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Geometry and Construction of Ribbed Vaults: Choir of the Braga Cathedral

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ABSTRACT

The study takes into account the choir vault of the Braga Cathedral as a paradigmatic example of the evolution process of Portuguese multi-ribbed vaults. In fact, it can be considered the first step of the features transmigration occurred throughout the Iberian Peninsula and evolved in a continuous transformation from building to building.

The stylistic/typological interpretation, as it is often conducted, is not exhaustive for what concerns stone vaults: conception and meaning of subtended space, construction processes and methods of form definition are essential to *read* the structure.

The study of late Gothic ribbed vaults fits into the research field of structural interpretation from the perspective of "form generators": this type of construction realizes a strict correspondence between the two aspects, materializing system stress lines through the rib.

We analyze one of the first work attributed to Joao de Castilho. The *cabeceira* of the Braga Cathedral clearly shows traits inherited from ribbed vaults with petal flowers design, typical of Seville and Burgos areas.

The various aspects that define the shape are mutually interpenetrating and inseparable: geometric definition, surfaces analysis, underlying spatiality and, finally, the way in which these three are connected to the constructive process.

The possibilities of the ribbed lattices are achieved here by a sort of "sphericity research", as if to mediate Gothic reminiscences with the desire to absorb new Renaissance influences.

The spatiality research is not an end in itself but can be considered, at the same time, result and assumption of precise constructive methods, giving rise to a logical sequence of steps connected to the building site economy.

KEYWORDS: ribbed vault, geometry, construction, Portugal, stone, stereotomy

1 INTRODUCTION

Definition of the term "Structure"(Mantova,1842):

"This term, derived from the Latin "structura", is a synonym of "construction", although usually considered in a more noble meaning. It expresses the manner in which a building is erected: it differs from "construction" in the sense that is generally applied to that part of architecture that includes material, mechanical and scientific aspects related to their use within the building; structure, on the contrary, is

considered a higher term, so to speak related to the language of poetry, and embraces the external relations of art and shows itself for the boldness of the overall static equilibrium, for the beauty of forms, for the proportion of architectural orders and the technical mastery".

The analysis carried out for the choir vault of the Braga Cathedral (1505-1509) tries to retrace the meaning of "structure" as intended by Quatremere De Quincy. The symbiosis of the various architectural issues reveals itself through the extroflexion of the ribbed line, intended at the same time as decoration and essential component. The specific case of the "vault with *combados"* can be considered a key moment of the architectural transition from Spain to Portugal within Joao de Castilho's works.

We can recognize three main cycles of his activity: the North-Portuguese cycle, the Central-Portuguese and North-Western African cycle (Coelho, 1983).

These are his phases of "maturity", but we should mention the years of apprenticeship on the native soil and a presumed period of artistic training in Italy.

Conflicting opinions can be found about attributions and movements: Sousa Viterbo affirms that he had an initial training period in Italy followed by the transfer to Portugal; Pedro Dias denies that possibility and supports, instead, his involvement in the construction of the Seville Cathedral.

Taking into account various sources, Pires Coelho (1983) assumes that this artistic exchange, clearly noticed in the Renaissance conception of the late works of Tomar, could have been originated from the ease of relations with Tuscany due to the triangle trade Florence-Seville-Lisbon. Then his visit to Italy can be reasonably included in this atmosphere of economic exchanges, assuming a departure from Seville.

His arrival in Portugal can be contextualized within the displacement of many foreign artists to Portugal due to the prestige of D. Manuel that was acting as a sort of patron in the manner of the Italian princes.

One of the first construction sites where he seems to have worked during his apprenticeship is the Cathedral of Burgos, where he arrived through his father's contacts. He took part in the erection of the Condestavel Chapel that the master Simão de Colonia had begun around 1482 in order to receive the remains of the Condestàveis de Castela. He has probably absorbed in this context the main trends of the Spanish gothic flamboyant, including the use of curved ribs. Burgos can be, indeed, considered the first iberic example in which this feature appears, giving rise to a great spread in Spain and Portugal (Moreira, 1991)

Domingues Moreira (1991) affirms that Castilho's maturation quite probably came during the period in which the Spanish flamboyant formulas reached their apex, although they have not significantly affected the simplicity of his structural representation, deep-rooted in the classical Gothic attitude.

