Two Masters, Two Methods. First Steps Towards English Standardisation in The Construction of The Sexpartite Vaults in Canterbury Cathedral

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Introduction

One of the most interesting documents for the history of construction is the well-known manuscript written by Gervase the monk, which describes the works carried out after the fire that destroyed the Norman cathedral of Canterbury in 1174. Gervase (1141-1210) witnessed the works directly and his account provides important information that serves to understand the complicated organisation of the work and the considerable mobilisation of resources for a construction of this type. His detailed description also allows us to attribute the vaults over the choir to a French master, presumably from Sens, and those over the east transept and the high altar to a master from England. I analysed the construction and geometry of these vaults on the basis of photogrammetric measurement, which has enabled me to corroborate this change of master. Comparing these results with an analysis carried out in Sens Cathedral (1138-75) enables us to confirm the origin of the first master mentioned, William of Sens, who used the geometric and construction resources of the French vaults. His English successor, on the other hand, replaced the geometry and the standardisation system with a completely new method, which had not been used in France, but which was later developed in the neighbouring Rochester Cathedral (1180-1240). This is known as English standardisation, where the particular use of geometry differs from that used in continental Gothic and was to give rise to one of the most refined and beautiful styles in Europe, the Perpendicular Gothic. The construction of the sexpartite vaults in Canterbury Cathedral (1174-80) is one of the first steps towards the development of this distinctively English system.

Figure 1: Cathedrals of Canterbury (A), Sens (B) and Rochester (C). Author's photographs.

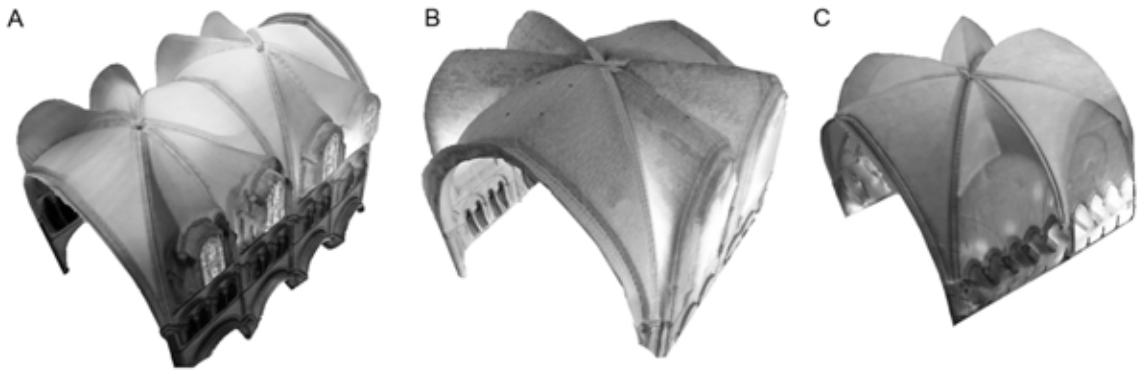

Figure 2: Photogrammetric models of Canterbury Cathedral (A), Sens (B) and Rochester (C). Author's drawings.

Sexpartite vaults. Method of study

Sexpartite vaults are one of the main early Gothic typologies. These structures had an ephemeral life [1]; they were used fundamentally between the second half of the twelfth and the first half of the thirteenth centuries and can be found in the most important buildings of the time. They have six ribs that divide their severy surfaces into six sections (Fig. 1). In order to carry out the comparative analysis of the cathedrals of Canterbury, Sens and Rochester, models were generated using photogrammetry (Fig. 2), which allowed their rib geometry and stereotomy to be studied in detail.

The importation of French geometries. The vaults of William of Sens

The manuscript written by Gervase the monk (1141-1210) is of exceptional interest [2]. In addition to describing the tasks carried out during the twelfth century reconstruction of the cathedral, where he specifies the exact date, it provides interesting details that help to understand how a construction of this type was organised in the Middle Ages. It is particularly interesting to note that the author mentions the name and provenance of the master masons who oversaw the works, uncommon in medieval sources.

Between 1174 and 1175, after the Norman Cathedral of Canterbury had been ravaged by fire, the monks hired William of Sens for the reconstruction work. The initial intention was to consolidate the remaining structures and reconstruct the building, a task that the French master considered feasible, or at least that is the idea he conveyed to the monks before the work began. However, once the works started, he suggested that a new building should be constructed, demolishing the previous one which he did not consider safe.

It is worth highlighting the qualities that the monks valued when hiring the master mason according to Gervase: “However, amongst the workmen there had come a certain William of Sens, a man active and ready, and as a workman most skilful both in wood and stone. Him, therefore, they retained, on account of his lively genius and good reputation, and dismissed the others. And to him, and to the providence of God was the execution of the work committed.” [3]. The master had to be skilled in stonecutting but also in working with wood, which confirms the importance of the temporary works needed to build the stone structures. Assembly of the vaults required large wooden formwork that could support the thrusts of the structure as the work progressed. These temporary works had to be resistant and robust, and designed to ensure the stability of the assembly. As ephemeral structures, which were removed after completion of the building, they had to be designed to make the most of the materials, in an effort to keep the costs of the work down [4].

