RESEARCH ARTICLE

Plotting Gothic: A Paradox

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The paradox of the title is that while most historians of medieval architecture agree that a combination of geometric and arithmetic methods was generally used to lay out a medieval church, there has been little consensus on the specifics of the process in relation to the design of any particular edifice. I begin by identifying four premises which underlie the debate. I then ask whether the new technologies — laser scanning and computer assisted design/drafting applications — can help. A case study uses newly generated point cloud data from a laser scan of the choir of Beauvais Cathedral. Finally, the notion of 'plotting' introduces essential sociological, anthropological and rhetorical dimensions. In the spirit of Roland Barthes (*Le plaisir du texte*) and Peter Brooks (*Reading for the Plot*), we can understand the urgency with which the architectural historian may seek to unscramble the hidden codes of the building as compulsive 'reading for the plot'.

Introduction

Here is my paradox. All students of Gothic architecture would surely agree that our great churches were laid out using some combination of geometric and arithmetic methods — methods that must leave their traces in the finished edifices. Yet attempts to define the process more closely in any given building, to establish patterns of practice common to many buildings, or to speculate upon the significance of numbers and shapes often result not in consensus or productive scholarly exchange, but rather in rancorous accusations of unacceptable methodology, sloppy measuring, wishful thinking, or skullduggery. Thus, Eric Fernie (1990) opens his 'Beginner's Guide to the Study of Architectural Proportions and Systems of Length' with a rueful reflection on the 'almost pathological condition once described as pyramidiocy,' which drives the idiot to explicate the forms and dimensions of the Great Pyramids through reference to geometrically encoded messages.[1] After this admirably skeptical introduction, Fernie proposes a useful set of critical working principles: that behind the conception of the great building may lie relatively simple geometric manipulations, often involving a basic proportional relationship like 1:√2. In order to crack the underlying code, Fernie insists, the investigator must actually measure the building and work with the numbers, or with accurate digitally scanned shapes. It is not enough to superimpose thickly limned geometric figures upon small-scale plans or sections. The work most often cited as a negative example is George Lesser's *Gothic Cathedrals and Sacred Geometry* with its small plans heavily overlaid with geometric figures (Lesser 1957).[2]

Interestingly, in the other notable recent wide-ranging essay on medieval architectural design, *The Wise Master Builder*, Nigel Hiscock takes positions diametrically opposed to Fernie's, insisting instead that one should work by imposing a limited range of geometric shapes on existing plans since the direct involvement of the investigator in measuring the building will, or so he claims, introduce an unacceptable level of subjectivity (Hiscock 2000; see also Hiscock 2007). Hiscock argues that older studies tended to place too much emphasis on the application of the manipulative mechanism of the square root of two: he suggests that we should concentrate instead upon the three 'Platonic figures': square, equilateral triangle and pentagon. Nobody would doubt the importance of these figures in the builder's design tool box, but Hiscock's bewildering geometric tangles inscribed upon small plans may leave the reader baffled. Why, the skeptical student might wonder, would the builder adopt such extraordinarily complicated design strategies as these? What advantage would have been gained? How could users or visitors have begun to comprehend the system?

The juxtaposition of Hiscock's and Fernie's views serves to illustrate the extent of disagreement in a field where a given building might be 'explained' in light of geometric or numerical systems that appear entirely at odds with each other. I think particularly of the conflicting interpretations of the design of St-Etienne of Nevers by Marie-Thérèse Zenner and James Addiss published in the recent volume, *Ad Quadratum*. Zenner (2002) proposes a series of greater and lesser circles; Addiss (2002) favors a modular system based upon a known foot unit. Given such disagreements in the application of geometric schemes to real buildings, Robert Bork, in the most recent major publication on design in Gothic architecture, *The Geometry of Creation*, restricts his purview to the plans and drawings

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made by medieval mason and artisans. These plans can be accurately photographed or scanned, imported into a computer-aided design (CAD) program and subjected to rigorous analysis.[3]

The extraordinary technological advances of recent decades have provided formidable tools (including the laser scanner and total station as well as computer-assisted drafting) that allow the investigator to avoid one of the pitfalls encountered by the metrological sleuth — the accusation of sloppy measuring. Is it now finally possible to reach 'scientific' certainty about the way that medieval buildings were designed? I will argue in the following pages that such 'certainty' may still remain elusive and that it would be well to maintain a high level of critical self-consciousness about the basic underlying premises in the search for proportion and measure in Gothic architecture. Having defined four such premises, I shall introduce a case study: an examination of the choir of Beauvais Cathedral based upon the computer-assisted analysis of new laser-scanned data. I will conclude by invoking the notion of 'plotting': with the recognition of the multiple meanings of the word 'plot' we may begin to find some resolution of the paradox defined at the start of this essay (see Murray forthcoming).

Four premises

My first premise is this: We may all surely agree that with the means available to the cathedral builders the best way to control the *terrain vague* was with ropes tightly stretched and pegged on the ground. Right-angled corners could be formed by the application of the Pythagorean triangle and orthogonal correctness assured by equalizing the diagonals. Although this was surely the way that most major building projects were laid out in the Middle Ages, the process left few direct written records.[4] Mention of the stretched cord as a means to establish rectitude finds it way into the written sources mainly as a tropological, mnemonic or visionary metaphor (Carruthers 1992; 1993; 1998).[5] Optical triangulation devices were probably available to cathedral builders: Villard de Honnecourt, the thirteenth-century *ymagier* who in the first decades of the thirteenth century witnessed the construction of several Gothic cathedrals and who left us a little book of images (Bibliothèque nationale de France, MS Fr 19093), shows us primitive triangulation devices, and in the archivolts of the central west portal of Chartres Cathedral, the angels carry astrolabes (fols. 20r–v in Barnes 2009: color plates 43–43).[6]

Second, we can also agree that the design and construction of a Gothic cathedral involved the systematic application of units of measurement of some kind. The range of pre-metric types of foot unit is well documented (see e.g. Zupko 1978; also Machabey 1962). However, we cannot assume that our edifice was necessarily laid out using the local foot unit: The master mason, probably not a local man, might have favored an imported unit of mensuration. The decades around 1200 saw the penetration of royal units of measurement beyond the Île-de-France — in some instances the royal foot of 32.5 centimeters may have displaced the local unit, which often corresponded

to a Roman foot of 29.5 cm (Hecht 1979). More than one type of unit might have been in use in the same worksite. This was certainly the case at Beauvais Cathedral, as will be shown shortly.

The picture becomes even more complicated with the recognition that in order to make useful divisions on the stretched cords of the plot, a rigid measuring rod of convenient length would be necessary. To form the side of a square of one hundred feet, for example, a rod of ten feet might be applied ten times. With each application the builders might mark the end of the rod on the fully extended rope and then use that mark to begin another ten-foot stretch. The fewer times the operation is repeated the smaller the risk of error. In other words, there was a distinct advantage to using a rod that was longer rather than shorter. Peter Kidson, in his 'Metrological Investigation', explores the range of variation in the multi-foot rod, pole, or perch and the overlap between the methods of the late-Roman *agrimensores* or land surveyors and the cathedral builders — an overlap that may have helped fix conventions concerning the appropriate length of the perch (Kidson 1990). Stefaan van Liefferinge suggests that control over the building site of Notre-Dame of Paris was established with a grid that enclosed an agrarian unit — an acre — that was subdivided through the application of a ten-foot perch (Van Liefferinge 2006; 2010). In my own work at Amiens I also propose that a ten-foot perch was used to establish a working relationship between a fifty-foot central vessel and thirty-foot aisles.[7] The length of the perch might also result from the transformation of the geometry of the Pythagorean triangle into round numbers in order to facilitate the accurate laying out of the building, as demonstrated by Peter Kidson in the article cited above, or it might offer an approximation to a round number in two different kinds of foot unit. In the late Middle Ages the *toise,* or fathom of six feet was frequently mentioned in the written sources relating to cathedral construction, as we shall see when we discuss Beauvais.

Third, to fix the boundaries and divisions of the roped-out plot which would determine the shape of the building, master builders employed polygonal figures of various kinds: squares (sometimes doubled, tripled or extended geometrically to form rectangles), equilateral triangles, pentagons or octagons, and such units might also have been projected upward to fix heights. Our consensus, however, is lost when it comes to determining what kinds of polygon and how exactly the figure might have been applied to fix plan and elevation: whether to center points or to wall surfaces; whether to the apex of the arch or to the capital? Medieval builders were not too clear on these questions either — we may recall James Ackerman's exploration of the extraordinary debate over the potential application of triangle and square in the spatial planning of Milan Cathedral (Ackerman 1949). As to the systematic application of such geometric figures, or hypothetical perch units, it seems likely that the rope-stretching exercise might have been applied several times over and for different purposes: at first to control the overall shape of the site at the commencement of foundation digging

and, subsequently, as the foundations reached pavement level, to ensure the desired geometric integrity and optical alignment of the piers and wall surfaces.

