Peregrinations: Journal of Medieval Art and Architecture

Volume 5 | Issue 4 1-40

2016

Practical Demands and Experimentation: Fabricating the Romanesque and Gothic Hemicycle Arch

Cynthia Marie Canejo
University of North Carolina, Ashville

Peregrinations: Journal of Medieval Art & Architecture
Vol. V, No. 4 (Autumn 2016)

Practical Demands and Experimentation: Fabricating the Romanesque and Gothic Hemicycle Arch[1]

By Cynthia Marie Canejo, PhD, University of North Carolina at Asheville

Through an investigation of the Romanesque and Gothic hemicycle arch, I will address particular construction requirements whose significant implications have not been previously recognized or examined. The recognition of the specific production constraints of the hemicycle arch as well as the distinct solutions developed by various designers allows us not only to distinguish the approaches of medieval builders to construction challenges, but also to better understand the reason for their choices. Physical evidence indicates that practical needs for fabricating a hemicycle arch had a key impact on aesthetic transformations that took place by the thirteenth century. The ramifications of this study change traditional perceptions of the

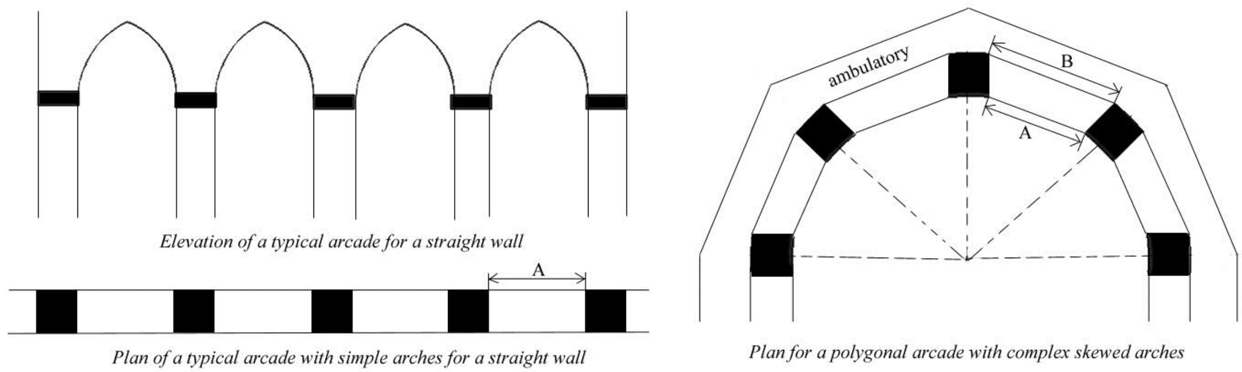
[1] This research was made possible by support from UNCA: a University Research Council Intramural Faculty Fellowship, research funds from the Belk Distinguished Professor, and Department of Art and Art History Travel Funds. Drafts of this paper were presented at the 46th International Congress on Medieval Studies, Cistercian Studies session, Kalamazoo, 12-15 May 2011, and the All Things Stone Colloquium: New Research into Masons and Sculptors during the Twelfth and Thirteenth Centuries, University of Wisconsin-Whitewater, May 9-11, 2011. Special thanks to the intense discussion led by noted medievalist, John James, and developed by scholars at this colloquium including: Vibeke Olsen, Roger Stalley, Janet Snyder, Chris Henige, and Tessa Garton. I am particularly grateful for the advice and assistance of C. Edson Armi; Christian Sapin, Gilles Févre, and the Centre d'Études Médiévales, Auxerre; Jean-Luc Benoit; Mayor Leroyer of Pontigny; Mayor Gendraud of Chablis; Monsieur Simonnet; Monsieur de Vaucorbeil; Pére Ponsot; Fabien Giclat; Abbé Rousseau and Neif Butara; Monsieur Aymar de Virieu, Administrateur, and Monsieur Vasseur, Archéologue, Châalis; the Archives départementales de l'Yonne, Auxerre; the Médiathèque des Monuments Historiques, Paris; the Bibliothèque Municipale, Auxerre; and the Bâtiments de France, Auxerre. Additional thanks to George Dexter for on-site assistance as well as offering challenging questions, to David Bates for pertinent comments and suggestions, and to the anonymous readers for rigorous perusal of this text.

development of Gothic form by shifting perspectives toward practical demands as a key factor in design modification.

Previously, scholars have questioned whether Gothic architectural transformations were generated by production needs, visual appeal, or structural considerations.[2] By initiating a similar inquiry focused on one particular design element, I have found that the arrangement of the hemicycle arch during the medieval period was modified for reasons other than the purely aesthetic or strictly structural: changes were instigated by practical demands encountered during construction. In due course from Romanesque innovation to Gothic transformation, builders experimented with methods for constructing hemicycle arches in order to find a suitable solution to an unusual construction problem.[3] During these periods, a polygonal or semi-circular apse with an ambulatory was typically erected with an arcade encircling the altar area, a layout that led to hemicycle arches unique in design and construction.[4] With this arrangement, builders had to take into consideration the curve or angle of the hemicycle arcade when designing the arches, and this requirement gave rise to an unusual type of skew or oblique arch (note that a skew or

[2] Erwin Panofsky, *Gothic Architecture and Scholasticism* (Latrobe, PA: Archabbey Publications, 2005 [1951]); Virginia Jansen, "Dying Mouldings, Unarticulated Springer Blocks, and Hollow Chamfers in Thirteenth-Century Architecture," *Journal of the British Archaeological Association,* 135 (1982): 35-54; Peter Kidson, "Panofsky, Suger and St Denis*," Journal of the Warburg and Courtauld Institutes* 50 (1987): 1-17; Charles Radding and William Clark, *Medieval Architecture*, *Medieval Learning: Builders and Masters in the Age of Romanesque and Gothic* (New Haven,: Yale University Press, 1992); Robert Bork, Robert Mark, and Stephen Murray, "The Openwork Flying Buttresses of Amiens Cathedral: 'Postmodern Gothic' and the Limits of Structural Rationalism," *The Journal of the Society of Architectural Historians* (1997): 478-493; Christian Freigang, "Changes in Vaulting, Changes in Drawing. On the Visual Appearance of Gothic Architecture around the Year 1300," in *The Year 1300 and the Creation of a New European Architecture,* eds., Alexandra Gajewski and Zoë Opacíc (Turnhout: Brepols, 2007), 67-77; Santiago Huerta Fernández, "Technical Challenges in the Construction of Gothic Vaults: The Gothic Theory of Structural Design," in: *Construction Techniques in the Age of Historicism*: *From Theories of Gothic Structures to Building Sites in the 19th Century* (Munich: Hirmer, 2012), 163-195.
[3] Arcades adjoining ambulatories were used earlier, especially in centrally-planned works. This paper will focus only on Romanesque and Gothic examples.
[4] Semi-circular apses with an ambulatory and their particular configurations will be discussed in a future article.

skewed arch, "an arch whose vertical sides are not at an angle of 90° to its face," is generally noted as synonymous with an oblique arch).[5]



(■ black squares and rectangles indicate abacus blocks)

Figure 1 General layouts: a straight arcade (at left) and a polygonal hemicycle arcade (at right). Photo: author.

