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Placing the keystone of the vault over the presbytery in Tortosa Cathedral, Spain (1428-40)

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Abstract

The Gothic Cathedral of Tortosa (Spain) was commissioned in 1345 and the construction of its heptagonal apse took place between 1374 and 1441. The construction began with the external ring of radial chapels while the original Romanesque cathedral was still in use. Its demolition began with the construction of the ambulatory and the temporary works which had to enable the location of the main keystone of the presbytery, known as Clau Major. It was an element of great weight whose installation involved a major challenge in the construction process. Its iconography represents the Coronation of the Virgin Mary, and its placing in position was celebrated on 27 September 1439. However, its manufacture and installation was a lengthy procedure between 1428 and 1440, beginning with the definition of its design in 1428, and culminating at the point when it acquired its full structural function in 1440. The size and the weight of the clau, nearly 9 tonnes, meant that substantial temporary works were extremely important in its positioning. A temporary column, called the pilar major, was built between 1428 and 1438 to perform the structural functions of the keystone until the latter was in place and able to adopt its final structural function in the building. Recent studies have enabled the overall geometry of the keystone to be determined and the temporary works necessary for the construction of this Clau Major to be understood. It is believed that this use of a large temporary pilar major was unprecedented in Gothic construction.

Keywords

Cathedral, Gothic and medieval construction, keystone, temporary works, Tortosa Cathedral, Spain.

Introduction

The apse of Tortosa Cathedral, about 150 km south west of Barcelona in Spain, was built between 1374 and 1441. (Fig. 1) The keystone of the Gothic presbytery, which represents the Coronation of the Virgin Mary after her Ascension into Heaven surrounded by a choir of ten angels, is a highly symbolic element that overlooks the high altar and was the culmination of the cathedral's construction. (Fig. 2) The keystone was placed during a public ceremony on Sunday 27 September, 1439, the feast day of the Assumption of Mary.[1] The Chapter of the Cathedral follows the design rules of St. Augustine (Aurelius Agustinus). The geometric and topographic metrology of the *clau major* of Tortosa Cathedral is strongly based in symbolic terms on the Rule of St. Augustine (10 x 100). Following this rule, its theoretical diameter is 10 palms (2.32 m) and its position is at a height of 100 palms (23.23 m) (1 palm is approximately 232 mm or 9.1 inches). Thus the keystone represents one thousand, the perfect number in the fullness of time that defined the *Civitatis Dei* (XX.7.2) of St. Augustine (354-420).[2] The keystone represents the volumetric concept of space. The square figure is flat, and it is given height to make it three dimensional or volumetric. The keystone therefore has a diameter of ten palms and is located at the

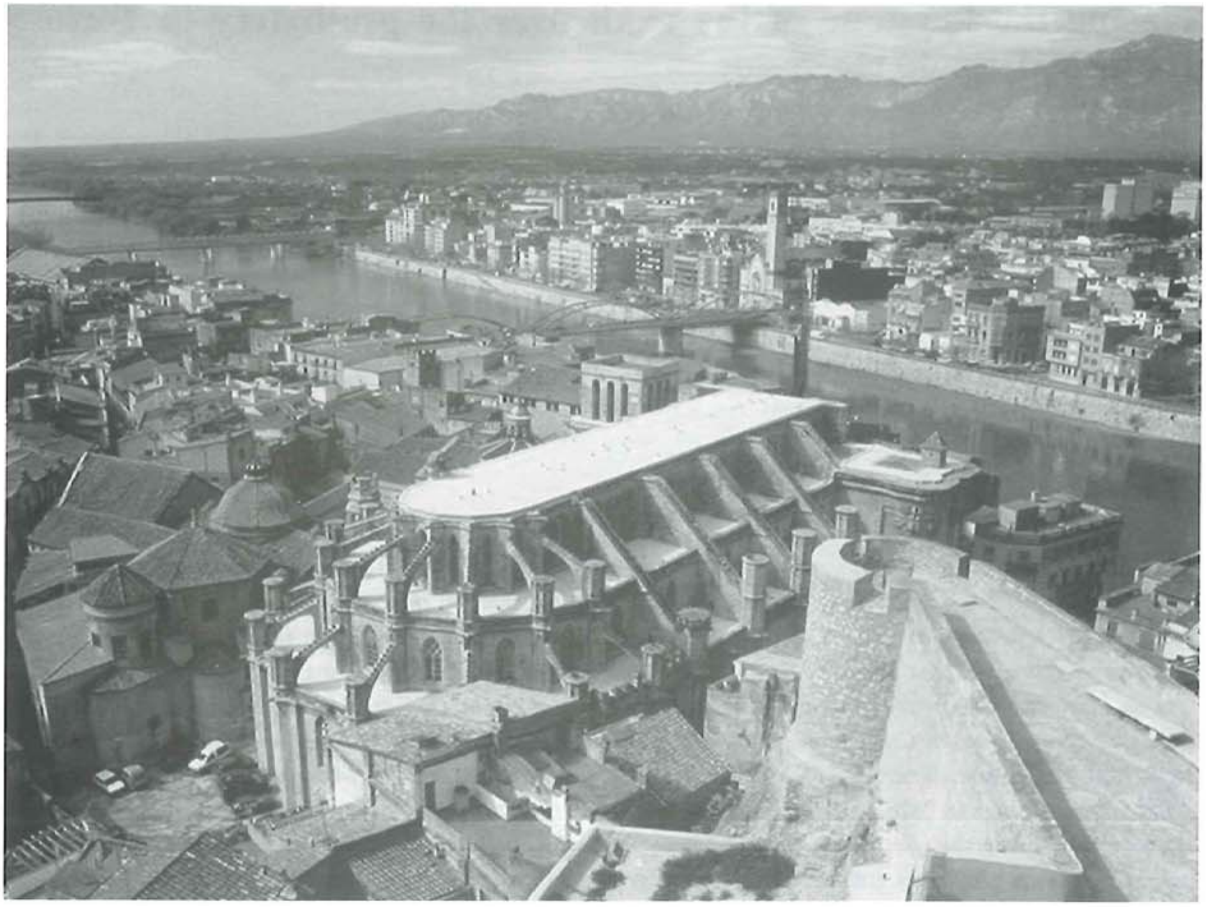

Figure 1. Santa Maria Cathedral, Tortosa

Figure 2. Santa Maria Cathedral, Tortosa - the presbytery and ambulatory. (Source: the authors)

height of one hundred palms, such that (10 x 100 = 1000). This appears in the twelfth century codex (ACTo. 20 fol. 337v-338v).[3]

The placing of the keystone, which weighs almost 9 tonnes, at a height of about 23 m, can be considered the greatest technical achievement in the construction of the Gothic chancel of Tortosa Cathedral. The objective of this research was to determine the process involved in the design and placing of this essential element in the completion of the Gothic apse. The study of historiography and the use of modern surveying techniques such as Ground-Penetrating Radar (GPR) or Terrestrial Laser Scanner (TLS) enabled a comprehensive approach to the entire process, through the design, manufacture and placing to the final assumption of its structural role in the vault. Thus, the study addressed the origin and the functional requirements of the keystone, as well as the temporary works needed for its lifting and final positioning.