The fourth and last premise widely shared by students of Gothic design methods was best defined almost half a century ago by François Bucher ('Design in Gothic') and Lon Shelby (in his work on Mathes Roriczer): the role of dynamic geometry is understood principally as 'quadrature' or rotated squares (Bucher 1968; Shelby 1976). Representation of quadrature, present already in the writings of Vitruvius (1999: 107 and 282, Fig. 110), is found in Villard de Honnecourt's little book (c. 1230), where an operation based upon inscribed rotated squares is oddly labeled as a means of dividing a stone into two equal parts (fol. 20r in Barnes 2009: color plate 42). The strategy, which introduces irrational numbers (in the ratio 1:√2) to the business of dynamic projection and the appearance of organic growth to the buttress or pinnacle, may be applied to particular details or to the space of an entire building. The two most essential Gothic elements, the pointed or broken arch and the rib vault, bring the potential for dynamic animation as the rotational mechanism of the compasses is transferred to the spatial behavior of the building itself. Gervase of Canterbury, describing the construction of an arch, uses the dynamic verb *volvere,* to turn with the arc of the compass.[8] Once designers had escaped the tyranny of the single center point fixing the height of the arch, proportions became infinitely fungible. Shelby (1976: 47–48) has reminded us of the essential *arbitrariness* of the application of dynamic geometry.

I have suggested that one way to help resolve the paradox — the credibility gap — defined in the opening paragraphs is for the historian to introduce new technology. Such technology will be especially interesting in the context of a monument that has been carefully studied using the old methods.[9] In 1978 I undertook an exhaustive survey of the choir of Beauvais Cathedral using a combination of a fifty-meter steel tape, able to stretch from one end of the choir to the other or from the vault to the pavement, coordinated with a system of quadrangulation, applied through the use of a *niveau de chantier* (theodolite), and direct triangulation, which is particularly useful for the wedge-shaped bays of the ambulatory and the exterior surfaces and buttresses of the radiating chapels. For pier sections I had recourse to an enormous pair of calipers. For wall thicknesses, armed with plumb bob and tape measure, I scaled a ladder and measured from inner and outer wall surfaces to the window glass, of negligible thickness. The laser scanner was then applied (thanks to Peter Allen and his team and to Andrew Tallon) in two phases: first in 2001–2 and again in 2013.[10]

The choir of Beauvais Cathedral
Let us start at the west end of the Beauvais choir, where construction began in 1225 (Murray 1989: 60). At a time very close to this, Villard de Honnecourt captured the plan of a Cistercian church designed around squares (*une [é]glize desquarié*) where the bays of the main vessel are made up of double squares equaling half the crossing

square and the aisles are squares equaling one quarter of that central square (fol. 14v in Barnes 2009: color plate 31; see also Hiscock 2004). With such a linear matrix the spatial form of the church can be *compressed*: conceptualized and held in the head as a mnemonic image. This compressive phase might then lead to *expansion* as the elements of the building are extended and laid out full scale on the ground, controlled by a grid of stretched ropes. Our search for a comparable mechanism at Beauvais Cathedral is frustrated because only one of the four crossing piers (to the south east) is original: the western crossing piers were built by Martin and Pierre Chambiges in the early sixteenth century, and the northeastern crossing pier was rebuilt after the collapse of the crossing tower in 1573.[11]

Figure 1 shows the laser-generated plan with inserted bay divisions and dimensions (center to center of the piers and to the interior wall surfaces) of the choir straight bays.[12]

In **Figure 2**, having projected the great crossing square, I have divided it into four and placed two such quarter squares on the western bay of the choir to give the main vessel (close to a double square) and one square on each of the transept towers. It should be noted that computer assisted drafting makes it impossible for the author to 'fudge' his geometric figures in order to make them fit perfectly between the bay divisions. In **Figure 2**, I asked my CAD program for a perfect square which I scaled to fit and then duplicated and dragged the identical squares into place, leaving visible the small discrepancies which work their way into the plan as it is worked out on the ground.

Now, what sense can we make of the lateral (north–south) organization of the straight bays of the choir? My old manually measured plan led me to propose three equal spatial corridors corresponding to the width of the main vessel (c. 15.3 m) and each double aisle to just beyond (0.15 m on each side) the exterior surfaces of the aisle walls (Murray 1989: Fig. 18). The new plan allows us to confirm this observation (**Fig. 3**).

A written description of the Beauvais choir, probably made in the early decades of the fourteenth century, provides a most significant number: the exterior width of the choir is said to be 24 fathoms. Since a fathom equals six feet, we have a total lateral spread of 144 feet divided into three corridors of 48 feet.[13] It will be remembered that in the Book of Revelation the Celestial City is represented as 144 cubits wide.[14] Closely related to this scheme is the one proposed by Alain Guerreau (1992), who looked at the dimensions between wall surfaces. Here we can find six roughly equal spatial corridors (**Fig. 4**).[15]

If the lateral (north–south) divisions of the plan provide broad symmetry, what are we to make of the progressive widening in the three original bays of the main arcade from west to east with the widest bay at the base of the hemicycle (**Fig. 1**)?[16] This is the reverse of the design of neighboring Amiens Cathedral where the widest bay comes next to the crossing. Is it possible that the three irregular bay divisions were simply inserted into a larger matrix designed to make overall sense numerically or geometrically?[17]
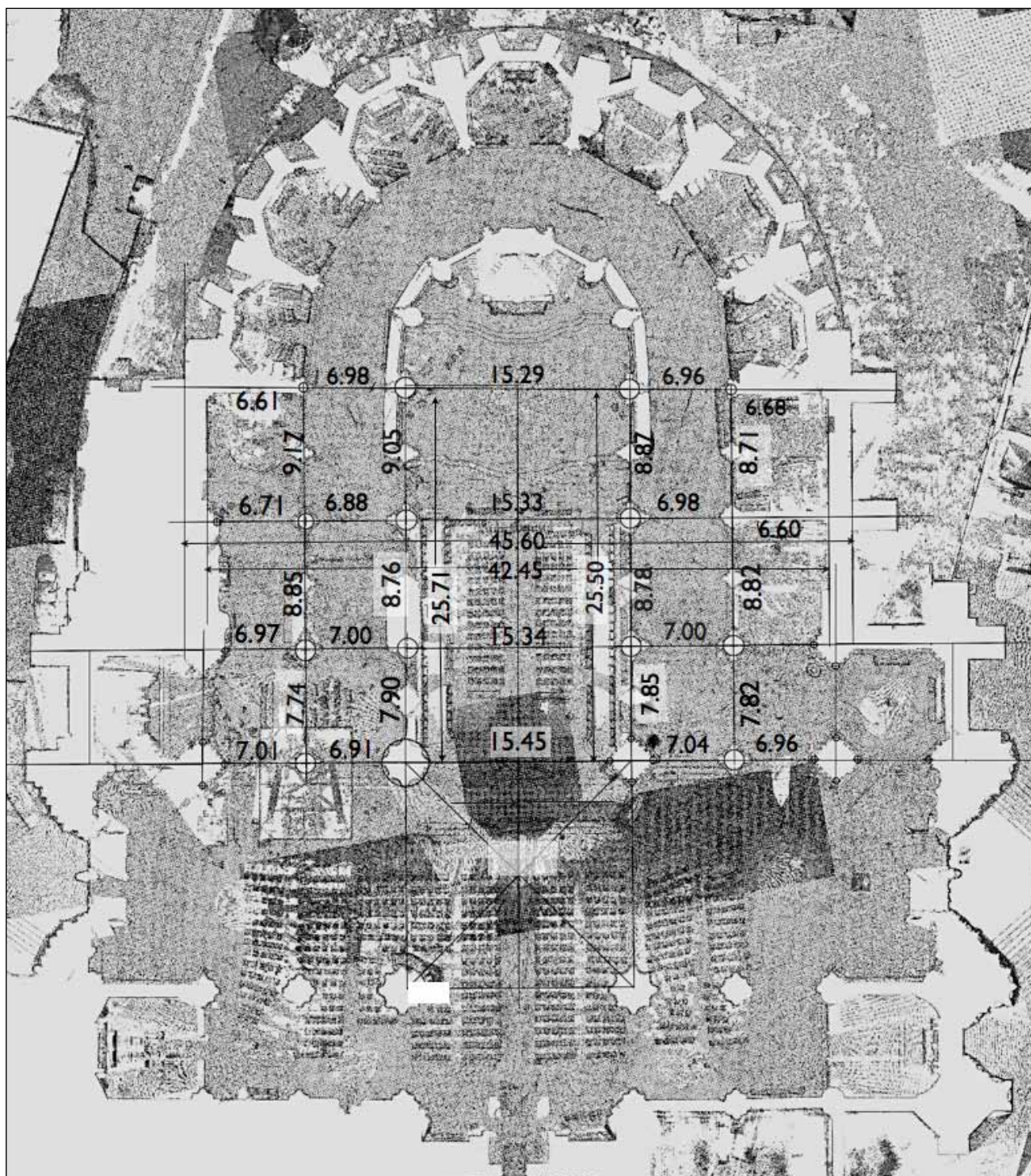
Fig. 1: Beauvais Cathedral, point cloud data from 2013 laser scan of the choir (by Andrew Tallon), rendered as a horizontal section at floor level, with insertion of pier center points, bay divisions and dimensions. Source: author.

