Rodrigo Gil is one of the greatest masters of Spanish architecture. His brilliant career is partially explained by the efficiency of his design methods and his building techniques, especially evident in his ribbed vaults. If we examine the latter as a whole, the first aspect to be noted is doubtlessly their great formal complexity. However, the detailed study discloses that rather limited geometric and building techniques are hidden behind those elaborated patterns, aimed at simplifying and making more economical the execution. In order to bring to light some of these devices, one of his most celebrated vaults was selected for an in-depth study. The construction of a large-scale model of it also revealed some interesting features regarding the placing of the centerings and shorings during the erection.
INTRODUCTION

Rodrigo Gil de Hontañón (1500-1577) is one of the greatest Spanish architects of all times. His work expanded over a vast territory of the Crown of Castile in which he got to build countless religious and civil buildings. He was fortunate to take part in the construction of two of the most important buildings of his time, the cathedrals of Salamanca and Segovia, and, besides, he is the author of the most complete manuscript on gothic construction existing in Europe.¹

The extraordinary amount of works carried out by Rodrigo Gil can only be understood if we consider his figure as the top of a guild pyramid that, from the time of his father, Juan Gil de Hontañón, had become the recipient of many of the most important commissions of the Crown of Castile. This Spanish guild peculiarity, not shared with the strictly professional European guilds, enabled the existence of family sagas that extended their influence for years over certain territories in which they developed their work activity. On the other hand, his brilliant career finds also a convincing explanation in the high degree of efficiency of his design methods and his building techniques, especially evident in his ribbed vaults. In this sense, and although his work has merited important and numerous studies,² virtually none of them analyzes the building practices used by this master.³

If we examine his ribbed vaults as a whole, the first aspect to be noted is doubtlessly its great formal complexity. This is derived from the use of liernes with a usually curved design, which are superimposed to the main ribbing in order to make up varied patterns, characteristic of Rodrigo Gil and his father and, by extension, of all Castilian Gothic: the quatrefoils. However, the detailed study of these vaults discloses that rather limited geometric and building techniques are hidden behind those elaborated patterns, aimed at considerably simplifying their execution and very effective in their results. In order to bring to light some of these building devices, one of his most celebrated

¹ Several editions have been made of the manuscript (1868, 1941, 1951, 1979, 1991), collected in Simón García’s treatise (García, 1681), only the latest of which is included in the list of references (García, [1681] 1991).
² Among them the following can be highlighted: Casaseca, 1988; Hoag, 1985; Redondo et al., 2003. Other authors have been dedicated to the analysis of Simón García’s manuscript from the point of view of structural calculation: Huerta, 2002; Kubler, 1944; Sanabria, 1982.
vaults was selected for an in-depth study: the one that covers the cimborio of Archbishop Fonseca College chapel in Salamanca, built between 1547 and 1549 (Figure 1 and Figure 2). Once finished initial analysis, research was completed with the construction of a large-scale model of it that enabled the verification of the formulated hypotheses, and another small-scale mockup with an educational purpose.

Figure 1: Ground plan of the chapel.

Figure 2: View of the cimborio or lantern built over the crossing.

1. INITIAL ANALYSIS

1.1. The plan view vault layout

The vault under consideration has a square plan 8,31 m wide, equal to 30 Castilian feet, formed by diagonal ribs and tiercerons. An elegant ogee quatrefoil placed in the middle of the vault encloses a four-pointed star and an inner square, while a series of concave liernes, tangents to the quatrefoil, is disposed around the perimeter, producing a 33-bosses design (Figure 3).

![Figure 3: View of the cimborio vault.](image)

First of all, the criteria for arranging this complex design are established in plan view. It can be seen that the tiercerons are placed in the bisector of the angle formed by the diagonal ribs and the formerets, as usual in the vaults by this master. Based on them, the other boss of the central star is obtained on the diagonal rib with the tierceron’s radius. This being found, a geometrical frame enables the location of the centers of the liernes that make up the main part of the quatrefoil and the ones of the tangent concave liernes. Finally, the endings of the quatrefoil (“pies de gallo” in 16th-century Spanish language) are traced with centers situated on the formerets. A quarter of a vault drawn, the rest can be obtained by symmetry, giving as a result all the bosses aligned and inserted in a grid (Figure 4).
1.2. The arches and the ridge: the vault shape