According to Gervase, the master was also responsible for designing the machines needed to load and transport the material, which again proves a knowledge of the wood he had to handle: " … And now he addressed himself to the procuring of stone from beyond the sea. He constructed ingenious machines for loading and unloading ships, and for drawing mortar and stones. He delivered templates for shaping the stones to the sculptors who were assembled and diligently prepared other of the same kind. The choir thus condemned to destruction was pulled down, and nothing else was done in this year…" [5]. He also designed the templates that the stonecutters used to cut the ashlars and voussoirs, in addition to preparing the drawings for the vaults, the so-called monteas, the full-scale working drawings that provided the geometry defining the shape of the arches and stone surfaces.

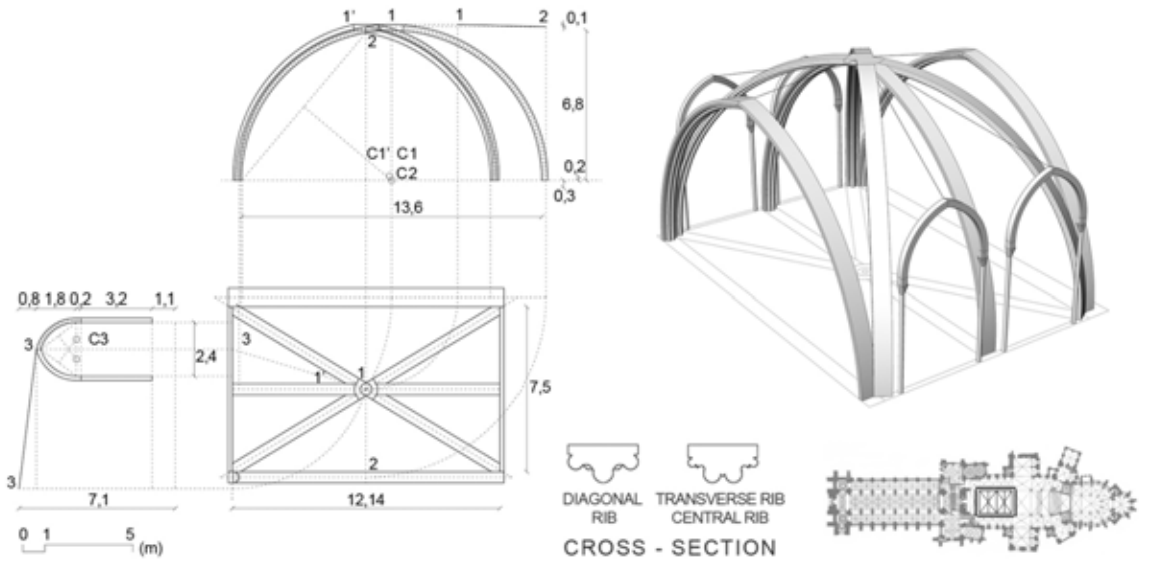

Figure 3: Geometric design of the two vaults over the choir of Canterbury Cathedral, by William of Sens. 3D Model based on the montea (full-size working drawing). Author's drawings.

Between 1176 and 1177, the French master worked on the construction of the three vaults of the choir, two of them sexpartite vaults (Fig. 3), and in the following year, between 1177 and 1178 prepared the temporary works necessary to build the remaining sexpartite vaults of the transept and the sanctuary. During the year 1178, the fourth year after the works began, William of Sens suffered a terrible accident that confined him to his bed and finally led to a change of master in the following year. The Frenchman fell to the ground from the wooden transept vault scaffolding, set up at the height of the vault springing at more than 14 metres above the church floor (50 feet).

> "… Upon these ten he placed arches and vaults. But after the two triforia and upper Windows on both sides were completed and he had prepared the machines for forming the great vault, suddenly the beams broke under his feet, and he fell to the ground, stones and timbers accompanying his fall, from the height of the [springing] capitals of the upper vault, that is to say, of fifty feet. … The master, thus hurt, remained in his bed for some time under medical care in expectation of recovering, but was deceived in this hope, for his health amended not. … And the master, perceiving that he derived no benefit from the physicians, gave up the work, and crossing the sea, returned to his home in France. And another succeeded him in the charge of the works." [6].

According to the manuscript, William of Sens built only two of the cathedral's sexpartite vaults. The analysis of their geometry reveals important differences in comparison to the remaining sexpartite vaults, those that were built by the second master mason (Figs 3-7).