It is with the geometry of the hemicycle that the value of the laser-scanned plan becomes most apparent. In my manual survey of 1978, mimicking the strategy of the builders, I had constructed the configuration of the hemicycle using a great rectangle pegged out with cords stretched on the pavement. Similarly, I pegged out rectangles in each of the radiating chapels, and triangulated measurements taken of the wedge-shaped bays of the ambulatory and around the polygonal shapes of the chapels. Control of the wall thickness then allowed integration of interior and exterior. My manual construction (meticulous as well as laborious) of the hemicycle plan on a 1: 50 scale led me to propose that it was generated from a single center point located about 2.40 meters east of the last transverse bay division, and that the radial geometry was fixed by a regular thirteen-sided polygon (Murray 1989: 15).[18] The laser survey has provided striking confirmation of these findings (**Fig. 6**).

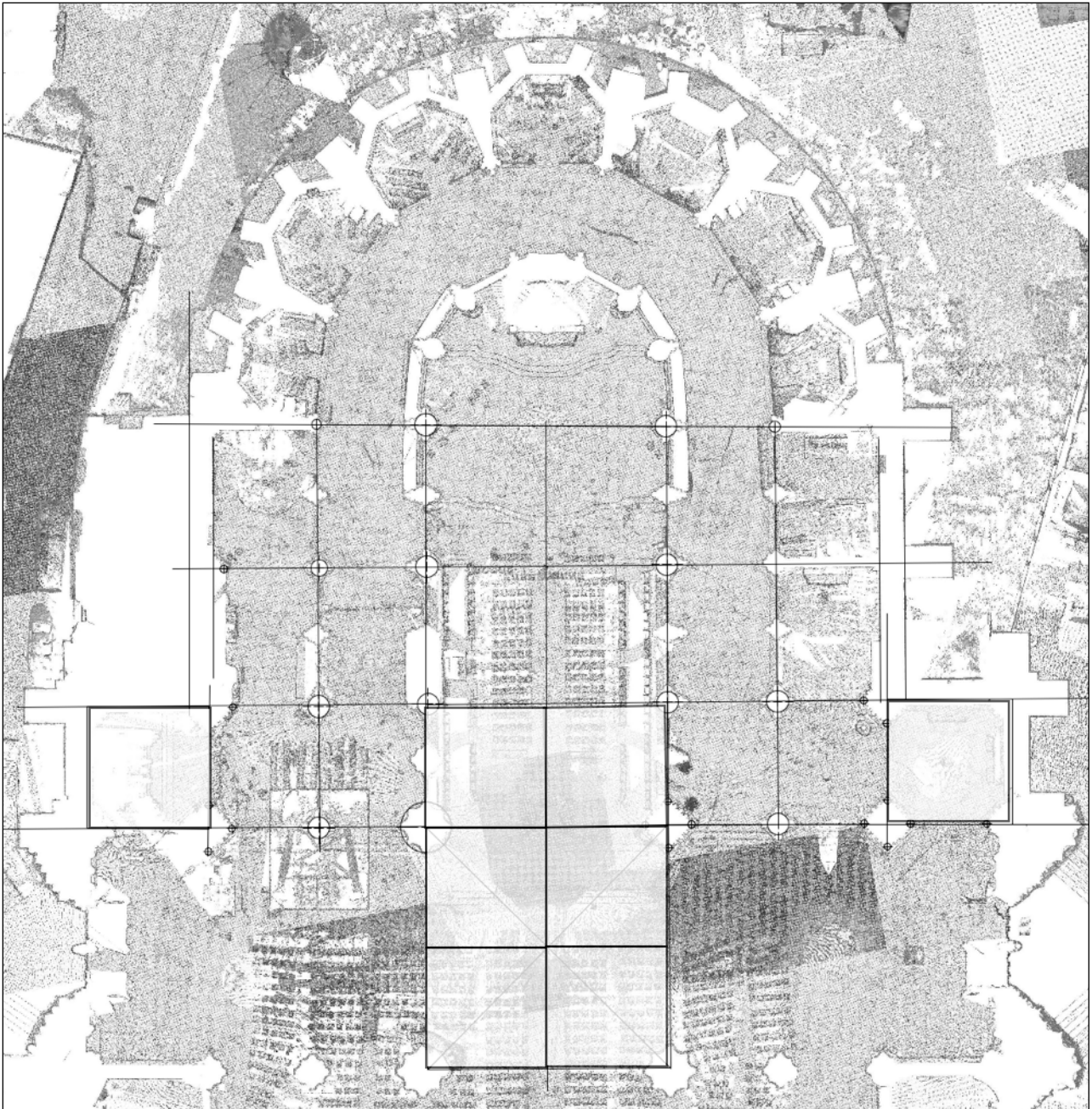With computer-aided design it was possible to find the centers of the great exterior buttresses and the interior

Fig. 2: Beauvais Cathedral choir plan, square schematism in the western bay. Source: author.

piers and to project lines inwards to find the hidden center point. These lines converged most satisfyingly on a point 2.26 meters east of the base of the hemicycle. It is impossible to escape the conclusion that the accuracy of the concentric composition was ensured through a central peg driven into the ground and the sweep of a cable or rope to fix the position of the hemicycle piers, the divisions of the mouths of the chapels, and the chapel depths. The walls and buttresses of the chapels sit atop a circular exterior plinth struck from the same center point, radius 22.4 meters.[19] This plinth, now much restored, helps evacuate rainwater out and away from the foundations. The diameter of this great circle (44.8 m) is slightly less than the total exterior span of the choir straight bays (45.5 m). The CAD program allowed me to generate the thirteen-sided polygon to fix the location of the hemicycle piers and chapel mouths — something which is very difficult to plot using traditional manual methods.[20]

In planning the spatial forms of the hemicycle the builders were probably driven by three factors: first, the desire for seven radiating chapels of equal depth — quoting the chevet of the Cistercian church at Royaumont (King Louis IX's favorite) — and thus signaling the close alignment of Bishop Robert de Cressonsac with the king; second, the need to have the width of each chapel match the width of the choir aisles; and, third, a desire for an overall internal shape corresponding to a square (**Fig. 5**). The reconciliation of these various desires probably lies behind the placement of the hemicycle center point.[21]

Let us now project plan into elevation and turn to the transverse section of the choir. Our laser scan at the base
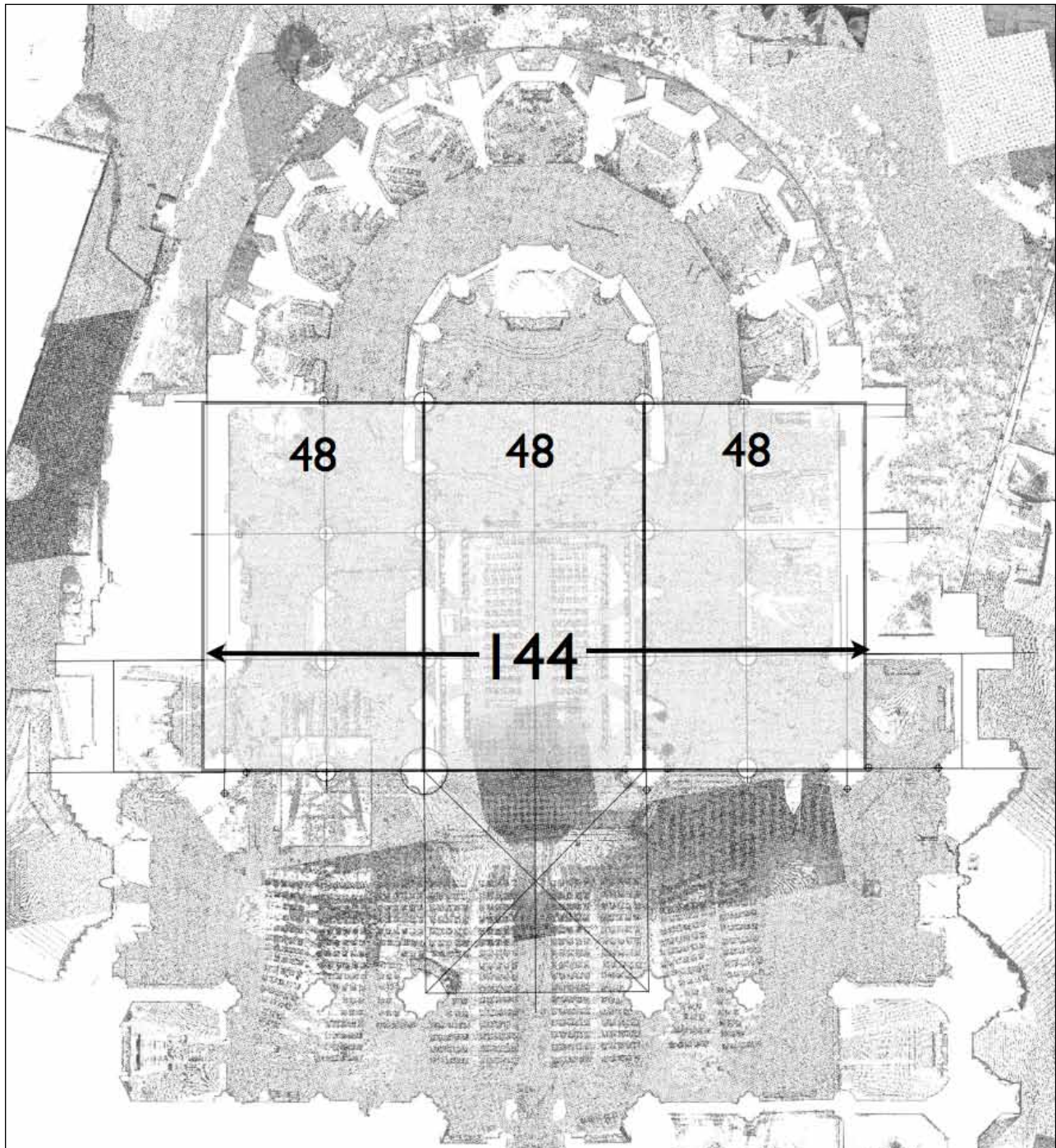
Fig. 3: Beauvais Cathedral choir plan, the three great corridors of space to exterior surfaces of aisle walls. Source: author.

