CONSERVAR PATRIMÓNIO

ARTICLE / ARTIGO

Geometrical and constructive analysis of the choir and crossing timber frames of the church of St. María (Alaejos, Valladolid)

Análise geométrica e construtiva da estrutura de madeira do coro e do cruzeiro da igreja de St. María (Alaejos, Valladolid)

RAFAEL MARTÍN TALAVERANO [1*]
MIGUEL CARLOS CABO FERNÁNDEZ [2]
ISMAEL GARCÍA RÍOS [2]
FEDERICO LUIS DEL BLANCO GARCÍA [2]

1. Universidad del País Vasco – Euskal Herriko Unibertsitatea, Plaza Oñati, 2, 20018, Donostia-San Sebastián, Spain

2. Universidad Politécnica de Madrid, Avenida Juan de Herrera, 4, 28040 Madrid, Spain

**rafael.martin@ehu.eus*

Abstract

This article presents a geometrical and constructive analysis of two significant carpentry works in the church of Santa María (Alaejos, Valladolid): the choir platform and the coffered ceiling of the transept. Both timber frames belong to the same historical period (between the 16th and 17th centuries), and have similar construction solutions, so they could have been probably made by the same author. The research was focused on the several pieces that configure these carpentry works. A design and construction hypothesis was then developed, including both the structural elements and some decorative elements, such as the *muqarnas*. This was done through a survey carried out with a laser scanner, which has provided us with an accurate 3D model. This study aims to deepen the knowledge of these carpentry works. We also provide graphic and written descriptions of both their current state and hypothetical internal configuration, which we believe could be useful for future conservation work.

KEYWORDS
Historical architecture
Renaissance
Carpentry
Wooden ceiling
Coffered ceiling

Resumo

Este artigo apresenta uma análise geométrica e construtiva de duas importantes obras de carpintaria da igreja de Santa María (Alaejos, Valladolid): a plataforma do coro e o teto em caixotões do transepto. Ambas as estruturas de madeira pertencem à mesma época histórica (entre os séculos XVI e XVII), e têm soluções construtivas semelhantes, pelo que poderiam ter sido realizadas pelo mesmo autor. A investigação centrou-se nas várias peças que constituem estas obras. Foi então elaborada uma hipótese de conceção e construção, incluindo tanto os elementos estruturais como alguns elementos decorativos, como as *muqarnas*. Isto foi feito através de um scanner laser, que nos forneceu um modelo 3D rigoroso. Este estudo tem como objetivo aprofundar o conhecimento destas obras de carpintaria. Também fornecemos descrições gráficas e escritas, tanto do seu estado atual como da sua hipotética configuração interna, que consideramos poderem ser úteis para futuros trabalhos de conservação.

PALAVRAS-CHAVE
Arquitetura histórica
Renascimento
Carpintaria
Teto de madeira
Teto em caixotões

Introduction

Study of Spanish carpentry works

Carpentry works are essential elements of a remarkable number of historical buildings. Although much research usually focuses on other constructive elements, namely masonry ones such as walls, piers and vaults, it should be underlined that also wooden elements sometimes have a great interest, and they need proper conservation and dissemination. Within the frame of the Renaissance Spanish carpentry work, there are some masterpieces which were created under the influence of the Muslim constructive legacy. However, many of them have not been properly studied.

At the beginning of the 80s of the twentieth century, the researcher Enrique Nuere succeeded in interpreting with high accuracy the carpentry treatise of López de Arenas [1] and he published an explanation of the triangles' method for the layout of the timber frames [2]. From its first manuscript in 1619 and its publication in 1633, this text was not properly disseminated given that the contemporary researchers were not able to correctly understand the geometrical explanations that the author included in his treatise. However, Nuere brought this hidden method to light and, since then, a noticeable interest in Spanish carpentry works arose [3].

Enrique Nuere continued his research with a special interest in the Spanish carpentry works of the sixteenth century. Nevertheless, this research framework has some empty areas, such as the new carpentry layouts that were used in Spain during the time of the Catholic Monarchs and Carlos I, especially regarding the works promoted by the Mendoza family [4]. Something similar happens with the timber frames of the choir galleries of some churches.

Besides the aforementioned knowledge gaps regarding these carpentry works, it should be underlined the fact that some of them have been damaged or lost due to inadequate conservation. Some others have been saved by moving from their original location to safer places. This is the case of the wooden ceiling of San Vicente church in Fallaves (Zamora, Spain) which is now located at the National Museum of Sculpture in Valladolid. However, during the disassembly of the pieces, before their transportation, the internal constructive configuration was lost.

Taking into consideration the previously summarized state-of-the-art, this paper aims to contribute to the better knowledge of such Renaissance timber structures that are nowadays being studied [5]. With this, we also look forward helping the conservation and dissemination of them. In particular, the main objective is to analyse the coffered ceilings of the transept and the choir gallery in the church of Santa María de Alaejos (province of Valladolid, Spain), which were constructed at the same time and probably by the same carpenter (Figure 1).

Technological and stylistic background

Towards the end of the sixteenth century and the beginning of the seventeenth, Renaissance architectural trends began to prevail, though in terms of carpentry, the old Hispano-Muslim and Mudejar stylistic traditions [6] remained part of the ornamental repertoire, especially in the Tierra de Campos region [7] and its immediate surroundings [8], including Alaejos. The Serliana latticework [9] was easily incorporated and essentially flat panels were replaced by coffered solutions with deep reliefs. Colour disappears from the surface of the wood, associated as it is with medieval traditions, and the wood is left in its natural form [10], except for a surface finishing treatment like linseed oil. All surface highlighting is based on the depth of the carving and moulding of cross-sections superimposed on the sections that form the structure, and on the incorporation of coffered ceilings to generate a chiaroscuro effect on the surfaces. We can see that Villalpando's prompt translation of Serlio's treatise [11] soon spread widely among carpenters of a certain level, but the mixing of cultural traditions continued and friezes, clusters and *muqarnas* (system of elements assembled in accordance with specific geometric rules, originating in Eastern Islam, which may be combined to create a variety of architectural configurations) ceilings remained present and entirely acceptable.

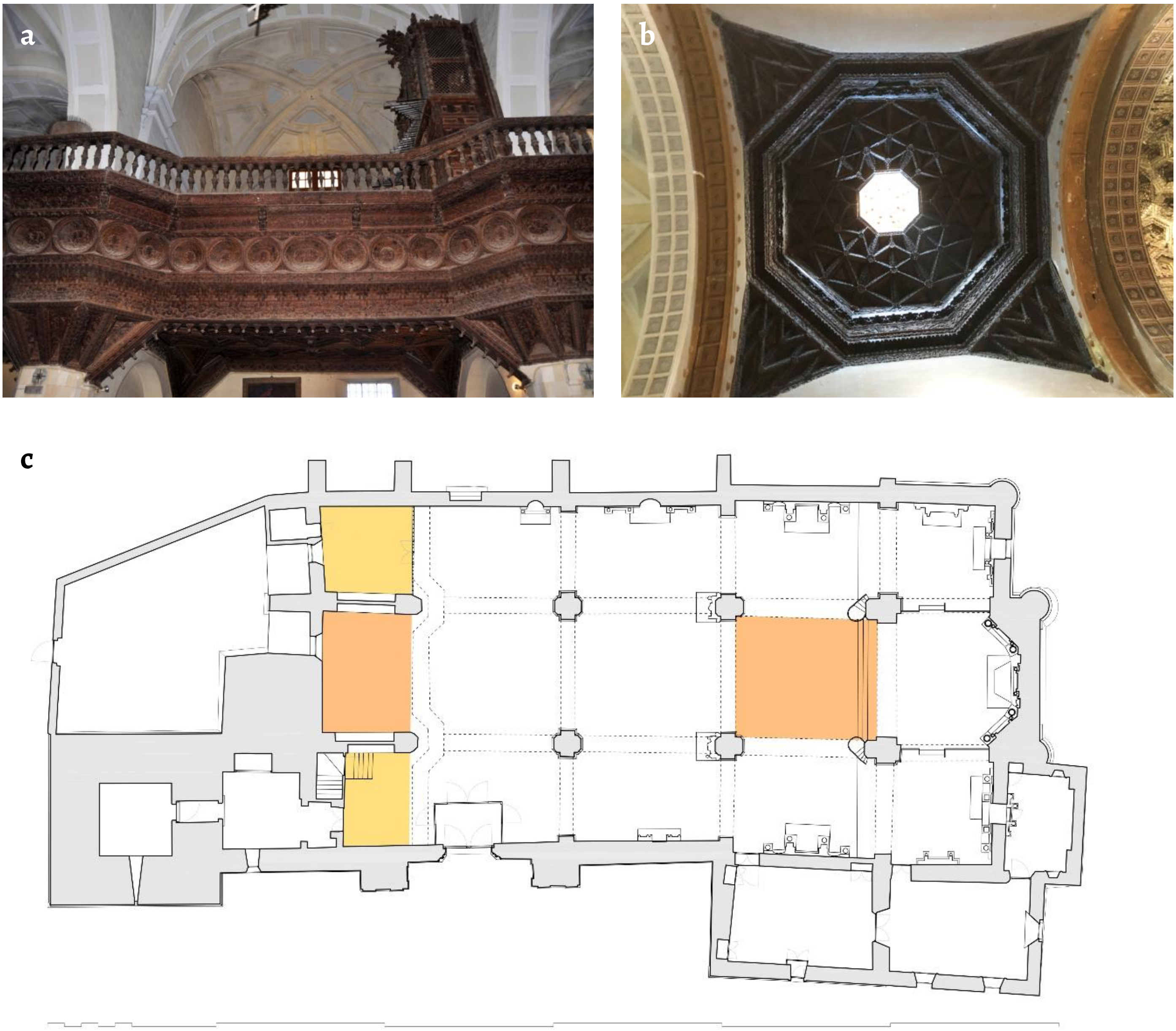

Figure 1. Views of the: *a)* gallery of the choir; *b)* octagonal dome; *c)* overall plan of the church with the location of the analyzed elements.

