Lost in the Labyrinth: The Unified Plan of Reims Cathedral

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Reims Cathedral ranks as one of the most important churches in Europe in terms of history and art history, but controversy continues to swirl around the history of its design, with many scholars attempting to sort out the roles played by the four architects memorialized in its famed labyrinth. In an effort to better understand Reims, Robert Bork and I undertook a new survey using a handheld laser that allowed us to produce a modern, comprehensive plan of the cathedral. Using the Vectoworks CAD system, we then explored the underlying geometry governing its design. On this basis, we have concluded that the plan of the whole cathedral was already established by its first architect.

The development of this new plan of Reims Cathedral was made possible by our using the LEICA S910 laser. The S910, while being compact and affordable, allowed us to collect data from the extremes of the cathedral and get high precision measurements on areas inaccessible to hand tools. It is especially useful for geometric studies as it allows for a selection of data points across long distances. This enabled us to add the exterior and nave zones to Nancy Wu's foundational geometry study, which was limited to the Reims chevet interior. We can distinguish between and explain two kinds of anomalies in the cathedral plan: one the one hand, buttress rotations and chapel displacements that appear to have resulted from errors in layout of the building; and on the other hand, peculiarities such as the different bay lengths in the choir and nave that can be shown to result naturally from an elegantly unified geometrical scheme.

Key words:
Gothic Architecture, Reims Cathedral, Gothic Geometry, Laser Scanning.

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INTRODUCTION

Reims Cathedral (Figs. 1a-1b) holds a great deal of significance for the history of Gothic architecture, as well as the larger history of France. Given the historic significance of Reims, it is not surprising that a great deal of scholarship has been dedicated to the building's architecture by giants in the Gothic architectural history community, from Eugène Emmanuel Viollet-le-Duc in the 19th century to Anne Prache, Peter Kurmann, Richard Hamann-Maclean, and Bill Clark more recently, just to name a few. Most studies dealing with the cathedral's architecture are based on stylistic and archaeological analysis, augmented by the use of surviving documents related to the construction.

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a.

b.

Fig. 1. Reims Cathedral, begun c. 1207: a) Exterior of the chevet b) Nave interior

Although much fruitful work has been done in this vein, important questions about the building's chronology and design still remain unresolved. The extent to which the design of the cathedral was established at the start of its construction, for example, continues to be disputed. The most recent monograph on the cathedral, published by Alain Villes in 2009, suggests that dramatic revisions to the overall plan, including significant changes in design in the transept and nave, were introduced during construction, but his theses remain controversial [Villes 2009]. Villes's argument that there were major revisions to the overall design follows a trend in Reims's scholarship that relies heavily on the famed labyrinth (Fig. 2), which provides us the names of the four architects of Reims Cathedral.[1] Although the chronological order of their work campaigns remains unclear, many scholars, including Villes, have argued that each new architect imposed his own influence on the layout of the cathedral, changing not only its detailing but also its overall plan when he took over leadership of the project.

[1] Although the labyrinth was destroyed in 1778, several drawings of the labyrinth survive. The best and most detailed drawing is the version drawn by Jacques Cellier, which was produced in the second half of the sixteenth century and is preserved in the Bibliothèque Nationale in Paris. Accompanying the drawing of the labyrinth were a series of inscriptions which gave the years of service of each architect, their name, and a description of their work on the cathedral. However, the inscriptions do not directly correspond to the figures drawn in the labyrinth, leaving scholars to puzzle which one is which. For more information about the labyrinth, see Robert Branner. 1962. The Labyrinth of Reims Cathedral. *Journal of the Society of Architectural Historians*, 21, 1, 18-25; and, Robert Branner. 1961. Jean d'Orbais and the Cathedral of Reims. *The Art Bulletin* 43, 131-3.

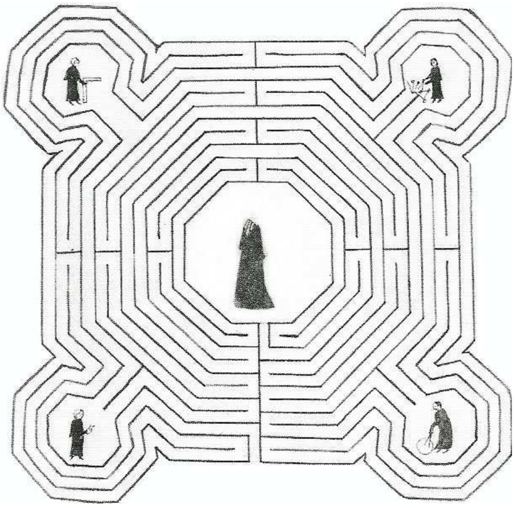

Fig. 2. Drawing of the Reims Labyrinth, drawn by Jacques Cellier, c. 1600-1620. Labyrinth destroyed 1778.