A detailed analysis of the vaults of the presbytery of Tortosa cathedral has always raised the issue of accessibility. A precise definition of the shape of the keystone has therefore been very difficult. The geometric model obtained in the survey in the *Pla Director de Sancta Maria Dertosae* (2000),[4] was sufficiently accurate for the ground floor of the cathedral, but is of little use in ascertaining the plan of the top of the vaults. In the next stage of the survey, three-dimensional survey techniques and massive data capture were used. In the first campaign (2012-13),[5] (Fig. 3) the survey was performed using tacheometric and photogrammetric systems. Given the geometric complexity of the space and technical limitations of the methodology, a further survey was conducted using Terrestrial Laser Scanner techniques (2013).[6] (Fig. 4) With these data, it has been possible to determine the geometry and the immediate surroundings of the keystone more accurately, with an overall accuracy of around ± 3 cm. A geophysical survey was also conducted between the topographical survey campaigns (2012-13),[7] in order to determine the existence of any remains of the *ecclesiam vetulam*, the Romanesque cathedral consecrated in 1178 which the Gothic cathedral replaced.

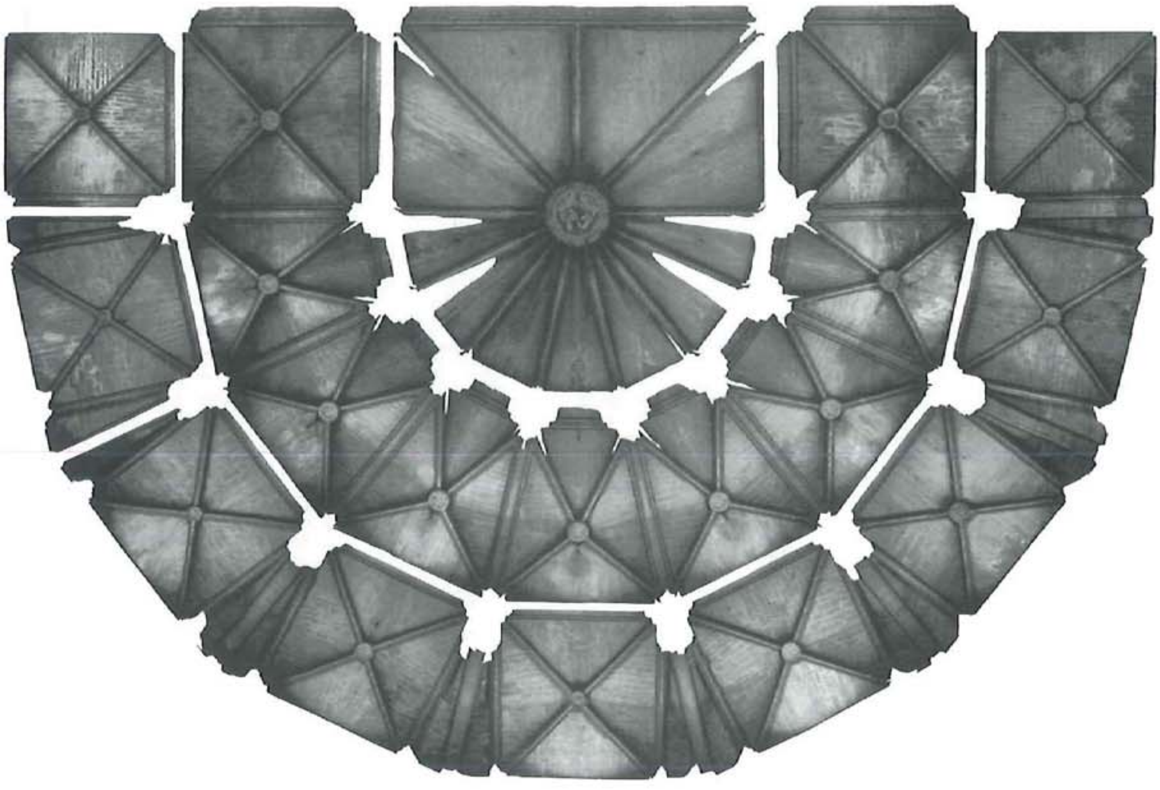

Figure 3. Photogrammetric model of the apse: ortho-image of the vaults (2012-2013). (Source: the authors)

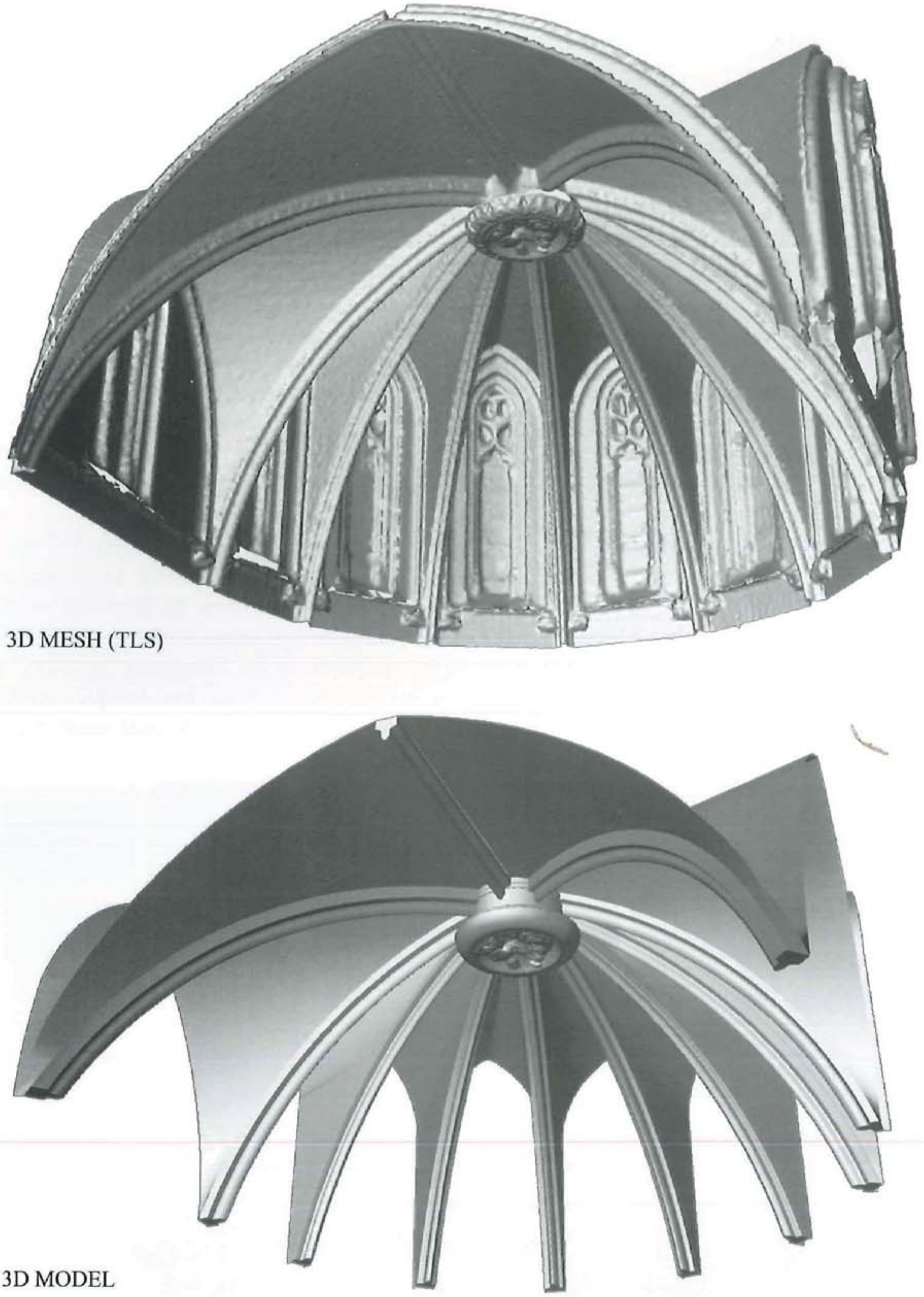

Figure 4. 3D Mesh (Terrestrial Laser Survey) & 3D Model of the presbytery and the clau major. (Source: the authors)