of the hemicycle where the vault survived the partial collapse of 1284 allows us to study how closely the overall height and width approximate a great square (**Fig. 7**).

In fact, the height of the keystone of the hemicycle vault, about 46.3 meters above the pavement, somewhat exceeds the total exterior lateral spread of the choir, 45.6 meters. However, the notion of square schematism is reinforced by the fact that the span of the main vessel (15.3 m, center-to-center) projected upwards, will produce the abacus of the capitals of the main arcade and three such squares will reach the main vault.[22] The great vertical division into three thus matches the organization of the plan into three corridors of space. The matching of span and height, as well as the number 144, allow

the cathedral to embody the attributes of the Celestial City, as witnessed by Saint John the Divine and described in Revelation 21.

The alarmingly steep elevation at Beauvais was not necessarily planned from the start. We might remember that the space frame of two of the cathedrals that formed key points of reference for the builders of Beauvais, Notre-Dame of Paris and Bourges Cathedrals, had both been designed around equilateral triangles (Sandron and Tallon 2013: 31). There is tantalizing evidence that Beauvais, as originally planned, may have shared this configuration. Attached to the outer flying buttress upright on the north side of the westernmost bay of the choir is a now-redundant flyer (**Fig. 8**).
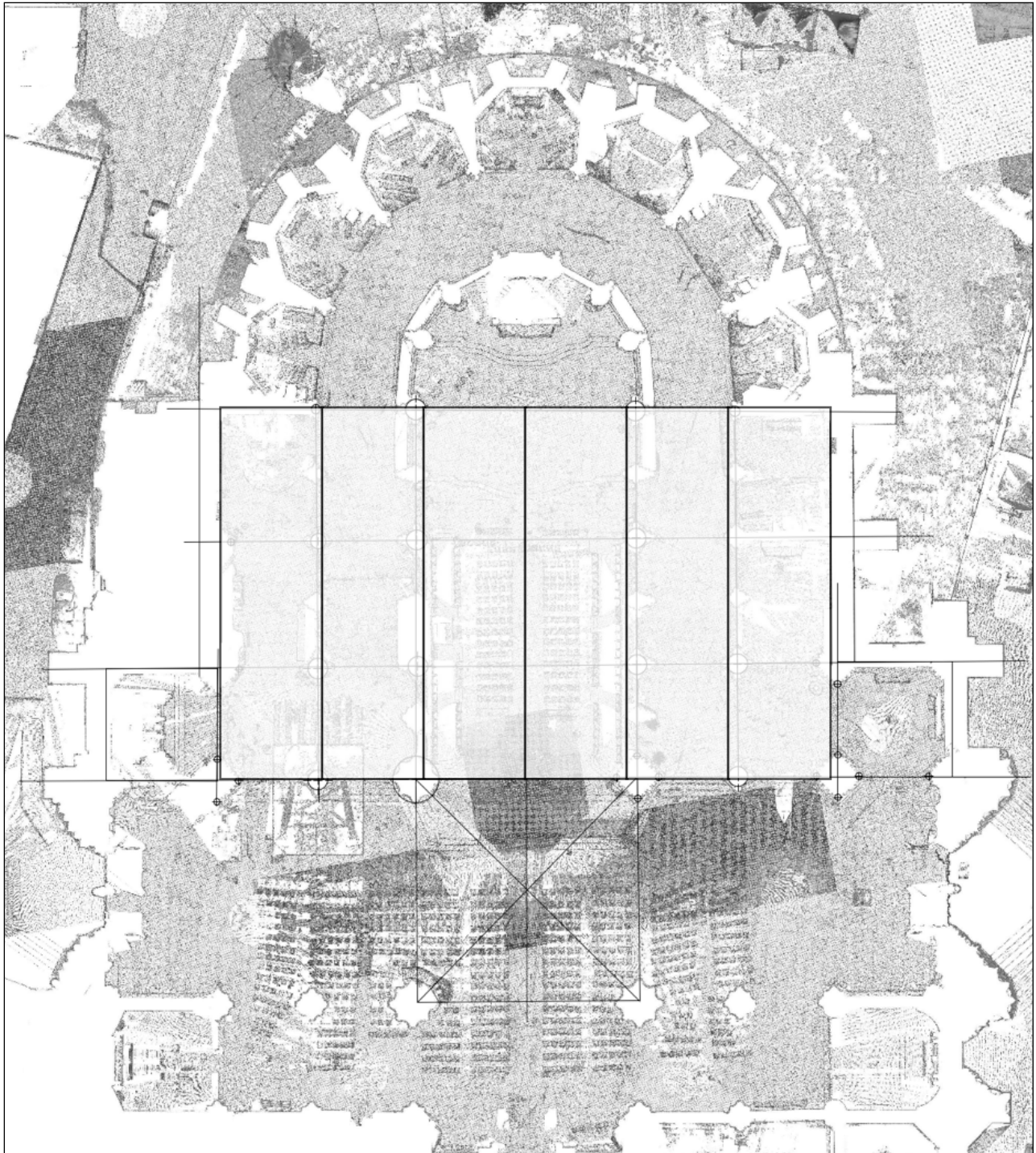
Fig. 4: Beauvais Cathedral choir plan, six corridors of space with divisions set on inner wall surfaces and pier circumferences. Source: author.

The form of the crockets set upon its crest suggests a thirteenth-century date, and since work at Beauvais progressed generally from west to east, with the north side ahead of the south, it may be concluded that this buttress is early work. If we project the trajectory of the flyer inwards and upwards it will come very close to intersection with the apex of an equilateral triangle inscribed between the outer surfaces of the lateral walls (**Fig. 8**). It was from this same base that the square that fixes the height of the existing vault was projected.