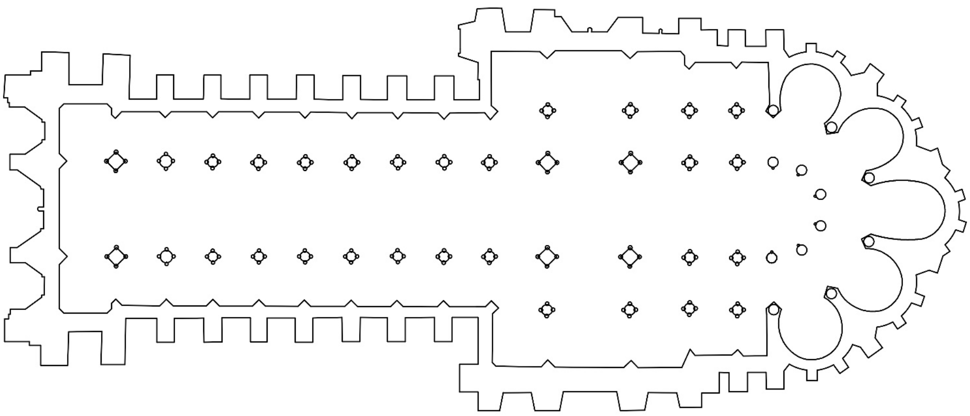

Fig. 3. Plan of Reims Cathedral by Robert Bork and Rebecca Smith, 2017.

In contrast, my dissertation, "Measuring the Past: The Geometry of Reims Cathedral," argues that a uniform plan, designed by the first architect, governed the layout of the cathedral. The uniform geometry is based off a new plan of the cathedral (Fig. 3). This work builds off the preliminary geometry studies conducted by Nancy Wu and my mentor, Robert Bork (Figs. 4-5). Wu, in writing her own dissertation in the mid-1990s, undertook a careful survey, measuring the cathedral's east end, but only on the interior [Wu 1996]. Bork has recently expanded on Wu's work by broadening the geometric analysis to include the whole cathedral, on both the interior and exterior, but he was forced to rely heavily on old surveys, which are sometimes too imprecise to permit the rigorous testing of geometrical hypotheses [Bork 2016; Bork 2013]. For example, while these older drawings work well to determine the geometry in large areas, such as the geometry of the crossing or the overall chevet, they are too imprecise for more detailed analyses, such as the minute geometry of the chapels or individual nave bays. Over the last four years, Bork and I have amassed thousands of measurements using traditional measuring techniques and using the LEICA Disto S910 laser measuring device to create a new plan of the cathedral, which allowed us to more precisely refine the intended geometry underlying the cathedral's design and glean better insight into the construction process.

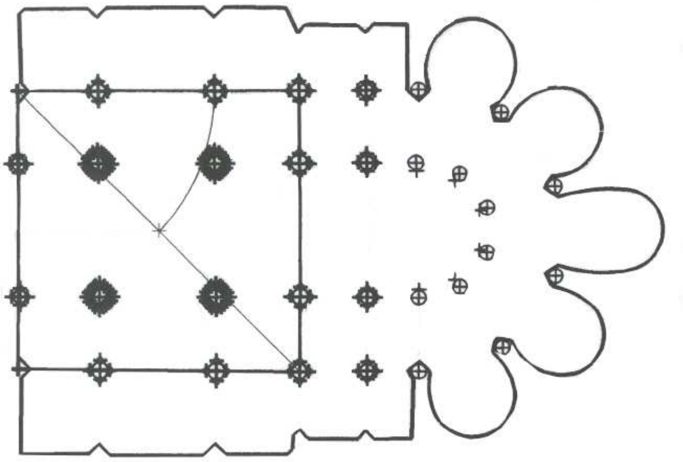

Fig. 4. Geometric analysis of Reims Chevet and Crossing [Wu 1996].