Research methodology

Description of the building

The church of Santa María in Alaejos (province of Valladolid) is organized, in its current state, on a hall with a central nave and side aisles, each one divided into three bays. The east end is separated by the hall with a transept, and the central apse follows a polygonal layout. The main structures of the building are made almost entirely of brick masonry: the perimetral walls with buttresses, the piers and the vaults. Regarding the covering system, two types of vaults can be distinguished: on the one hand, the bays of the transept and the east end are covered by star-ribbed vaults, probably made of brick; on the other hand, the bays of the hall are covered bay baroque barrel vault with lunettes also made of brick. As an exception to such brick elements, several timber frames are built over the main points of the church: the main chapel, the crossing and the upper choir at the west end. Two of them are analyzed in this paper (that is, the timber frame of the upper choir as well as the coffered ceiling of the crossing), while the third one (the octagonal dome over the main chapel) has been previously studied [12]. The inner sides of the walls, piers and vaults are covered by plaster, and the whole building has a roof supported by a timber frame.

Perhaps one of the most impacting elements of the church is its tower, given that its total height reaches about 52 m. This massive brick masonry structure can be seen far away from the town of Alaejos, and it configures a territorial group together with other brick towers in this region.

Regarding the historical context of this building, it may be underlined that it is not the product of a single phase of construction and may not be ascribed to a single historical period, as it usually happens with almost all historical constructions. For this reason, the building that we see today is the result of a series of transformations that have occurred throughout history, and which are synthesised in the main historical stages of the building [13]. For this research, this historical-constructive sequence has been used to correctly locate and contextualize the construction of the elements studied here.

Prior to the current church, there was an ashlar building which was perhaps the first Santa María church, smaller in size than the existing one. The first great transformation of this original church involved the expansion of its ground plan to the east, using bricks, which in turn led to the construction of a new apse to the east. It is this phase, which can be dated to between the mid-fifteenth and sixteenth centuries, which saw the construction in the main chapel of the octagonal dome with a coffered ceiling lined with gold leaf.

Between the end of the sixteenth century and the beginning of the seventeenth, major changes were made to this second church, with the prolongation of the lateral naves to the east around the apse from the previous phase, the transformation of the southern facade and the construction of the great western tower. The old structures of the roof of the nave were also demolished and replaced by new star-ribbed vaults. In the transept, a domed octagonal coffered ceiling was built, and it is this, along with the gallery of the choir, also dating from this period, which forms the focus of this article.

Basis for the research

The analysis of the timber frames has started with geometric and constructive data acquisition. Before this research, the regional government (Junta de Castilla y León) commissioned a general architectural survey of the entire building. Within the frame of such work, a Terrestrial Laser Scanner (TLS) measurement was carried on the timber frames of the gallery of the choir and the coffered ceiling of the transept. For that purpose, a Leica laser scanner was used with the support of a total station with which several reference points were measured. As a result, both 3D point cloud models were obtained with high accuracy, and they could be integrated within the global coordinate system used for the whole architectural survey of the building. Such data have been used as a measure for the 3D modelling and graphic reconstitution carried out in this study. In addition, manual measurements were taken *in situ* of the extrados of the coffered ceiling of the transept, and sketches and supporting photographs were also used.

Besides, the historical context of both works has been taken into consideration. Given that the historical buildings are the product of a sequence of transformations that take place throughout their whole life, it is necessary to put in relationship each part of the buildings with the corresponding historical phase in which they were created. In the case of the church of Santa María, a specific analysis was also promoted by the regional government of Castilla y León, so that its results have been considered for this research as it is shown in the previous section.

As mentioned before, the continuous sequence of transformations that have taken place throughout the life story of the building is in relationship with several restoration works. For instance, during the twentieth century, several damages were observed in the perimetral walls of the church, and due to them, the vault of the second bay of the north aisle had to be reconstructed in the 60s [13]. Moreover, in the last years of the twentieth century, during a violent storm, a lightning struck the tower, causing further damage.

The architectural survey promoted by the government of Castilla y León was developed within the frame of a contemporary restoration project of the building, which aimed to solve the pathological problems of the church from an integral perspective. Our study of the timber frames also aims to provide more information about the building, as a thorough knowledge of it is one of the foundations for its proper conservation and restoration.

Analysis of the timber frames

The proper study of the coffered ceilings of the transept and the choir gallery has been divided into three main issues: geometric, constructive and ornamental analyses. The 3D point cloud models have been imported into a 3D modelling application in order to carry on the geometric and constructive analyses, as well as to generate a 3D analytical model showing the constructive elements of the analyzed structures.

The geometric analysis has developed using mainly horizontal and vertical projections of the 3D point cloud models, trying to identify alignments, modulations or geometric relationships between the elements of the analyzed structures. It has provided results regarding the geometric concept and layout of the patterns which are the main basis of the construction. Within the constructive analysis, the several pieces that form the structures have been identified. Besides, a hypothesis of the joint system between them has been studied. As a result, it shows the constructive elements that configure both timber frames, as well as some ideas regarding the execution process. Finally, the analysis of the ornamentation has been focused on how the decorative elements and *muqarnas* were conceived.

As final conclusions, several ideas have been underlined regarding the understanding of such historical carpentry works as well as the evolution of the Hispano-Muslim legacy into the Renaissance.

The gallery of the choir

Results of the geometrical analysis

The plan for the geometric design of the *alfarje* (structure of parallel wooden beams that form the framework of a floor) ceilings is based on an orthogonal network of octagons connected by their vertices, following a clearly Renaissance way of beginning construction. The voids left by the network of octagons produce a network of four-pointed stars (Figure 2a), and naturally this conditions a Diophantine (between natural numbers) proportional relationship between the respective spaces, leaving aside adjustments to the plinths and perimeter mouldings. Given the proportions of the holes used to set the pilasters that support the central nave, the carpenter opted for modulation of 3×3 tangent circles for the lower choir of the north nave, and 2×3 in the bays of the central and south naves. As a variation on this flat design, he incorporated a solution – inspired by the Hispano-Mudejar tradition – involving the formalisation of pendentives hanging in the corners, which obviously altered the plan of the modulation. Having to fit in the modulated design, with octagons in Diophantine proportions, creates the challenge of adapting it to the masonry of the church, which was already there before the carpentry of the gallery of the choir. To modify the proportions of the network, the carpenter used the margin of manoeuvre allowed by the adjustment of the contour of the mouldings of the *alfarje* ceilings, as well as the projection of the gallery itself, to tailor the measurements of the wooden ceilings to something resembling Diophantine proportions. This is evidence of the carpenter's aesthetic intentions in his designs and his desire to create a composition that demonstrates regularity and modulation.

Starting from the grid of octagons and four-pointed stars, a grid of squares suggested by the orthogonal grid of the beam filling (beams and joists) is added, as is required to formalise the structure that supports the *alfarje* ceiling. The addition of the diagonals of the squares increases the density of the ribs, necessary to cover with standard widths of board the flat ceilings that are not filled with beams.

The design could be reduced to a tile containing the graphic information necessary to generate the entire layout by replication, as in a chessboard. Depending on which elements are used to generate the rotations and displacements, two different tiles would be obtained, one of them in the form of a four-pointed star and the other in an octagonal shape. Either of these two tiles would generate the same layout, although each would produce a different perimeter contour [14]. In this case, the carpenter would have opted for the octagon-shaped tile for the design.

At the front of the choir, at an intermediate height, there is a frieze decorated with a sequence of medallions in the form of tangent circles. The initial intention of the carpenter was presumably to achieve for all these circles to be regular, keeping the radius constant and maintaining the tangents between them, limited as they are by the upper and lower parallels that make up this frieze. Had it been a flat element, without any break between the side walls of the church, he would simply have had to take the total distance between the interior walls of the three naves and divide that distance in modular terms into several equal parts. The value would be the constant diameter of the circles, and this would define the height of the frieze, so one would only have to try different integer divisions to obtain an acceptable frieze height for the design. However, the fit is complicated by the fact that the perimeter is broken by the balconies surrounding the pilasters of the central nave, and so two factors must be taken into account: the total perimeter of the new contour and the fragmentation in the straight sections of the contour, meaning that any of the straight fragments of the perimeter is a multiple of the module or the diameter of the circle selected [15]. With even a basic knowledge of geometry, the carpenter would realise that if he used a hexagonal module for the cantilevered outline of the balconies, he would make the transverse and perimeter modulation compatible and thus achieve the desired tangents for the circles along the frieze (Figure 2b). There would remain still other possibilities for adjustments, too, modifying the contour of the balconies by using other angles if the distances between the central pilasters were not consistent with the desired modulation. In the design as finally executed, notwithstanding, there are mismatches in the expected geometric regularity. For example, in the sections that make up the balconies and right on the axis of symmetry of the whole frieze we can see that the medallions have the approximate form of two semicircles separated by an intermediate strip, creating an extended shape. This could have been used to adapt the initial design to the length of the constructed contour, should an error of calculation have taken place during construction.

In support of the carpenter, it should be noted that there is another problem in addition to the aforementioned one, and one which may justify the increasing difficulty of achieving a continuous frieze of tangent circles without any deformation. This is the *muqarnas* frieze that is set up as a transition between the main beams facing the choir, the beams on which the beams of the *alfarje* ceiling rest. The design and construction of the series of *adarajas* (each of the prismatic pieces that make up a work of *muqarnas*) or prisms that make up the *muqarnas* frieze condition the modulation of the contour of the frieze precisely, and in such a way as to leave very little freedom to adapt its measurements to enable it to fit properly. As the carpenter executed the work from the bottom up, he began by placing the main beams and their respective braces to set up a support base for the beams of the *alfarje* ceiling, and only then can the *muqarnas* frieze be assembled.