Concerning the design of the arches, the studies in which standardization, one of the most important tools of the ribbed vaults’ builders, is mentioned, have begun to appear only lately. This relatively modern term refers to a geometric device that aims to simplify the execution of the vaults tracing their arches, if possible, with the same radius. From the simple cross-ribbed vaults Gothic evolved towards more and more complex ribbings, being the ribs multiplied. The arches of these vaults could all be different taking whatever outline, but the builders quickly realized that if they executed them with the same curvature the work was extraordinarily simplified: all their voussoirs, as well as the curved pieces of the centerings needed for their construction, could be the same. As a consequence, and contrary to what happens in other architectures, the final shape that a gothic vault takes is frequently not predetermined, namely, it is not chosen by the builder, but results from the standardization of its arches.

When a vault is built using the same curvature for all its arches the shape obtained is very peculiar, with its ridges (“rampantes”) noticeably horizontal. In fact, the semicircular outline of the diagonal ribs determines the height of the central keystone; if the four perimeter arches are traced with this curvature, these, having a smaller span, will be slightly pointed and with their keystones only a little lower than the central one: the vault has a flat ridge (“rampante llano”). If tiercerons appear on it,

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5 Palacios, 2009: 18-19.
there is no inconvenient to trace them again with the same radius, resulting in a ribbed vault that may be extraordinarily complex but whose construction has simplified significantly.

If the vaults built by Rodrigo Gil are examined we found that in most cases the ridge takes this flat shape, with a light slope from the central keystone to those of the perimeter arches, as it happens in the vaults that cover the aisles of the New Cathedral of Salamanca (Figure 5(a)). In some cases the ridge adopts a somewhat rounder shape, like in the vaults that cover both the nave and the aisles of the cathedral of Segovia (Figure 5(b)); on the contrary, in other cases its shape is strictly horizontal, like in the transepts of the cathedral of Astorga (León); it may even be horizontal in the longitudinal direction of the building and flat in the transverse direction, like in the presbitery of the cathedral of Ciudad Rodrigo (Salamanca) or in the nave of the New Cathedral of Salamanca. However, as we have already noted, the flat ridge is much more usual. The cimborio vault of San Esteban monastery chapel in Salamanca, maybe the most outstanding one conceived by this master, is precisely this kind. Even though built after the death of Rodrigo Gil, it clearly shows his influence, being related to the one we are analyzing. It is solved with a square plan about 14.35 m wide, double tiercerons in both directions and 37 vertical bosses (Figure 5(c)).

![Figure 5: Other vaults built by Rodrigo Gil: 3D virtual models. (a) and (b) Vaults over the aisles of the New Cathedral of Salamanca and the cathedral of Segovia (top left and bottom left respectively). (c) Cimborio vault of San Esteban monastery chapel in Salamanca (right).](image)
Returning to the vault under discussion, a height measurement is carried out to get to know the design of its arches. The diagonal rib is found to be half a circle of 5.88 m radius that, at the line of the impost, located at 17.09 m above the floor of the chapel (61 Castilian feet), springs with a slight stilt of 0.23 m. Both the tiercerons and the formerets start with the same stilt, and they are equally one-centered arches tangent to the vertical at the springer. The tiercerons are traced with the same radius as that of the diagonal rib, simplifying construction in this way, but the formerets require a different one, with a slightly sharper curvature, of 5.47 m. By using this radius the height of the perimeter is reduced, the ridges get a certain curvature and the vault shape is rounded (Figure 6).

![Figure 6: Design of the arches of the vault.](image)

### 1.3. The bosses

One of the most interesting features of 16th-century Spanish Gothic is the appearance of inclined bosses, that is to say, with their axis oriented towards the center of the vault, that gradually replace traditional vertical bosses, with their axis perpendicular to the horizontal floor plane. The explanation
Rodrigo Gil and 16th-century building techniques

to this fact seems to be incontrovertible: any arch meets at the boss at a certain angle that is acute and variable in the case of vertical bosses, and constant in the case of inclined ones. This circumstance multiplies the farther from the center of the vault the boss is, and the rounder the shape of the vault is, the angle becoming increasingly more acute, giving as a result that vertical bosses require a bigger volume of material, while, on the contrary, inclined ones maintain a fixed and smaller volume, regardless of the place they have in the vault ribbing. Therefore, inclined bosses mean a considerable stone saving that explains their more and more usual appearance in 16th-century Spanish gothic vaults.6