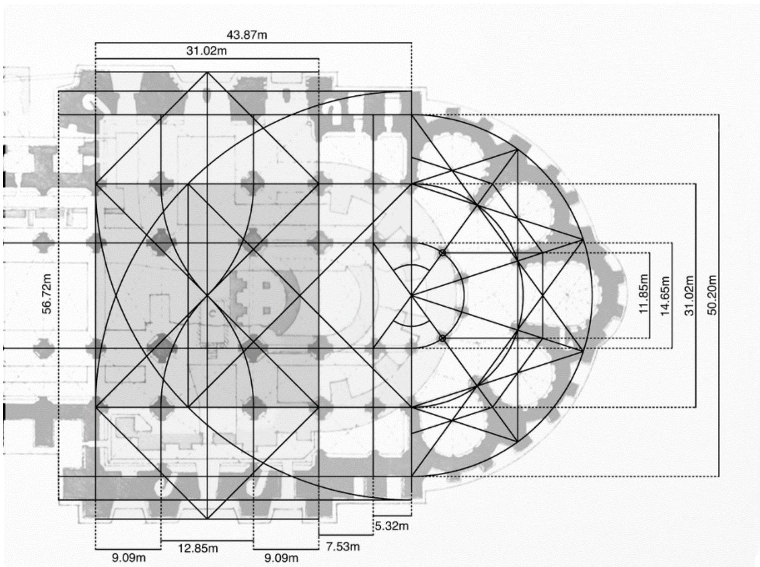

Fig. 5. Geometric analysis of Reims Chevet [Bork 2016].

DEVELOPING THE PLAN

Laser scanning is not a recently developed tool for archaeology and architectural history. Its application to Gothic architecture studies has given information about structural issues and construction snafus, as seen in Stephen Murray's work on Amiens and Andrew Tallon's work on Saint Denis. In contrast to the largescale LiDAR scanners used by Murray and Tallon, which often require extensive permits, a team of surveyors, and access to funding resources on par with Columbia University, a broke grad student can afford the S910 laser and survey the building alone.

While the S910 laser does not produce beautiful, fully developed models with millions of points, it works exceptionally well for analyzing Gothic geometry. The laser takes data point by point within a single, connected data set, enabling the surveyor to carefully choose the specific measurements needed. The data produced generates a small three-dimensional point cloud based on the selected measurements taken, ideal for determining a building's geometry, which has a limited number of critical measurements and does not require every detail of the building fabric. Unlike traditional measurement techniques, the S910 can measure extremely large ranges within the same data set, providing a framework within which you can add other, more detailed point clouds or analyze larger portions of the building. For example, the single data set shown in the red lines in figure 6 measured 30 points ranging from the aisle roof line of the south chapels to the tip of the spire all the way to the western transept buttress. Using Vectorworks CAD software, I created a 3D point cloud model of Reims Cathedral, a portion of which is shown in green lines in figure 6, by carefully knitting multiple data sets together, using a minimum of three identical points as a control and aligning identical points. I was also careful to interlock the interior and exterior by sighting to points visible from both sides, such as the centers of the window rosettes.

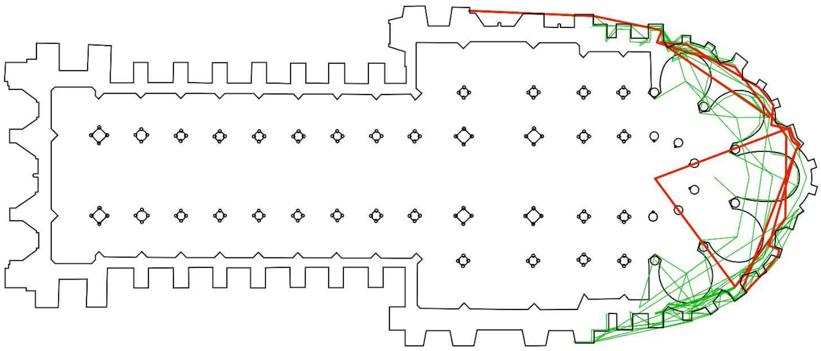

Fig. 6. New plan with laser data sets.