A comparison of a typical arch in a straight arcade and a complex atypical skew arch in a polygonal arcade will help to clarify the conditions. Generally, the intrados (inner curve) of an arch in an arcade would be aligned perpendicular to a straight wall **(fig. 1, left)**. In a hemicycle, however, the arcade is positioned in a polygonal shape **(fig. 1, right)**. Since the standard 12th-century method was to align the front face of a square-edged abacus of each capital (the solid black squares in figure 1) perpendicular to hypothetical lines radiating from the center of the apse,[6] builders had to find a way to construct an arch to correspond to a space that is wider on the ambulatory side **(fig. 1)**.

The employment of ashlar voussoirs instead of rubble arches in hemicycle arcades designed with monolithic or multi-drummed columns, especially during the twelfth century, required builders to either construct a complex skew arch or find an alternative solution. Builders used varied solutions from fairly simple decisions to well-thought out and innovative

[5] Cyril M. Harris, *Dictionary of Architecture and Construction* (Fourth Edition, McGraw-Hill, 2006), 895.
[6] Shaped abaci were often used to the same effect (discussed later).

arrangements based on their knowledge, skills, or aesthetic choices.[7] It is important to note that, even though the type of arch differed at each site, the hemicycle arcades encountered diverged little from each other in general visual appearance.

In attempting to deliver an adaptable, efficient, and stylish solution to this construction challenge, physical facts indicate that, by the 13th and 14th centuries, many builders abandoned the hemicycle design featuring drummed or monolithic columns and employed a new type of Gothic pier, in Rayonnant style, to create an innovative arrangement that unified profiles of the arches, ribs, and supports. This design revision resulted in a sophisticated appearance and a clever arrangement that integrated profiles into a continuous molded arch and support and made the earlier need for complicated templates for cutting the stone voussoirs superfluous.[8]

Working out the complications of the hemicycle arch construction led me to conclude that the modifications in design were related to factors of production. Evidence suggests that aesthetic preferences were not the major motivating factor behind the builder’s selection of an appropriate solution to the construction challenge encountered. Consequently, in regard to modifications to the Gothic hemicycle arch design, I contend that the practical process of construction seems to have eventually brought about significant changes in aesthetic choices by the 13th century.[9]

Since my reasoning relies heavily on issues of stereotomy and geometry, the following discussion focuses on pertinent scholarship that sheds light on the requirements for, and setup of, the hemicycle arch. Subsequently, the six groups of hemicycle arch types investigated (selected

[7] It may become clear that funding or patronage was also a factor, but so far regional influence does not seem to have affected the variety of arrangements.
[8] On the developments leading to the introduction of the continuous molded arch in the thirteenth century, see Freigang, “Changes in Vaulting, Changes in Drawing,” 67-77.
[9] Rayonnant style has been dated by Jean Bony to begin around 1230 (a suggested end-date is often 1350 when we again see a change in style called Late Gothic or Flamboyant architecture).

from churches in the Paris basin) will be presented, with at least one representative arch from each group analyzed using photos, layouts, and/or plans. In this way, the reader becomes gradually immersed into the complexities and subtleties of the construction of the hemicycle arch and is able to fully grasp the nature of the changes.

Past Scholarship: From the Hemicycle and its Arch to Issues of Geometry and Stereotomy

Despite the extensive focus on the arch and related structural systems over the years, scholars have neither touched on the identifiable variations evident in the design and construction of the hemicycle nor addressed the relation of the hemicycle arch to the curve (or angle) of the ambulatory.[10] Researchers of Gothic architecture have examined a variety of aspects of the arch including shape and origin of design,[11] while structural engineers have investigated the masonry arch in order to arrive at conclusions about stability and behavior under various and variable conditions. The interest in the arch by engineers, architects, and other

[10] Stefaan van Liefferinge, "The Hemicycle of Notre-Dame of Paris: Gothic Design and Geometrical Knowledge in the Twelfth Century," *Journal of the Society of Architectural Historians*, 69/1 (2010): 490-507) laid out the design of the hemicycle at Notre-Dame, Paris. Even so, he didn't comment on the complex geometrical considerations necessary for building the stone hemicycle arch. C. Edson Armi, "First Romanesque Wall Systems and the Context of the Ambulatory with Radiating Chapels," *Journal of the Society of Architectural Historians*, 65/4 (Dec., 2006): 494-519) has investigated ambulatories in hemicycle arrangements, but did not address the skewed configuration of the hemicycle arch. Viollet-le-Duc discussed the hemicycle (*rond-point*) in his *Dictionnaire de l'architecture médiévale*, vol. II (Paris: Bibliothèque de l'Image, 1997 [1854-68]), without discussing the specific requirements for the hemicycle arch. For works on the ambulatory, see André Rhein, "Étude sur les voutes des déambulatoires," *Bulletin Monumental* 82 (1923): 255-290; Hans Reinhardt, "Hypothèse sur l'origine des premiers déambulatoires en Picardie," *Bulletin Monumental* 88 (1929): 269-288; Fr. M.-Anselme Dimier, "Origine des déambulatoires a chapelles rayonnantes non saillantes," *Bulletin Monumental* 115/1 (1957): 23-33.

[11] On the arch, see Lon R. Shelby, "Setting Out the Keystones of Pointed Arches: A Note on Medieval 'Baugeometrie,'"*Technology and Culture* 10/4 (Oct., 1969): 537-548; Camilla Edwards and David Edwards, "The Evolution of the Shouldered Arch in Medieval Islamic Architecture," *Architectural History*, Vol. 42 (1999): 68-95; C. Edson Armi, (*Design and Construction in Romanesque Architecture: First Romanesque Architecture and the Pointed Arch in Burgundy and Northern Italy* (Cambridge: Cambridge University Press, 2004]); Peter Draper, "Islam and the West: The Early Use of the Pointed Arch Revisited," *Architectural History* 48 (2005), 1-20; John James, "The Peaked Arch and the Earliest Domical Rib Vaults in the Paris Basin," *Avista Forum Journal* (Fall 2005): 3-7.

scholars ranges from structural limitations of the arch to problems of statics and equilibrium.[12] Specifically relevant are the scholars specializing in stereotomy or descriptive geometry who have examined the geometric layout of elements such as arch voussoirs.[13]

With regard to shaping stones, Giovanni Mocchi noted that 18th-century stereotomists tried to prove that geometry (and rationality) lay behind the development of architecture even though practical builders often found the results of stereotomists to be incomprehensible due to the abstract nature of their works (e.g., few stereotomists clearly demonstrated the actual size or shape of the stone blocks);[14] nonetheless, a closer relationship seems to have existed between