These survey data can be compared with those in the church construction accounts (Ll. o.) of the Tortosa Chapter Archive (ACTo), which mention the construction of a *pilar major*.[8] Victoria Almuni (1959 -) has dated this element to the year 1428, during the construction of the central section of the presbytery.[9] This column was dismantled in 1440. Josep Lluis i Ginovart (1958 -) and Victoria Almuni,[10] have hypothesised that a large temporary works structure was needed for construction. Subsequently, Artur Llunart (1987-) and Josep Lluis have proposed an initial construction hypothesis for the scaffolding systems, suggesting the temporary central stone column as an element to support the centring for the vaults in the presbytery and the keystone.[11]

These data enabled a combined analysis of the results of the geophysical survey (2012-13) with the topographical baseline by Lluis (2000). These results of this information were checked against the direct documentary sources on the keystone, cited by Ramon O'Callaghan (1834-1991) in the *Anales de Tortosa* (1887) and Victoria Almuni (2007). It has thus been possible to determine the chronological sequence of the construction process and the placement of the keystone. In further survey work, the presbytery vaults were defined geometrically in surveys undertaken in 2011-12 and 2012-13. With these results, it was possible to give geometric specifications for the keystone and quantify its main physical properties analytically. These characteristics were significant when evaluating the complex construction process involved in the placement of the keystone of the presbytery.

The keystone

The dimensions for the keystone established by Lluis (2000) were a diameter of 10 palms at the base, 3½ palms at the neck, and a height of 5½ palms from the upper surface of the rough tiling of the roof. The new survey has enabled the accuracy of these dimensions to be improved and a three-dimensional model of the keystone and the fit with the contiguous vault ribs to be determined. The diameter of the keystone has now been measured as 2.04 m (a little more than 8½ palms) at the base, and 1.62 m (7 palms) in diameter at the neck, with a total height of 1.51 m (6½ palms). The volume of the keystone has thus been calculated to be 3.64 m^3 and it weighs 87.47 kN (assuming a density of 24 kN/m^3). Thus, in the quarry, the stone block from wich it was carved must have been around 8.77 m^3 with a weight of 210 kN.

Due to the large size of the keystone, the choice of the stone block for carving must have been difficult. An initial attempt to extract a suitable stone from the quarry at Vinebre or Asco was unsuccessful. As result, Pere Pasqual, the right-hand man of Joan of Xulbi, the master working between c.1416 and 1458, visited the quarry in June 1438. He did so to ensure the correct choice of a second block, which would be cut to the final form.[12] The transportation of the keystone by river and its unloading required that repair work was carried out to the quay in the port and to the street that led from the workshop to the cathedral, along which the stone was carried. During the transfer of the keystone, which only had to travel a distance of 150 m with a slope of 4 metres, animal fat was smeared on the street surface to help it slide along the ground. The labour of seven men over three days was required to undertake this transportation work in January 1439.[13] The grinding and carving of the block with the sculptural decoration is attributed to the sculptor Bartomeu Santalínia who came from a family of goldsmiths, and was employed to work on the masonry for 59 days in the summer of 1439. (Fig. 5)

The final cut of the keystone had to resolve both the problems involved in carving the iconography of the Coronation of the Virgin Mary, and the problems related to the geometry of the Gothic stonework. The lower carving is set out on a circumference and the neck of the keystone had to accommodate the nine diagonal arches of the presbytery that converged on it. There must be a relationship between the length of the circumference, its diameter and the dimensions of the diagonal arch that meets the keystone.

As a result, this circumference had to be divided into seven equal parts. The keystone was cut prior to the completion of the diagonal arches, and the size of the mould of the arch was dictated by the mould of the base of the column in the presbytery. The geometry of the neck needed to accommodate the diagonal ribs. Its size can be determined using simple proportion, 9:4, using either the ratio of the circumference to the rib, or vice versa. The ratio 9 (radius of the circumference) to 4 (side of the inscribed polygon) is highly effective for the division of the circumference into 14 equal parts.[14] The axes of the arches are equidistant 36 cm, and the neck of the keystone has a radius of 81 cm, corresponding to the ratio of 9:4.

Figure 5. The Coronation of Virgin Mary in the main keystone of Santa Maria Cathedral, Tortosa. (Source: the authors)

The temporary works and scaffolding

The vaults were built using construction techniques in which the positioning of the keystone played a crucial role. For Gothic keystones, the space to be covered was specified precisely in geometric terms, as well as fulfilling its structural role as the keystone of the vault. These construction processes included a requirement for counterbalancing certain forces from adjacent arches and vaults which required the use of temporary elements and structures in the intermediate stages of the execution of the stonework, and which were essential for the building's future overall stability. These elements included wooden scaffolding and wooden centring, as well as items made of masonry such as temporary columns. These various elements carried the thrusts and vertical and horizontal actions of the vault during construction. Some of the techniques used by Rodrigo Gil de Hontañón (1500-77), were included by Simón García in his *Compendio de arquitectura*.[15] Similar details are found in the expert appraisals for the construction sequence of the vaults in Segovia cathedral carried out by Enrique Egas (1455-1534) in 1532 and by Francisco de Cologne (1470-1542) in 1536.[16]

This was also true of lifting mechanisms used in Gothic construction which, being influenced by Aristotelian mechanics, were used to illustrate several editions of Vitruvius from the 16th and 18th centuries.[17]

The need for such temporary works in major construction projects has been present since Roman times to the present day. They were, for example, addressed in the main French treatises of the nineteenth century such as *Traité theorique et pratique de l'Art de Bâtir* by Jean-Baptiste Rondelet (1743-1829)[18], and the *Dictionnaire raisonné de l'architecture française du XIe au XVIe siècle* by Eugène Emmanuel Viollet-le-Duc (1814-879)[19]. Scaffolding is also mentioned in *On the construction of the vaults of the middle ages* by Robert Willis (1800-1875)[20] in England, and the *Lehrbuch der Gotischen Konstruktionen* by Georg Gottlob Ungewitter (1820-1864)[21] and the *Handbuch der Architektur* by Josef Durm (1837-1919)[22] in Germany. The techniques described in such construction manuals were used by Spanish restorers in the nineteenth century, for example, the work done by Juan de Madrazo (1874) and Demetrio de los Rios (1879) at León Cathedral[23], by Fernández Casanova at Seville Cathedral (1882-88)[24], by Repullés and Vargas at San Vicente de Ávila (1889), and by Vicente Lampérez at Cuenca Cathedral (1888-89).[25]

Interest in the study of temporary works in Gothic construction has revived more recently since the classic publications by John Fitchen,[26] James H. Acland[27] and Roland Bechman.[28] Hence, the success of recent studies on the mechanics of Vitruvius by Philippe Fleury[29], on the lifting of materials in medieval Italian masonry construction of the Trecento and Quattrocento undertaken by Stefano Borsi[30] and on the XV and XVI century construction by Giangiacomo Martines.[31] In Spain, there are also studies on construction machinery by Amparo Graziani[32] and by G. de Ignacio Vicens, M. A. Florez and J.L.J. Pérez[33], and research on temporary works in Gothic buildings by Amparo Graziani[34] and by Arturo Zaragozà and Mercedes Gómez-Ferrer in the context of the architect Pere Compte.[35]

A temporary column for construction: the geophysical results and the church construction accounts

The results obtained from the geophysical survey in 2012-13 have revealed the existence of various anomalies in the cathedral's subsoil which match the location of the remains of the earlier Romanesque cathedral. Three construction anomalies were found in the presbytery. One is located in the centre of the choir under the modern keystone [1], and two more are concentric to the columns of the current presbytery [2 and 3]. (Fig. 6) The anomaly [1], with a circular image in the geophysical survey, is of a similar size to those of the columns in the presbytery. This evidence, at the centre of the present altar, can be related to the location of the large temporary stone column used to aid construction of the vault and the positioning of its large keystone.