2 CATHEDRAL OF SANTA MARIA DE BRAGA – CHOIR VAULT

The actual choir is the result of the demolition and reconstruction of the original Romanic one. The first choir was contemporary to the cathedral and dated from the eleventh or twelfth century.

The new "perspective conclusion" of the nave clearly shows the modern Hispanic influences through the first introduction of the curved ribs. Its features create a certain contrast with the previous ecclesiastical building, described by more severe and essential components.

This structure is interpreted according to a double point of view, at the same time innovative and retrograde: innovative if related to the architectural context of the Portuguese sixteenth century, retrograde if compared to the contemporary blooming of the Italian Renaissance.[2]

This mediation attempt probably derives from the client influence (Sousa, 1460) and, at the same time, from the need to be connected with the preexisting Romanesque building. The stylistic continuity implied by the "annexation factor" limits, therefore, the opportunities for innovation.

It is necessary, however, to remember that the transition from Gothic to Renaissance and also the mixture of their features, can be considered a recurring aspect of the entire Joao de Castilho's production. In some cases we can find hybridizations and unusual coexistences of traits within the same building.

2.1 Architectural Survey

The previous survey carried out for the Monastery of Jerònimos in Lisbon has validated the correspondence between the 123dcatch photo modeling tool and the total station data. This validation has allowed us to use here only the first method with reference to significant measurements. Through the "decomposition" of the mesh thus obtained, it was possible to perform a more detailed analysis of the different constructive aspects.

2.2 Geometric Analysis

The space presents the recurring transition from square to polygonal shape through two angular *trompe.* The vault lattice is defined by a strict planimetric pattern composed of circles having two different radii, shifted and combined (Da Silva et al. 2009).

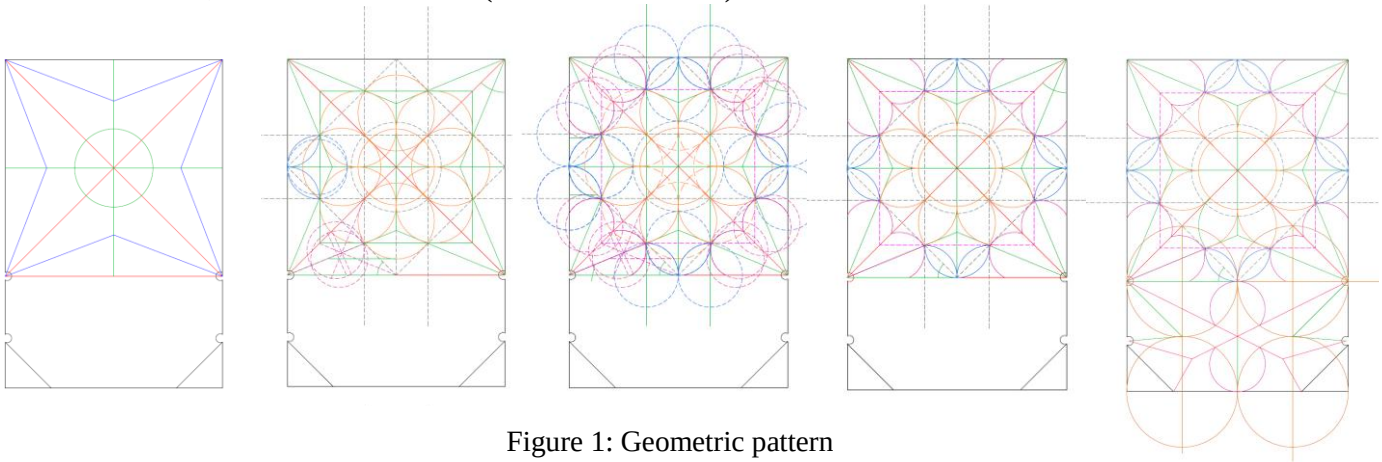

Figure 1: Geometric pattern

The pattern is developed from the basic type of the star vault, implemented to obtain a surface the more rounded as possible. We can suppose a gap from the general geometrical conception and the final result, probably due to simplifications carried out for constructive reasons.