This is the key moment for the adjustment of the measurements of the contour of the balconies and the precise lengths of the straight sections of the beam so that they coincide with the total contour and the partial contours into which the design and composition of the *adarajas* will have to fit. The most likely scenario is that the carpenter tried first to solve this modulation problem, leaving the modulation of the belt of circles for a second phase. The aim would have been to achieve perfection by making the pattern of modulation of the tangent circles coincide with the modulation of the *adaraja* compositions. The vertical plane of the circle frieze flies is superimposed on the outer vertical face of the beams, reaching the upper part of the *muqarnas* frieze. This difference in planes entails a difference in proportion between the vertical faces of the contour of the balconies and the straight sections of the front of the choir, making it impossible to preserve the modulation achieved in the *muqarnas* frieze in the context of the contour.

Finally, it should be noted that the space between the braces that rest on the walls and the main beam at the front of the choir is shaped like a vertical pendentive (Figure 3) and is covered with a coffered design of interlocking strips. This strip design is created by placing a wheel of 12 loops onto the bracket of the pendentive, combined with 16 loop wheels on the sharp corners. The carpenter then made some adjustments to the shape of the *zafates* (interior polygon over the spokes of the wheel) to complete the triangle of the pendentive.

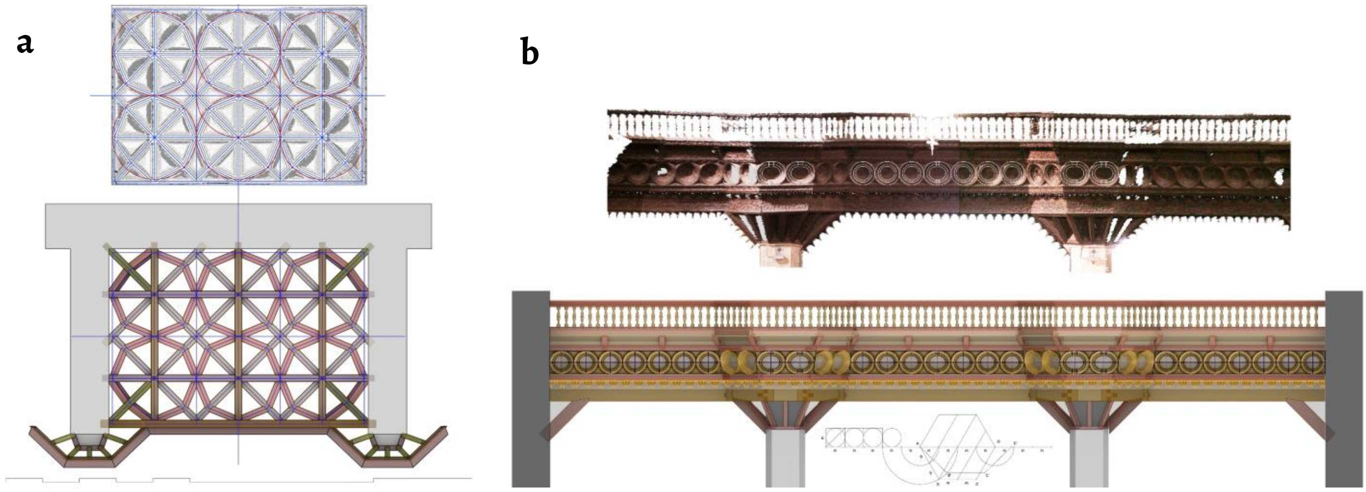

Figure 2. Structure of the gallery of the choir: laser scanner orthoimage and geometrical analysis; b) Frontal views of the point cloud obtained with the scanner laser and of the 3D model with the geometrical analysis.

Results of the constructive analysis

Concerning the *alfarje* ceiling, we can see that the centres of the octagons are placed at the joins of the beams with the main joists, forming a design which features the intersection of a network of octagons with a lattice of squares formed by the beams and main joists. This layout hides the actual constructional and structural processes (Figure 3). Wooden reticular joist frameworks cannot be made using traditional procedures, as there must always be a dominant direction for the beams and a secondary direction for the joists that act as flanges.

For this reason, the *alfarje* ceiling is built using beams aligned in such a direction as to provide the main support for the reticular framework. Structural logic would advise positioning the beams in the shortest span of the room, forming a first plane for the structure, and then adding the joists in a transverse direction, simply resting them on the beams with no need for any assembly or joinery. The solution actually used involves crossing the joists, and this displays poor constructional logic, since it reduces the resistance of the beams because mortices have to be set into them to hold the tenoned ends of the joists, as well as losing the continuity of the bar on the supports (continuity of moments in support). It is surely clear that this cross-joisted solution is only justified from an aesthetic point of view: the aim is to achieve a flat arrangement of the ceiling beams in which the different structural components are blurred and the whole becomes an essentially flat geometric layout, where the mitre joints of the beams are covered with carved lining boards that match all the pieces of the beams. This is very much a formalist concept and one that is very typical of Mannerism.

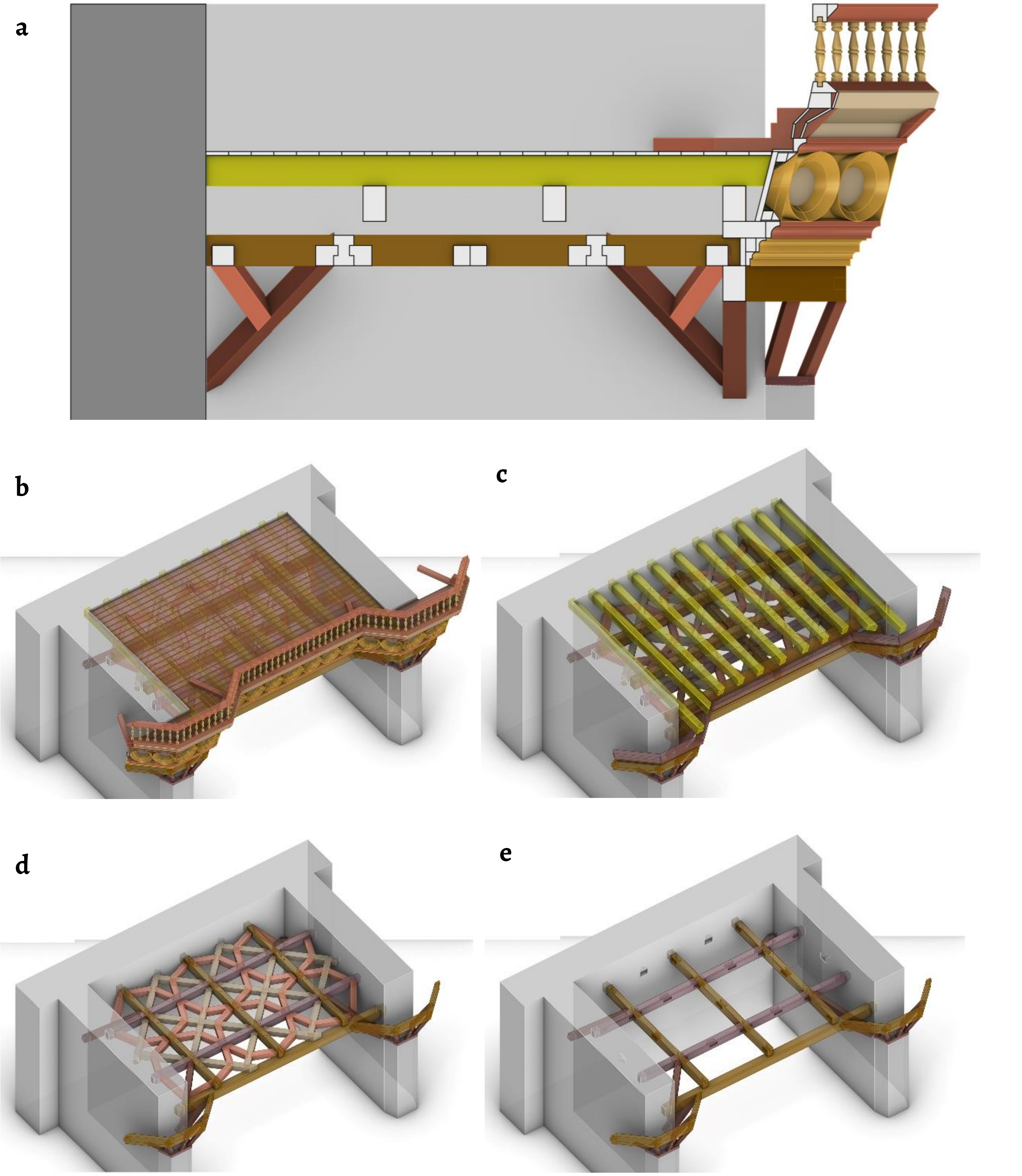

Figure 3. Gallery of the choir: *a)* section of construction: b-e) process of construction; the planar decorative grid located beneath the upper gallery floor is supposed to be an independent structure from the load-bearing system located above it.

Onto these main beams are fastened with mortice and tenon joints other beams of the same size, with the mortices on the main beams and the tenons on the joists. This means that the construction process must be based on attachment and not on superimposition: that is, a main beam is placed first, then the transverse beams are fastened on one side (leaving square spaces), and then these are fastened to another parallel beam which is awaiting positioning. The logical course of action is to carry out the assembly process in pairs of beams, so as not to have to prop up the joists meanwhile. This is known as skirt roof assembly, like the two parallel poles that hold up a stretcher. As usual, it is the simplest and cheapest hypothesis that is the most likely (Figure 4).