Construction of the vaults over the choir of the Cathedral (1138-75) at Sens, the place where the master was originally from [7], began more than thirty years before the sexpartite vaults at Canterbury Cathedral, however the vaults over the nave were constructed from 1158 onwards. The last section at Sens was completed between 1175 and 1180, therefore overlapping with the works in the English cathedral [8]. Master William of Sens may have participated in both works. The similarity between the vaults of the two buildings is not only evident in the details of the keystones, the cross section of the ribs and the springers used for the supports but can also be seen in the use of the same geometry (Table 1) (Figs 3-5). A detailed comparison of the two vaults shows that the rib geometry is the same: the diagonals are semi-circular, and the transverse ribs are pointed, and the centres of both are on the impost line. The central ribs are pointed and slightly stilted above the impost line. In both cathedrals this slight stilt, 35 centimetres in Sens (Fig 4) and 20 centimetres in Canterbury (Fig 3), allowed the master to use the curvature of the diagonal ribs to create the central rib, making it possible to use just one type of formwork for the vault assembly. In Sens Cathedral, the transverse ribs are not standardised, their curvature is different from the others and therefore two kinds of formwork were needed for their execution (Fig 4). This change introduced an improvement in the English Cathedral, where all the ribs were built with one type of formwork (Fig 3). In Sens Cathedral, the transverse ribs seem to have been built before the vaults, as if they were an independent system. The application of standardisation indicates a thorough knowledge of construction, and the use of the same type of formwork for the execution of the different ribs of the vault made it possible to facilitate and simplify assembly [9] and reduce its cost.

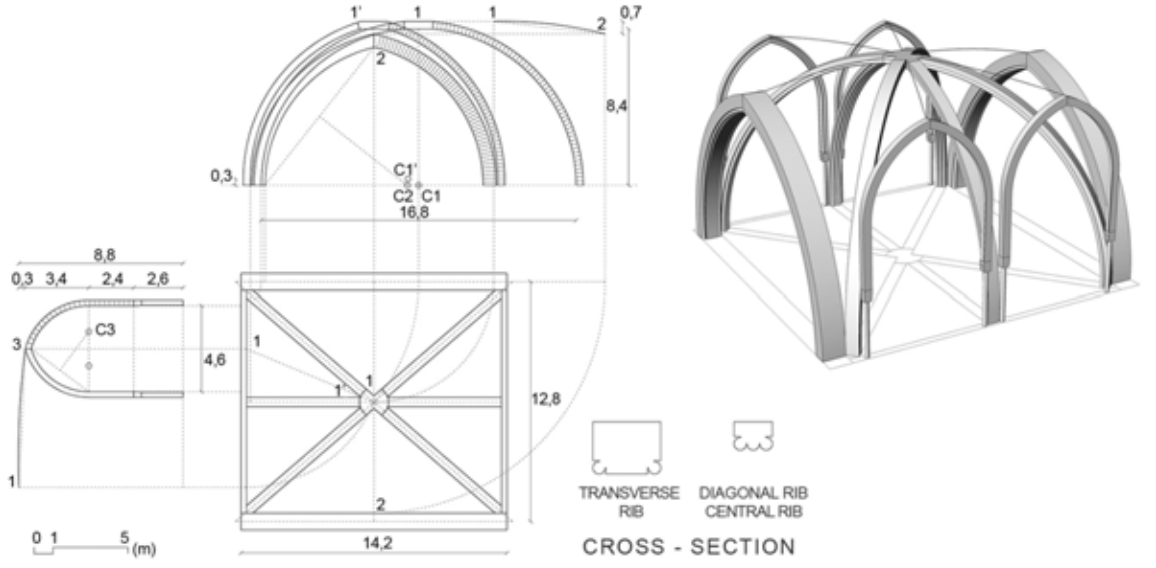

Figure 4: Geometric design of the vaults of Sens Cathedral. 3D Model based on the montea (full-size working drawing). Author's drawings.

Table 1: Comparison of the overall dimensions and of the voussoir dimensions of the vaults at the cathedrals of Canterbury, Sens and Rochester

	Construction date	Mean *voussoir* length (metres)	Plan (width x length) (metres)	Height of the keystone (metres)
Sens Cathedral	1138-80	18-22 (straight *voussoirs*)	12.78 x 14.19	24.25
Canterbury Cathedral (choir)	1176-77	16 (straight *voussoirs*)	12.14 x 9.70 (west choir) 12.14 x 7.50 (east choir)	21.61
Canterbury Cathedral (transept)	1179-80	16 (straight *voussoirs*)	10.23 x 9.51	20.82
Canterbury Cathedral (west sanctuary vault)	1179-80	17 (straight *voussoirs*)	12.09 x 10.14	20.82
Canterbury Cathedral (east sanctuary vault)	1179-80	16 (straight *voussoirs*)	12.13 (west side) x 10.26 (lenth) x 7.60 (east side)	20.82
Rochester Cathedral (sanctuary)	1180	21 (straight *voussoirs*)	8.67 x 6.42	14.88
Rochester Cathedral (east transept)	1240	14 (straight *voussoirs*)	8.63 x 9.11	15.47
Rochester Cathedral (choir)	1240	20 (straight *voussoirs*)	8.61 x 8.46	15.72
Rochester Cathedral (west transept)	1340	35- 54 (curved *voussoirs*)	9.43 x 6.25	16.68

Similarities in the stereotomy of the sexpartite vaults in the Cathedrals of Sens and Canterbury

The analysis of the stonecutting techniques used for the *voussoirs*, severies and keystones reveals remarkable similarities between the vaults as well as some differences (Fig. 5). In Sens Cathedral, the cross section of the transverse ribs is much larger than that of the other ribs and the shape of their *voussoirs* is also different. This feature highlights the fact that the nave was conceived as a series of different vaulted bays. In Canterbury, on the other hand, the interior of the building is composed as one space, where the transverse ribs are the same size as the other ribs and the *voussoirs* of the transverse and central ribs share the same cross-section design. This last feature seems to be intended to blur the function of the transverse ribs as a separation between the vaulted bays. Here the cross-section of the diagonal ribs differs from that of the other ribs, although they are all the same size.