The geometric shape definition can be assimilated to the description of vaults with *oval arcs* that Palacios et al. (2012) explain for the San Esteban monastery in Salamanca (Carlos, 2012) : the starting point is fixed by the definition of the oval diagonal arc, while all the others are derived from the rotation or translation of that one, creating simple pointed arches or 4 centred arches (also called Tudor).

In the specific case of Braga, however, the diagonal is defined by a 3-centred arc but this happens for the progressive flattening of the central spherical cap. All the derived arches (*formeiros, terceletes,* etc) inherit only the first part, giving form to a simple one-centered arc.

The same thing is verified for the *cabeceira*[1], in which the same arc can be found both in the lunettes and in the diagonal ribs that connect the two sides.

The *combados* configuration can be conceptually compared to spatial curves of connection, but on a practical level this seems to occur according to an approximation to flat curves. These are rotated according to the plane that connects the interested intersection points.

[1] The *cabeceira* is the final part of the choir space.

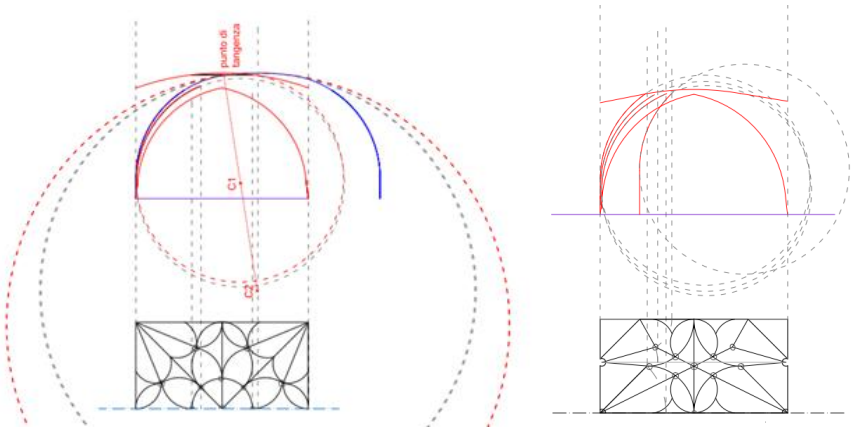

Figure 2: Geometric definition of the rib curves

2.3 Analysis of forms

The obtained general shape is intentionally rounded, following the style of the *abobada moderna* (modern vaulting), and is determined by the diagonal and transverse ribs and two concentric levels of bosses at the same height (Sorraya et al. 2009).

It is possible to make a conceptual subdivision of the overall structure in two distinct surfaces. This idea supports, in a certain sense, Atanàzio's interpretation that associates Manueline multiribbed vaults with squared plan to "sail vault reinforced with ribs": the central part seems, in fact, to retrace a domical volume; the elements that flow into the *tas de charge* are mostly comparable to portions of "fan". This shape is given by the already mentioned rotation and repetition of the same arc.

The final result looks like a synthesis between a spherical dome and a cross vault, also for the need to link up with the perimetral ogives.

It's clear that this interpretation pertains to a speculation about "geometric genesis" rather than constructive: in fact the *combados* are not spatial curves (as would result from a rigorous definition of this geometric type), but bidimensional arcs.

Bringing on a vertical plane the curves obtained through the photomodeler data, we find that their profile is almost comparable to a straight line (excluding the hypothesis of a spatial curvature); further confirmation is given by the webbing texture, which is not in accordance with the curvature direction but seems to connect the ribs in a planar way.

Moreover, the assimilation to the sphere can be seen as an anticipation of the so-called vaults "*a lo romano*". This evolution will appear clearly through other examples, characterized by circular layers subdivisions: they maintain the same organization of the multi-ribbed vault but fitting into a sort of progressive "research of sphericity."