In her dissertation, Nancy Wu carefully measured the interior of Reims's east end and argued that the chevet was designed using decagonal geometry, the width of which is set by the dimensions of a great square in the crossing, shown via the blue square (Fig. 7a) [Wu 2002]. In 2013, Robert Bork built on her discovery and established the rest of the chevet's intended geometric plan, shown through the red and orange lines [Bork 2016]. He has argued that the chevet's geometry begins from the orange semi-circle struck from the 31.02 m width of the crossing square, inside which a half decagon can be inscribed. These decagonal points establish the location of the engaged, ambulatory piers separating the radiating chapels. When the sides of the half-decagon are lengthened, forming the orange star, the resulting geometry establishes the width of the choir straight bays along their exterior walls. The interval between this outer envelope and the original semi-circle arc determines the width of the straight bay chapels and ultimately the scale of each radiating chapel, although the geometry of each chapel is complex, and beyond the scope of this short essay. The 14.65 m width of the hemicycle, and consequently the width of the main arcade, is determined by a line, shown in green (Fig. 7b), struck from the central cross of the orange star to the neighboring diagonal establishing the ambulatory pier center. Vertical lines - struck from these intersection points to the next ambulatory pier diagonal - locate the point from which the hemicycle springs.

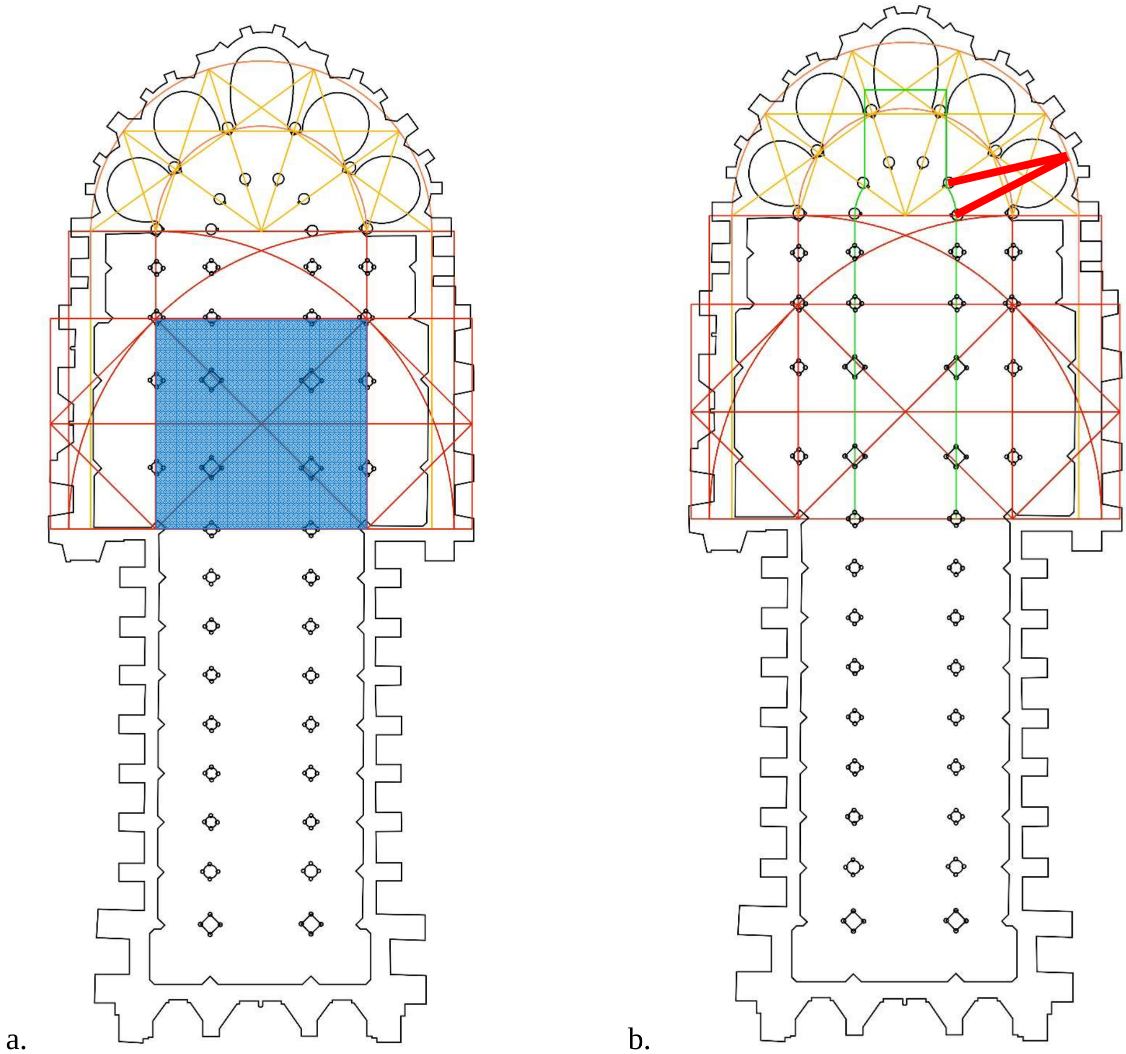

Fig. 7. a) New plan of Reims Cathedral with geometry of transept and crossing. b) New plan with hemicycle geometry and measured hemicycle rays.

The laser measurement data supports Bork and Wu's initial geometric hypotheses regarding the east end. Logically, it makes sense that five chapels arranged in a semi-circular order correlates to a half-decagon. Measured rays, shown in red, taken from the glass plane of the middle lancet window in each chapel to the center of each hemicycle column were used to establish the chevet's overarching geometric layout. When a circle is circumscribed around these points, the circle closely matches the outside perimeter of the choir walls.

ANOMALIES IN THE SOUTHERN CHAPEL: A CASE STUDY

The new plan also enables us to distinguish between designed quirks and actual mistakes. One such mistake can be seen in the chevet, specifically in the anomalies present in the southernmost chapel, dedicated to the Virgin Mary. Overall, the builders were incredibly careful when they laid out Reims's chevet; however, the southern chapel is shallower than its neighbors measured from its back wall to the ambulatory, and it measures nearly 40cm wider across its interior than its northern counterpart. The ambulatory pier on the southwest corner of the chapel is placed too far to the north and too far eastward so that it hooks into the chapel space, creating a slightly horseshoe-shaped entrance to the chapel. One consequence of this displaced ambulatory pier is that the corresponding hemicycle pier also shifts slightly. As a result, the hemicycle appears more horseshoe-shaped than truly semicircular, something