What can we conclude from this case study? First, that while the laser-scanned plans and sections coupled with computer-assisted analysis provide invaluable investigative mechanisms and powerful means of representation, they do not 'solve' the problem of understanding the application of several different kinds of units of measurement, changing intentions on the parts of the builders, or the scholarly audience's skepticism about the search for shapes and numbers that appear to emerge, yet not always with sufficient precision to convince us that they necessarily reflect the intentions of the builders. The number 144 emerges particularly clearly at Beauvais, expressed by the external width of the choir, which is very close to 144 royal feet and just a little less than the height of the
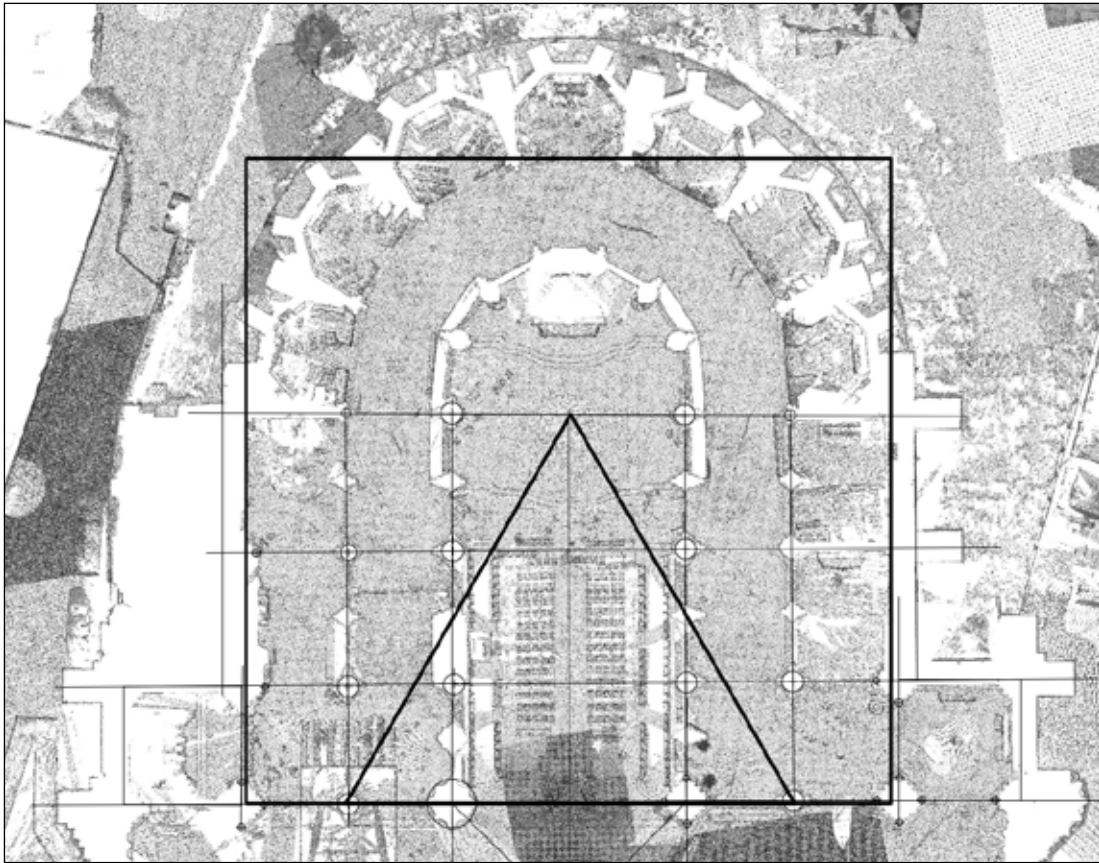
Fig. 5: Beauvais Cathedral choir plan: overall spatial shapes (square and equilateral triangle). Source: author.
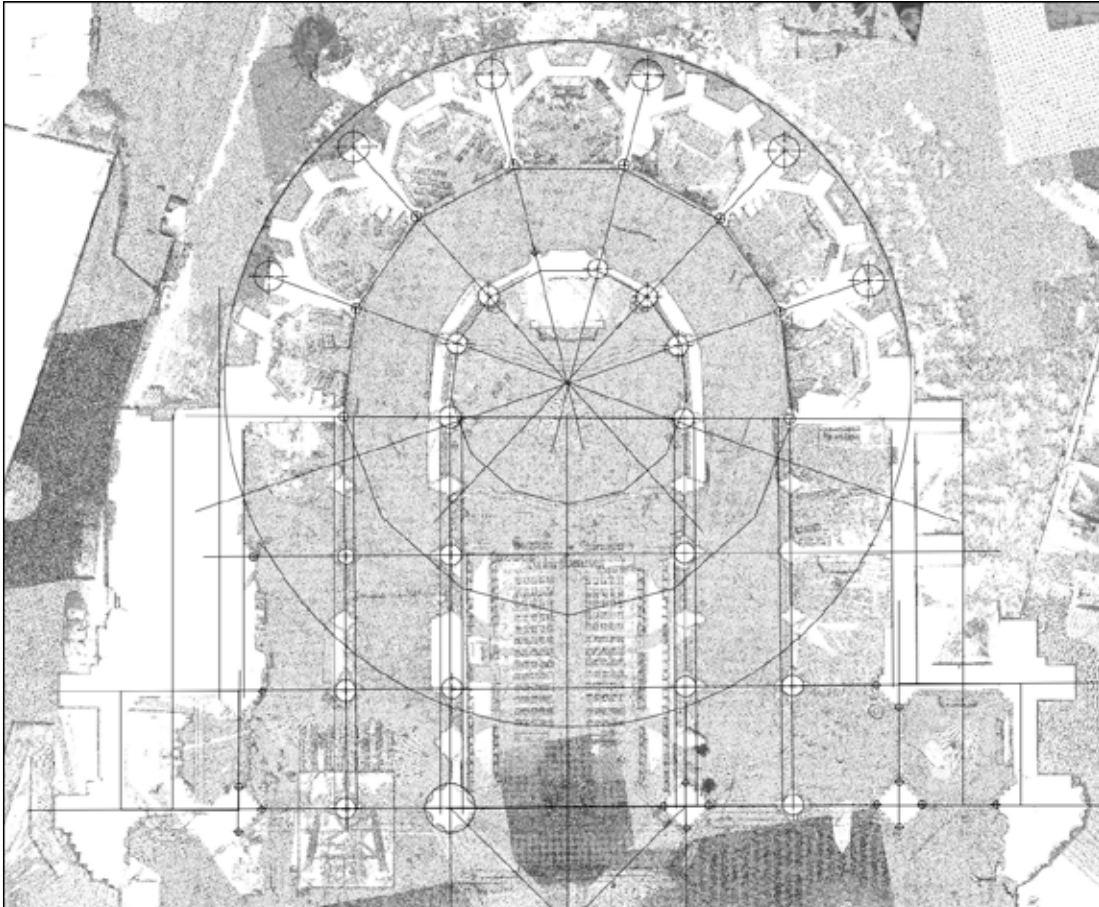

Fig. 6: Beauvais Cathedral choir plan, analysis of the hemicycle. Source: author.
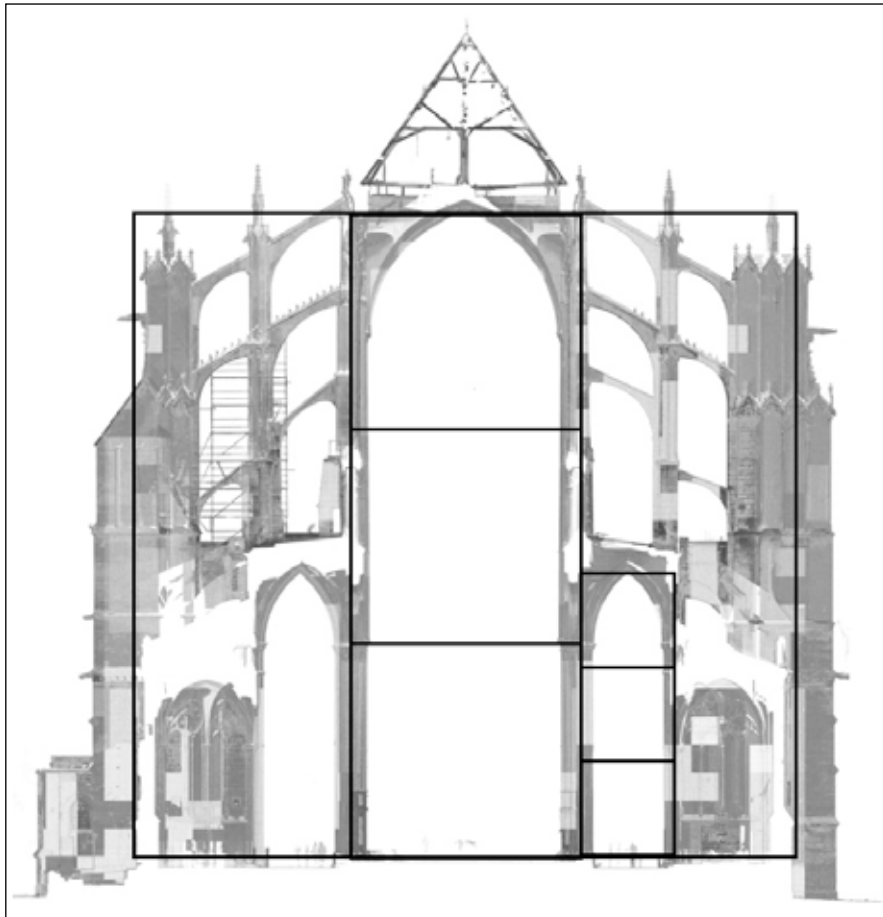
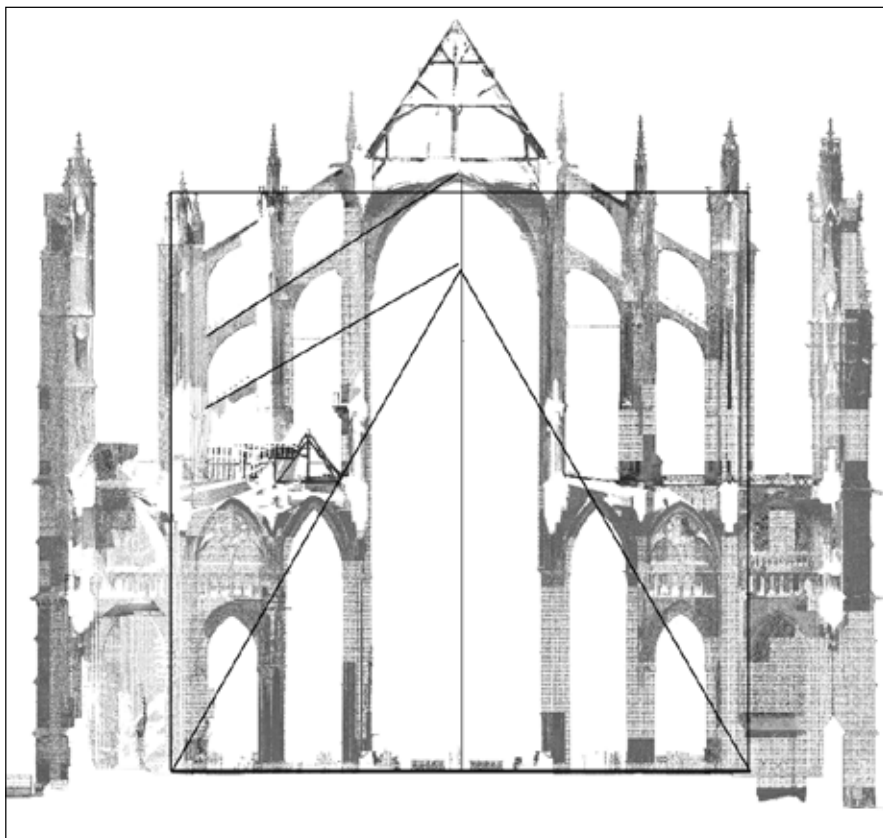**Fig. 7:** Beauvais Cathedral choir, transverse section at the base of hemicycle. Source: author.