Later on, two joists were assembled diagonally within the grid of main squares. As the crossing is coplanar with the rest of the beams of the *alfarje* ceiling, the issue could be resolved using two solutions that were common at the time. The first of these is known as half wood. This type of join has a significant drawback, namely that it weakens by half the resistant section at its midpoint, which is the point that undergoes the greatest stress through bending. The other, perhaps more likely, is to use a diagonal with one third of mortice in the middle and then set the two pieces of the counter-diagonal in by tenoning the beam heads. The problem here is how to support the two diagonals on the grid of main beams and joists, and again there are two possible solutions: the first is to resort to using cross bars with mortice and tenon joints, which weakens the section of the main structure of beams and joists, and the second is to use nails for the fastening, which seems to be more probable. The remaining small coplanar joists which complete the graphic design of the ceiling of the choir, could also use the mortice and tenon method, but the construction process involved in assembling the tenons presents boundary conditions that affect the whole structure as it is put together at the same time. The most likely solution in this case was therefore to resort to the use of nails.

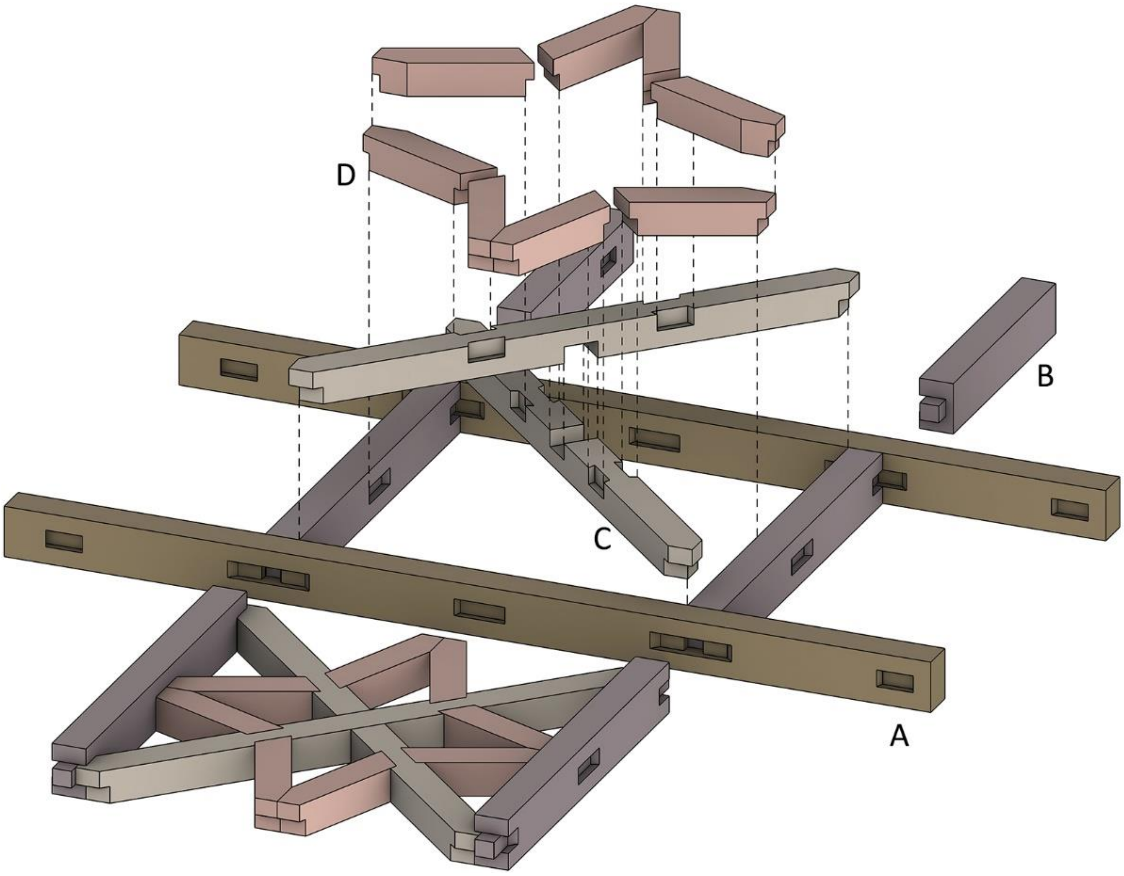

Figure 4. Assembly of the *alfarje* sections of the choir: (A) *jácena*, (B) *jaldeta*, (C) *diagonal* and, (D) *mangueta*.

The section of parallel beams which form the first level of the structure and which rest on the wall, on the one side, and on the master beam at the front of the choir on the other, are of significant size, given that they have to support the load of the entire *alfarje* ceiling. Our estimation is a section of one foot high, that is, one third of a rod (a rod is a historical metric unit used in Castile whose length is 0.836 m, and which is equivalent to three feet), and two thirds of a foot per beam width. The joists, supported in a perpendicular direction, have considerably less space between the supports (between half and one third of the main span, depending on whether they support the lateral or central *alfarje* ceiling). Because of this, the section of beam to be used should at least be less deep, though the width remains the same so that it is constant in the projected geometric design. The diagonals have spans similar to the cross joists and thus the beam will have the same section. The pieces that complete the geometric design, *peinazos* (short piece with identical cross-section to the rafter or collar beam, which is placed perpendicular to these as a form of bracing) and *manguetas* (piece joining the rafters with the collar beam, marking the join with each of the limits of the structure), have much shorter spans, so that they can be executed with a lesser beam depth, though they retain the constant width that is required by the geometric design. The ceiling boards above the small caissons, which complete the design, are positioned at a different height from the finishings of the floor of the choir, and this clearly confirms that the horizontal level of the intrados ceilings and the floor of the choir are set at different levels. Based on this, it may be deduced that there must be some variation in the edges of the beams to accommodate the ceiling boards of the coffered ceilings, as we can see in the construction detail of the section (Figure 3).

As regards the front of the choir, the problem of getting the cantilevered balconies to go around the pillars is worthy of mention. Since the choir is designed to occupy the entire width of the three naves of the church, the carpenter was faced with the obstacle of having to cross the two pilasters of the central nave. Instead of making a discontinuous front with three separate sections, he decided to make a continuous structure, and to achieve this, his innovation was to build two wooden balconies around the two pillars, thus providing the entire front of the balustrade with continuity and allowing users to pass in front of the pillars. The main beams at the front can be supported either from the side wall to the column or between columns, but the support of the overhanging balconies must be solved in another way. On the framework of the beams of the *alfarje* ceiling that must be built to assemble the choir, the carpenter placed several beams diagonally to form the cantilever beams resting on individual braces, which in turn would be supported by small putlog holes made in the central pillars. By doing this, a perimeter frieze was created that would support the whole, serving as reinforcement for the front of the continuous balustrade, with a wall plate and a crowning slab that would act as a handrail, and between which are fitted the mortice and tenons of the turned balustrades.

Results of the analysis of ornamentation

The decorative linings are conceived as elements added to the beams of the *alfarje* ceiling, which is constructed in straight sections cut with a saw (Figure 5). These linings are taken from sawn boards or planks and then gouged with a fairly flat decorative ridge on the boards and with gouge-like mouldings on the planks. The shallow depth of the carving allows the saving of the wood section, and the stylistic result is in keeping with the style known as Plateresque, typical of the chisel-cut embossing work performed by the silverware guild. All the lower faces of the joist are lined with moulded planks of similar size to preserve the beam width and the height of the moulded carving regardless of what is supporting what. The decorative geometry is at the forefront and is used to hide the structural order. The lateral faces of the beams are lined with a board carved with plant motifs and placed on a slight incline, as is usually done with the wooden sections of the *arrocabe* (frieze supporting a coffered and frameworked structure) frieze of the roof trusses. This incline intends to make them easier to see by positioning them slightly more perpendicular to the observer.

These side linings do not reach the full height of the beams, so they need crowning boards to top the small coffered ceilings produced by the geometric layout of the beams and their *peinazos* and *manguetas*. In some cases, these boards are decorated with carvings of vegetal ornamentation. All the intersections of the set of boards that line the lower part of the beams are fixed with mitre cuts, and to hide these as much as possible some circular pieces have been placed in their central crossing area, like small medallions of different diameters. Those positioned at the crossings of the grid of squares are larger than those at the intersections of diagonals and secondaries. It is possible that the carpenter wanted to emphasise the importance of the structural design of the *alfarje* ceiling.

Figure 5. Gallery of the choir: *a)* ceiling; *b)* front.

The main beams, brackets and the rest of the main structure of the front of the gallery, on the other hand, have their surfaces carved with shallow floral motifs. For greater contrast in the reliefs, small fleurons have been inserted with mortice and tenon onto the base of the main beams and brackets. Perhaps the carpenter was thinking of a dialogue with the small hanging elements normally left by the *adarajas* of the *muqarnas* frieze? The gaps left between the brackets of the balconies are covered with boards, forming coffered ceilings with triangular, rectangular and quadrangular shapes, and the mitre joints of the brackets that make up the hidden structure are covered with carved linings.