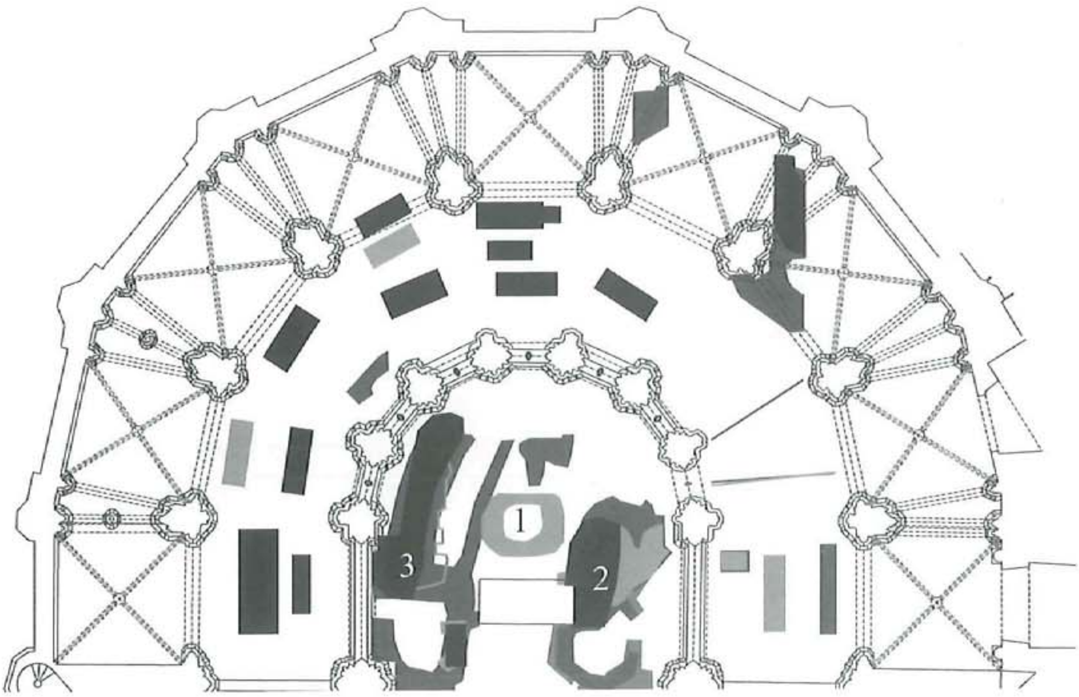

Figure 6. Major anomalies found in the geophysical survey (to a depth of 1.62 m) (2012-13). (Source: the authors)

Mention is made of a *pilar major* in the church construction accounts in May 1428. This follows the completion of the nine radial chapels which surrounded the Romanesque cathedral. This is contemporary with the demolition works in the chancel of the Romanesque cathedral which was undertaken gradually, beginning in August 1428.[36] This leads us to the hypothesis that the central column was a temporary construction that was subsequently dismantled and its temporary nature is supported by the lack of permanent foundations. According to results from the ground-penetrating radar (2012-13), the column stood at the centre of the presbytery, and is confirmed in the church construction accounts.[37] The column was already constructed before the first vaults in the ambulatory, which were begun in July 1431, were completed. The column was dismantled after the decentring of the vaults in the presbytery in March 1440.[38]

Using a temporary column, centrally located beneath the keystone of the presbytery, has significant advantages in construction. First, it reduces the span for scaffolding for the presbytery vault by half. Second, it can be used for the placement of the heavy keystone. Third, since it was built before the ambulatory was completed, it probably had a structural function related to the construction of the vaults of the ambulatory.

The vaults in the ambulatory were completed between 1432 and 1434. The severies (or webs) of the vaulted ceiling are trapezoidal and were executed symmetrically on the axis of the presbytery. They were constructed at the same time as the vaults of the epistle and the gospel. During the construction of the radial chapels and the ambulatory, the equilibrium and stability of these ribs and vaults of these intermediate phases had to be achieved by providing temporary structures to carry the out-of-balance thrusts. As a result, although the outward thrusts from the main cathedral vaults may have been equilibrated by the radial chapels while the ambulatory was being built, the thrusts into the presbytery needed to be resisted.

The characteristic section of the apse was assessed using thrust–line analysis, and limit-state analysis.[39] The assessment of the statics in the masonry prior to the completion of the presbytery shows that some auxiliary element was essential to balance the thrust of the vaults. Assuming the following densities – 24 kN/m^3 for the stone, 3 kN/m^3 for the light infill and 18 kN/m^3 for the heavy infill – the equilibrium was assessed using the method of slices. This analysis showed that a horizontal force of 50 kN applied to the impost would give rise to a line of thrust lying within the middle third of the column. Thus, a tie-beam to apply this equilibrating force would need to have been placed at the level of the imposts located at a height of 11.67 m (50 palms and 3 digits) (1 palm is 10 digits; 1 digit is 23.2 mm). This solution would have provided the necessary stability for the building as a whole until all the vaults of the presbytery were completed.[40] (Fig. 7)

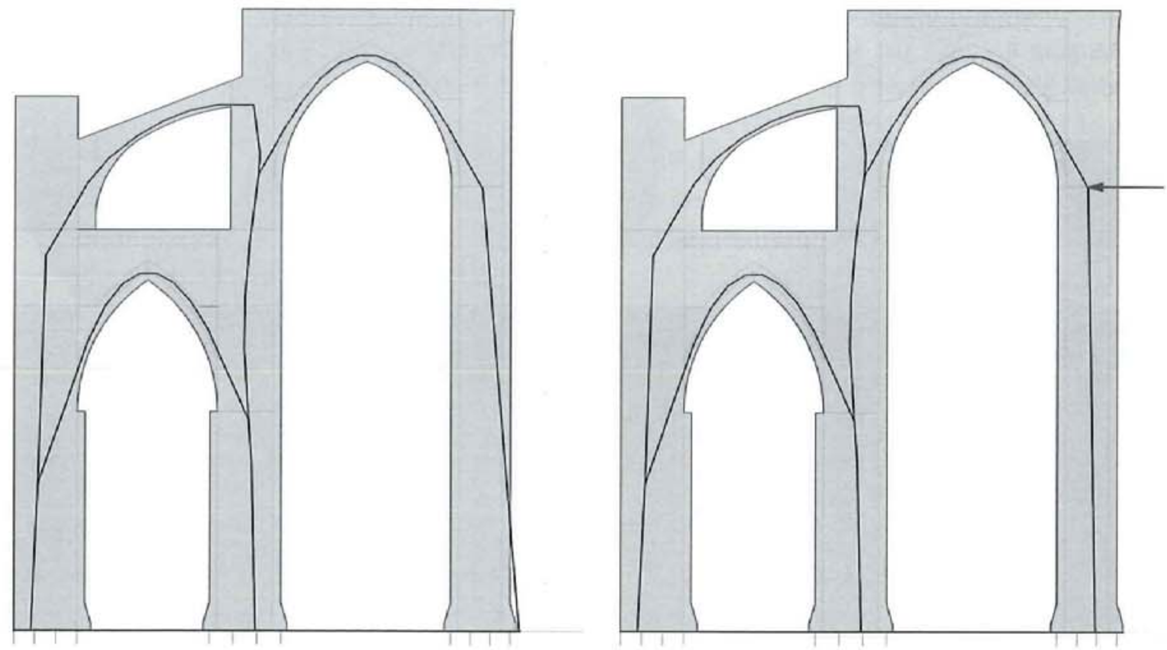

Figure 7. Line of thrust before the construction of the presbytery. Hypothesis without scaffolding (left), and with a counter-thrusting scaffold (right). (Source: the authors)