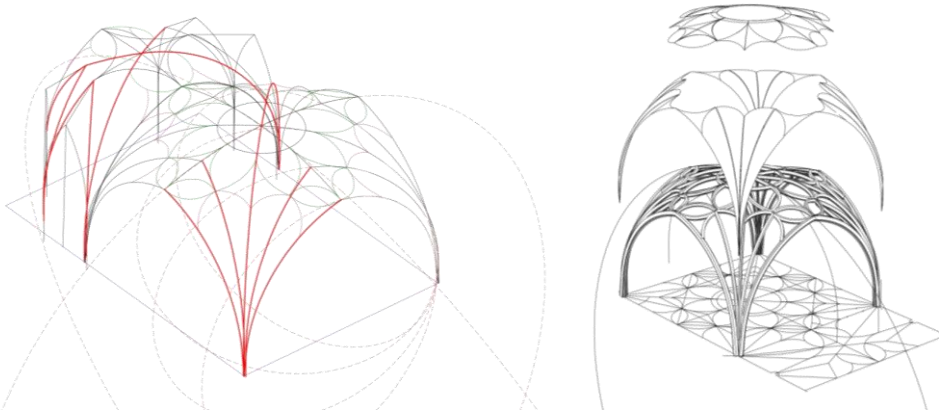

Figure 3: Curves and surfaces composition

Pinto Puerto (2000) reports the example of the Sacristy of the Seville Cathedral, in which we can see several analogies with Braga, among which the presence of the flower pattern and the central circular crown. The obvious difference is in the voussoirs arrangement of the infilling.

The Cantabrian origin of its architects Juan de Badajoz and Juan Gil Hontañón, strengthens the bond with Braga, giving form to the connecting link with Joao de Castilho's roots . On the other hand, as Pinto Puerto shows, the relationship between the Sevillian, Portuguese and Cantabrian buildings are very strong because of the constant river and maritime trades. In particular, he identifies a direct connection between Seville and Lisbon through Diego de Riaño. Indeed his presence with *Juan de Castillo* on the Lisbon building site of the Santa Maria de Belém Monastery can be witnessed between 1517 and 1522.

This hybridization between ribs and spherical shape can count a recurring feature, that is the permanence of the perimetral ogival arches: the "readjustment" of the spherical profile aims to link up with them creating ruled surfaces. The *combados* concentration in these connection parts is not a coincidence, but is due to the need of dividing the shell through more easily manageable portions.

The condensation of the ribbed lattice in correspondence to the linking parts can be considered a constructive method as well as an aesthetic outcome.

The general geometry is, therefore, defined by ruled surfaces joined through the ribs profiles, in order to create the necessary connection between the central spherical shape and the perimetral arches.