Nancy Wu has long observed [Wu 2008; Wu 1996]. Additionally, the champenois passage along that wall makes an exaggerated turn and requires a bent, angled passage to access the south-side straight bay chapel (Fig. 8).

Fig. 8. Bent champenois passage in the southern-most chapel.

The southern chapel is also significantly rotated on its base, so that it sits twisted clockwise. Each chapel has a step, which runs around the interior wall and upon which rest the engaged colonnettes decorating the wall surface. In every other chapel, the depth of the step remains largely unchanged; however, the Virgin chapel step varies significantly, running from 4.5cm deep to 17.0cm deep. On the exterior of the chevet, the upper portions of the minor buttresses on the Virgin chapel are pushed to the west side of their bases and the windows are situated off kilter, indicating that the chapel superstructure had to rotate to meet the straight-bay wall (Fig. 9a).

a.  b. 

Fig. 9. Buttress anomalies in the south chevet: a) twisted minor buttress on exterior of southern-most chapel b) displaced buttress on the south side of the choir.

The most critical anomaly is found at the base of the chevet. Comparatively, the south-western-most chevet buttress visibly does not align with its neighbors, sitting substantially inboard (Fig. 9b). The dimensions of the south-western-most buttress also do not correspond with the measurements taken from its northern counterpart. For example, the eastern faces of these buttresses, measured from the exterior wall surface to the outside edge also has a 20cm discrepancy, measuring 2.81 m on the south and 3.05 m on the north.

The rotation, caused by the displacement of the south-western-most buttress and indicated by the mismatched dimensions, impacts the design of the cathedral to some extent and creates other anomalies in the transept and nave zones. These visible anomalies might represent a solution to the construction problems that developed on the north side. Dendrochronological evidence from the northern ambulatory piers suggests that construction started on the north side of the chevet [Prache 2008; Tegel and Brun 2008]. The north-western-most buttress is only 10cm off from the location predicted by our postulated ideal geometry—a subtle divergence that likely would have gone unnoticed by the masons. However, the displacement grows as the chevet turns, and by the time construction starts on the southern chapel, the chapel profile must twist significantly to meet the straight-bay wall, explaining the severe offset visible in the southern buttress and the warped minor buttress in figure 9.