Strangely, Rodrigo Gil does not use this kind of bosses, but he utilizes almost invariably the ones with the vertical axis, perhaps influenced by the medieval tradition of his father. His bosses and central keystones nearly always maintain a stone cylinder around the axis that makes easier the connection of the ribs that meet at them, having their lower surface parallel to the plane tangent to the vault at that point. Only as an exception this cylinder is removed from certain bosses, as it happens in the vaults that cover the presbytery of the church of Santiago de los Caballeros in Cáceres, or the apse of the cathedral of Ciudad Rodrigo (Salamanca). As we have seen, the volume of vertical bosses considerably increases the farther from the center of the vault they are, and the rounder the shape of the vault is. Consequently, this effect is much smaller in flat ridge or horizontal ridge vaults, where most of the bosses are placed in the upper part of the vault, which can explain the almost constant use of flat ridge and vertical bosses in the vaults by Rodrigo Gil.

Two kind of vertical bosses appear in the vault under discussion, those in which the ribs intersect cleanly, and those that are provided with a central cylinder in order to facilitate the connection of the ribs. The first ones are more numerous, while only the lowest diagonal ribs and tiercerons bosses are of the second type (Figure 7 and Figure 8). This is an uncommon occurrence in the vaults by Rodrigo Gil, who almost always maintains this central cylindrical element, as already mentioned.

6 Palacios and Tellia, 2015.
1.4. The tas-de-charges

The huge tas-de-charge solid ("jarja" or "jarjamento") of the vault draws attention. It is composed of eight horizontal courses, roughly equivalent to half the interior height of the vault (Figure 9(a)).
These high tas-de-charges are usual in the vaults carried out by Rodrigo Gil. A section along the diagonal rib reveals that from this extraordinary tas-de-charge to the first boss there is only room for three voussoirs, while a single voussoir separates the three bosses situated in this rib from each other (Figure 7). Furthermore, the elevation of the tierceron shows four voussoirs from the tas-de-charge to the first boss and, once again, only one voussoir appears between the two bosses located in this arch (Figure 8).

1.5. The centering and the formwork

Following this analysis a detailed observation of the vault enables us to confirm that, invariably, there is only room for a single voussoir between each pair of its 33 bosses (Figure 9(b)). A building hypothesis turns up clearly: virtually the whole vault surface needs no centerings for its construction. It could be carried out, as Rodrigo Gil asserts in his treatise, placing the bosses on top of vertical wooden struts (“mazas”) (Figure 10).\(^7\) In this way, the laying of each voussoir between two bosses could be solved using, at the most, a light isolated support.

The great height of the tas-de-charge does not seem to be a chance either: it enables the reduction of the distance between its upper bed and the lower boss of each rib, thus diminishing the length of the curved pieces of the centerings needed for the construction of the initial section of the ribs,

\(^7\) García, 1681: chapter 6: 24r-25v, illustration 25r.
formed, as we have seen, by three voussoirs for the diagonal ribs, and four for the tiercerons. The formerets have little impact in this respect, considering that these ribs, being bonded into the perimeter walls, do not need any shoring.

![Figure 10: Drawing that illustrates the vault assembly process used by Rodrigo Gil (García, 1681: chapter 6: illustration 25r).](image)

Concerning the web, it is composed of large pieces, the courses of which run parallel to the vault sides, that is to say, as in French practice. The space left between two adjacent ribs is closed in most cases with a single slab of stone that can be placed again without using any formwork.

In order to corroborate the formulated hypothesis, and to go more deeply into the analysis of the several geometric and building aspects, this vault was reproduced at the School of Architecture of the Technical University of Madrid, within the framework of the course “Gothic construction workshop”, developing a model 3 m wide during the 2015 spring semester, which is equal to approximately one-third the actual size. The material used for the scale model is the solid gypsum in blocks, in order to facilitate the carving process keeping acceptable resistant characteristics.