On the perimeter contour of the main beams and the beams of the balconies of the gallery, there is a *muqarnas* frieze topped by the arches of the *albernica* (piece which is used as finishing for the perimeter or to cover a join in the prisms that make up a *muqarnas* cluster), which then gives way to a distinctly Renaissance frieze of circular medallions incorporating bas-reliefs with carved faces in the centre. This set of tangent circles (except for the geometric irregularities already pointed out in the geometric analysis) fits between a lower band with floral carvings and an upper one with carved cherubs. The medallions are hollowed out towards the centre, both in the outer moulding and in the intermediate section until they reach the face. It seems that the carpenter was emphasising chiaroscuro to achieve the effect of coffered ceilings, like those that surround the cantilevered underside of the balconies. This type of dramatic contrast is typical of Mannerism. The carpenter could have finished this off with the finial of the balustrade, but here he chooses to highlight the importance of the frieze of medallions by adding an upper frieze and, above this, cantilevering the wall plate that supports the balustrade. On the floor of the choir, we can see the upper face of some diagonal beams that support the entire cantilevered structure of the balconies, and the ends of these beams are finished in the form of cantilevers on which the wall plate of the balustrade rests. Everything is shallow-carved with floral motifs, and it is finished off with vertical balusters inserted with mortice and tenon onto both the lower wall plate and the upper piece that forms the railing. The balusters are set up as surfaces that revolve, so it is assumed that they were carved on a lathe rather than by casting a prismatic piece, and the outline of the balusters is finally taken up by the Baroque balustrade models. The entire balustrade assembly (except for the balusters themselves) is carved with plant motifs, except for its intrados, the part that the viewer at the foot of the nave cannot see.

The octagonal dome of the transept

Results of the geometrical analysis

To create this structure, the carpenter started from the idea of an octagonal dome, using transverse and bent corner rafters for each skirt of the octagonal dome. The width of the dome was determined by the width of the transept. On the triumphal arch of the main chapel, there is an added arch that can only be explained by the need to achieve a square plan onto which an octagonal dome of regular proportions could be fitted. Had there been a partitioned vault like those in the naves, any irregularity in the plan would not affect the geometry of the vault, but when a ceiling is finished with a wooden octagonal dome, the width and depth of the enclosed area has to be adjusted to guarantee the regularity of the base of the structure and so to avoid having to build an irregular octagonal dome [16]. The structure is also equipped with a lantern tower, though paradoxically the presence of overhead light obscures the vision of the coffered ceiling due to a chiaroscuro contrast effect.

In the Hispanic-Muslim carpentry tradition, the norm was to begin the design of the octagonal dome by fitting the ornamental layout onto the sample of the skirting, reintegrating the incline of the panels according to the lateral contours of the full extent of the skirting. Here, though, the carpenter took another approach to the ornamental design of the octagonal dome, based on the idea of using two squares rotated by 45° as the decorative theme for the skirt roofing. He begun by working on the plan for the octagonal dome using the plan rather than basing it on the true size and draws a new octagon using the midpoints of the sides of the base octagon. At the midpoints of this new octagon, he placed two squares rotated by 45° (Figure 6 and Figure 7a) and drew the radial lines representing the rafters of the octagonal dome and used the position where these radii are cut onto the rotated squares to place the vertices of a new family of smaller rotated squares.

Above the band of windows of the lantern tower, a *muqarnas* ceiling is installed, confirmation of the survival of the Hispano-Muslim tradition, as well as the knowledge of its geometry on the part of the Spanish carpenters of the time, which thus prove that they were equally at ease within both Renaissance ornamental design and the Muslim tradition. Using this technique, the carpenter managed to resolve the layout of the skirt roofing from the point of view of his plan, but not in its true dimensions. The deployment of the length of the skirt roofing that would enable him to work with the true extent must be approached from a double orthogonal projection, which also provided the incline of the panels and the angle and real length of the corner rafters necessary to proceed to their construction. The geometric knowledge that enabled the calculation of the lowering and deployment of planes is a concept that forms part of Euclidean geometry, but which appeared for the first time in Spain with the Vandelvira (1544-1626) treatise on stonework [17], and in France a little earlier, thanks to Philibert De L'Orme (1514-1570) [18]. In the field of carpentry, the first work to be published was the treatise of Diego López de Arenas (1579–?) [1], though he probably used earlier manuscripts as a reference, considering the many textual coincidences with chapters of other authors, such as Fray Andrés de San Miguel [19] and Rodrigo Álvarez [3].

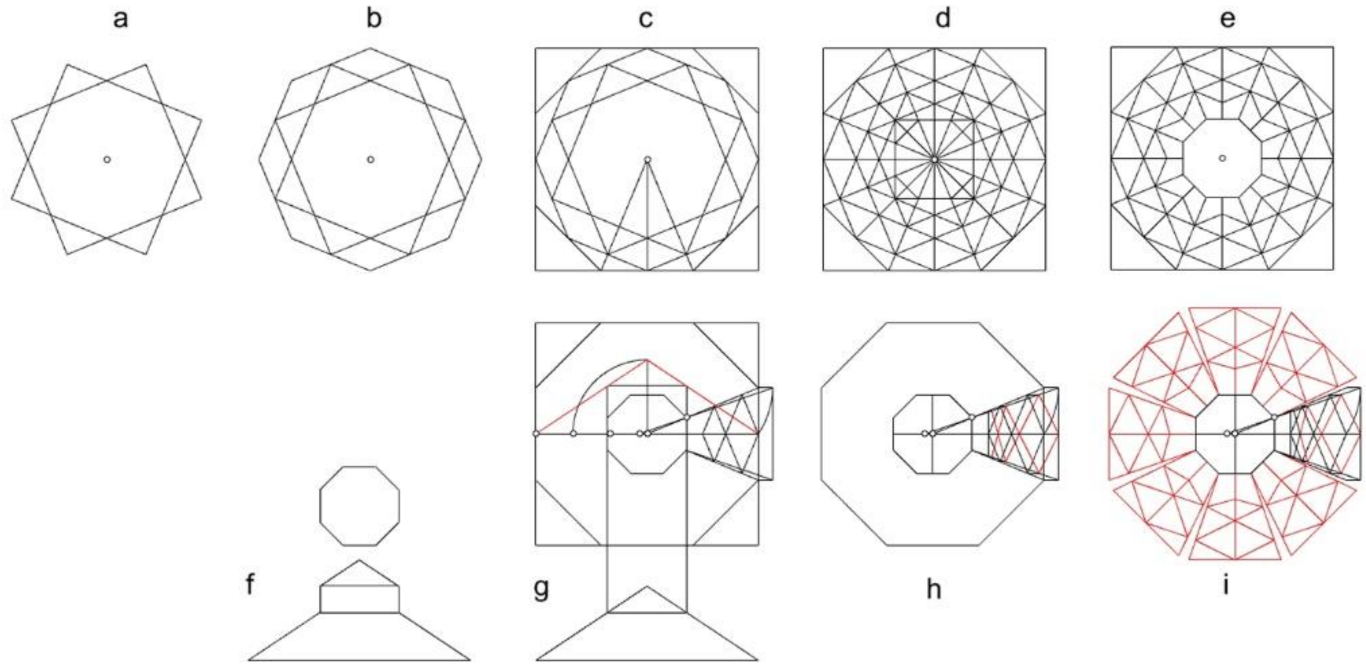

Figure 6. Geometrical analysis of the layout of the octagonal dome of the transept.

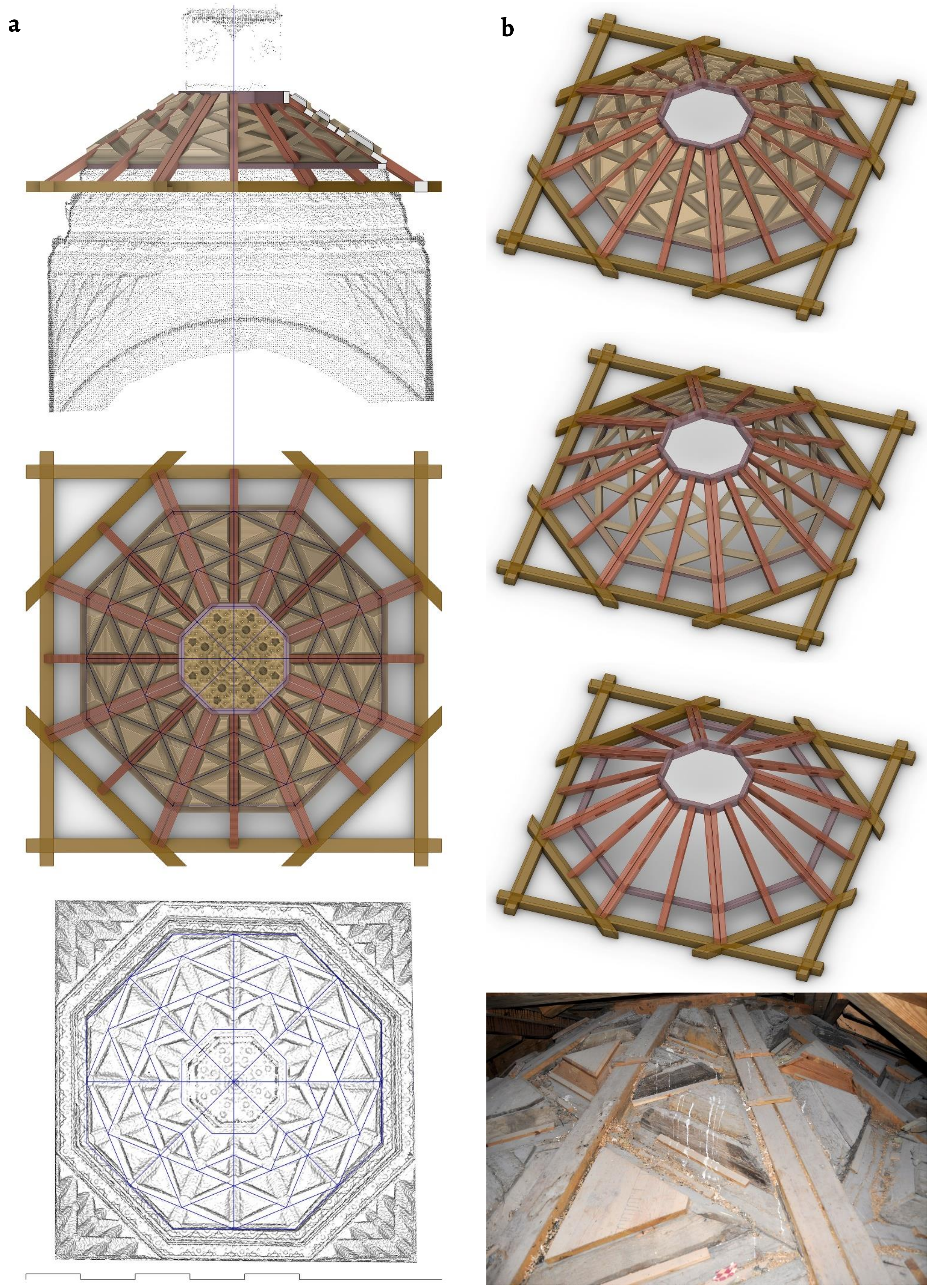

Figure 7. Octogonal dome: *a)* of the transept: elevation/section of the structure, plan and orthoimage from scanner laser; *b)* Structure: construction process and detail of its extrados.