THE GEOMETRY OF THE TRANSEPT AND NAVE

The layout of the transept, shown in red (Fig. 10) is also based on the crossing square, the diagonals of which unfold to mark the exterior boundaries of the walls, while a double square struck from the central axis of the crossing square locates the edges of the transept buttresses. Once again, the measurement data taken from the building correlate closely with the predicted geometry. The ideal geometry suggests that the total width of the double square framing the exterior faces of the major buttresses should be 62.04 m, in close conformity with the aggregate measurement data taken from the transept's western end. The eastern side of transept do not match the predicted dimensions because the north transept façade was redesigned during construction and the portals are situated 1.04 m inboard of the western transept buttress (Fig. 11). The transept also provides a continuous geometric link between the nave and chevet layouts, supporting the notion that a single, master plan governed the cathedral's layout and proportions.

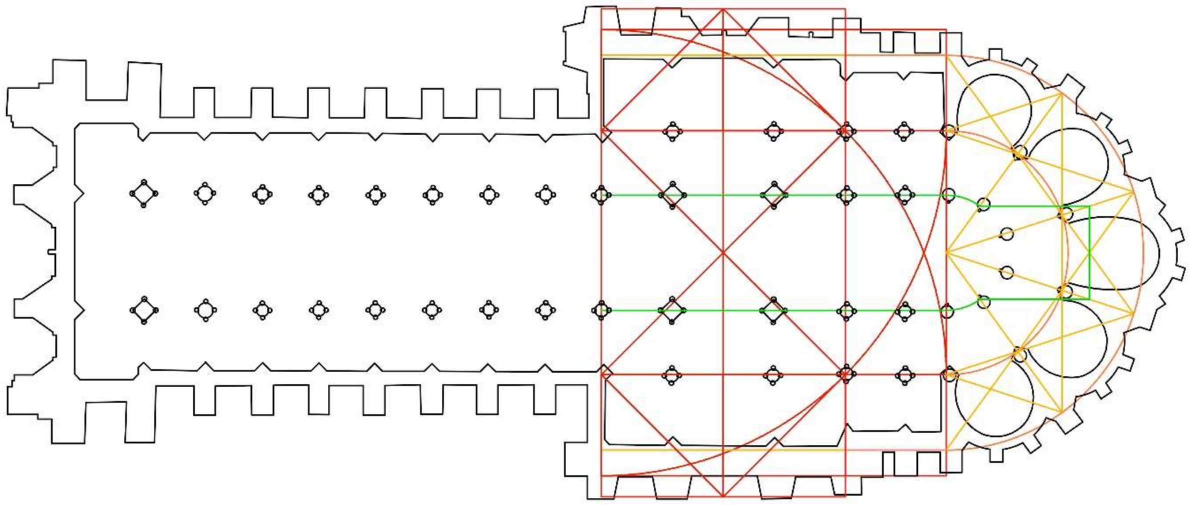

Fig. 10. New plan with geometric analysis of transept.

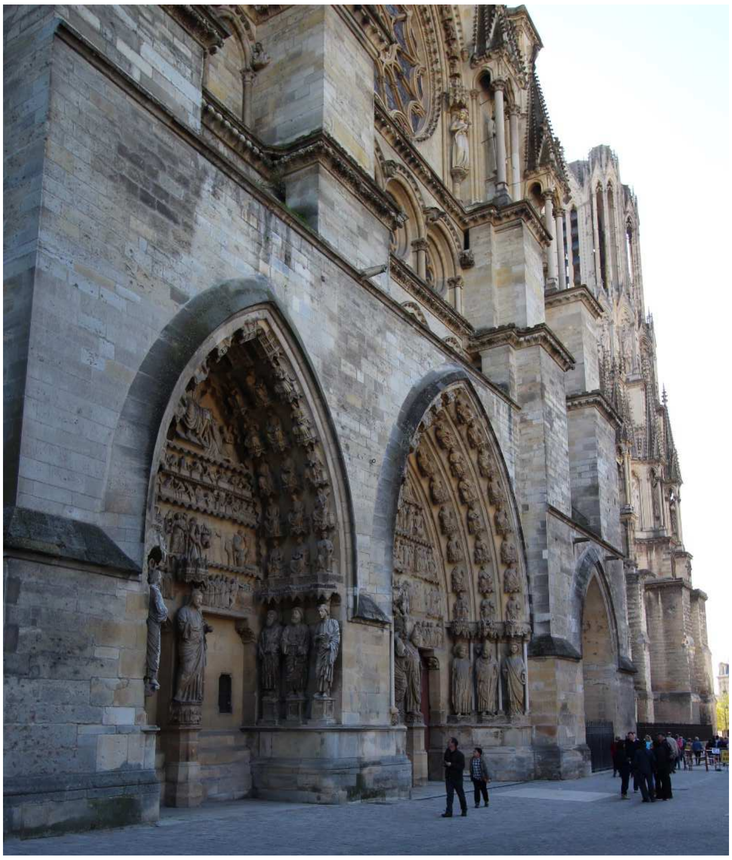

Fig. 11. North transept façade, Reims Cathedral.