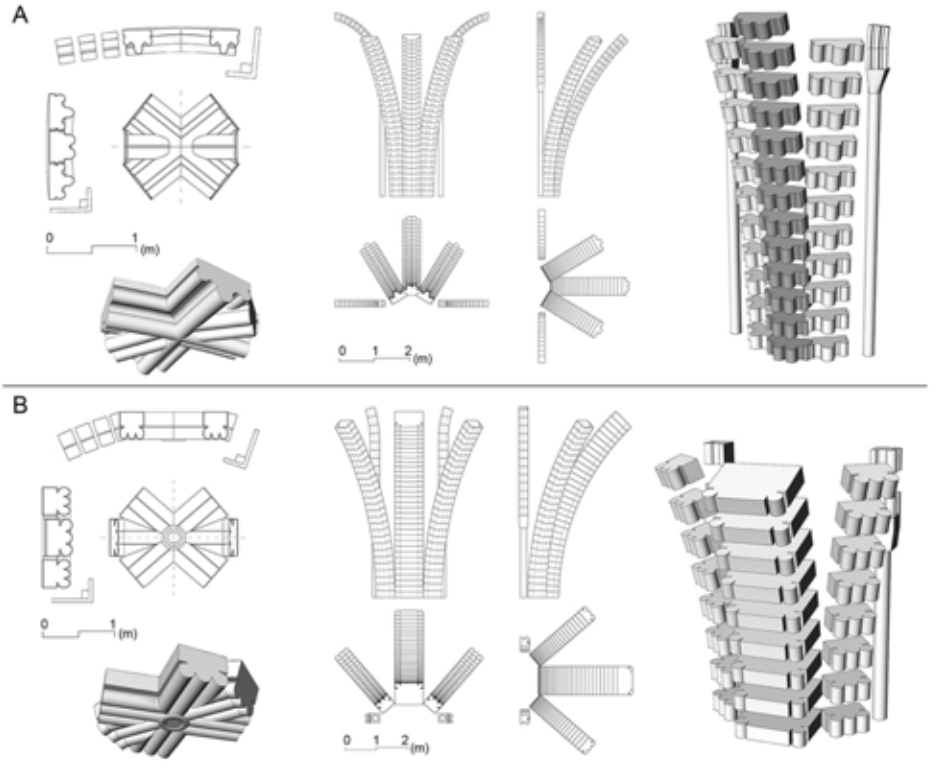

Figure 5: Comparison of rib cross-sections and construction of the springers and keystones in the cathedrals of Canterbury (A) and Sens (B). Author's drawings.

In both cathedrals the *voussoirs* are exceptionally short [10]. So short that they resemble brick *voussoirs* (Table 1). This proportion is very unconventional, to the point that within my extensive analysis of sexpartite vaults in Europe [11], these are the only two cases where the *voussoirs* were cut to this proportion. They have a very similar cross-section, although in the case of Sens the ribs have three shafts and in Canterbury, they have only two (Figs 3-4). The use of short *voussoirs* implies the use of the same type of tool to cut them, the square [12], which allowed them to be cut straight without a curve, unlike the vaults built with curved *voussoirs* where the bevel was the tool used.

In both buildings, the vault supports have no *tas-de-charges* (Fig. 5). The ribs rise up from the springer: the different *voussoirs* of each rib are trimmed to fit the available space on the support and are separate from each other. The absence of *tas-de-charges* is a very significant characteristic. Their beds are horizontal and so form part of the walls, not of the ribs, where the beds of the *voussoirs* lean toward the geometric centre of the arches. The *tas-de-charges* made it possible to reduce the size of the ribs and thus their thrust and the formwork used in their assembly. They also reinforced the structure on their supports by joining the different ribs of the vault in one piece of stone, avoiding misalignments and movements between them during the work. The absence of this type of solution indicates that the master's knowledge of this construction system was still rudimentary [13], which would again indicate the presence of William of Sens in both works.

The way the keystones are cut is peculiar to Sens and Canterbury, so this similarity also demonstrates the relationship between the two buildings. In both cases they have six very long arms dominated by the shape of the shafts. The outer faces were cut with a slant to receive the ribs. The dominant presence of the arms over the sculpted central boss highlights the unusual shape of these keystones, which differ from those that normally crown this type of vault (Fig. 5).

In both vaults, the severy stones are small ashlars, which must have been easy to cut in spite of the large quantity needed to close the stone surfaces at the ribs.

The consistent use of the same type of tools to cut the stones and of the same construction techniques for the rib connections, indicate the master's degree of knowledge. The latter decades of the twelfth century and the early decades of the thirteenth century marked a moment of great change for the medieval architecture of Europe, where some structures of this type can be seen to have evolved much more than others. Therefore, a comparison of the techniques used is very useful in assessing the knowledge of the master who created them and makes it possible to establish authorship relationships between different buildings.