Positioning a column as a central and permanent feature in Gothic architecture was not unknown in 1430. This arrangement appears to have been used the construction of hall structures,[41] it is shown in Villard de Honecourt's notebook[42] and found in the chapter houses of Lincoln Cathedral (1215-55) and Salisbury Cathedral (1263-84). These *Palmier*-style structures, as they are known in the Jacobins of Toulouse (1275-92),[43] provide support, like fan vaults, for the ceiling vaults.[44] However, the use of a central, *temporary* column to aid construction, seems to have been done for the first time at Tortosa Cathedral.

The design of the Gothic chancel and the keystone

An important consideration about the construction programme was to determine at what point decisions were taken that influenced the future construction of the keystone which was cut in 1439. Pasqual of Xulbi, the master working between c.1402-20 had built part of the radial chapels which were executed consecutively, from the gospel area to the epistle area between 1383 and 1424. Joan of Xulbi had replaced his father as master during the layout of the ambulatory. The new columns in the presbytery were constructed at the same time as the *pilar major* (1428). In the formal design of the new columns of the presbytery, the master had to work with mouldings which converged from the radial chapels. These carvings had been predetermined since the construction of the chapel of San Pedro (1377-83).[45]

Joan of Xulbi proposed new mouldings on the opposite side of the column which were lengthened to meet the arches that formed the vaults of the presbytery. The columns of the presbytery thus have two moulding patterns: the original mouldings in the radiating chapels (1377-83) and the new mouldings that converge on the keystone of the presbytery, which were added from 1428 onwards.

The span of the arches between the columns of the presbytery was set at six palms (1.39 m) to create a visual effect contrasting with the inlay of the keystone (Fig. 8). Viewed from the centre of the radial chapels, the keystone appears as tangential to the curvature of the arc and gives expression to the tracery of the arches. The large keystone thus presides over the entire space and highlights the symbolism of the Coronation of the Virgin by her Son surrounded by ten Angels. This visual adjustment had to be achieved by changing not only the spacing of the columns in the presbytery, but also the cross-section of the cathedral. The original ratio in the cross section of the radial chapels, 9:5, was reduced to 9:6 giving a width of 150 palms and height of 100 palms (34.8 x 23.2 m). Hence the lower diameter of the keystone is ten palms, producing a visual effect with the keystone perfectly framed by the arches of the presbytery. At this point, the mouldings of the columns in the presbytery, which will be critical to the measurement from the neck of the keystone, are also established.

Figure 8. Visual effect of the keystone: view from the central radial chapel. (Source: the authors)

Another issue to consider was the angle of engagement between the keystone and the future ribs. According to Enrique Rabasa Díaz (1957-), Gothic design rules would suggest that the plane at which the ribs meet the keystone is vertical.[46] However one 17th century manual on stereotomy, *De l'art de* *picapedrer* (1653) by Joseph Gelabert (b.1621), contains a representation of various vaults (fol. 131 v-146 r)[47] in which the plane between the ribs and the keystone is inclined to the vertical. In the case of Tortosa Cathedral, the survey of the vault revealed that the ribs meet the keystone in a plane that is at 22° to the vertical. (Fig. 9)

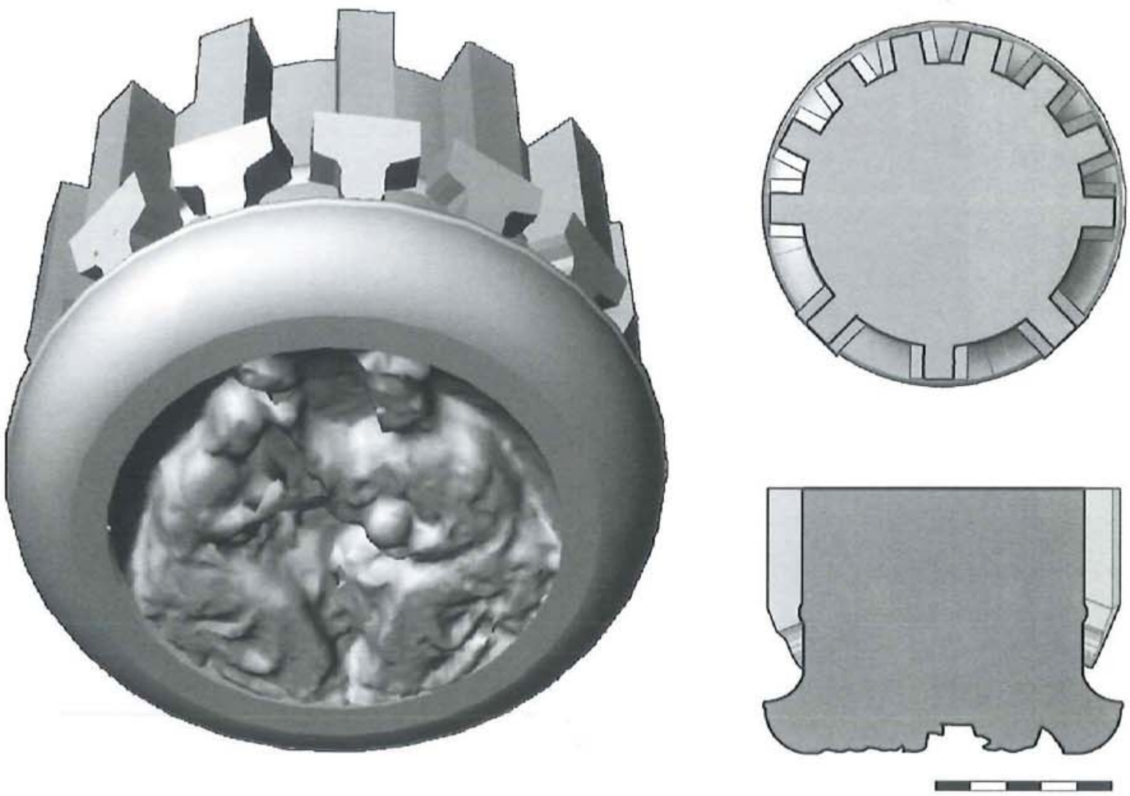

Figure 9. Geometrical survey of the clau major (main keystone). (Source: the authors)

The design of the keystone in the presbytery which was produced (1438-39), was conceived by 1428. This was a time of great change in the design of the Gothic chancel introduced by the master Joan of Xulbi, and also coincided with the removal of the chancel of the Romanesque cathedral, the construction of the auxiliary column and the start of the ambulatory.