The nave layout begins from an octagon, the sides of which equal the 14.65 m width of the nave vessel, situated on the western edge of the transept double square. The total height of this octagon will be 35.36 m. A series of circumscribed and inscribed octagons and circles, a process Robert Bork has termed octature, establishes the major elements of the nave walls: taking one octature inward from the primary octagon locates the glass plane, as shown in figures 12 and 13. The next two inscribed octatures set the surface of the inner wall plane above the respond steps and the profile of the wall responds in the side aisles. The actual distance between the glass planes, measuring 32.68 m, comes extraordinarily close to the predicted width of 32.67 m, which is twice the 16.33 m distance from the building centerline shown in figure 13.

The nave octagon structure (Fig. 12])also holds the key for determining the length of the nave and the proportions of each individual bay. A Golden Rectangle can be unfolded from the half-diagonal of the square framing the original octagon, as the yellow arc in figure 13 shows. Since the square measures 35.36 m on a side, and since the proportions of a Golden Rectangle are 1.618:1, the long side of the rectangle measures 57.22 m. This length approximately matches the total length of the nave, excluding the larger bays at the east and west that correspond to the transept aisles and western towers, respectively. Since there are eight regular bays in this section, the theoretically predicted bay length would be 7.16 m from pier center to pier center. The measurements in the three bays closest to the crossing, which were likely constructed first in the nave sequence, closely match this ideal figure, measuring 7.22, 7.19, and 7.17 m. The nave bay lengths get longer as construction moved west after the first three bays, particularly after the coupure in the fourth nave bay [Villes 2009], which historians have long acknowledged as the point where construction stopped, perhaps due to the 1233 civic revolts.[2] After the revolts ended in 1236, construction started anew, and the architect was careful to bring the building back to plan in the west block.

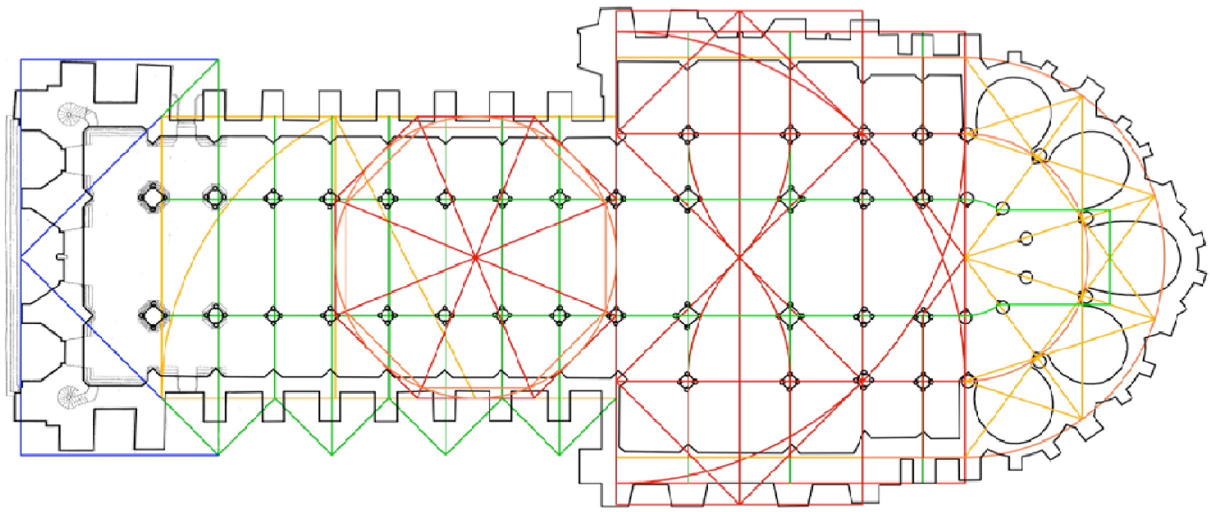

Fig. 12. New plan of Reims Cathedral with full geometric analysis.