---

12 John Fitchen, *The Construction of Gothic Cathedrals: A Study of Medieval Vault Erection* (Oxford: Clarendon Press, 1961); Jacques Heyman, *The Masonry Arch* (Chichester: E. Horwood, 1982) and *Arches, Vaults, and Buttresses: Masonry Structures and their Engineering* (Aldershot, Hampshire: Variorum, 1996); Rowland J. Mainstone, "Structural Analysis, Structural Insights, and Historical Interpretation," *Journal of Architectural Historians* 56/3 (Sept. 1997): 316-340; John Ochsendorf, "The Masonry Arch on Spreading Supports," *The Structural Engineer* 84/2 (2006): 29-36; Neil K. Burford, Fraser W. Smith, and Christoph Gengnagel, "The Evolution of Arches as Lightweight Structures – A History of Empiricism and Science," *Proceedings of the Third International Congress on Construction History* (Cottbus, May 2009). John A. Hodgson has reviewed a history of the scholarship on the arch in "The Behaviour of Skewed Masonry Arch Bridges," (Ph.D. diss., University of Salford, UK, 1996).

13 "Stereotomy," is the science or art of cutting solids into certain figures or sections (such as shaping stones into arches) or, as Sergio Luis Sanabria, "From Gothic to Renaissance Stereotomy: The Design Methods of Philbert de l'Orme and Alonso de Vandelvira," *Technology and Culture* 30/2 (1989): 266-299, here 266) emphasized, the "art of cutting solids precisely so their parts fit together tightly." Engineer, Joël Sakarovitch, "Stereotomy, a Multifaceted Technique," *Proceedings of the First International Congress on Construction History,* vol. I (Madrid, 2003): 69-79, here 69), considers the structural application; namely, a view of "stereotomy as part and parcel of the construction technique itself." In contrast, "descriptive geometry," developed by Gaspar Monge in the late eighteenth century, is the "science of graphic representation and solution of space problems." (Northeastern Oklahoma A & M College, 2012, accessed July 6, 2014, http://neo.edu/Academics/MathScience/Courses.aspx). It is more of a theoretical stereotomy, detached from its original function as a technique of construction [stone cutting] and in radical opposition to the stereotomy of the work site." Sakarovitch, "Stereotomy, a Multifaceted Technique," 75.

Works of interest include: Santiago Huerta Fernández, "The Use of Simple Models in the Teaching of the Essentials of Masonry Arch Behavior," in *Theory and Practice of Constructions: Knowledge, Means and Models. Didactis and Research Experiences* (Ravenna: Fondazione Flaminia, 2005), 747-761; Santiago Huerta Fernández, "Galileo Was Wrong: The Geometrical Design of Masonry Arches," *Nexus Network Journal: Architecture and Mathematics* 8 (2006): 25-51; Stella De Paola and Vincenzo Minenna, "Oblique Vaults," *Proceedings of the Third International Congress on Construction History* (Cottbus, 2009), 453-458.

14 Giovanni Mocchi, "The Relationship between Scientific Knowledge and the Building Achievements: The Evolution of Stereotomy in the Eighteenth and Nineteenth Centuries," *Proceedings of the First International Congress on Construction History,* vol. III (Madrid: Instituto Juan de Herrera, 2003), 1453-1461, here 1455, 1459. In addressing aspects that can be traced to Gothic construction, Enrique Rabasa Díaz, "Los arcos oblicuos en la traza de cantería," *EGA Revista de expresión gráfica arquitectónica* 2 (1994): 145-154, here 146) discussed the difficulty of extracting practical characteristics from the nineteenth century treatises on stereotomy. While numerous scholars will be addressed in this paper, a review of the history and development of stereotomy will not be attempted.

stereotomical texts and construction practice during the Middle Ages and the Renaissance.[15] How familiar were medieval masons with issues of geometry? Lon R. Shelby suggested that, although medieval builders and masons were probably not formally schooled in geometry, they may have picked up knowledge through apprentice/master relationships.[16]

Indeed, all periods of Gothic building reflect how mediaeval masons regularly applied geometrical formulae to problems of design and construction, and that these formulae consisted of series of rules and practical procedures in the manipulation of geometrical forms.[17] Villard de Honnecourt's 13th-century sketchbook may be the earliest example of these "practical procedures." Shelby has emphasized, however, that Villard's references to geometry may be better interpreted as "constructive geometry" (since it is not clear that masons understood the principles of practical geometry) which was accomplished through the use of tools of the trade—the compass, straightedge, and square—and would have sidestepped the need for mathematical or geometric calculations.[18]

Contemporary scholars, following the writings of the 19th-century architect, Eugène-Emmanuel Viollet-le-Duc, have often indicated that structural considerations led to innovations or new form(s).[19] While practical demands might include structural requirements, in the case of

[15] Relevant texts include: Werner Müller, "The Authenticity of Guarini's Stereotomy in his *Archittetura Civile*," *Journal of the Society of Architectural Historians* 27/3 (1968): 202-220; Lalbat Claude, Margueritte Gilbert, Martin Jean, "De la stéréotomie médiévale: la coupe des pierres chez Villard de Honnecourt," *Bulletin Monumental* 145/4 (1987): 387-406 and "De la stéréotomie médiévale : la coupe des pierres chez Villard de Honnecourt (II), " *Bulletin monumental* 147/1 (1989): 11-34; Michael T. Davis, "Stereotomic Drawings in the Villard Manuscript," *AVISTA Forum* 3 (1989): 13-14.
[16] Lon R. Shelby, "Geometrical Knowledge of Mediaeval Master Masons," *Speculum* 47/3 (July 1972): 395-421. See also Andrew Tallon, "Divining Proportions in the Information Age," *Architectural Histories* 2/1 (2014): 1-14.
[17] Lon R. Shelby, "Mediaeval Mason's Templates," *Journal of the Society of Architectural Historians* 30/2 (May 1971): 140-154, esp. 154.
[18] Shelby, "Geometrical Knowledge," 409, 420.
[19] Discussing structural or rational thinking and innovation, see Robert Mark and David P. Billington, "Structural Imperative and the Origin of New Form," *Technology and Culture* 3/.2 (April 1989): 300-329. On the "limits of structural rationalism," see Bork, Mark, and Murray, "The Openwork Flying Buttresses of Amiens Cathedral," 478-493.

the hemicycle arch, we seem to be looking at practical changes which are less-structural and related more to design, particularly the cutting of the stone blocks (or stereotomy).[20] John Ochsendorf indicated that the modifications to the hemicycle arch would be more relevant to stereotomists than structural engineers since "the shape of the stones has a very minor effect on the flow of forces in the structure, so the choice of joint geometry is probably more related to the construction process."[21]

Concerning the specific type of arch required, contemporary stereotomists, such as Enrique Rabasa Díaz and José Calvo López, have discussed an arch similar to the hemicycle arch: a variation on the skew or oblique arch.[22] In *Guía práctica de la Estereotomía de la piedra*, Rabasa introduced a variant of the oblique arch called a *cuerno de vaca* (cow horn), trapezoidal in plan and constructed using two arches of equal size for the intrados, that is very close to the complex construction of the hemicycle arch.[23]

A variation of this arch, the *cuerno de vaca de arcos desiguales* (cow horn of unequal arches)—designed by employing two round arches of unequal size—is central to this

---

[20] Suggesting connections between stereotomy and mechanics, see Danila Aita, "Between Geometry and Mechanics: A Re-Examination of the Principles of Stereotomy from a Statical Point of View," *Proceedings of the First International Congress on Construction History* (Madrid: Instituto Juan de Herrera, 2003), 161-170.