A style of his own. The work of William the Englishman

Shortly after his accident, William of Sens was temporarily replaced by a monk qualified in the arts of construction: "Nevertheless, as the winter approached, and it was necessary to finish the upper vault he gave charge of the work to a certain ingenious and industrious monk, who was the overseer of masons,... But the master reclining in bed commanded that all things should be done in order. ... Two quadripartite vault-bays were also constructed on each side before winter [1178]. Heavy downpours did not permit of more work." [14].

In the fifth year after the works had begun, the master returned to his native land and was replaced by William the Englishman, who was also highly skilled and very knowledgeable in various tasks, an essential characteristic for this work: "...And another succeeded him in the charge of the works; William by name, English by nation, small in body, but in workmanship of many kinds acute and honest. He in the summer of the fifth year [1179] finished the transept on each end, that is, the north and the south, and closed the vault over the great Altar, …" [15]. Geometry was one of these essential areas of knowledge since it was necessary to rethink and design the building and the more complex structures, such as the vaults. As Foyle says, William the Englishman had to review his predecessor's design, which apparently was conceived on the basis of one large geometric scheme [16]. Perhaps he did not have the same experience as William of Sens, as there are important differences in the design of the two masters' vaults.

William the Englishman constructed the two sexpartite vaults of the transept (Fig. 6) and the two over the sanctuary (Fig. 7) and continued with the foundations for the construction of the chapel of St Thomas, at the east end of the cathedral (Table 1). The vaults built by William the Englishman did not use the same geometry as the vaults of his predecessor. The geometry of the vaults on the transept arms is similar to that of the vaults of the Cathedral of Paris, in turn different from the vaults at the Cathedral of Sens since the central ribs are not pointed but semi-circular. However, contrary to the case of the French vaults based on the Parisian model, standardisation was employed for the transverse and the central rib rather than the diagonal and transverse ribs [17]. Perhaps the master initially tried to continue the vaults following the typical French designs, but rather it seems more likely that the formwork was already prepared for these vaults, preventing significant changes to be made to these structures. At the time of the accident, the transept's central vault was ready for assembly, and the temporary works had already been built for it, as Gervase mentioned. The master fell from the platform that supported the formwork of this vault, which would then be built by the abovementioned monk under the orders of William of Sens. The formwork and voussoirs of the vaults on the transept arms would probably already have been prepared.

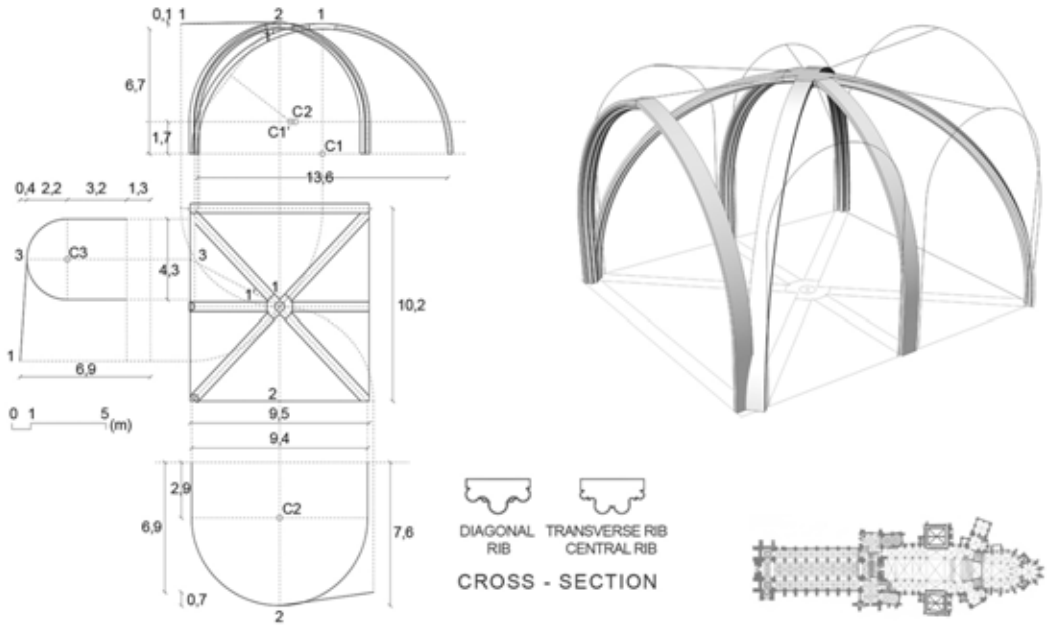

Figure 6: Geometric design of the two vaults over the transept arms of Canterbury Cathedral, by William the Englishman. 3D Model based on the montea (full-size working drawing). Author's drawings.