In 2013, Robert Bork determined that the geometry of the elevation [fig. 13] is based on the same octature pattern as the nave’s horizontal dimensions and uses the Golden Section in an identical manner [Bork 2013]. By using the Golden Section in the elevation, the arc hits the roof line precisely. The nave elevation and the design for the west façade also link into the nave geometry, showing that the uniform design extends through every aspect of the cathedral on both the horizontal and vertical planes.

[2] Some scholars have concluded that this break coincides with the end of the Carolingian nave and the break occurs because they planned a different west façade design. For information about the 1233-1236 civic revolts, please see Barbara Abou-el-Haj. 1988. The Urban Setting for late Medieval Church Building: Reims and its Cathedral between 1210 and 1240. *Art History*, 11, 1, 17-41.

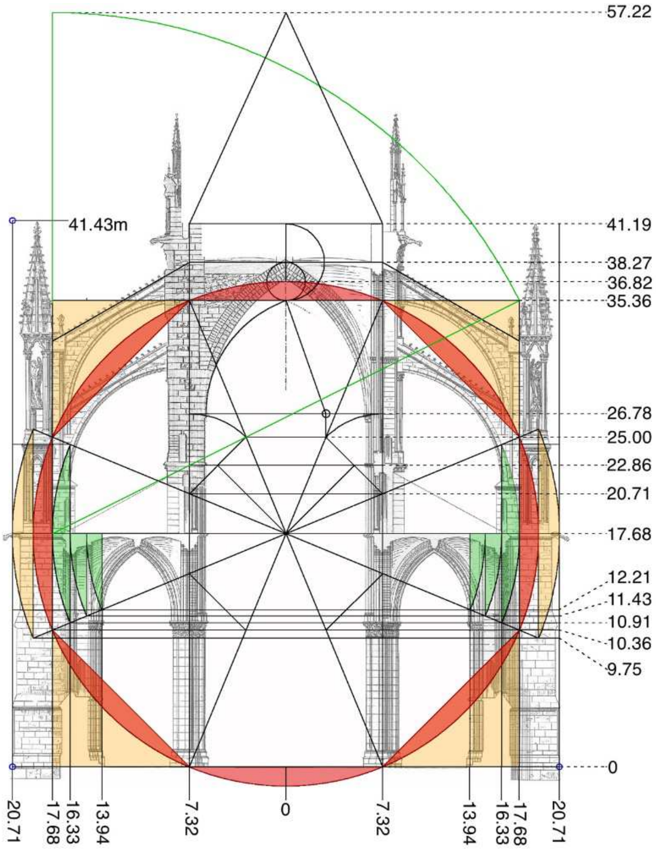

Fig. 13. Geometric analysis of Reims's elevation [Bork 2013].

Due to the current restoration efforts on the west façade's grand rose and sculpture, Bork and I combined the hand measurements, laser data, and Richard Hamann-Maclean's excellent survey of the west facade, which you can see layered along the bottom of the plan, to determine the details of the west block in figure 12 [Hamann-Maclean and Schüssler 1993]. The precision afforded by the laser and the measurements we took on the interior of the west façade, allowed us to precisely align Hamann-MacLean's façade plan accurately and determine the geometry of the west block and its link to the rest of the cathedral's design. The west block geometry directly links to the scheme determining the individual bay length. A double square, shown in the blue system, struck from the apex of the western-most 45-45-90 green triangle, marks the end of the cathedral and precisely hits the top of the front steps and the edge of the buttresses flanking the central portal. Thus, although construction of the west façade likely started after 1252 [Kurmann 1987; Salet 1967], almost half a century later than the onset of construction in 1207, and uses a different aesthetic in its decorative elements, the last master mason was careful to re-impose the geometrical order conceived by Reims's first architect.

In conclusion, the continuity present throughout the cathedral's geometry strongly indicates that a single, uniform plan governed the building. No doubt, each of the men named in the labyrinth enacted his own aesthetic decisions and introduced minor alterations to the design, such as the change in capital articulation or the implementation of the Rayonnant style in the west façade; however, each architect generally adhered to the design concept established at the onset of construction. Thus, the layout of the entire building, in terms of the proportions, nearly all the main heights and widths, and the overall spatial design, was the creation of the cathedral's first architect.

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