[21] Email communication with noted structural engineer, John Ochsendorf, August 18, 2008 and August 1, 2014.

[22] Enrique Rabasa Díaz, "Los arcos oblicuos en la traza de cantería," *EGA Revista de expresión gráfica arquitectónica* 2 (1994): 145-154; and his *Guía práctica de la estereotomía de la piedra* (León: Centro de los Oficios, 2007); José Calvo López, "Estereotomía de la piedra," In: *Master de Restauración del Patrimonio Histórico* (Murcia: Colegio de Arquitectos - Colegio de Aparejadores y Arquitectos Técnicos, 2005), 117-153.

Scholars, from the late 16th through the early 20th century, examined stone construction, especially the fabrication of the skewed or oblique arch. Relevant works include: Samuel Edward Warren, *Stereotomy: Problems in Stone Cutting, In Four Classes. I. Plane-Sided Structures. II. Structures Containing Developable Surfaces. III. Structures Containing Warped Surfaces. IV. Structures Containing Double-Curved Surfaces. For Students of Engineering and Architecture* (New York: J. Wiley and Son, 1875), Class III on "Structures Containing Warped Surfaces"; G.A.T. Middleton, *Modern Buildings, Their Planning, Construction, and Equipment*, (London: The Caxton Pub. Co., 1905), Vol.5, Chapter VIII on Arches – Circular on Plan, Oblique and Battered, especially "Arched Openings in Circular Walls;" and Clarence Ward, *Mediaeval Church Vaulting* (Princeton: Princeton University Press, 1915) on ambulatory vaults (Chapter IV). Other texts of interest include: E. W. Hyde, *Skew Arches: Advantages and Disadvantages of Different Methods of Construction* (New York: D. Van Nostrand, 1899); and Jacques Heyman, "La Coupe des Pierres," *Proceedings of the Third International Congress on Construction History*, (Cottbus, May 2009), 807-812; and Fitchen, *The Construction of Gothic Cathedrals*, 266-270.

[23] Rabasa (Díaz), *Guía práctica de la Estereotomía de la piedra,* 175.

investigation.[24] This configuration is found in the medieval hemicycle arch (except that the arch is often pointed rather than round): the arch on the ambulatory side **(fig. 2, in green)** is wider than the arch on the inner hemicycle side **(fig. 2, in red)**.[25]

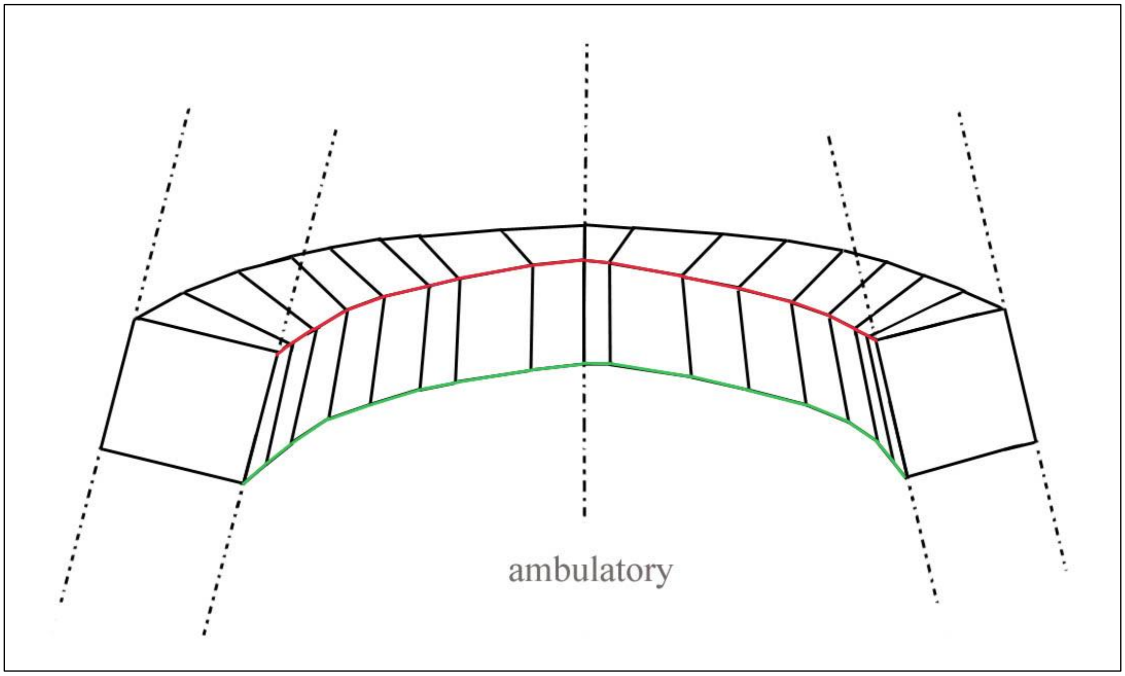


Figure 2 *Cuerno de vaca de arcos desiguales* (cow horn of unequal arches) or skewed pointed arch designed using unequal arch patterns, perspective view from under the arch. Photo: author.

Practical Demands, Aesthetic Choices, or Structural Leanings

The builders' decisions transformed the hemicycle during the Romanesque and Gothic periods. Romanesque hemicycle arcades often incorporated traditional colonnades (with a row of columns topped by capitals supporting arches).[26] In conforming to arch patterns of unequal size (*cuerno de vaca de arcos desiguales*), the employment of rubble and mortar with centering and

[24] See CAD 3-D images under *Regladas alabeadas anaxiales y axiales* (Anaxial and axial twisted ruled)*: Regladas axiales* (Ruled axial) using unequal arches placed axially: "Cad Projects: Especialistas en proyectos CAD," Cad-Projects España, 2011, http://www.cad-projects.org/4.2.1.5.2.1.2-superficies_regladas_alabeadas/index.php?art=1 (accessed January 2, 2016).
[25] Neither Rabasa (Diaz) nor CAD-Projects España have related these arch designs to medieval hemicycles.
[26] In most of the hemicycle column arrangements investigated, the capitals would have had square or squared abaci.

lag boards (instead of ashlar blocks) allowed some flexibility in raising the arcade arches and permitted them to be almost molded in place (see, e.g., **fig. 3**).