Results of the construction analysis

The tie beams on which the octagonal dome is built rest entirely on the perimeter walls of brick masonry, and the wall continues with the same section and type of masonry above these beams. This circumstance is very unusual, since the correct practice for carpenters was to make the masonry as independent as possible from the wooden framework to avoid any incompatibility of movements between the two. However, these circumstances are related to the existence of constructions inherited from earlier phases of the life of the building.

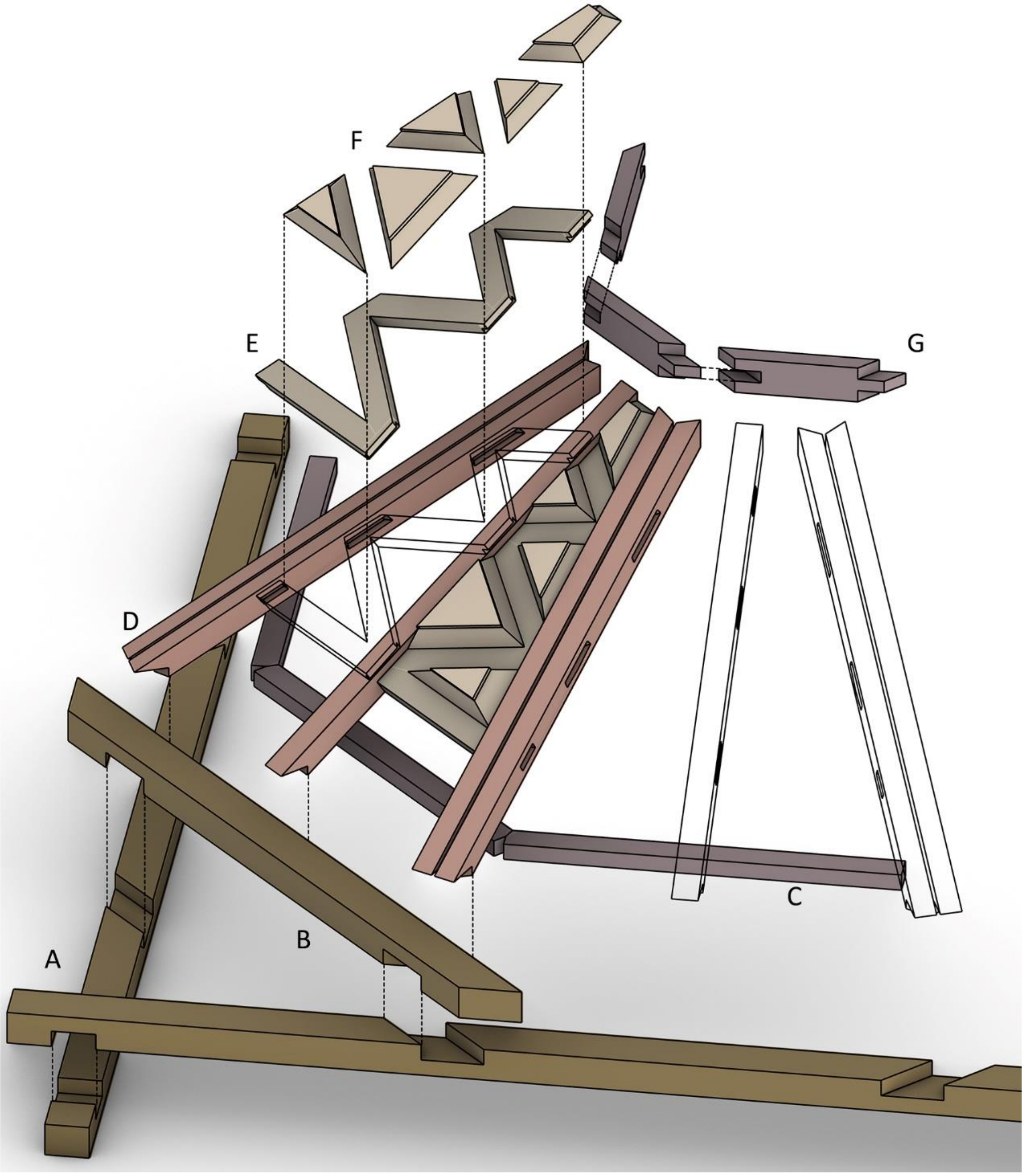

Figure 8. Assembly of the parts of the octagonal dome: (A) *estribo*, (B) *cuadral*, (C) *durmiente*, (D) *par*, (E) *peinazo*, (F) triangle, (G) upper ring.

The usual procedure consisted of prefabricating the trapezoidal panels of the octagonal domes in the workshop and then taking them to the site and raising them two by two to assemble them. This entails the need to duplicate the corner rafters so that the structure of the skirt roofing is independent (Figure 7b). The traditions of correct carpentry imply that the upper extrados of the corner rafters is coplanar with the upper face of the transverse arches, to guarantee that the mortice and tenon structure of the *peinazos* that support the geometry of the coffers is done with the face of the mortices in the plane of the skirt roofing, always in parallel planes which are perpendicular to the dimensions of all the pieces. That would be the usual method if *moamar* (referring to a corner rafter or piece used for a change of plane of the structure, made up of two pieces rather than just one) or double corner rafters were used. This clearly requires knowledge of geometry and the use of a set square, necessary to make the correct cuts in the supports and sections, as is the case of the belling of the corner rafters, which requires a trapezoidal section. In this case, the carpenter seemed to want to avoid geometric problems and instead resorts to "dirty" solutions when assembling the joints against the corner rafters (Figure 8), duplicating the corner rafters in the hinges of the octagonal dome, but this does not solve the issue of the belling. He used two straight pieces attached, forming an intermediate plane between that of the adjacent skirt roofing, and the sides of the corner rafters, along with their boards, are set in a vertical position. This is a poor solution when it comes to mortices, as the lack of right angles means that it has to be done by trial and error. Resorting to such a solution would have been a reason for disqualification from the trade for a master in carpentry, but in this case, it is most likely that the carpenter was, in fact, a carver [20], more familiar with the construction of altarpieces, in which the geometry of the cuts is basically resolved in two dimensions and where there is no need to make cuts involving elements including three dimensions, as is the case with corner rafters.

On the plane of the horizontal roof panel an octagonal ring is formed to support the skirt roofing, and the ring joints are assembled with through tenons. This ring serves as a base on which upright feet are set up to support the ceiling of a lantern tower with vertical glazed panels, alternating glass panels with others lined with wood incorporating a carved bust on each panel, which removes a lot of light. The ceiling of the lantern tower is covered with *muqarnas* in the Hispano-Muslim tradition, entirely covered with *adarajas*. This ornamentation receives enough light to be clearly visible from the floor level of the church.

The octagonal dome stands on a highly developed and ornate frieze, which surpasses the typical formalisations of Hispano-Muslim *arrocabes* (Figure 1b). In the lower part of the structure there is a first level of tie beams in the form of an octagonal dome, and from this perimeter beaming there are some flat hanging pendentives, resting on the squares (Figure 7a). The structure is formalised with simple parallel joists and oblique *peinazos* that form diamond-shaped coffers. The whole is assembled with mortice and tenon, with the tenon on the *peinazos*. The mitre joints of the beams are lined with carved boards and the ceilings with flat boarding. To the eye, it is similar to the finish of the upper skirt roofs, where the structure forms the basis for the decorative geometry. The intrados faces of the tie beams are lined with boards carved with reliefs of floral motifs, and on the abutment belt, there is a moulded wall plate, to support a *muqarnas* frieze, with its *adarajas* resting on the lower tie beam. The band of *adarajas* rises over the intrados plane of the first tie beaming, creating a new strip at the top that needs to be formalised with more tie beaming in the form of an octagonal dome, hidden behind a carved moulding covering the intrados. On this tie beaming there is in turn a board, formalised by a wooden frieze without an incline. The upper part of this frieze, carved with floral motifs, is completed by another moulded perimeter belt that serves as the base for a new *muqarnas* frieze, rising above the vertical of the previous frieze. Between the structure of the octagonal frame and the upper part of the *muqarnas* frieze there is a board which acts as a vertical *cinta cavea* (upper belt or band of frieze or *arrocabe*, which marks the start of a loop design on the sloping roof panels), hiding the meeting at an acute angle of the frieze and the framework, and marks the beginning of the structure of the octagonal dome itself, already described above. The structure of the octagonal dome has its own belt of tie beams on which it rests, independently of the whole set of friezes and pendentives.

Results of the analysis of ornamentation

The construction solution for the decorative finishes of the intrados is very similar to that used in the gallery of the choir, which leads us to believe that the same carving carpenter was responsible (Figure 9). The mitre joints of the truss beams are lined with boards carved with chains of low-profile reliefs and vegetal ornamentation. The corner rafters are lined with two separate pieces, and it is easy to see the join line that marks the separation. This clearly indicates that the decorative linings were positioned either in the workshop or on-site, before the skirt roofing was hoisted up into place, and proves that prefabrication by skirt roofing was the method used by the carpenter. The coffered ceilings are made from carved boards and a simple flat crowning top, also carved with floral motifs. As in the *alfarje* ceilings of the choir gallery, the carpenter used a few small circular fleurons to cover the joining mitres of the lining boards, a good way of applying the finish and concealing the construction joints.