Fig. 8: Beauvais Cathedral choir, transverse section of westernmost bay. Source: author.

Fig. 9: The three builders (frontispiece to Viollet-le-Duc's *Dictionnaire raisonnée de l'architecture française*).

vaults. The division of this width into three equal parts (48 feet) appears to be a feature of the transverse section where the span of the main arcade fits three times under the high vault and the total width where the main vessel almost equals each of the double aisles.

How should we understand the apparent irregularities of the east-west dimensions and the twisted hemicycle? What we are dealing with at Beauvais is a combination of error and artifice. The error may be easily quantified: as work advanced from west to east, exterior to interior, the builders failed to coordinate the bay divisions anticipated in the great exterior buttresses with the placements of the interior supports, which, at the base of the hemicycle on the north side, have been allowed to slip a full 60 centimeters beyond their due positions.[23]

This much is susceptible to 'proof' through the application of 'scientific' methods. But what about artifice? Vitruvius provided the builders of late antiquity and the Middle Ages with invaluable advice on the reconciliation of the demands of symmetry and the 'flashes of genius' that allowed the architect to violate the requirements of regularity in response to local considerations and the desire for beauty.[24] While we can never be certain about the *intention* that lay behind the progressive widening of the three original arcade openings of the Beauvais choir, the *effect* would have been readily available to the eyes of the user or viewer standing in the crossing space — the arrangement served to counter the visual effect of foreshortening, allowing the arcade to retain more of the *appearance* of regularity than it would have had with equal spacing of the piers.[25] The arrangement would have allowed the gaze to penetrate freely into the peripheral spaces, organized in the plan as a double aisle of approximately equal value as the main vessel and in elevation as a spectacular series of descending spatial diaphragms.[26] The same kind of optical sense can be found in the fact that the colonnettes attached to the main arcade piers (toward the central vessel) have been recessed into the cylindrical

body of the pier, reducing the projection of the colonnette and allowing the gaze to slip more easily past the front surface of the pier. The glimpse of the sublime at Beauvais is not just the result of great height, but in the artful correlation of horizontal expansiveness and the truly awe-inspiring chasm created by the three-to-one elevation of the central vessel.[27]

The Gothic plot

While the metrological investigation of great medieval churches may certainly be understood partly as a 'scientific' enterprise facilitated through the systematic application of accurate measuring equipment and computer-assisted analysis, we should remind ourselves that cathedral space was and is *living space.*[28] In the creation, application and reception of proportional systems we are dealing with a human phenomenon with an extraordinary range of sociological, anthropological and neurological implications.[29] In attempting to correlate and to reconcile the various ways in which meaning is put into the great church by the builders and unscrambled by the users, I have become increasingly preoccupied with the multiple meanings of the 'plot' — not just as a piece of land staked out with cords (a cabbage plot, a burial plot, a building plot) but also in a social sense as a conspiracy to ambush the future (Murray 2011). And then, of course, there is a third dimension: 'plot' is the story line intended to impel the reader compulsively forward. Common to all three kinds of plot, spatial, social and rhetorical, is the human desire to control, to possess and to represent. We may postulate that humans from earliest times have looked for ways to distinguish a controlled plot of land from the *terrain vague* 'out there'. This control is exercised not just in order to secure protection and shelter; there are profound religious and sociological dimensions that appear to transcend cultures.[30] In social terms, cathedral building is akin to a kind of conspiracy — an attempt to anticipate and control the future with the *appearance* of perfection and manifest destiny in the finished edifice — in which the three builders: master mason, churchman and patron or budget provider may be seen as the conspirators (**Fig. 9**).

The successful working out of a plot may involve technology or a secret weapon of some kind, whether barrels of gunpowder placed beneath the House of Parliament or the mason's formidable iron compasses and the geometry of the 'Egyptian triangle'. The plot will always bring the potential for *deceit* — and it may also bring compelling persuasiveness. The most powerful weapon at the disposal of the master mason as he attempted to sell his vision of the unbuilt church to his prospective employers was the kind of mnemonic device we have encountered in the pages of Villard de Honnecourt in the 'squared-up' church. Through such a device even the layperson could commit to memory the complex spaces of a great edifice that could hardly be constructed in a single lifetime.

It is with the third meaning of the word 'plot' that I want to end. In storytelling the plot is the mechanism that lends shape and momentum to the narrative. 'Reading for the plot' implies the compulsive reaching forward to grasp the dynamics of the story (Brooks 1984). This is what

Roland Barthes (1973; *Le plaisir du texte*) called *jouissance*. Humans compulsively control the shapes of their artifacts and unscramble them with a similar compulsion — this is not a disease and we are not idiots (Fernie's pathological 'Pyramidiocy'). Some, including myself, have confessed to a desire to possess our beloved building by grasping its essential geometric matrix, believing, rightly or wrongly, that we can in some measure enter into the brain of the designer in a process of *co-creativity* (Murray forthcoming). This is the human condition that Erwin Panofsky (1958) invoked with his notion of 'mental habits' and Pierre Bourdieu (1993) with his '*habitus*', a domain of activity that has more in common with the social than with the physical sciences. In the Middle Ages such activity might have been considered as edification in moral terms or as the quest for salvation, as in the penitential act of measuring the Temple (Carruthers 1998: 232).

The key to the resolution of the paradox outlined in the opening passages of this essay may lie, finally, in the recognition of the unstable combination of science, artifice (including deceitfulness) and desire peculiar to the business of plotting. To stake out the building plot accurately, some understanding of practical geometry was essential (especially the nature of the Pythagorean triangle); and erecting the structure demanded knowledge of the practical working of the principles of physics which lie behind the working of the pulley systems of the great lifting machines. Villard de Honnecourt called such devices *engiens* (see Godefroy 1884, 3: 171); Gervase of Canterbury applied the word *machinas.* Both words are synonymous with tricks or ruses — in modern English we might remember the linkage between 'devices' and 'desires,' and between 'machine' and 'machinate.' Our enterprise, finally, should lead us not only to equip ourselves with the newest high-tech *engiens* — the laser scanner and computer-assisted drafting — but also to remain aware of all the other slippery dimensions of the plot. In plotting, science without art is nothing.