The hoisting of the keystone

The keystone was the first piece laid to complete the presbytery. It should be borne in mind that the keystone was not only an important construction feature, it was also a very significant piece of sculpture. The polychrome carved stone used in the keystone is a very sensitive and extremely dense material. Up to this point in the construction of the cathedral, the largest and most complex elements had been the bases of the columns in the radial chapels, weighing approximately 21.9 kN. By contrast, the keystone was four times as heavy (almost 9 tonnes), and had to be raised to a height of more than 23 m.

The central column of the chapel of San Pedro again played a central role as an auxiliary element for lifting the keystone. First, it had to support the scaffolding necessary to cover the presbytery. Secondly it supported the temporary structures used for lifting and positioning the keystone. The imprints of the scaffolding are clearly visible in the masonry of the top enclosure wall of the presbytery and are located at heights of between 17.08 m and 17.13 m above ground level. (Fig. 10)

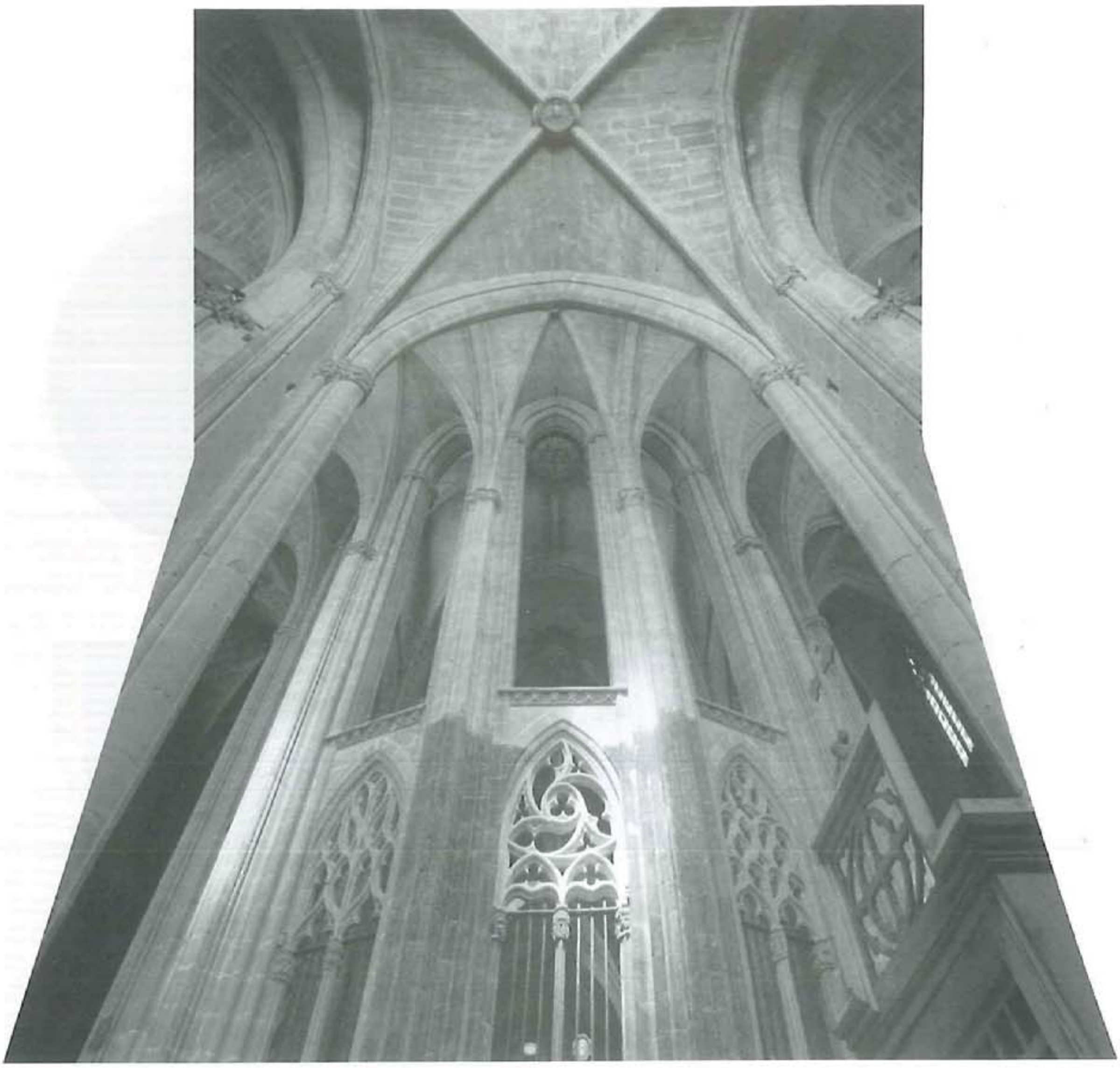

Figure 10. Imprints of the scaffolding in the piers of the presbytery. (Source: the authors)

The presbytery had a span of 11.15 m (6 canas or 48 palms; 1 cana = 6 palms = 1.39 m), and so the central column substantially reduces the lengths of timber needed struts needed to support the working platform. This timber structure had to support the centring for the vaults as well as the weight of the keystone and the workers involved in hoisting it. The platform thus had an initial working level at the springing of the vaults at a height of 74 palms (17.19 m). A second working platform was needed for positioning the keystone, at a height of just under 100 palms. As a result, this multifunctional column must have worked on three different planes. The first at the level needed to balance the thrust of the vaults of the presbytery at a height of 50 palms, the second at the level of the centering of the presbytery, at 74 palms, and the third for placing the keystone at a height of 100 palms. (Fig. 11)

After the keystone had been carved, it had to be protected to avoid damage to the fragile polychrome sculpture, especially at the edge featuring the carvings of the Angels surrounding the Coronation. The keystone therefore had to be packed and transported in complete safety, from the workshop to its final location.

The keystone must have been lifted with a block and tackle. The construction of the column could have acted as a counterbalance to the mechanism used, preventing the displacement of the device that had to be built. From accounts of the construction, it is evident that this work was performed by the city's sailors.