Once builders turned to using stone voussoirs, fabricating and erecting each hemicycle arch became much more involved. In carving these designs, each voussoir must be skewed along the intrados in order to have both sides of the arch meet precisely at the keystone; consequently, multiple skewed templates would have been necessary for one arch.[27]

Data gathered onsite from selected 12th and 13th-century churches with hemicycles in the Paris basin reveals that builders had been searching for a simpler, more-flexible method. By 1300, an entirely new setup for a Gothic hemicycle arcade was devised with a novel integrated design where the profiles of the supporting elements were integrated directly into the arches (seen in the Rayonnant style).[28] The resulting continuous molded arch and support both efficient in construction and easily altered for use in diverse building designs.[29]

Aesthetic and practical consequences also were taken into consideration when modifying the design of 13th-century hemicycle pier arrangement (including the arch molding profiles).[30] For example, Freigang wrote that, on the Rayonnant façade of Cologne Cathedral, "the design reconciles the technical problems of the structure with the requirements of visual appearance."[31]

[27] When constructing multiple arches of equal size in one building, one set of templates could be reused for the entire hemicycle arcade. Naturally, if a change in size or layout of the hemicycle arcade was desired for a new building, new templates would be generally required.
[28] This change usually takes place with the elimination of the capital with a square or polygonal abacus (although this was not always the case). See also fig. 29.
[29] The continuous molded arch and support will be discussed in more depth later in this paper.
[30] For a discussion of aesthetic desires and utilitarian needs related to Rayonnant and Late Gothic styles, see Jansen, "Dying Mouldings," and Freigang, "Changes in Vaulting, Changes in Drawing." Panofsky had earlier addressed this subject eloquently in *Gothic Architecture and Scholasticism*, esp. 56-79.
[31] Freigang, "Changes in Vaulting, Changes in Drawing," 75.

Alternatively, referring to the development of “dying” moldings during this same period,[32] Virginia Jansen has convincingly argued that:

> Builders have devised various solutions to fit mouldings onto a narrower springing or support below. Whereas some techniques are primarily functional, such as cutting one block of stone for each of the lowest courses of the joint, others such as the abacus serve as an element of design as well. A distinction between utilitarian and design usage cannot always be made, but sometimes what seems to have been a practical technique later became a motif used for deliberate visual effect.[33]

That is to say, construction practice that began as a workable solution to a technical problem may have been desirable for both practical and aesthetic or stylistic purposes. In support of the line of reasoning that the relation between production requirements and aesthetic concerns is also relevant for the hemicycle arch, the range of solutions envisioned by the builders follows.

Various Solutions to the Requirements for the Hemicycle Arch

Arch designs of selected hemicycles in the Paris basin can be grouped according to related construction techniques into six general categories (with variations within each): [34]

1. Simple Axial Skew Arch (Designed Using Unequal Arches)
2. Intrados NOT Parallel with Abacus Blocks (Designed Using Equal Arches)

[32] “Dying” moldings are moldings that seems to penetrate or disappear (i.e., they seem to “die out” or dissolve) into other supporting stones.
[33] Virginia Jansen, “Dying Mouldings,” 35.
[34] Color photographs documented the variety of configurations of hemicycle arch designs. While photos are advantageous for accurately representing physical connections, they are not only limited in their ability to show specific three-dimensional configurations of the overall design (especially since other elements are often in the way in photographs), but also ineffective in revealing stereotomical shapes or deformations. Note that the six categories are only roughly set in chronological order; the first five types can be found in both Romanesque and Gothic works. The sixth type is only found at sites built around 1300 or later. These arches could be grouped in other ways, but the categories were chosen in consideration of the consistency of the construction techniques and for ease in classification. While the employment of “dying” moldings could be considered as an additional group, the utilization of this technique often falls within one of the six groups. In an attempt to place Cistercian elements in a broader context (in line with my previous research), both Cistercian and non-Cistercian architecture are included as examples.

3. Shaped Abaci[35]
4. Complex Axial Skew Arch (Designed Using Unequal Arches)
5. Advanced Arch Construction
6. Continuous Molded Arch and Support

The First Group: Simple Axial Skew Arch (Designed Using Unequal Arches)

The first group, the Simple Axial Skew Arch (Designed Using Unequal Arches), generally has a rubble arch constructed over columns or piers in a polygonal or circular hemicycle arcade. Among the Romanesque examples is the church of Saint-Étienne at Vignory (Haute-Marne), a northern First Romanesque building constructed in frame and fill **(fig. 4)**, dated to *c*. 1050.[36]

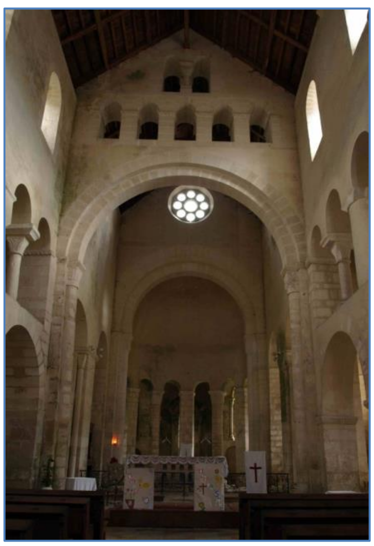


Figure 3 Vignory, Saint-Étienne, chevet, hemicycle arcade, view from ambulatory, capital at C2-3 (right). Photo: author.

[35] This category of various shaped abaci includes continuous capitals, engaged columns, and corbelled capitals.
[36] Armi, "First Romanesque Wall Systems and the Context of the Ambulatory with Radiating Chapels," 496, has dated the church around 1050. On Vignory, see Henri Focillon, "L'église Saint-Étienne de Vignory ses dates de construction," *Revue Archéologique*, Sixième Série, 10 (July-Dec. 1937): 73-89) who posits 1040-1050 (since the church was consecrated in 1050); François Deshoulières, "L'eglise de Vignory," *Bulletin Monumental* 88 (1929): 88-107, dated the church *c*. 1045, with the choir constructed after the nave.

In the hemicycle arcade of this church, the supports for the round arches alternate between drummed ashlar columns and coursed rectangular piers **(fig. 4, A-G)**.[37] The abaci are square-edged and the front faces are positioned at a 90° angle to lines radiating from the apse center, in the standard method.