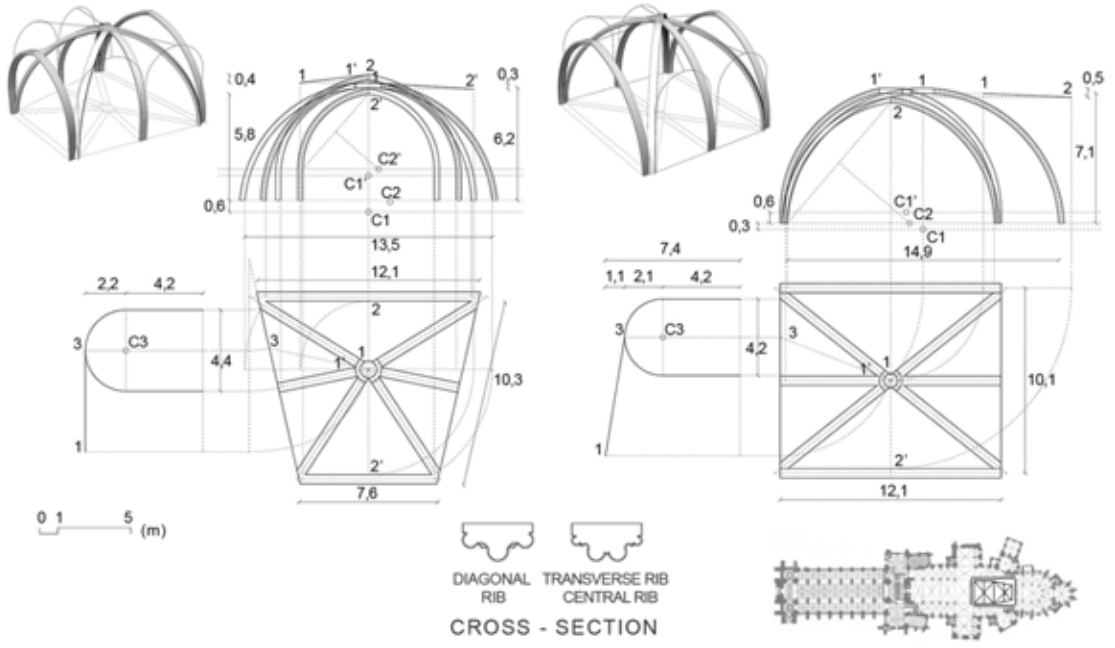

Figure 7: Geometric design of the two vaults over the sanctuary of Canterbury Cathedral, by William the Englishman. 3D Model based on the montea (full-size working drawing). Author's drawings.

Once the transept was completed, William the Englishman seemed to give free rein to his creativity, designing the two remaining sexpartite vaults based using completely different geometries. The vaults above the sanctuary had depressed diagonal ribs (Fig. 7). The transverse ribs and the central ribs were pointed arches with their centres level with, or above, the impost. In both these vaults, the ribs are partially standardised as in the others. In the western vault of the sanctuary only the transverse and the central ribs share the same curvature, while in the eastern vault only the diagonals and the western transverse rib have the same curve.

In the vault over the western section of the sanctuary the master could have standardised all the ribs easily, he would simply have had to lower the stilt of the central rib by half to be able to construct the rib with the curvature as the diagonal ribs. The transverse ribs could also have been constructed with these curves and would have been 27 centimetres higher at the keystone than they actually are. Both changes would have slightly varied the volume of the vault, but these modifications would not have been visible to the naked eye. In turn, one type of formwork could have been used instead of two. In addition, these vaults require the formwork to be placed at different heights for each rib, making different platforms necessary to lift each set of formwork into place above the previous one, again complicating construction. Perhaps this is the result of a lack of technical skill or simply the search for new designs using other geometric resources that would later culminate in the English medieval Late Gothic. What we can say is that these designs are distinctive and unique, especially the eastern vault of the sanctuary. Some of the ribs in this vault rise at a tangent to the impost line while others lean forward because they are depressed. In the Perpendicular Gothic, this same idea was used but was developed further: the ribs were tangential to their support or leaned forward or backward, with their centres on or above the impost [18]. In this way, the masters would have used the same arc to construct all the ribs, inclining them appropriately depending on the height they needed to reach. William the Englishman used different arcs without making use of the advantages offered by this methodology.

The stereotomy used in the vaults erected by the English master is the same as in the vaults of William of Sens (Table 1) (Figs 3-7). According to Gervase, the French master arrived from his native land with a group of stonecutters, who perhaps remained after his departure. In any case, continuing the cutting based on the templates defined by the first master would not have been a complicated matter.

First steps towards English standardisation. The vaults of Rochester Cathedral

A devastating fire broke out in Rochester Cathedral in 1179 that seriously affected the eastern end of the building. Sexpartite vaults were used for the reconstruction over the sanctuary (1180), the eastern transept (1240), the choir (1240) and the northern arm of the western transept (1340) (Table 1) (Figs 8-9) [19]. These vaults share a common feature whereby most of their ribs are depressed. The vaults covering the sanctuary, the eastern transept and the choir are similar to each other (Figs 8-9). Their diagonal ribs are semi-circular with their centres below the impost line. The centres of the transverse and central ribs, which are pointed arches, are located on or below the impost line. The vaults over the sanctuary, the first to be built, were the only ones where the ribs were completely standardised. The diagonal ribs and the central rib of the vaults over the eastern transept and over the choir show partial standardisation. Despite the use of similar geometries, this characteristic could indicate a different master mason in the sanctuary, which would not be surprising given that its vaults were built sixty years before those erected over the eastern transept and the choir.