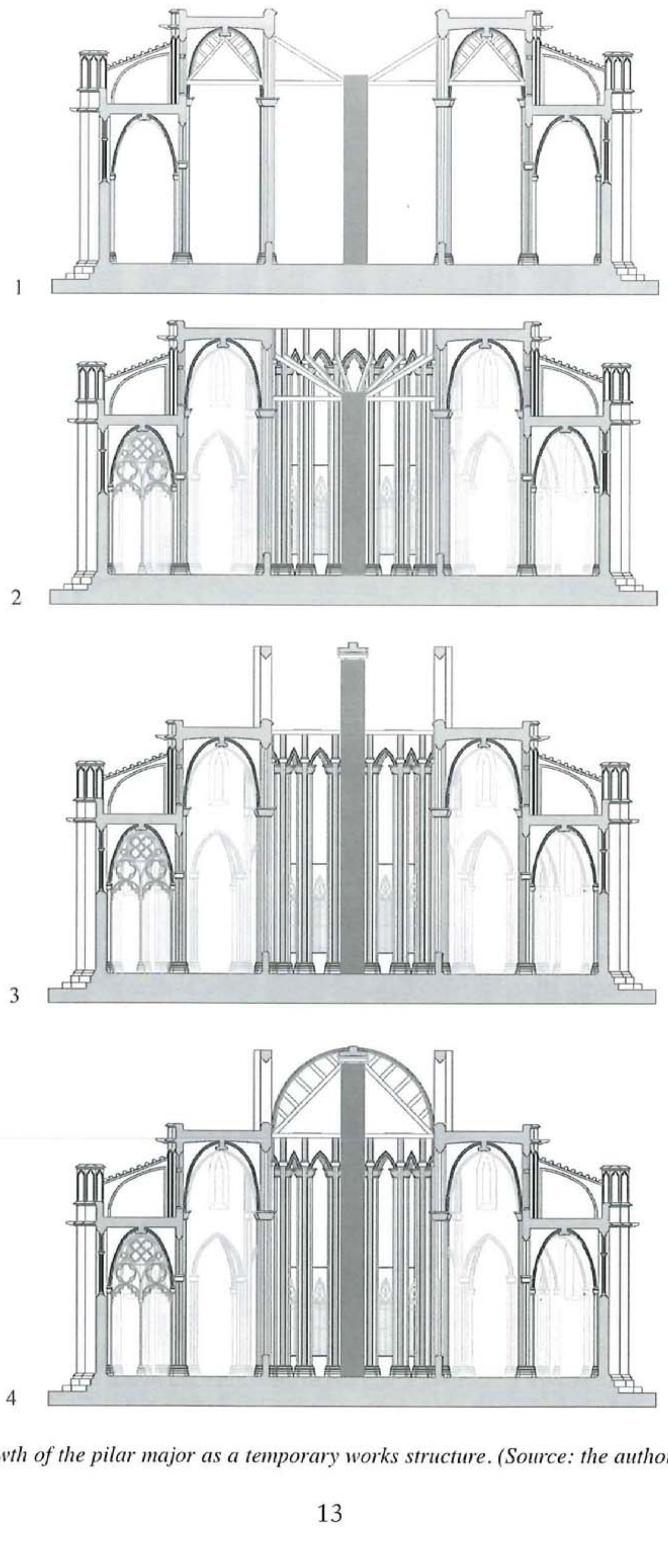

Figure 11. Growth of the pilar major as a temporary works structure. (Source: the authors)

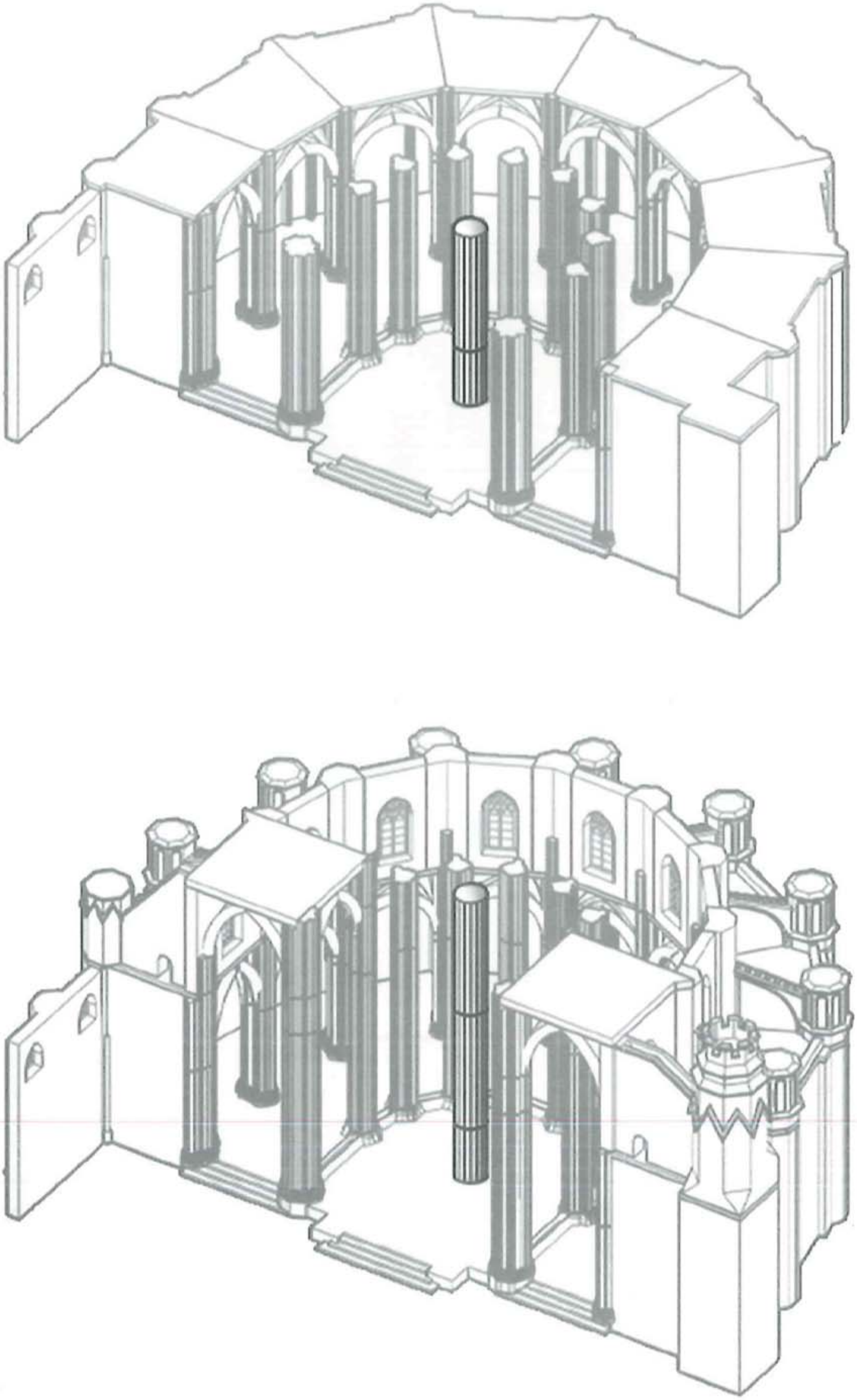

Figure 12. Construction stages of the pilar major. (Source: the authors)