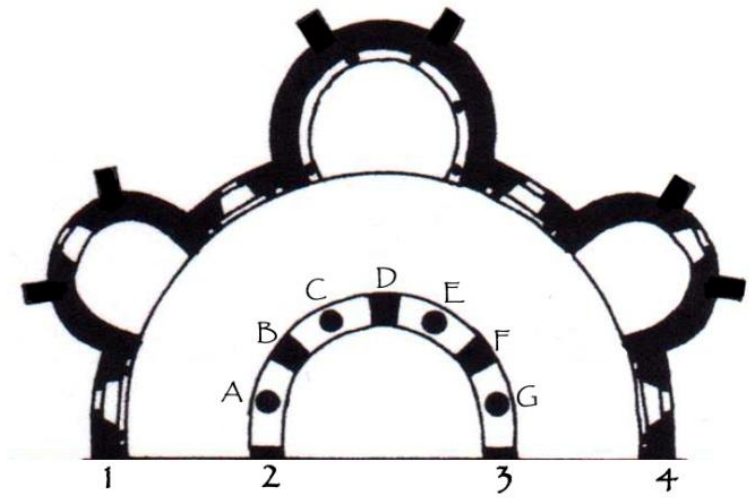


Figure 4 Vignory, chevet, hemicycle arcade, plan. Photo: author.

In order to accommodate the curve of the hemicycle as well as make sure that the lower edge of the arch intrados is aligned parallel to the square-edged abaci, the intrados of each arch is skewed (set at a progressive angle away from one side of the abacus) and the arches are designed from two unequal patterns (with a wider arch on the ambulatory side of the intrados). Since this is a rubble and mortar arch, rather than built of carefully shaped stone blocks, the twist of the intrados could easily have been formed using wood centering. This group shows a simple solution to a practical demand that does not change the visual appearance of the hemicycle arcade; while aesthetic choice controls the visual look of the hemicycle, the practical mechanics of raising the arch accounts for the modifications.

[37] The plan in figure 4 was modified following Armi's plan,"First Romanesque Wall Systems," 497.

The Second Group: Intrados NOT Parallel with Abacus Block

The second group, Intrados NOT Parallel with Abacus Block, can be clarified through the Early Gothic design of the chevet of Saint-Martin at Chablis (Yonne) **(fig. 5)**. The lower portion of the five-segment hemicycle arcade at Saint-Martin, dated to 1165-85,[38] eschews rubble; each hemicycle arch is cut from limestone blocks and lands on a monolithic column with a large capital. Similar to the chevet of Vignory, the standard method is used: the square abacus is set perpendicular to hypothetical lines radiating from the center of the apse (these lines follow the layout of the hemicycle rib vault at the clerestory level **(fig. 5, right)**.[39]

Oddly, the Saint-Martin builder did not adjust the arches to conform to the curve of the hemicycle (the hemicycle arches are built the same as the arches in the straight arcade—without skewing). Hence, the arcade turns around the polygonal hemicycle, but the intrados of the arch is NOT set parallel to the square edge of the abacus blocks (red lines in **fig. 6**). While the

[38] For dates of construction of the church of Saint-Martin at Chablis, see Cynthia Canejo, "Transforming Early Gothic Form: The Cistercian Church of Pontigny, Saint Martin at Chablis, and Northern Burgundian Architecture," (Ph.D. diss., University of California, Santa Barbara, 2005). On Saint-Martin at Chablis, Maximilien Quantin, "Mémoires pour servir à l'histoire des communes du département, Chablis," *Annuaire historique du département de l'Yonne* (1839): 296-316, esp. 297, and Jean Vallery-Radot, "Aspects et tendances de l'architecture religieuse dans les pays de l'Yonne jusqu-au début du XVII[e] siècle," *Congrès archéologique* (1958): 8-25, esp. 19, who dated the beginning of the ex-collegiate church of Saint-Martin at Chablis to the end of the 12th century. Abbé G. Bonneau. "La collégiale de Saint-Martin de Chablis," Extrait du *Bulletin de la Société archéologique de Sens*, XXX 1916-1918: 30-84, here 35) proposed 1160 for the earliest campaigns. Francis Salet. "Chablis," *Congrès archéologique* (1958): 197-213, esp. 205) believed that the initial construction took place after 1279. Robert Branner, *Burgundian Gothic Architecture* (London: A. Zwemmer Ltd, 1960), 12,3 following Salet, suggested 1212 for the beginning of the chevet. Elise Baillieul has reduced this date to 1170-1180 "Le chevet de la collégiale de Saint-Martin de Chablis," *L'architecture gothique à Auxerre et dans sa région (XIIe-XIXe siècles): naissance, transformations, et pérénnité,* ed. Timbert (Auxerre: Monuments historiques de l'Yonne, 2012), 33-41.

[39] The plan of Saint-Martin at Chablis was based on the 1849 plan by Emile Amé (Architect of the Monuments Historique and Architect in charge of the restoration of Saint-Martin at Chablis) and has been adjusted following on-site measurements and observations. In my work, the individual architectural elements have been carefully measured by hand using a variety of devices including a laser distance meter, square, angle finder, spirit-level, clinometer, plumb-bob, measuring tapes, and calipers. All measurements are verified using a second or third method (depending on the location of the architectural element, this is often accomplished through use of numerous photographs uploaded to the PhotoModeler 3-D photogrammetry program or through baseline offset, trilateration, and/or triangulation).

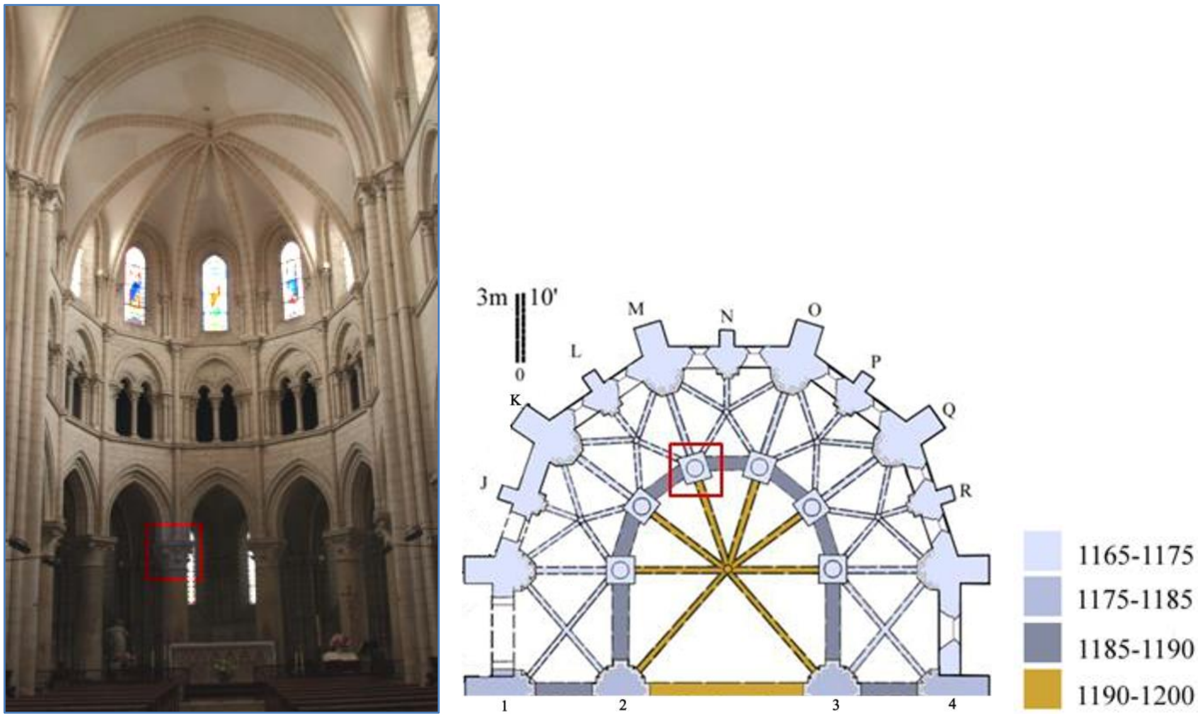


Figure 5 Chablis, Saint-Martin, hemicycle arcade, chevet view (left) and plan (right), column at M 2-3 in red. Photo: author.