Acknowledgements

Notes

1   See also Fernie (1978) and 'Introduction' in Wu (2002: 1–24).
2   Lesser's work received a scathing review by Branner (1958). Branner objected that the author's research methods and demonstrations were inadequate: the buildings themselves had not been re-measured and were presented in small-scale plans thickly overlaid with geometric figures (mainly squares rotated to form lozenges and eight-pointed stars); with such a 'system' it is possible to prove anything. Branner also objected to Lesser's dependence upon Emile Mâle's notion of 'iconography' where the lozenge-stars formed by the geometric 'matrix' took on meaning in relation to parallels in the figurative arts. Branner did not make any attempt to verify whether Lesser's geometric schemes might actually have some foundation. I have compared his analysis of Amiens with the carefully measured plan prepared by James Addiss and myself. I have to report that Lesser's matrix, based as it is upon a square of 140 local feet (corresponding to the total exterior width of the frontispiece), does, in fact, yield some of the critical dimensions of the building. Particularly interesting is the fact that the module exactly fits between the center point of the crossing and the center of the hemicycle, just as predicted by Lesser. On the other hand, the span of the transept, which is supposed to correspond to the same module, is more than a meter wider. It is time for a systematic reexamination of Lesser's work.
3   See Bork (2011: particularly 1–27) for an excellent overview of the problem. Bork rightly points to the rigor of the CAD-based analysis where geometry cannot be 'fudged' and line thickness is not a problem. However, the geometric facility provided by computer-assisted drafting may exacerbate an old problem: over interpretation. The author's joy in projecting multiple polygons on to the plan or elevation of the Gothic church may translate as arid prose and confusion for the perplexed reader.
4   Hiscock (2000) provides a useful compendium of written sources, including (p. 196) this frequently cited one from Gerald of Wales *De rebus a se gestis* 89: 'For I seemed to myself to behold the King's son, John, in a green plain, appearing as though he were about to found a church […] after the fashion of surveyors, he marked the turf making lines on all sides over the surface of the earth, visibly drawing the plan of the building.' Salzman (1952: 327) finds references to the purchase of ropes in the administrative sources, but mostly in connection with cranes and lifting gear. Knoop and Jones (1967: 56) cite the Vale Royal building account for July 1278 which mentions payment of 6d. 'for lines for the layers of the walls […] used no doubt to mark out the foundations of the intended structure.' Du Colombier (1973: 85–87) commented on the paucity of written or graphic sources. See also Harvey (1972: esp. 120–130). The fullest treatment of the roped-out plot in the secondary sources comes not from the West but from the domain of Byzantine architectural production, see Ousterhout (1999: esp. 58–85, 'Drawing the Line and Knowing the Ropes').
5   Particularly valuable is the passage from Hugh of Saint Victor: 'When the foundation has been laid, he stretches out his string in a straight line, he drops his perpendicular, and then, one by one, he lays the diligently polished stones in a row. Then he asks for other stones and still others […] See, now, you have come to your [reading], you are about to construct the spiritual building. Already the foundations of the story have been laid in you; it remains now that you found the bases of the superstructure. You stretch out your cord, you line it up precisely, you place the square stones in the course, and, moving around the course, you lay the track, so to say, of the future walls.' (Cited in Carruthers 1998: 20.) Gunzo, abbot of Baume, in a dream-vision, saw Saints Peter, Paul and Stephen laying out

the ropes (*funiculos)* to mark the edges of the great church, see Carruthers (1998: 226). Most recently, see Tallon (2013).

[6] Abbot Suger, in an ambiguous passage that has provoked various interpretations, claimed that the central vessel of the new choir was equalized with the old nave by geometric and arithmetic means: *geometricis et aritmeticis instrumentis,* see Panofsky (1979: 100–101 and 1958: 9–24); also Binding (1985).

[7] The ratio of 5:3 provides an approximate numerical expression of the Golden Section.

[8] 'Hic in anni quinti aestate crucem utramque australem scilicet et aquilonalem consummavit et ciborium, quod desuper magnum altare est, volvit […].' Stubbs (1879, 1: 21).

[9] Although the laser-generated plan imported into the CAD program can, of course, be accurately scaled, it is most reassuring to be able to check the key dimensions against direct measurements that have been taken manually.

[10] I also want to thank Robert Magorien who launched me into Vectorworks, and Emogene Schilling and Lindsay Cook who helped with the interpretation.

[11] The span across the eastern crossing piers is 15.48m; however it is particularly difficult to find the exact center point of the northeastern pier with its undulating surfaces. The western crossing piers deviate slightly from their correct positions at the corners of the great crossing square.

[12] In **Figure 1**, I have checked measurements from my 1978 manual survey against the new data from the laser scan.

[13] Archives départementales de l'Oise, G707, *Mémoire de ce qui reste à parfaire de l'église St Pierre de Beauvais. Il y a en largeur 24 Toises en comprena[n]t les pilliers qui seront par dehors.* Written in a post-medieval hand, this document appears to be a copy of a fourteenth-century text recording plans to complete the transept towers, see Murray 1977. A second (mid-sixteenth century) description of the Beauvais choir is entitled *Les mémoires de ce que contient le cuer de l'église de St. Pierre de Beauvais, a scavoir de haulteur, largeur et longueur* […]. A further text from the early sixteenth century records that Roman and royal feet were both in use in the Beauvais workshop (see Murray 1977: 135 n. 9). It is, of course, impossible to measure the external width directly and the number may have been drawn from memory or from sources in the Beauvais Cathedral workshop.

[14] 'And he [the angel] measured the wall thereof an hundred and forty-four cubits […].' (Revelation 21: 17) The notion of the cathedral as the Heavenly City has become unfashionable these days, yet the foundational work on the subject remains valid, see Stookey (1969).

[15] Guerreau (1992: 90), where the author proposes that each of these six corridors was fixed by a perch of 22 feet of c.0.30m.

[16] It will be remembered that after the collapse of the choir vaults in 1284 the supports were doubled and sexpartite vaults installed, creating a six-bay choir where there had originally been only three bays.

[17] The total east-west length of the straight bays is difficult to fix with precision since it is longer on the north side. If we take the exterior envelope as marking the original intention, the length will be 25.40 m, which translates as 86.1 Roman feet and 78.15 royal feet. Was the length of the straight bays fixed by geometric means? The metrological sleuth equipped with computer-assisted drafting might find that the length was fixed by an equilateral triangle with its base corresponding to the width of the main vessel and inner aisles placed upon the western bay division or that the east-west length of the choir to the opening of the axial chapel is fixed by a square with its base on the same bay division and sides aligned with the interior surfaces of the walls (**Fig. 5**). The skeptical reader might ask whether such figures were actually used by the builders or whether they result from 'pyramidiocy' now exacerbated by the new facility of CAD analysis. I count myself amongst the skeptical.

[18] Given the extemporized nature of my manual surveying techniques, I considered my own conclusions to be somewhat tentative.

[19] See image at Murray, S, Tallon, A, and O'Neill, R, Exterior, north chevet buttresses, *Mapping Gothic France*, Media Center for Art History, Columbia University, website available at http://mappinggothic.org/image/30648 [last accessed June 3, 2014].

[20] Guerreau (1992: 94) affirmed that the division of a circle into thirteen equal parts was an 'opération alors presque irréalisable.' Yet the builders appear to have achieved the impossible. Peter Kidson found a thirteen-sided figure in the chevet plan at S-Denis, see Kidson (1987: esp. 14).

[21] Guerreau (1992: 87–88) claimed that the hemicycle center point was placed exactly four perch units (each of 22 feet) from the western bay division and that the interior width of the choir was fixed by six of the same units. His calculations make some sense for the internal width of the choir but the application of four such units stretched from the westernmost bay division to fix the center point of the hemicycle does not quite work: there is a discrepancy of 0.48 m. based upon manual and laser-generated measurements.

[22] The proportion of the inner aisle is also close to a triple-square.

[23] Guerreau (1992: 94) claimed that the error was 'minimal' and that orthogonality was not a major concern for medieval builders. The extraordinary accuracy of the hemicycle at Beauvais does not provide support for such assumptions.

[24] Vitruvius (1999: 6.2.4): 'since things are sometimes represented by the eyes as other than they are, I think it certain that diminutions or additions should be made to suit the nature or needs of the site, but in such fashion that the buildings lose nothing thereby. These results, however, are also attainable by flashes of genius, *and not only by mere science* [my italics].' Bork (2011: 22) expressed the same idea with an unusual

simile: 'a Gothic design can be seen as an architectural topiary, in which geometry provides the quasi-random growth factor, while artistic judgment guides the pruning process.' It is, of course, the *artifice* of the pruner that lends the topiary its final shape.

[25] Was this the *intention* of the builders? Or the accidental product of concealed geometric machinations? Different readers will reach different conclusions.

[26] The double aisle with roughly equal value as the main vessel may provide a reflection of Notre-Dame of Paris.

[27] On the vision of the sublime in Gothic architecture, see Binski (2010).

[28] I learned much from the multiple understandings of space presented by Lefebvre (1991).

[29] It is to be anticipated that the collaborations between humanists and neuroscientists will add new dimensions to our understanding of the phenomenon: see especially Rizzolatto and Sinigaglia (2008). Interestingly, in the Preface (p. ix) the authors invoke Peter Brooks, author of *Reading for the Plot*: 'with the discovery of mirror neurons, neuroscience had finally started to understand what has long been common knowledge in the theatre: the actor's efforts would be in vain if he were not able to […] share his bodily sounds and movements with the spectators, who thus actively contribute to the event and become one with the players on the stage.'