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8 The course is taught by Prof. José Carlos Palacios Gonzalo since its creation in 2008.
2. THE SCALE MODEL

2.1. The full-scale vault drawings

Construction begins with the vault drawings ("monteas"), that is to say, the full-scale tracing of its plan view or a significant part of it, and of its section or, more specifically, of each of its arches. It is carried out on a wall (as in our case) or a floor, in order to geometrically establish the shape and dimensions of each of its parts. Nowadays the existence of this kind of drawings is well-known, being indispensable for vault construction, and many studies related to this topic, turned into a specific research subject, have been published.⁹

First of all the ribs are traced in plan view. Having done this, the bosses are also located and drawn in detail, being the length and shape of their branches accurately established, since the templates needed for their carving, one for each boss, will be extracted from this horizontal section. These templates will enable the initial shaping of the vertical prismatic volume that contains each boss with its branches by using an extrusion method.

Then the tracing of the vault elevation starts. Firstly the drawing of the main ribs required for vault construction must appear on it. It must be recalled that this vault is built with two arcs of different radius: the diagonal rib arc, also suitable for the tiercerons, and the formeret arc. Based on this drawing the four templates or, more correctly, the four bevels, which enable the carving of the voussoirs with the pertinent curvature, will be obtained. A bevel is a stone-cutting instrument composed of two immobile rulers at a certain angle, one of which has the radius direction, and the other has the curvature of the arch it is produced for. This curvature may be concave or convex, depending on whether it matches the intrados or the extrados of the arch, so that two bevels will be needed for each arch.

On the other hand, Rodrigo Gil decides the diagonal ribs and tiercerons cross-section and depth to be the same in this vault. This fact contradicts what he advises in his own manuscript, in which he

⁹ Among the researches on this topic the following are of special interest: Ruiz and Rodríguez, 2011; Tain and Natividad, 2011.
establishes a clear hierarchy between the several ribs, although, if we observe other vaults by this master, cases are equally found in which this agreement happens or not. Therefore, the main ribs cross-section requires of two different templates: one for the diagonal ribs and tiercerons, and another one for the formerets. We must notice that in the scale model simplified outline templates were used so as to simplify the carving, without however altering the actual proportion x, y of the original vault (Figure 11(a) and Figure 11(b)).

Figure 11: The ribs. (a) Diagonal ribs voussoir already finished (top left). (b) Vousoirs of the main ribs, with the bevels that match their intrados curvatures and the templates that enable the carving of their cross-sections (top right). (c) Carving of a curved lierne (bottom left). (d) Curved liernes, showing their symmetrical or asymmetrical cross-section, depending on the case; deformated templates for the carving of the latter (bottom right).

In addition, the section of the tas-de-charge must be drawn in the elevation, with the horizontal planes for each level. These, by cutting the arches, enable us to draw in turn the several superimposed levels in plan view, as if they were contour lines. Although the tas-de-charge is carried

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10 García, 1681: chapter 6: 23r-23v, illustration 25v. Their actual depth is around 0.329 m, representing an intermediate value between those prescribed in the Compendio for the diagonal rib (s/24 being s the span of the vault, understood as the arithmetic mean of its sides) and the tierceron (s/28). The formeret is about 0.278 m, coinciding with the greater of the two figures given in the manuscript (s/30 and s/36).
out with eight horizontal courses in the actual vault, the scale model was built with nine due to material constraints, without however altering the proportion between tas-de-charge and vault crown heights. Therefore the outline of the ten levels or beds must be drawn, from the lower (level 0) to the upper one (level 9), with the purpose of creating ten templates, one for each level, that will be essential for the construction of each horizontal course. We must notice that the templates for level 0 and 1 are the same, since the first course corresponds to the stilt.

It is found then the normal procedure used by Rodrigo Gil to provide the vault with very high tas-de-charges: the rib outlines are set out radially at level 0, their extrados axes sharing a common rotation center located in the vault vertex; this way the bunch of ribs springs very tightened, and the tas-de-charge must rise significantly until the ribs become mutually independent. On the contrary a tas-de-charge in which base the ribs are placed radially but somewhat far from the vertex will need less height to reach their mutual separation (Figure 12).