The sexpartite vaults of the western transept are different due to their typical fourteenth century geometry (Fig. 9). The diagonal ribs form basket-handle arches and the transverse and central ribs are either pointed and depressed, or semi-circular with their centres on the impost line. In this case, standardisation was also partial, where the shapes of the diagonal, central and wall ribs was based on the same segment of a circle.

The methodology used by William the Englishman in Canterbury continued to be applied for the standardisation of the vaults at Rochester. The same arc leans to a greater or lesser extent from its springing on the impost line. A more complex

and developed version of this method was to be used later in the Perpendicular Gothic. In France, the methodology used by the master masons to standardise the ribs of vaults in the High Middle Ages was different. There, they were slightly stilted on the impost to reach the required height with the same curvature [20]. Depressed ribs were not used, and mainly the transverse and central ribs were stilted. The Cathedrals of Canterbury and Rochester could be the first examples that used English standardisation, although it would be necessary to study other buildings with other types of vaults of the same chronology in England.

The stereotomy of the vaults of Rochester Cathedral (sanctuary, western transept and choir) shares similarities with Canterbury (Fig. 10). Neither vaulting systems had *tas-de-charges* at the base and their *voussoirs* were cut with a square (Table 1). Their transverse and central ribs share the same cross-section, while the diagonals are different. The stereotomy of Rochester's western transept is different and more developed with *tas-de-charges* and curved *voussoirs* cut applying a bevel (Table 1).

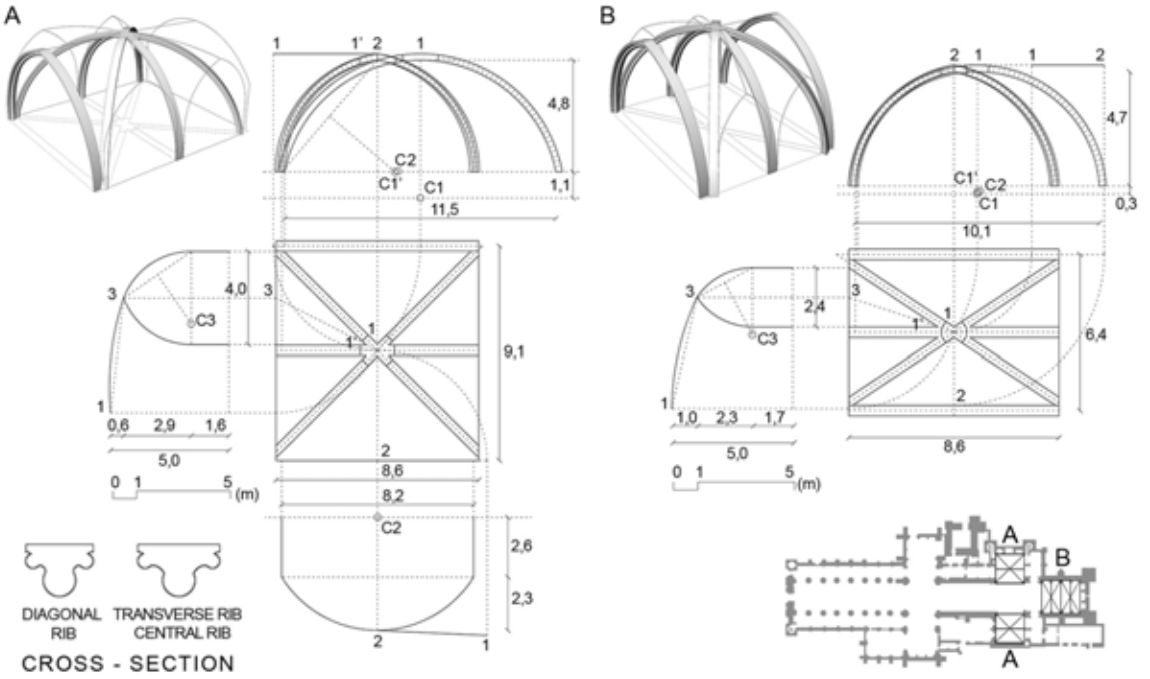

Figure 8: Geometric design of the two vaults over the sanctuary (B) and the east transept (A) of Rochester Cathedral. 3D Model based on the montea (full-size working drawing). Author's drawings.

