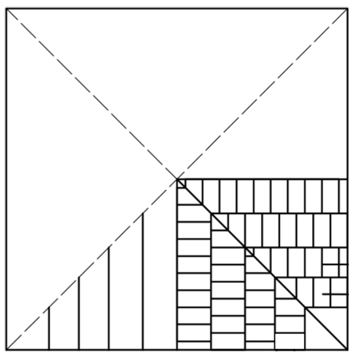

Figure 9.

Brick disposition on groined vaults with header work bricks: organ hall of Castell de Cabres faces. Based on its morphology and chronology, it is safe to say that this model might have been highly influenced by the treatise of Choisy 1883: figure 118.

Barrel vaults with double guiding arches

The suggested constructive process was similar to that of the groined vaults. First of all, the diagonal guiding arches were built by means of solid bricks joined on their header faces, followed by the guiding arrches that ran from one arch crown to the opposite one. Finally, the vaults panels were completed with rowlocks of bricks arranged parallel to the sides, and bound on their header faces, right above the guiding arches.

The smaller sides of these vaults were lightened by stretcher-bond arches, the thickness of which determined the separation of the vault's upstand brickwork, which was separated from the downstand one by means of load bearing partitions.

Barrel vaults with rowlocks of bricks parallel to their largest sides

This constructive process consisted on the arrangement of rowlocks of solid bricks, bound on their header faces, parallel to their largest sides. These rowlocks were simultaneously built from both sides, meeting at the crown, which was then bricked with irregularly arranged ceramic pieces. This type of constructive process was normally used for small vaults.

Barrel vaults with lunettes and rowlocks parallel to their perimeter

The construction of these vaults started by bricking their perimeter and continued with rowlocks of bricks parallel to them, with the additional complexity of having to take into account the double curvature corresponding to the two cylinders that intersected (the one of the nave vault and the one of the lunettes). Probably influenced by the Treaty of Choisy (1883): figure 119.

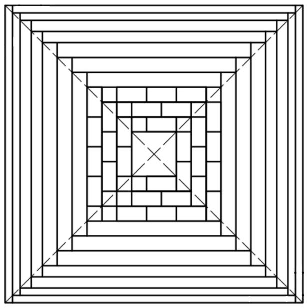

Figure 10.

Brick disposition on groined vaults with correlative rowlocks of bricks parallel to their perimeter: reconstructed vaults of the lateral naves of Vilar de Canes

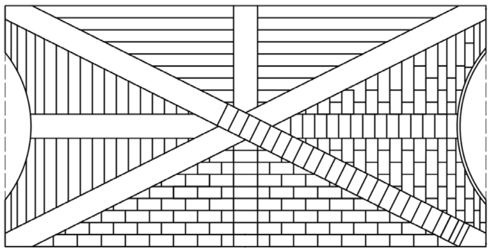

Figure 11.

Brick disposition on barrel vaults with guiding arches: Vila-real's roof

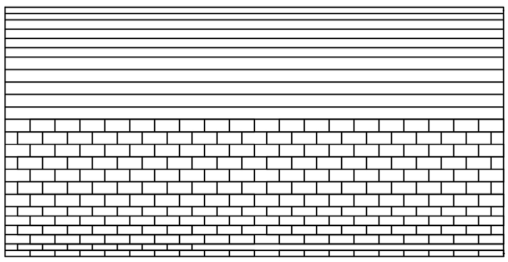

Figure 12.

Brick disposition on barrel vaults with horizontal rowlocks: apse of Benifairó de les Valls

Domes

Essentially, the bricks that made up the domes were arranged just like in sail vaults, that is, in concentric rowlocks. However, we established three characteristics that differentiated them from each other:

- Whether they were inner or outer domes.

Inner domes were not visible from the outside, they were sheltered under the roof and work independently from it. On the contrary, outer domes were visible from the outside and considered structural roof elements. The treatment of their extrados, depended on whether they projected or not to the outside. Inner domes were covered with plaster mortar, while outer domes were treated just like the roof, with the exterior surface finish generally being a layer of glazed blue curved tiles.

- Its greater or lesser cant (raise to span ratio)

This feature allowed for their classification in semicircular, slightly stilted, and two-thirds stilted domes.

- Their number of brick layers

It could be assumed that inner domes consisted of just one layer of bricks, however, this statement was found not to be so assertive with regards to outer domes, since they could have one or two.

The only outer dome of which there was evidence of its constructive composition is that of the Vila-real crossing. It consisted of an upstand and a downstand made of rowlocks of solid bricks bound on both sides. These two layers were linked by on-edge solid brick load bearing partitions, with a separation of about 30 cm (VILA et al., 2016). On the outside, it was finished with blue-glazed tiles.

3.4 ABUTMENT ELEMENTS

Abutment elements were pivotal for the stability of the vaults. Although it was necessary to establish a direct relationship between the types of vaults and their abutment systems, the research carried out in situ on the intrados of the vaults of the 18th century Valencian hall churches, highlighted the different solutions provided by their master builders.