Figure 12: The tas-de-charges. (a) The nine courses once assembled (left). (b) Full-scale vault drawings: plan view detail, showing the several superimposed levels (top right). (c) Templates for the carving of the several courses (bottom right).
Rodrigo Gil’s vault is embellished with plenty of liernes, which in fact are the cause of the great number of bosses. These decorative ribs are hanged from two bosses, as the master asserts in his treatise.\footnote{García, 1681: chapter 6: 23v-24v.} There are two different kinds of them in the vault we are constructing, depending on their shape in plan view: curved and straight. Curved liernes ("combados") are those that form the great quatrefoil and the concave ribs tangent to the latter, while straight liernes are those that make up the central star and the inscribed square.

Once established their shape in plan view, we must consider that these liernes present an aesthetic and building added difficulty: their cross-section must be vertical. In reality, gothic aesthetics seem to impose all the ribs as well as the bosses to be always vertical, instead of radial to the vault center.

While the vertical design of the bosses is a feature that makes easier to determine the geometric position of their points and to obtain the templates for their carving, the vertical design of the liernes, on the contrary, creates important building difficulties: this fact implies that, depending on their position in the ribbing, their cross-section has to deform to a greater or lesser extent in order to conform to the local curvature of the web surface at each point. This problem does not occur with the main ribs, since the web takes approximately the same position at both sides of their cross-section, but it may arise with the liernes, where the web may be at a very different height at both sides of the cross-section.

Lierne deformation depends on its position in vault surface: it grows when the angle that the vertical axis of the lierne forms with the vault slope turns more acute, or, in other words, it increases the farther from the center of the vault the lierne is, and the rounder the shape of the vault is. From a purely theoretical point of view, and considering the vault under discussion, the concave curved liernes tangent to the quatrefoil, being very far from the center, would have their cross-section very deformed; the curved liernes that make up the quatrefoil, located in an intermediate position, would have a somewhat lesser deformation; finally, the central star and square, placed in the upper part of the vault, would have a symmetrical cross-section, that is to say, with no deformation.
Nevertheless, if the actual vault built by Rodrigo Gil is examined this deformation is found to also change depending on the particular position that each lierne has in relation to the vault slope, and on the difference in height required for each lierne, in such a way that the cross-section may gradually vary along the decorative rib. The cross-section is not deformed in those points in which the curved lierne is placed in the slope direction, as it happens in the connection points with the intermediate bosses of the diagonal rib and the formeret. By contrast, the cross-section is deformed in those points in which the curved lierne is placed in the direction perpendicular to the slope, as it happens in the connection points with the intermediate boss of the tierceron. The rest of liernes, that is to say, the central star and square and the points of the quatrefoil have no deformation, due to the fact that they are in the upper place of the vault and their endings are virtually at the same height. In short, it is checked that this deformation aims to reach an adjustment of ribs and web surface as approximate as possible at each point.

The liernes, therefore, are solved with two different cross-sections in the connection points with the bosses, depending on the case: one of them symmetrical and another one asymmetrical (“recta” and “revirada”, respectively), giving rise to two templates; just as for the main ribs, simplified outline templates were used in the scale model so as to simplify the carving. In order to complete the design of the decorative ribs, the position of the bosses that they connect must be located. Based on the latter, the slopes of the former are determined. Concerning the curved liernes, it should be noted that, although the bosses that they connect may be placed at different heights, each section from boss to boss describes however a planar curve, along which the several pieces (only one in our case) that make up the curved lierne are connected to one another (Figure 11(c) and Figure 11(d)).

Finally the bosses must be correctly placed along the main ribs in the elevation. The design of each one of them is derived from the vertical prismatic volume that contains it, as we have already discussed, and its horizontal upper and lower surfaces are used as a reference to establish the position and inclination of each of its branches and the angles to cut the beds of the latter. Besides, each of these branches must have a certain cross-section, given by the proper template, depending
on the rib it matches. The elevation of some of the bosses in this vault, indispensable for proceeding to their carving, is unusually complex, owing to the great amount of liernes. The intermediate diagonal rib boss, with eight branches, or the one situated in the lower part of the tiercerons, with six, can be highlighted in that regard. We must consider that, in the elevation, each branch springs in a different direction, upwards or downwards, its cross-section being or not deformed, and, in addition, its design can be straight or curved in plan view. The drawings of these bosses bring to light the high level reached in the 16th century by geometry, which, by simply using the agreement between plan view and elevation, had enabled ribbed vault construction from the deepest Middle Ages (Figure 13).