arrangement overall looks less integrated than arches that have been skewed to fit (Vignory), the simplicity of the solution isn't really noticeable until pointed out to observers. This setup is not apparent to visitors because both the ribs of the ambulatory vaults and the colonnettes responding to ribs of the hemicycle vault land on the same abacus obscuring the lower portions of the hemicycle arch blocks. The top of the capital, too, was placed much higher than the head of the viewer, rising to over four meters.

'The hemicycle arch molding profile at Saint-Martin, Chablis, was common in the twelfth and thirteenth centuries **(fig. 6)**. Richard K. Morris noted the recurrence of certain moldings, adding that around 1140-1240, "The most common moulding for all types of arches was the angle roll…The classic High Gothic arcade consisted of two orders with angle rolls and a flat

soffit, popularized at Chartres Cathedral…It was remarkably persistent in the thirteenth century in France and French-influenced architecture elsewhere."[40]

Figure 6 Chablis, Saint-Martin, hemicycle arcade, chevet, column with capital at M2-3. Photo: author.

A version of this common molding of two orders with an angle roll (torus) at the corners is found at Chablis. The use of true geometrical forms (the circular tori) in the roll design was characteristic not only of the period, but also of the distinct workshop of the Yonne Valley builder.[41] In these works, the molding block is generally rectangular in shape with hollow quirks (rounded grooves or cavettos) flanking each circular angle roll and the intrados (soffit) is flat.

[40] Richard K. Morris, "An English Glossary of Medieval Mouldings: With an Introduction to Mouldings *c.* 1040-1240," *Architectural History* 35 (1992): 1-17, esp. 2.
[41] Cynthia Canejo, "The Yonne Valley Builder: An Identifiable Master Introducing a Unique Blend of Cistercian and Non-Cistercian Northern Burgundian Design to the Oise," *Peregrinations Journal of Medieval Art and Architecture*, Volume III, Issue 3, Summer (2012): 19-65.

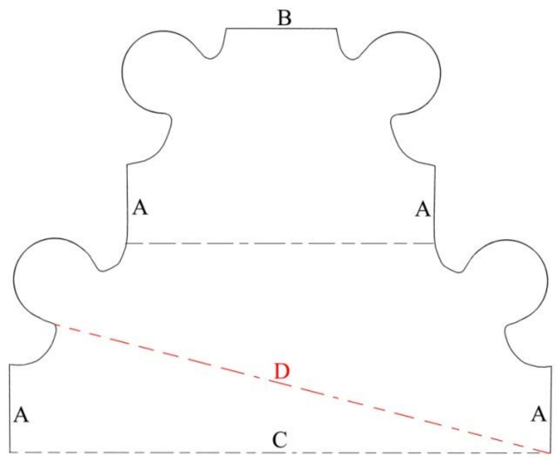


Figure 7 Chablis, Saint-Martin, hemicycle arcade, chevet, arch profile. Photo: author.

At Saint-Martin, each arch constructed in one of the five hemicycle segments corresponds to the rib vault **(fig. 5, right, fig. 7)**. The profiles of the arch block are positioned on the square abaci. While the intrados of the hemicycle arch was not placed parallel to the abacus block, the arch was constructed with the intention that the intradoses of the impost blocks on each side of the arch were parallel to each other **(fig. 8, B)**. The individual arch blocks for these polygonal bays were cut diagonally **(fig. 7, line D; fig. 8, arrows)** in order to allow the two blocks to butt up along the flat edge (D/D; **fig. 8**) and fit in a reduced space.

The Chablis arcade arrangement was designed and constructed as simply as possible; no complex templates were necessary (since the arch is not skewed). Here (as at Vignory), practical needs, working hand in hand with aesthetic choices, led to these modifications. Remarkably, while the builder chose ease of construction at Chablis, he did not introduce any significant aesthetic changes while devising the arrangement of the hemicycle arches; the hemicycle arcade remains visually similar to others raised during the period.

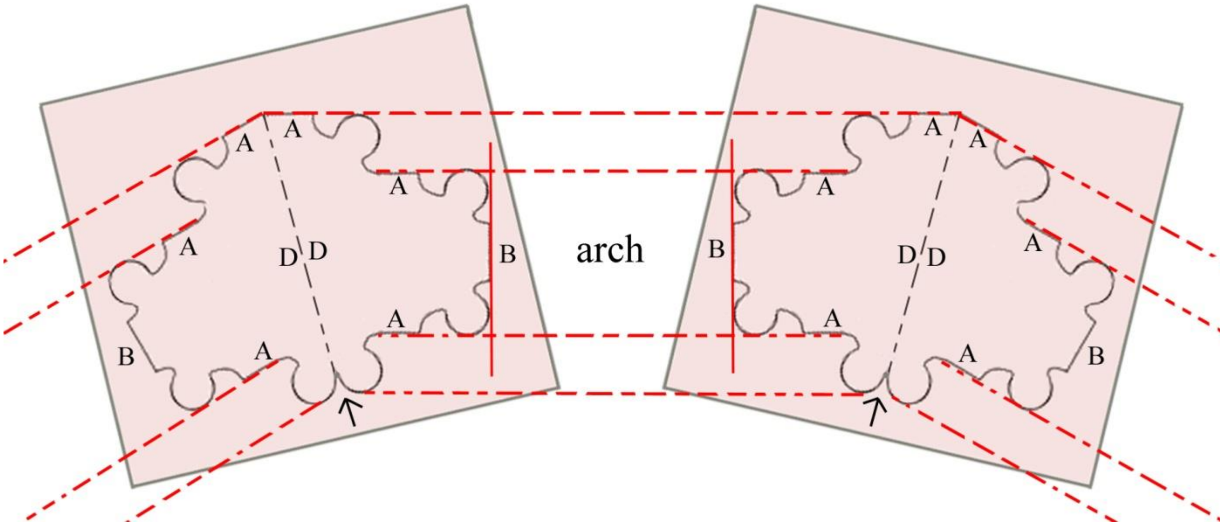


Figure 8 Chablis, Saint-Martin, hemicycle arcade, chevet, and abacus layout (with the correspondence in red). Photo: author.