[30] The deforestation of Brazil has uncovered geoglyphs forming geometrically perfect squares and segments of circles, see Ranzi (2000).

References

Ackerman, J 1949 'Ars sine scientia nihil est'. *Art Bulletin* 31: 84–111. DOI: http://dx.doi.org/10.2307/3047224

Addiss, J 2002 Measure and Proportion in Romanesque Architecture. In: Wu, N Y (ed.) *Ad Quadratum: The Practical Application of Geometry in Medieval Architecture*. Aldershot: Ashgate. pp. 57–82.

Barnes, C 2009 *The Portfolio of Villard de Honnecourt*. Farnham: Ashgate.

Barthes, R 1973 *Le plaisir du texte*. Paris: Seuil.

Binding, G 1985 Geometricis et aritmeticis instrumentis: zur mittelalterlichen Bauvermessung. *Jahrbuch der rheinischen Denkmalpflege* 30/31: 9–24.

Binski, P 2010 Reflections on the 'Wonderful Height and Size' of Gothic Great Churches and the Medieval Sublime. In: Jaeger, C S (ed.) *Magnificence and the Sublime in Medieval Aesthetics: Art, Architecture, Literature, Music*. New York: Palgrave MacMillan. pp. 129–156.

Bork, R 2011 *The Geometry of Creation: Architectural Drawing and the Dynamics of Gothic Design*. Farnham: Ashgate.

Bourdieu, P 1993 *Field of Cultural Production: Essays on Art and Literature*. New York: Polity.

Branner, R 1958 Review of Lesser, Sacred Geometry & Gothic Cathedrals. *Journal of the Society of Architectural Historians* 17(1): 34–35. DOI: http://dx.doi.org/10.2307/987839

Brooks, P 1984 *Reading for the Plot: Design and Intention in Narrative*. New York: Knopf.

Bucher, F 1968 Design in Gothic: A Preliminary Assessment. *Journal of the Society of Architectural Historians* 27: 49–71. DOI: http://dx.doi.org/10.2307/988429

Carruthers, M 1992 *The Book of Memory: A Study of Memory in Medieval Culture*. Cambridge: Cambridge University Press.

Carruthers, M 1993 The Poet as Master Builder: Composition and Locational Memory in the Middle Ages. *New Literary History* 24: 881–904. DOI: http://dx.doi.org/10.2307/469399

Carruthers, M 1998 *The Craft of Thought: Meditation, Rhetoric and the Making of Images, 400–1200*. Cambridge: Cambridge University Press.

Du Colombier, P 1973 *Les Chantiers des cathédrales: Ouvriers – architectes – sculpteurs*. Paris: Picard.

Fernie, E 1978 Historical Metrology and Architectural History. *Art History* 1: 383–399. DOI: http://dx.doi.org/10.1111/j.1467-8365.1978.tb00025.x

Fernie, E 1990 A Beginner's Guide to the Study of Gothic Architectural Proportions and Systems of Length. In: Fernie, E, and Crossley, P (eds.) *Medieval Architecture and its Intellectual Context: Studies in Honour of Peter Kidson*. London: Hambledon Press. pp. 229–237.

Godefroy, F 1884 *Dictionnaire de l'ancienne langue française*. Paris: Vieweg (reprint).

Guerreau, A 1992 Edifices médiévaux, métrologie, organization de l'espace à propos de la cathédrale de Beauvais. *Annales: Histoire, Sciences Sociales* 47(1): 87–106.

Harvey, J 1972 *The Medieval Architect*. London: Wayland.

Hecht, K 1979 *Mass und Zahl in der gotischen Baukunst*. Hildesheim: Olms.

Hiscock, N 2000 *The Wise Master Builder: Platonic Geometry in Plans of Medieval Abbeys and Cathedrals*. Aldershot: Ashgate.

Hiscock, N 2004 The Two Cistercian Plans of Villard de Honnecourt. In: Kinder, T (ed.) *Perspectives for an Architecture of Solitude: Essays on Cistercians, Art and Architecture in Honor of Peter Fergusson*. Turnhout: Brepols. pp. 157–172.

Hiscock, N 2007 *Symbol at Your Door: Number and Geometry in Religious Architecture of the Greek and Latin Middle Ages*. Aldershot: Ashgate.

Kidson, P 1987 Panofsky, Suger and St. Denis. *Journal of the Warburg and Courtauld Institutes* 50: 1–17. DOI: http://dx.doi.org/10.2307/751314

Kidson, P 1990 Metrological Investigation. *Joural of the Warburg and Courtauld Institutes* 53: 71–97. DOI: http://dx.doi.org/10.2307/751340

Knoop, D, and **Jones, G P** 1967 *The Medieval Mason: An Economic History of English Stone Building in the Later Middle Ages and Early Modern Times*. Manchester: Manchester University Press.

Lefebvre, H 1991 *The Production of Space*. Nicholas-Smith, D (trans.). Malden: Blackwell.

Lesser, G 1957 *Gothic Cathedrals and Sacred Geometry*. 3 vols., London: Tiranti.

Machabey, A 1962 *La métrologie dans les musées de province et sa contribution à l'histoire des poids et mesures en France depuis le treizième siècle*. Paris: Revue de métrologie pratique et légale.

Murray, S 1977 An Expertise at Beauvais Cathedral. *Journal of the British Archaeological Association* 130: 133–144.

Murray, S 1989 *Beauvais Cathedral: Architecture of Transcendence*. Princeton: Princeton University Press.

Murray, S 2011 Narrating Gothic: The Cathedral Plot. In: Hourihane, C (ed.) *Gothic Art and Thought in the Later Medieval Period: Essays in Honor of Willibald Sauerländer*. Princeton: Princeton University Press. pp. 55–63.

Murray, S [forthcoming] *Plotting Gothic*. Chicago: University of Chicago Press. (Anticipated in 2014.)

Ousterhout, R 1999 *Master Builders of Byzantium*. Princeton: Princeton University Press.

Panofsky, E 1958 *Gothic Architecture and Scholasticism*. New York: Meridian.

Panofsky, E 1979 *Abbot Suger on the Abbey Church of St.-Denis and its Art Treasures*. (first edition 1946) Princeton: Princeton University Press.

Ranzi, A 2000 *Paleoecologia da Amazonia: Megafauna do Pleistoceno*. Florianópolis: Editoria da Universidade Federal de Santa Catarina.

Rizzolatto, G, and **Sinigaglia, C** 2008 *Mirrors in the Brain: How Our Minds Share Actions and Emotions*. Anderson, F (trans.) (first published 2006) Oxford: Oxford University Press.

Salzman, L F 1952 *Building in England Down to 1540*. Oxford: Oxford University Press.

Sandron, D, and **Tallon, A** 2013 *Notre-Dame de Paris: Neuf siècles d'histoire*. Paris: Parigramme.

Shelby, L 1976 *Gothic Design Techniques*. Carbondale: Southern Illinois University Press.

Stookey, L H 1969 The Gothic Cathedral as the Heavenly Jerusalem: Liturgical and Theological Sources. *Gesta* 8: 35–41. DOI: http://dx.doi.org/10.2307/766672

Stubbs, W 1879 *Historical Works of Gervase of Canterbury*. London: Longman.

Tallon, A 2013 An Architecture of Perfection. *Journal of the Society of Architectural Historians* 72(4): 530–554. DOI: http://dx.doi.org/10.1525/jsah.2013.72.4.530

Van Liefferinge, S 2006 The Choir of Notre-Dame of Paris: An Inquiry into Twelfth-Century Mathematics and Early Gothic Architecture. Unpublished thesis (PhD), Columbia University.

Van Liefferinge, S 2010 The Hemicycle of Notre-Dame of Paris: Gothic Design and Geometrical Knowledge in the Twelfth Century. *Journal of the Society of Architectural Historians* 69: 490–507. DOI: http://dx.doi.org/10.1525/jsah.2010.69.4.490

Vitruvius 1999 *Ten Books of Architecture*. Rowland, I, and Howe, T (trans. and ed.). Cambridge: Cambridge University Press.

Wu, N Y (ed.) 2002 *Ad Quadratum: The Practical Application of Geometry in Medieval Architecture*. Aldershot: Ashgate.

Zenner, M-T 2002 A Proposal for Constructing the Plan and Elevation of a Romanesque Church Using Three Measures. In: Wu, N Y (ed.) *Ad Quadratum: The Practical Application of Geometry in Medieval Architecture*. Aldershot: Ashgate. pp. 11–24.

Zupko, R E 1978 *French Weights and Measures before the Revolution: A Dictionary of Provincial and Local Units*. Bloomington: Indiana University Press.