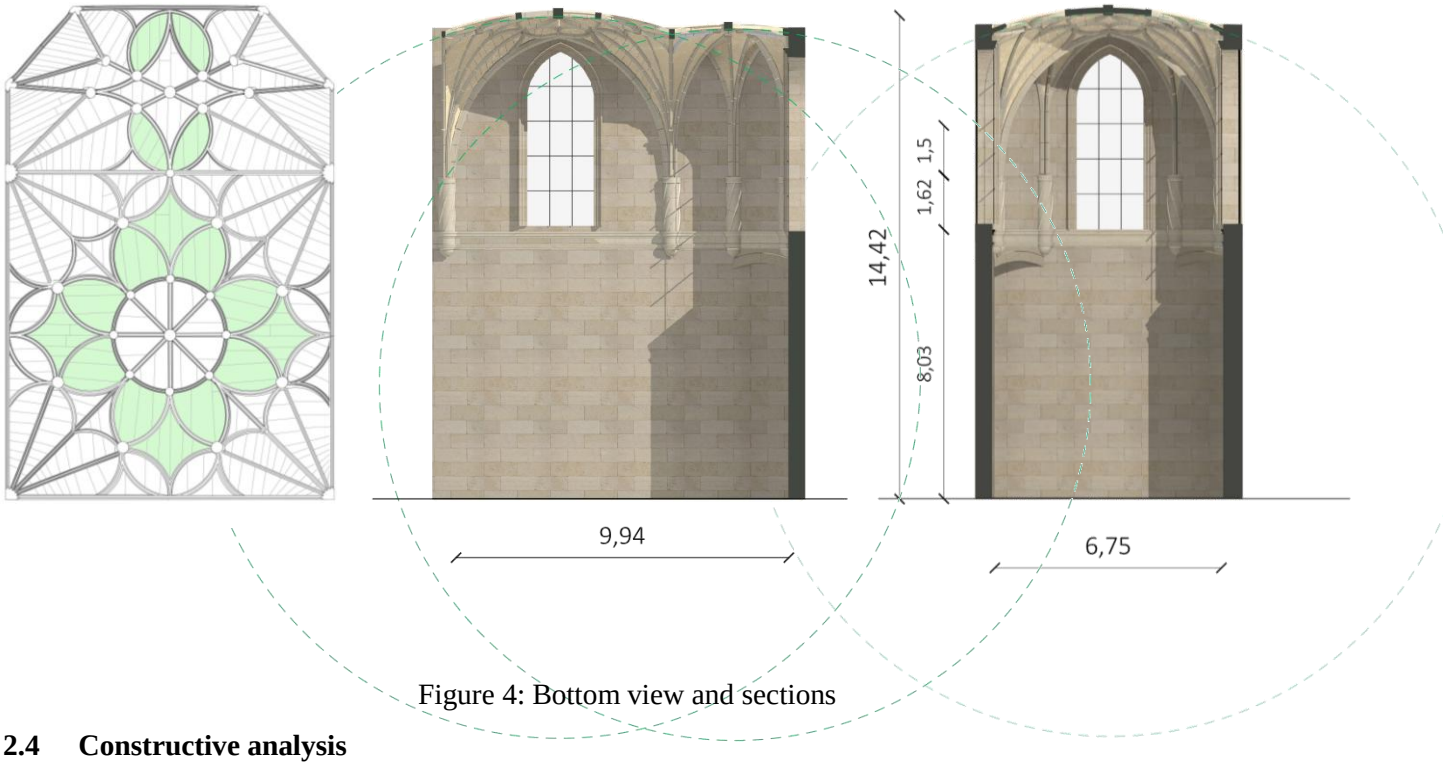

Figure 4: Bottom view and sections

2.4 Constructive analysis

We believe that the building process was made through a double centering: the double frame allows to insert the rib moulding in the central space, in order to create a sort of rail for placing the voussoirs (Fitchen, 1961).

In this way the already finished pieces could be positioned with the advantage of having a precise and fast reference for the assembly.

If we consider this idea, we can affirm that the particular profile of the Late Gothic ribs may be a constructive device rather than a mere aesthetic element.

We reaffirm once again the close link between the various aspects of the architectural object and the close relationship between the “structure” and its intentionally proposed “perception”.

The centering frames arrangement has been probably made only for the diagonal arches and *terceletes*. All the other bosses are supported on isolated points resting on the scaffolding structure and having additional segments to accommodate the *combados*. In fact the *combados* are generally made by no more than two blocks, and sometimes only one.

Then it is not difficult to have an independent assembly once you have defined the bosses positions and the principal arches through the vertical projection.

In this way the centering work is reduced to an X-frame in correspondence of diagonal arches and *terceletes*, the latters limited to the first intersection boss.

The first phase of construction corresponds to the assembly of *formeiros* arches and *tas-de-charges*: the *formeiros* are incorporated into the walls and do not require any intermediate support.

The same type of frame can be rotated and integrated with a different profile in the central part through an additional element to be embedded in the middle. The middle part corresponds to the section contained in the central circle of bosses, that is the central segment of the oval arc that defines the diagonal rib.
The working platform was built at the level of the higher block of the *tas de charge*, so as to serve as a stable support of the centering and bosses temporary supports.