Once solved the geometric problems found in the vault drawings, a 3D virtual model was carried out reflecting the various peculiarities of the design. The aim was to produce, based on it, a plastic mockup with an educational purpose, by using a 3D laser printer. A vault reproduction of about 0.25 m wide was made, which is equal to a scale of 1/33, and some of the bosses and liernes were also produced on a larger scale (Figure 14).

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12 The 3D virtual model was carried out by Miguel Rivera Corullón, and the plastic mockup by Diego Martínez Moreno, both scholarship assistants in the course “Gothic construction workshop” during the 2015 spring semester.
Figure 14: (a) and (b) Plastic mockup of the vault: general view; bosses and curved lierne section produced on a larger scale (left and top right respectively) (Diego Martínez Moreno). (c) 3D virtual model of the vault (bottom right) (Miguel Rivera Corullón).

2.2. The construction

The geometric data and the templates derived from the full-scale drawings enable to start carving the various pieces that make up the vault. The process starts with the voussoirs of the main ribs: the four bevels obtained from the elevation drawing make possible to give them the appropriate curvature, and their cross-section is carved with the two pertinent templates (Figure 11(a) and Figure 11(b)).

The liernes start being carved too. The straight liernes do not pose a problem, since they have no curvature in plan view and their carving only requires of a cross-section template with no deformation and at times of a roughly-calculated slight lengthwise curvature. Concerning the curved liernes, the carving of each section is carried out based on its plan view, taking a template from it and cutting a block with this shape. Then the difference in height required for the lierne is marked on it, being obtained from the elevation, and an oblique cut is carried out in it; this cut is not needed for the liernes that make up the points of the quatrefoil, since their endings are virtually at the same height. Finally, the cross-section of each piece of curved lierne is given its proper shape using the two pertinent templates, with and without deformation (Figure 11(c) and Figure 11(d)).
Right after the carving of the tas-de-charges begins, which courses require two templates each that match their lower and upper beds. The outline of each template is drawn on the lower and upper surfaces of a block and the latter is gradually carved until the former are properly connected (Figure 12 and Figure 15).

Figure 15: Carving of the tas-de-charges.

The last and difficult task that the construction of this vault demands is the carving of its bosses. The shape in plan view of each one of them is derived from the template taken from the horizontal drawing of the vault. On the one hand, the position and inclination of the branches that correspond to the main ribs as well as the angles to cut their beds are directly obtained from the elevation. On the other hand, the inclinations of those that correspond to the liernes match the slopes of the latter, previously established in order to carry out their oblique cut, as we have already discussed; their beds are cut at a roughly-calculated slight angle. In both cases the inclinations and angles can be copied with a bevel square. Finally, the cross-section of each branch is given its respective shape and deformation using the various templates (Figure 13 and Figure 16).
2.3. The erection

All the pieces being carved, the erection of the vault begins. The assembly process used by Rodrigo Gil is known thanks to an extraordinary drawing collected in his treatise and provided with the pertinent explanation (Figure 10).\(^\text{13}\) Firstly, a main scaffolding was constructed, located at the impost level and supported by a huge wooden structure, which would probably rise from ground level, or perhaps from some beams fixed to the cimborio walls. The perimeter walls were constructed from this position, together with the formerets and the tas-de-charges, which make part of the former. This scaffolding is not needed in the scale model developed since impost line and ground level match. Once assembled the nine courses of each tas-de-charge, the result is an outstandingly slender and high solid (Figure 12(a)).

Next a horizontal platform is constructed, supported on the scaffolding or, in our model, on the floor and situated at the upper level of the tas-de-charges. This enables the placing of the centerings and shorings that bear the vault weight during the erection. Note that the higher the tas-de-charge is, the smaller the work surface is in this assembly process. According to Rodrigo Gil the setting out of the

\(^{13}\) García, 1681: chapter 6: 24r-25v, illustration 25r.
vault, that is to say, the drawing of its plan view, is carried out on this platform, in order to locate the position of its 33 bosses. Then vertical wooden struts are placed on each point, cutting them at the right height. This problem is solved again with the elevation drawing, since the relative height of each boss can be easily known tracing a horizontal line on it at the platform height.