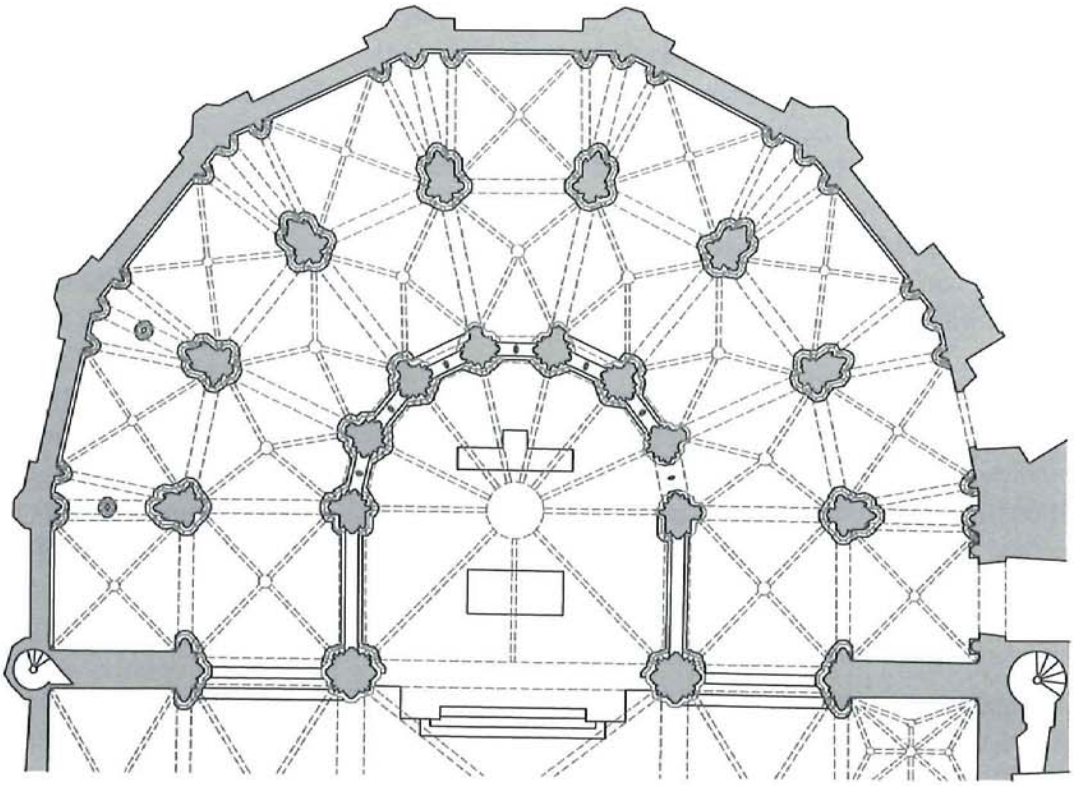

Figure 13. Plan of the apse, Santa Maria Cathedral, Tortosa.

Assuming a mechanical advantage of 4, it would have required between 25 and 30 men to lift the keystone. The temporary column and scaffolding therefore had to support a total of about 110 kN. (Fig. 12)

The documentation lists two other elements of the temporary works used for the operation that placed the keystone in position – the *bastiment* and the *matraç*.[48] The *bastiment* was probably a timber frame made to fit the complex shape of the underside of the stone and to bear on robust parts of the stone to protect the delicate polychrome carvings. The term *matraç*[49] also appears in accounts of the construction of Barcelona Cathedral (1418), in relation to the placement of the keystone of the *volta major de la façana*.[50] It is therefore likely to have been material that formed a bed or matrass placed on the *bastiment* to cushion the bearing between the timber and the stone. The upper side of the keystone was left open to the sky.

The final position and orientation of the keystone had to be very precise, as the eleven ribs of the vaults of the presbytery would subsequently converge on it. The *bastiment* therefore played an important role in positioning the keystone in its final position.

Finally, the keystone had to be positioned on another element which was precisely aligned with the precise geometry of the diagonal ribs. The central temporary column was essential for this purpose, not only as a means of support, but also to ensure the precise position of the keystone. One hypothesis is that a second timber *bastiment* was erected on the top of the column, and the main *bastiment* carrying the keystone was lowered on top and located in its correct position. The lower *bastiment* served as the means for decentring when all the ribs of the vault were in place. The decentring wedges and the two *bastiment* structures would have needed to allow enough free movement, both vertically and horizontally as the entire vault settled into its final position, to avoid damaging the sculpture base.

After the placing of the keystone in December 1439, the rib between the transverse arch of the presbytery and the keystone was centred and built.[51] The other two diagonal ribs were positioned subsequently, forming the four vaults that make up the first bay of the presbytery. The remaining seven vaults were then built symmetrically, starting from the nave, and completed in 1440. (Fig. 13)

The final stages of placing the keystone and the demolition of the temporary column

Once the presbytery had been covered with its eleven vaults, the roof of the cathedral was placed. One of the features of Tortosa Cathedral and southern Gothic architecture in general, is that these buildings are finished with a significant thickness of *opus ceamenticium* which served to protect the vaults from water ingress. The layer of lime mortar, traditionally called the *trespol,* was placed on a lightweight ceramic filler on top of the voussoirs of the vault. In Tortosa cathedral, the bulk of the *trespol* ranges in thickness between 23 and 46 cm, which means its self-weight is greater than that of the masonry vaults. The *pilar major* was kept in place while *the trespol* was applied and the weight of the entire vault was shared between the 10 columns of the presbytery and the central column. The column was dismantled in March 1440 and the keystone finally assumed its full structural role. There was a significant rebalancing of the stonework at this point. As the keystone descended, the ten columns of the presbytery each shared their proportion of the entire vertical load that had been taken by the central column.

The weight of the keystone makes a direct contribution to the stability of the whole structure through the lateral and vertical thrusts of the ribs of the presbytery, which are equilibrated with the thrusts of the ambulatory and the buttressing system. The keystone has a full depth that is greater than the portion which interfaces with the ribs of the vault. This upper section is embedded in the stones of the *severy* (web of the vault) and protrudes even beyond this layer of masonry and is embedded in the *trespol*. This helps to stabilise the keystone and reduce its movement as the vaults settle. Furthermore, the great weight of the *trespol* layer serves to reduce any tendency for the keystone to be lifted in the event of the columns supporting the vaults below moving inwards which, ultimately, could lead to the formation of the hinges which are the typical mechanism for the collapse of a pointed arch.

Conclusion

The keystone of the presbytery of Tortosa cathedral represents the Coronation of the Virgin Mary by her Son surrounded by ten Angles, and serves as an allegory for the Augustinian fullness of time in its measures of 10 x 100 palms (10 palms in diameter and situated 100 palms above the ground). It acquired this symbolism during the ceremony for the laying of the keystone when it had been placed in its final location on 27 September 1439, the feast day of the Ascension. Traditionally, historiography identifies the date of the keystone of Tortosa with this date in 1439. However the issue is quite different when viewed from the perspective of the history of construction which recognises the ceremony of placing the keystone of the main vault as just one day in a long and complex process of designing, planning and executing a major element of Gothic construction. The design concept for the keystone of Tortosa Cathedral was first developed in 1428 yet it only fulfilled its full structural role after decentring in 1440.

The full story of a Gothic keystone can thus be understood as an evolving process, with symbolic and formal aspects, which went through several transformations during its design, production and installation. The keystone was designed at a decisive point in the execution of the apse in 1428. Its extraction from the quarry, transportation to site by river, and the final carving of its imagery took place in 1438-39. It was subsequently placed at the zenith of the presbytery in 1439, which event was marked in a public ceremony full of symbolism. Finally, it achieved its full structural role after the removal of the centring and the central column in 1440.

The keystone's large size and weight meant that major temporary works were of crucial importance. A temporary central column, known as the *pilar major* in the church construction accounts, was therefore built between 1428 and 1438. This temporary column had various functions: it acted as a temporary counterbalance to loads from the vaults in the ambulatory; it served as a structure that facilitated the hoisting and placement of the keystone; and finally it served as a support for the scaffolding needed to span the presbytery to enable the vaults to be constructed and decorated. The column was dismantled after the keystone took on its final structural role in 1440.

Abbreviations

ACTo: Chapter Archive of Tortosa *(Arxiu Capitular Catedral de Tortosa)*
GPR: Ground-penetrating Radar
Ll.o.: Cathedral construction accounts *(Libres d'Obra)*
TLS: Terrestrial Laser Scanner

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13. It is hard to unload the keystone in the day of Aparicio and after two days with the master Antonio Alcañiz, Francisco Alcañiz and Bernardo Comes, and four young people who with great eagerness unloaded the keystone...(translated from the original: *costa lo descarregar de la clau lo dia de Aparici e apres dos jorns los quals maestre Anthoni Alcanyiç, Francesch Alcanyiç Bernat Comes e IIII jovens qui an continuament aydat al dit descarregar ab gran afany*). (ACTo, ll. o. 1438-1439 . fol. 27r).
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