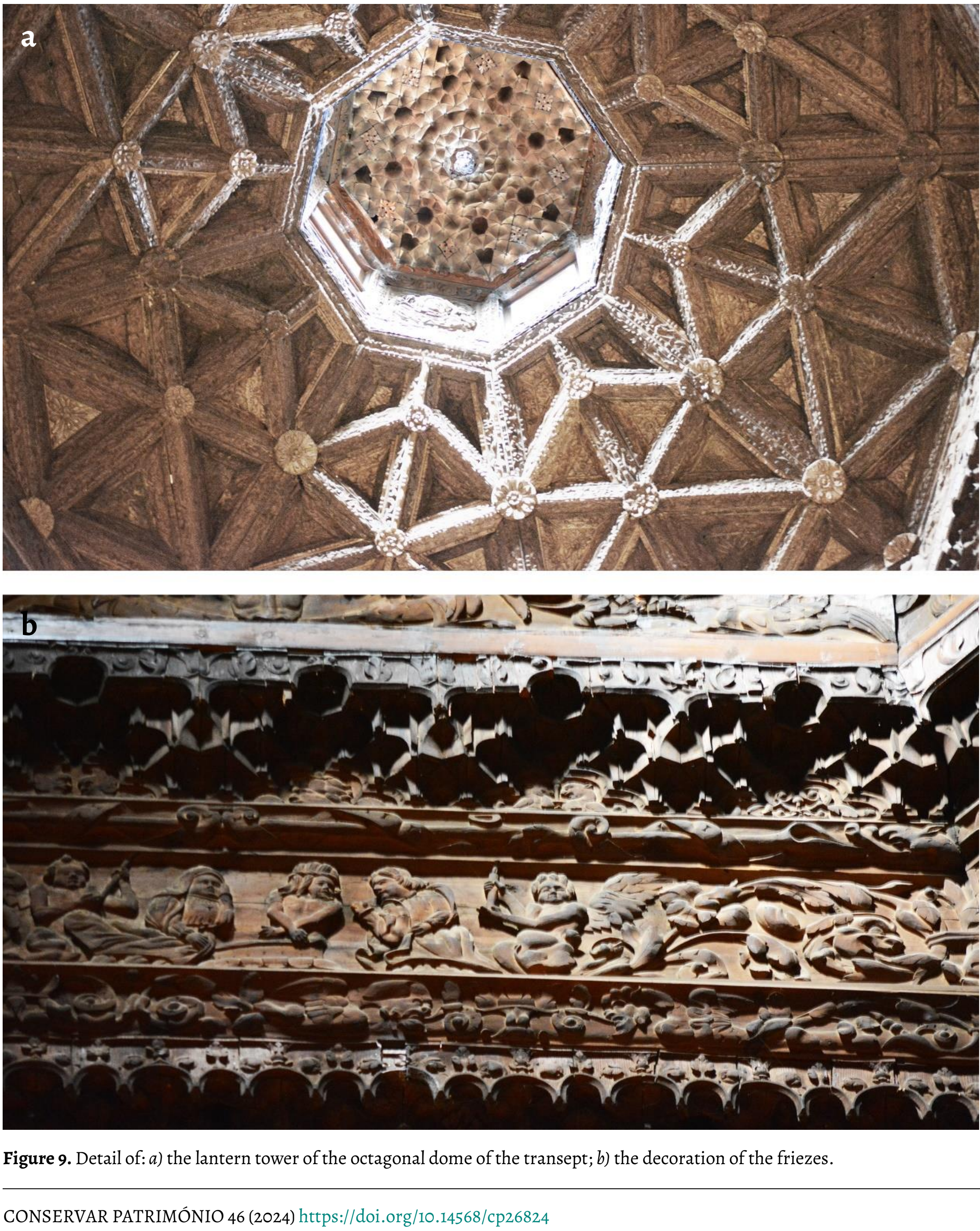

Figure 9. Detail of: *a)* the lantern tower of the octagonal dome of the transept; *b)* the decoration of the friezes.

Prefabrication and assembly

The sequence of assembly would have begun with the lower tie beams, on which the pendentives would have been hung. Perimeter moulding would have been set up to begin to build the *muqarnas* frieze, adjusting all the required *adarajas*. The thickness of the moulding could have been modified to adjust the size of the *adarajas* to suitable values in Spanish inches. It should be remembered that the *conça* (*adaraja* that is obtained from the cross-section of a rectangular prism) was cut only from the *chaplón* (board of a specific thickness from which the various *adarajas* that form the clusters or cubes of a *muqarnas* are obtained) to the thickness of the chamfer, that is, five units, while the rest of the *adarajas* described could be cut from the *chaplón* with a thickness of five-sevenths of the thickness of the chamfer (Figure 7b). From that point on, the next step would have been a vertical wooden frieze, and above this another *muqarnas* frieze, supported on a base of tie beams. The tie beams of the octagonal dome would then have been inserted into the walls, with more important sections, and the prefabricated skirt roofs would have been hoisted up and mounted with the support of the belt of *almizate* (plan or horizontal ceiling of a coffered and frameworked wooden roof), on which would have later come to support the lantern tower, previously prefabricated in vertical panels. Before this, the *muqarnas* ceiling of the lantern tower would have to be raised, so that the lantern tower could pass through the hole without incident [21].

Results of the analysis of the *muqarnas*

In the caption for a photograph of ceiling of the lantern tower of the transept, Nuere [22] refers to the image: "(...) the details of which are practically impossible to appreciate owing to the height at which they are". For the purposes of our study and graphic reconstruction of the *muqarnas* frieze of the gallery of the choir and of the two friezes and ceiling of the lantern tower of the transept, we have taken as a starting point photographs and measurements taken *in situ*.

The friezes are designed in accordance with a general configuration to which variations are then applied (Figure 10a). The lower frieze of the octagonal dome of the transept and that of the gallery of the choir are made up of equal modules, with the same composition of *adarajas* that is then repeated. In the gallery frieze, the tails of the *adarajas* have been shortened in comparison to *adarajas* cut from the usual templates. The flexibility of this system makes it possible to adapt the *muqarnas* to different conditions of spatial dimensions and architectural elements. In this case, it seems likely that the relatively low height of this frieze made this solution necessary. On the other hand, the tails of the *adarajas* in high parts of the building seem to be shorter than those that are lower down, as is the case of those in the lower frieze in the octagonal dome, which is just over four metres high. Longitudinally, the module of the higher frieze is half the size of the lower one, in which two *atacias* (*adaraja* that is obtained from the cross-section of an isosceles triangle prism) have been replaced by a half-square on the outer edge so that the *albernica* could be fixed. There is a special piece used in the *muqarnas* compositions of both the lantern ceiling and the two similar friezes: a prism with a square section that enables four *conças* to be joined and which displays carved floral ornamentation [23].

The roof of the lantern tower is conceived in accordance with an order eight rotational symmetry, with the central part configured in the form of a cluster (Figure 10b). Eight small domes with a regular hexagonal plan and many others with a non-regular pentagonal plan are inscribed within the outline of an eight-pointed star, the vertices of which coincide with those of the octagon on the perimeter of the roof. It could well be the case that the composition of two *atacias* joined at the widest part has been resolved in the form of a single *adaraja*. It would then be a very particular type of *adaraja* formed from a prism with a square plan with a side measuring five units, which could easily be cut from the *chaplón* of the same thickness.