Placed over the 33 vertical wooden struts their respective bosses, it is checked that the important amount of the latter for a relatively small vault surface, and the great length of their branches, make the space between the bosses intentionally limited, so that there is only room for one voussoir, both in the main ribs and in the liernes, that can be put in place without any ancillary support. In addition, the great height of the tas-de-charge reduces drastically the distance from it to the lower bosses, and therefore the length of the laborious curved pieces of the centerings required for these sections of the diagonal ribs and tiercerons. Consequently, almost all the vault shoring is composed of vertical wooden struts (Figure 17).

Figure 17: The horizontal platform, the centerings and the shorings already placed. The tas-de-charges, the bosses and the main ribs partially assembled.

This situation verified the assembly of the ribs is carried out. Diagonal ribs and tiercerons need small centerings from the upper bed of the tas-de-charge to the lower boss of each rib, especially reduced
for the diagonal ribs, and from this point on their voussoirs are put without any support. Next the liernes are placed, which are hanged from each pair of adjacent bosses, so their positioning requires no shoring either (Figure 18). In addition to this a part of the web is built, carrying out a vault quadrant with its courses running parallel to the sides, that is to say, as in French practice, and another two with their courses running perpendicular to the bisector of the angle formed by each pair of adjacent main ribs, that is, as in English vaulting. No formwork is used for its laying.

![Figure 18: Placing of the liernes.](image)

Vault erection finished, its shape reveals the above mentioned flat ridge, as a result of the standardization of its main ribs. It also shows the unique beauty of Rodrigo Gil’s patterns, which perhaps constitute the formal peak of Castilian Gothic (Figure 19 and Figure 20).
CONCLUSION

The construction of a large-scale model of Rodrigo Gil’s vault brought to light, as initially expected, some building constants of this architect’s work.
Firstly we should highlight his adherence to flat ridge vaults, used over both square plans, as is the case here, and rectangular plans. This vault shape may occasionally result from the standardization of the main ribs, which simplifies the carving of the voussoirs of the arches, as partially occurs in the vault under discussion. However, many times the main ribs are not designed with the same radius, although the vault keeps a flat ridge.

On the other hand, diagonal ribs and tiercerons cross-section and depth match in Rodrigo Gil’s vaults more often than expected, whereas perimeter arches and liernes have usually different cross-sections, as in the present case. This standardized procedure contradicts what he advises in his own treatise, in which he establishes a clear rib depth hierarchy depending on their position in the vault.

In contrast, the design of the bosses is invariably vertical. This is an interesting peculiarity since Rodrigo Gil’s career develops in a moment in which the more economical inclined bosses gradually replace the traditional vertical bosses. The design of the latter, however, requires of a less-developed geometric knowledge, hence a larger number of stonemasons would have a good command of it. By using these bosses the master can delegate design to any of his assistants, which perhaps accounts for the lack of interest in this technical innovation. On the other hand, the drawing that illustrates in his treatise the assembly process of a ribbed vault shows one inclined boss, which creates contradictions between theory and professional practice again and questions the manuscript authorship.

If we link flat ridge and vertical bosses design to the polar patterns typical of Spanish Late Gothic vaults, we must notice that their joint use has as a consequence, apart from other spatial and aesthetic considerations, the minimization of the volume of stone needed for the carving of the bosses. This idea can explain the pairing of flat ridge and vertical bosses found almost constantly in the vaults by Rodrigo Gil.

Perhaps the most interesting feature that the construction of this vault has disclosed is precisely its erecting strategy. The utilization of elaborated patterns causes an increase in the number of bosses and liernes that logically complicates design and construction. Nevertheless, as we have seen, the
use of high tas-de-charges and the presence of a large number of bosses make the erection of the whole vault more efficient and economic, since both devices enable the placing of the greater part of the ribs without any centering. The proliferation of liernes makes equally possible the laying of the web courses with no shoring.

Rodrigo Gil is without a doubt one of the most prolific masters of Spanish architecture. His professional success is partially explained by the building devices used in his vaults, very limited but remarkably effective: flat ridge with occasionally standardized arches, high tas-de-charges and a multiplicity of vertical bosses and liernes in order to reduce rib centering and web formwork. This limited techniques enabled him to develop an intensive building activity, based on simplicity and economy.
References


Palacios Gonzalo, José Carlos. 2009. La cantería medieval. La construcción de la bóveda gótica española. Madrid: Munilla-Leria. (English excerpt in Palacios, José C. 2006. The Gothic Ribbed Vault in