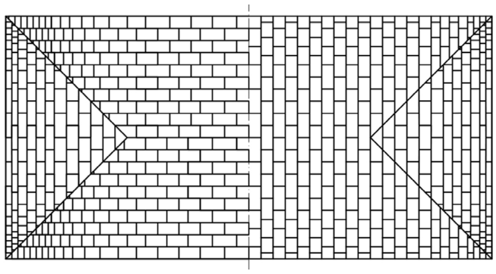

Figure 13.

Brick disposition on barrel vaults with lunettes: Rebuilt vaults of the central nave in Vilar de Canes

The analysis of the abutment systems used in the different cases studied suggested the greater or lesser formation of their master builders. Whilst there was only reliable evidence of the knowledge of the treaty of Friar Lorenzo de San Nicolás by Juan José Nadal, the architect of the archpriestal church of Vila-real (GIL 2004: 334), in view of the results obtained in other construction areas, it was possible to assume their knowledge of other treaties dating from the seventeenth and eighteenth centuries (HUERTA 2004: 250-251).

Thanks to the inspection of the extrados of the vaulted areas, we were able to establish the use of the following abutment systems:

Spring filling

In all the temples, vault haunches used compact fillers, capable of carrying the imposed loads. In general, the thickness of the spring's filling could be estimated around 1/3 of the vaults' height.

Stiffeners

A wide range of materials were used for the construction of these elements, on the one hand attending to the means available and to the surrounding materials and, on the other hand, to the master builders' know-how.
In this sense, we observed: partitions of up to approximately 2/3 the height of the vaults in Cinctorres and Vila-real. Round wood logs acting as braces in Vilar de Canes and Culla. Likewise, the load bearing

partitions supporting the roofs of Les Coves de Vinromà, Suera, San Vicente de Piedrahita and Vila-real could also be considered counterfort elements.

Filling of the domes' spring
The spring of the vaulted domes of the temples of Benifairó de les Valls, Cinctorres, Culla, San Vicente de Piedrahita, Montán and Vilar de Canes were extended, the last two of which were also reinforced along their perimeter by a wall, arranged from pillar to pillar, which, in some occasions, like in Montán, was also filled.

Point load on the pillars
All the pillars of the temples with roofs formed by wooden frameworks, as well as with the extensions needed to support the roof slab, carried the weight of the roofs in the form of punctual loads, which produced a centring effect resulting from the thrusts of the vaults.

The abutment systems used complied with the advice given by Friar Lorenzo de San Nicolás in his treatise: filling of the springings, use of stiffeners and staggered alignment of the spherical domes (Huerta 1999: 88, 250-251). The use of point charges to centre the results of the stresses, although not included in the aforementioned treaty, was already done in Gothic architecture. It should also be noted that estimations performed for the analysis of the stability of these vaults showed their importance in this regard (Sáez 2013: 549-5552).

4. VAULT PATHOLOGY ANALYSIS

The damages subject of this chapter are the result of direct observation and bibliographic research, the latter also allowing us to verify their degree of stability in those cases in which a recent restoration prevented their appreciation.

4.1 TYPES OF DAMAGES

The vaults studied featured, basically, two types of damages: fissures and humidity. Almost all the vaults researched suffered or had suffered the consequences of water entering through the roof, however, since this could be consider an indirect cause and a result of their conservation condition, this type of damage was not further developed, thus focusing the study on the damages inherent to vaults and domes: the fissures.

4.2 FISSURES ON VAULTS

The fissures present in the vaults were observed both in the timbrel, following the axis of the main nave (40%) and, depending on the beds, to one third of the imposts (17.65%), and on the transverse (64.7%) and longitudinal (11.76%) arches of the central nave. We also found fissures around the lunettes (11.76%), as well as around elements that carried specific loads such as pillars or jambs (23.53%), and contour fissures (47%).
The most serious fissures found were those on the arches of the central nave in Suera (5.8%), around the lunettes in San Vicente de Piedrahita, and the contour fissures found in Culla and Vilar de Canes.

4.3 FISSURES ON DOMES AND SAIL VAULTS

This type of vaulting was characterized by fissures on its meridians and parallels, as well as on its toral arches, transverse and longitudinal.
The fissures found on the domes' webs were usually radial, located around their meridians (23.5%), and around their parallels to a lesser extent (11.75%) and, in some cases, even intersecting in both directions (29.4%)
With regards to the arches, practically all the transverse arches featured fissures on their crown (82.35%), while they were found on longitudinal arches to a much lesser extent (29.4%). It is worth mentioning that the previous types of fissures were never found simultaneously.