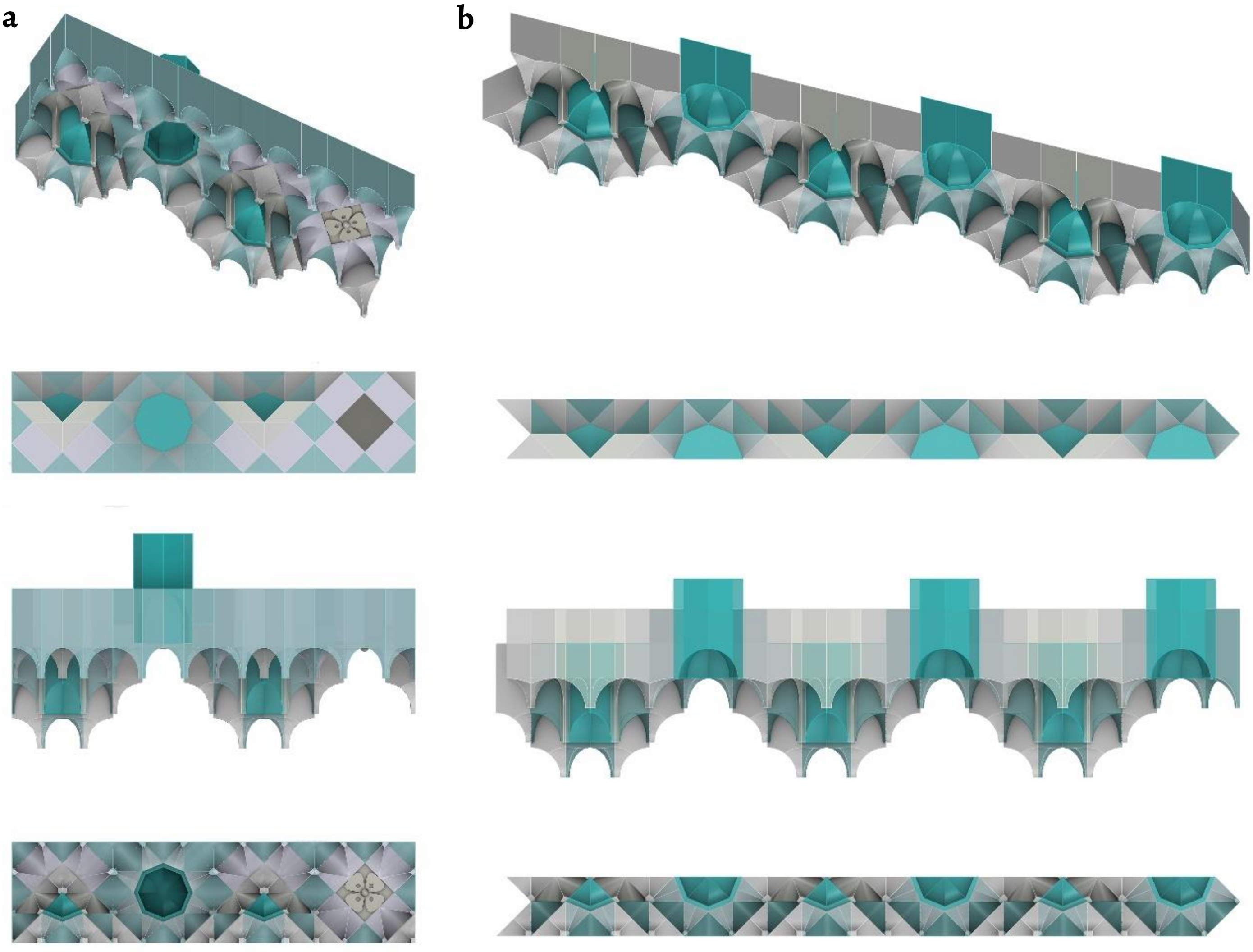

Figure 10. Plans (seen from above and below): *a)* elevation and perspective of the friezes below the octagonal dome and in the gallery of the choir; *b)* high frieze in the octagonal dome.

Conclusions

This paper describes the main results of the geometric and constructive analysis of two of the three timber frames located in the church of Santa María (Alaejos, Valladolid), that is, the structure of the upper gallery of the west end and the coffered ceiling of the crossing. The third one (the octagonal dome of the main chapel) is probably the oldest, while the timber frames of the upper gallery and the crossing date to a later, with all indications pointing to the carpenter or carver being the contractor and executor of both works.

This assumption is based on the finishing treatment of both works of joinery and the use of certain construction joints, especially that of through tenons in the broken joints. We can surmise that the carpenter's expertise was in the field of altarpieces rather than roof trusses, based on certain errors made in the use of corner rafters in the octagonal dome of the transept. A reasonably experienced carpenter-builder would have had little difficulty in finding a way to fit the corner rafters with the intrados and extrados planes coplanar with the toral rafters of the skirt roofing. This is proof that the task of designing and cutting pieces in oblique planes is neither simple nor intuitive, and neither is the use of hinges in the structure of octagonal domes. Specific knowledge of geometry, including both training and practice, is required if a craftsman is to turn and unfold planes and successfully use drawing tools such as the set squares used with the floor plans and shifters, once the inclines of the panels have been decided [24].

The analysis has provided several ideas about the geometric design and the constructive configuration of both timber frames. Thanks to this, a hypothetical 3D digital reconstruction of the unseen parts of such structures has been obtained. These results could help to deepen our knowledge of some of the masterpieces of the Spanish Renaissance carpentry, not only in terms of the construction process itself, but also in relation to the geometric resources and strategies used by the craftsmen to materialize the designs that they had in mind. A better knowledge of these works will also help to improve the conservation and dissemination of the building, allowing more rigorous and accurate works in relationship with the analysed timber frames.

Acknowledgements

This research has been made possible thanks to the collaboration of the General Directorate of Cultural Heritage of the Junta de Castilla y León, which granted access to the graphic documentation on the church of Santa María (Alaejos, Valladolid) required to carry out this study. We would also like to thank Javier Sánchez Matías, parish priest of the church, and J. Javier Beltrán Eliz, manager of the Alaejos tourist office, for their help providing access for the collection of data.

.

REFERENCES

1. López de Arenas, D., *Breve compendio de la carpintería de lo blanco y tratado de Alarifes: con la conclusión de la regla de Nicolás Tartaglia y otras cosas tocantes a la geometría y puntas del compás*, Estupiñán, L., Sevilla (1633).
2. Nuere Matauco, E., *La carpintería de lo blanco. Lectura dibujada del primer manuscrito de López de Arenas*, Ministerio de Cultura, Madrid (1985).
3. Fernández Cabo, M., *Armaduras de cubierta*, Ámbito, Valladolid (1997).
4. González Uriel, A.; Miguel Sánchez, M. de; Fernández Cabo, M. C., 'Los artesonados renacentistas del Palacio Ducal de Pastrana (Guadalajara): análisis geométrico', *EGA. Revista de Expresión Gráfica Arquitectónica* **24**(36) (2019), 60-71, https://doi.org/10.4995/ega.2019.10530.
5. Miguel Sánchez, M. de; González Uriel, A.; Cabo Fernández, M. C.; García Ríos, I., 'Transición hacia el Renacimiento de la carpintería de armar en Tierra de Campos', *Informes de la Construcción* **74**(565) (2022) e427, https://doi.org/10.3989/ic.82242.
6. García Nistal, J., '¿Artesonados mudéjares? de algunas cuestiones terminológicas e investigadoras en los estudios sobre carpintería de armar española', *Anales de Historia del Arte* **21**(no. extra) (2011) 211-223, http://dx.doi.org/10.5209/rev_ANHA.2011.37458.
7. Vasallo, L.; Pérez, R., *Artesonados: la carpintería de lo blanco en la Tierra de Campos Zamorana*, Junta de Castilla y León, Zamora (2010).
8. Castán Lanaspa, J., *Catálogo monumental de la provincia de Valladolid*, Tomo XXI. Antiguo Partido Judicial de Nava del Rey, Diputación de Valladolid, Valladolid (2006).
9. Cuesta Salado, J., 'El seguimiento de los modelos de Serlio en los artesonados del sur de Tierra de Campos y el maestro de carpintería Alonso de Porquera', *BSAA Arte* **83** (2017) 71-102, https://doi.org/10.24197/bsaaa.83.2017.71-102.
10. Aira, J. R.; Cabo Fernández, M. C.; del Blanco García, F. L.; Gonzalo Calderón, L., 'Puentes de madera con estructura recíproca. Análisis comparativo del puente tradicional chino y el puente de Leonardo', *Informes De La Construcción* **74**(565) (2022) e430, https://doi.org/10.3989/ic.85874.
11. Villalpando, F., *Libros III y IV de Serlio*, Juan de Ayala, Toledo (1552).
12. Blanco-García, F. L. del; Cabo-Fernández, M. C.; García-Ríos, I.; Martín-Talaverano, R., 'Análisis geométrico y constructivo del artesonado de la capilla mayor de la iglesia de Sta. María (Alaejos, Valladollid)', *Informes de la Construcción* **74**(568) (2022) e475, https://doi.org/10.3989/ic.91635.
13. Murillo Fragero, J. I., 'Memoria de la lectura de paramentos de la iglesia de Santa María (Alaejos, Valladolid)', Junta de Castilla y León (2011).
14. Salcedo Galera, M.; Natividad Vivó, P.; García Baño, R.; Calvo-López, J., 'El "Ochavo de La Guardia", ¿tórico o esférico?', *Informes de la Construcción* **73**(561) (2021) e374, https://doi.org/10.3989/ic.74582.
15. Wolff, C.; Cárcamo, M., 'Enactive or symbolic representation? When the order alters the product', *VLC Arquitectura* **8**(1) (2021) 173-188, https://doi.org/10.4995/vlc.2021.12534.
16. Blanco García, F. L. del, 'Reconstructing Pérez Piñero's Anoeta Velodrome', *Nexus Network Journal* **24** (2022) 913-934, https://doi.org/10.1007/s00004-022-00590-3.
17. Vandelvira, A., Libro de cortes de cantería de Alonso de Vandelvira, arquitecto; sacado a luz y aumentado por Philipe Lázaro de Goiti, arquitecto, maestro mayor de obras de la Santa Iglesia de Toledo [manuscript] (1646), Biblioteca Nacional de España – Biblioteca Digital Hispánica, Mss/12719.
18. De L'Orme, P., *Le premier tome de l'architecture*, Morel, F., Paris (1567).

19. Nuere Matauco, E., *La carpintería de lazo: lectura dibujada del manuscrito de Fray Andrés de San Miguel*, Colegio Oficial de Arquitectos de Málaga, Málaga (1990).
20. Martín Jiménez, C. M.; Martín Ruiz, A., *Retablos escultóricos: renacentistas y clasicistas*, Diputación de Valladolid, Valladolid (2010).
21. Güzelci, O. Z.; Alaçam, S.; Şen Bayram, A. K.; Lacroix, I., 'Measuring the entropy of Sinan's muqarnas patterns', *Nexus Network Journal* **23** (2021) 85-105, https://doi.org/10.1007/s00004-020-00521-0.
22. Nuere Matauco, E., *La carpintería de armar Española*, Instituto de Conservación y Restauración de Bienes Culturales, Madrid (1989).
23. Gasperi, A. A.; Garcia Augustin, R. F., 'Transdisciplinarity of preservation: postgraduate programs associated with conservation and restoration in the Brazilian context', *Conservar Património* **37** (2021) 116-132, https://doi.org/10.14568/cp2019047.
24. Prieto y Vives, A., *El arte de la lacería*, Hijos de J. A. García, Madrid (1904).

RECEIVED: 2022.3.25
REVISED: 2022.5.11
ACCEPTED: 2023.10.23
ONLINE: 2024.5.19