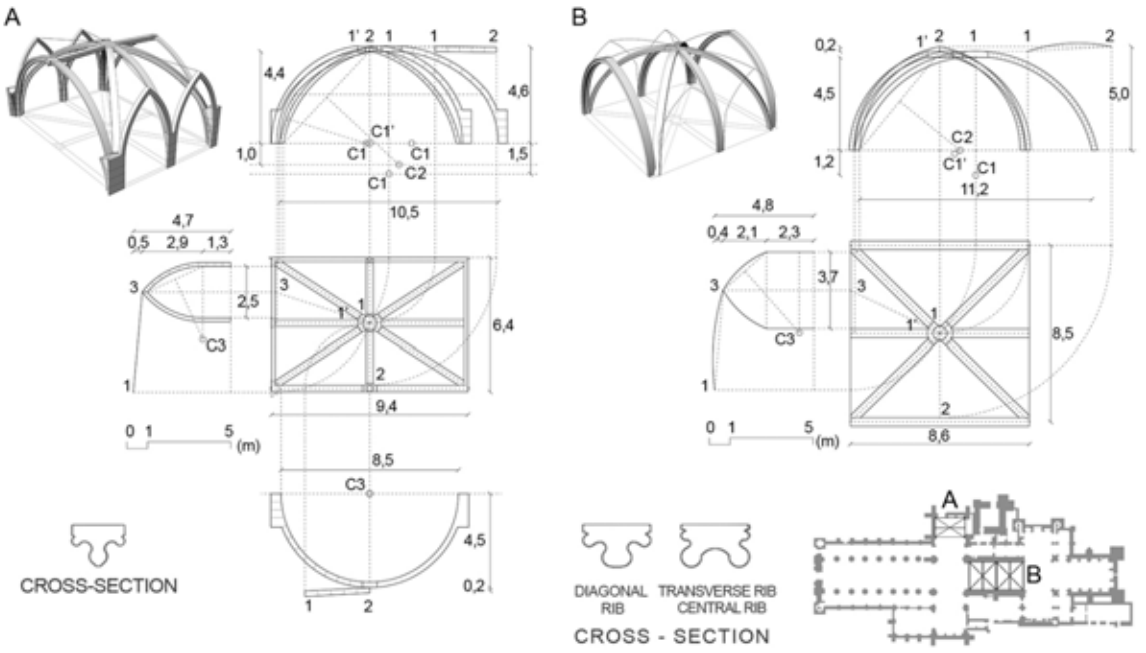

Figure 9: Geometric design of the two vaults over the choir (B) and the west transept (A) of Rochester Cathedral. 3D Model based on the montea (full-size working drawing). Author's drawings.

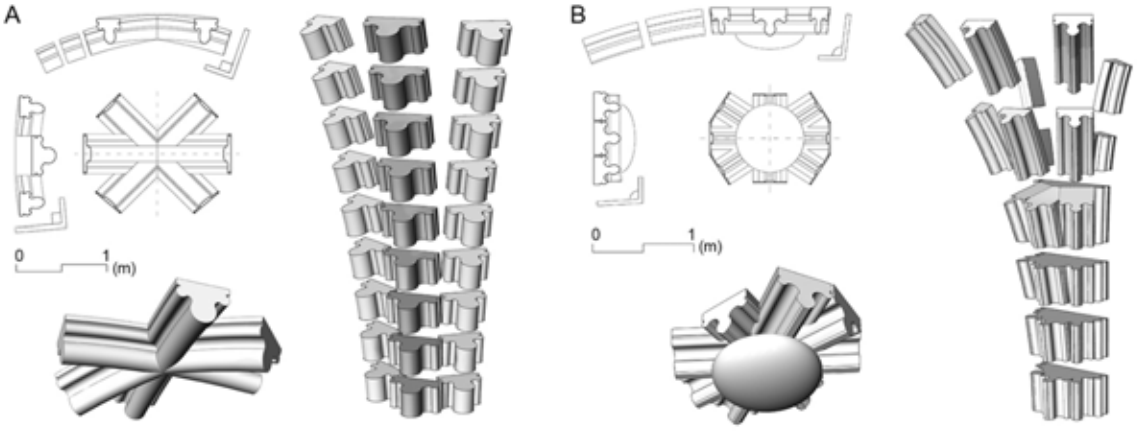

Figure 10: Construction details of the ribs, springers and keystones in Rochester Cathedral (A sanctuary, B west transept). Author's drawings.

Conclusions

This research aims to show new ways of analysing the authorship of buildings and of providing new data on their construction dates. By comparing the knowledge applied by the masters, different buildings can be related to each other based on the geometric and structural resources used. The end of the High Middle Ages was a fruitful period for architecture when some structural improvements began to be implemented and new tools started to be used. This development was not uniform, which is an advantage when studying authorship.

We can confirm that the vaults which according to Gervase are the work of William of Sens follow the geometric model of the Cathedral of Sens, the master's place of origin. In addition, their stereotomy and the technical solutions used are similar. However, the design of these structures changed with the change of master. The templates that William the Englishman employed for the geometry were different from those used by the Frenchman and showed a particular personality. These resources remind us of those used later in the Perpendicular Gothic, when all the ribs of the vault were built based on the same segment of a circle and leaned inwards from the springing to a greater or lesser degree. Canterbury and Rochester Cathedrals are evidence of the first attempts at using this technique, where the arches lean from their supports, but the curve is not always the same. These are the first examples to have been detected of this type of standardisation, which when further developed was to result in one of the most beautiful Gothic architectures in Europe, the Perpendicular Gothic.

The east end of Canterbury Cathedral is considered the first Gothic edifice in England to import the construction techniques being used in the Île de France. The vaults over the choir and the east transept are the only example of sexpartite vaults built in England following French models of geometry, since the geometries used in the neighbouring cathedrals of Rochester and Lincoln, also studied by the author of this text, have little in common with the designs imported to England by William of Sens.

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