Fissure	BG	CC	CL	CP	CS	LA	MA	PA	QM	RC	SA	VB	VE	VG	VJ	VL	VV
VAULT																	
a-CN			*(x)*	*X*	*(x)*		*X*		*X*	*X*	*X*						*X*
1/3p-CN	*X*					*X*									*X*		
ta-CN	*X*	*X*	*X*	*X*		*X*	*X*		*X*	*X*	*X*	*X*					*X*
la-CN											*XX*	*X*					
l	*X*																*XX*
pi							*X*		*X*	*X*							*X*
o	*X*	*XX*	*X*				*(x)*		*X*	*X*						*XX*	*(x)*
CUPPOLE, GOINED																	
mm	*X*					*X*	*X*				*X*						
pp			*X*													*X*	
ta	*X*	*X*	*X*	*X*	*X*	*X*	*X*		*X*	*X*	*X*			*X*	*X*	*X*	*X*
la		*X*	*X*						*X*	*X*	*X*					*X*	
LEGEND																	

a: axis, CN: Central Nave, l: lunettes, la: longitudinal arch, o: outline, p: panel, pi: pillars, ta: transverse arch, mm: meridian, pp: parallel
XX (muy afectadas), X (afectadas), (x) (poco afectadas)

Table 3.

Fissures

4.4 ASSESSMENT OF THE VAULTS CONDITION

Areas of fissure concentration

On the whole, the most fissured areas were found to be the central naves, being more pronounced in the vicinity of the crossings, although in Castell de Cabres, Suera or San Vicente de Piedrahita we found fissures all over the temple, and in Culla and Vilar de Canes they were concentrated in the perimeter.

The severity of some fissures, like the contour ones in the hermitage of Culla and in the archpriestal church of Vila-real, as well as in the arches between the main nave and the lateral ones in the parish church of Suera, and of those surrounding the lunettes in San Vicente de Piedrahita should be stressed.

17.65% of the temples did not show any fissures during the data collection period, while 82.35% showed some type of cracking. Furthermore, 17.65% of the temples featured at least one of the aforementioned fissures, one that could be considered minor and another one considered serious. 23.53% of the temples featured two types of fissures, 11.76% three, 23.53% four and 5.88% five.

Causes

Generally speaking, the fissures found in the vaults were the result of the descending movement of their support points. Although the study of each case would provide more specific data, it was not the subject of this investigation, so we opted for providing some brief information on the matter, in order to shed light on the main causes.

In Castell de Cabres, part of the vault covering the organ hall had collapsed, allowing us to verify the coarseness of its construction, which could be considered the cause thereof. On the other hand, the use of a different kind of vaulting from the other temples in the central nave could be the reason for the type of fissures observed in the lateral naves. At this point, mention should be made of the similarity between the type of fissures and the condition of this temple and that of the hermitage of San Marcos de

Olocau del Rey, which is not a hall church, but the vaults of which were the work of the same builder, Fernando Molinos.
The source of the fissures found in the churches of Suera and San Vicente de Piedrahita could be attributed to the load bearing partitions in their roofs, carrying huge direct loads, which, although very distributed, would cause great deformation of the vaults and arches.
Furthermore, the fissures found around specific constructive elements could be indicative of their descent, either because of the removal of the adjacent building (Benifairó de les Valls), due to the land slope or as a result of the excessive weight of the tower (Ribesalbes).

5. CONCLUSION

5.1 MORPHOLOGY

This research allowed us to verify the use of specific types of vaults depending on the area of the temple to be covered, concluding that the most common type of vaulting in these churches were barrel vaults with straight lunettes in the central naves and in the aligned transepts; groined vaults on the lateral naves and sail vaults and semicircular inner domes and stilted outer domes on octagonal drum.
Moreover, we were able to classify the vaults of the hall churches in three phases: Those finished between 1750 and 1760, under the influence of Aragon; those completed between the 1770s and 1780s, which represented an aesthetically undefined period, and those built during the 1790s, marked by the academic influence.

5.2 CONSTRUCTION AND MATERIALS

They were bricked vaults, bound by grout and finished with plaster, arranged in 1, 2 and 3 rowlocks.
There was a generalized use of 2-rowlock-vaults during the second half of the 18th century, evolving towards a one-rowlock type of vaulting in the mid-twentieth century.
The studied vaults made up a huge array of vault bricking technique examples.
We observed an evolution of the vaulting systems that went from the coarseness of the organ hall vault of Castell de Cabres, to the impeccable execution of those of Vila-real, or the more recent perfection of the reconstructed vaults of Vilar de Canes.
The application of the recommendations of Friar Lorenzo de San Nicolás, with respect to the abutment systems, seemed unanimous in terms of the filling of spring of vaults and domes.

5.3 PATHOLOGY: FISSURES

The type of fissures affecting the vaults of the temples studied the most were those running through the naves axis and beds, on the arches and around the lunettes or elements carrying point loads, as well as their outline.
The most fissured areas were located in the transverse arches of the main naves and crossings.
The level of damage was quantified in minor, moderate and severe fissures, the most serious being detected in the naves (on the longitudinal arches and around the lunettes and vaults).
Although the percentage of vaults with no fissures was much lower than that with fissures, we established that this type of damages were not to be understood as an imminent threat to the vaults stability, since in most cases they were stable fissures. However, we do feel it would be necessary to monitor and take preventive measures on some of them.

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