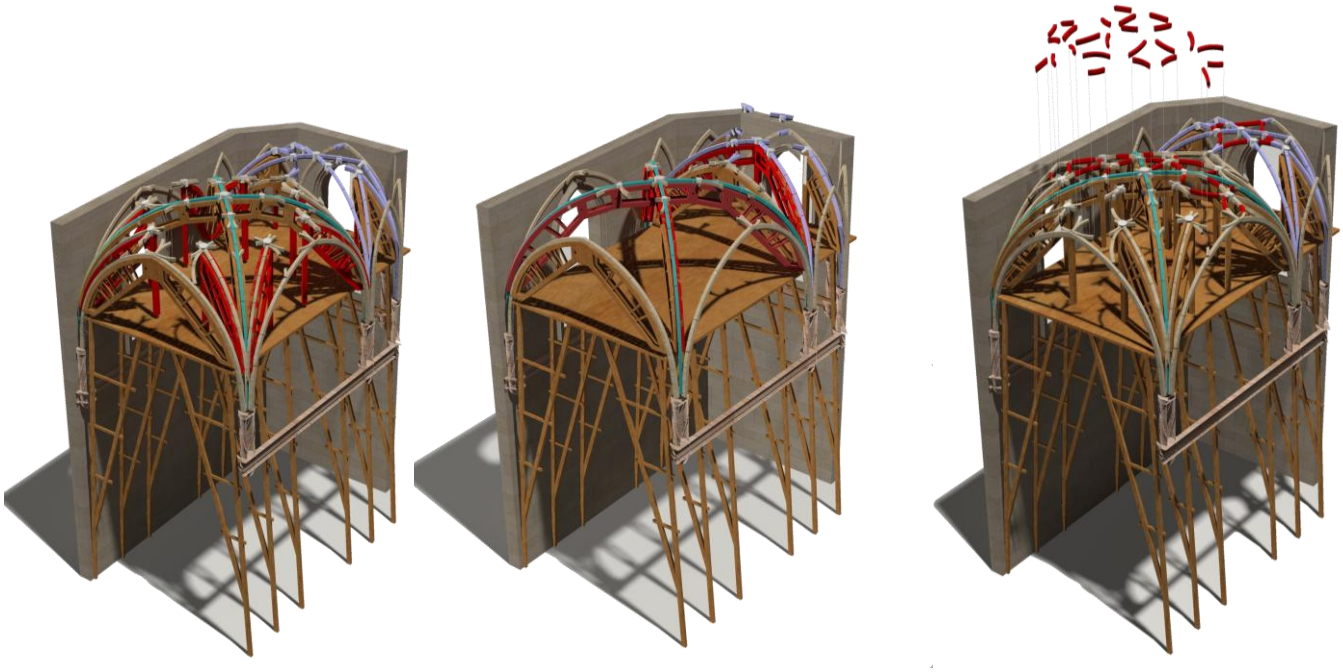

Figure 5: Construction phases

Recap of constructive phases:

1. Assembly of the *formeiros* and *torais* arches (the first within the perimetral wall, the second supported by the double framework)
2. Assembly of the second type of centering for the diagonal arches, followed by the arrangement of *terceletes*.
3. Completion of the “*terceletes* ideal system” through the "rhomboidal" connection of *combados*.

4. Insertion of the remaining *combados* elements into the arranged spaces.
5. Positioning of the webbing slabs into the interlocking slots.
6. Placing of a mortar layer to uniform the extrados, crowned by a lightened filling (depending on the case with hollow clay elements or others).
7. Arrangement of the screed coat.

3 CONCLUSION

The multi-ribbed typology with flower design, or more generally multiple ribs with *combados*, does not represent a pure "aestethic exercise" but also a constructive expedient for the obtainance of the desired quality of space and geometric outcome. In this way it's possible to connect different elements by a fragmentation of adjacent surfaces. The rib assumes a practical function within the whole process, which is always ruled by an extreme logic and consequentiality.

Moreover, the three-dimensional complexity of the vaulted system can be interpreted in terms of bidimensional reduction: as a matter of fact it seems to be the result of a composition of two-dimensional arches.

This research aims to reconnect all the various aspects merged into the building through a global motivation, and to recognize the links between technique, form and construction methods. We can assume, indeed, that every aspect does not present a clear individuality but it's possible to identify a continuous influence from one to another.

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