The Third Group: Shaped Abaci

Figure 9 Vézelay, La Madeleine, view from the nave to the chevet (left) and the chevet hemicycle (right). Photo: author.

A fascinating case in point of the third group, Shaped Abaci, is evident at the church of La Madeleine at Vézelay (situated in the southernmost region of the Yonne Valley). In the late 12th century, a Gothic chevet was added to the Romanesque nave **(fig. 9),** where the arches of the five-segment hemicycle can be dated *c*. 1190-1200 **(fig. 10)**.[42] The plan of the east end of this church was prepared after those of Viollet-le-Duc and Francis Salet; in their plans of, or texts on, Vézelay, neither scholar mentioned the odd shape of the abaci on the monolithic columns of the hemicycle arcade **(fig. 11)**.[43]

Instead of adjusting the arches at Vézelay to conform to the curve of the hemicycle, the abaci were carved into unique shapes that, at a glance, give the viewer the illusion of a square block (especially when viewed from the choir) **(figs. 9, 11)**. The abaci are four-sided, but the design was modified so they are not squared (the sides are not set at 90° as those along the straight bays). Each abacus is curved on two sides **(fig. 11, A and B in red)** to follow the arc of the hemicycle arcade. While the other two sides are straight **(fig. 11, C and D in red)**, they are angled rather than parallel to each other (since the abacus is wider on the ambulatory side). Each

[42] Canejo, "Transforming Early Gothic Form," 258-260. On Vézelay, see: Maximilien Quantin, "Notice sur la restauration de l'église de la Madeleine de Vézelay," *Annuaire historique du département de l'Yonne* (1851): 265 and Charles Porée, "Vézelay," *Congrès archéologique,* Avallon (1907): 29, dating the chevet after the fire in 1165 to the end of the 12th century. Francis Salet, *La Madeleine de Vézelay, étude iconographique* (Melun: Librairie d'Argences, 1948), 82-83, dates the beginning of the chevet to 1185-1190, with completion after 1215. Lydwine Saulnier and Neil Stratford, *La sculpture oubliée de Vézelay*, Bibl. Société Française d'archéologie 17 (Paris: Arts et Métiers Graphiques, 1984), 135) dated the second campaign of the chevet reconstruction 1180-1215. In a dissertation meticulously measuring and recording elements of the chevet of Vézelay, Arnaud Timbert,"Le chevet de la Madeleine de Vézelay et le début de l'architecture gothique en Bourgogne," (Ph.D. diss., Université Franche Comte, 2001), published as *Vézelay: Le chevet de La Madeleine et le premier gothique bourgignon* (Rennes: Presses Universitaires de Rennes, 2009) re-dated the chevet to 1165-1175; yet, on-site evidence suggests that elements of the second chevet campaign are far too advanced for these dates.

[43] Eugène-Emmanuel Viollet-le-Duc, *Monographie de l'ancienne église abbatiale de Vézelay* (Paris: Gide, 1873); Francis Salet, *La Madeleine de Vézelay*. In his *Dictionnaire de l'architecture médiévale*, Viollet-le-Duc discussed oddly shaped abaci at the Langres Cathedral, IV, 70-71, fig. 37 and at Poissy, IX, 494-495, fig. 18, but not at Vézelay or Auxerre.

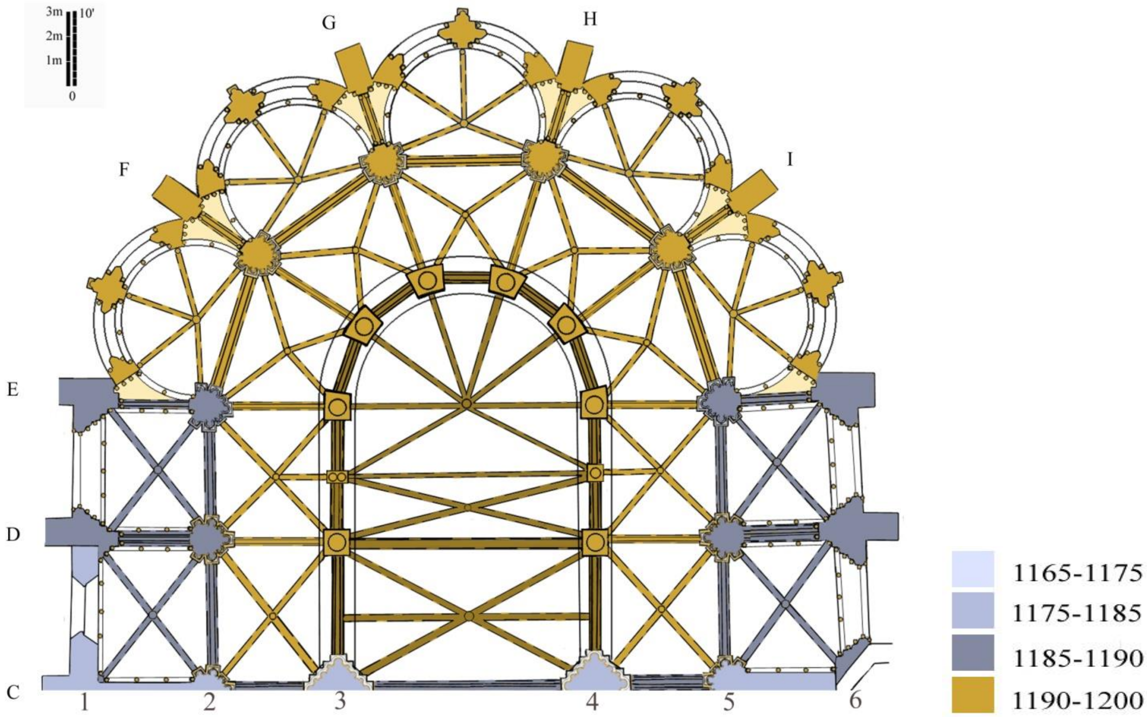


Figure 10 Vézelay, La Madeleine, chevet, plan. Photo : author.

of these two sides, however, is parallel to the closest side of the adjacent abaci (connected by the arches above) allowing for the construction of arches without skewing (as created for the straight bays). At Vézelay, these shaped abaci occur only in the hemicycle (conforming to the turn), not in the straight bays of the arcade (where the abaci are square-edged).

Another version of the Shaped Abaci is the massive eight-sided abaci found in the Gothic chevet of Saint-Étienne Cathedral at Auxerre (Yonne), *c*. 1215-1234 **(fig. 12)**.[44] Elevated high above the lower city, the east end of Auxerre Cathedral faces the Yonne River. This portion

[44]Charles Porée, "Auxerre," *Congrès archéologique* (1918), 167-198, esp. 169) dated the chevet to 1215-1234. Other scholars have followed this date for the beginning of construction. Jean Vallery-Radot, "La cathédrale Saint-Étienne. Les principaux textes de l'histoire de la construction," *Congrès archéologique* 116 (Auxerre, 1958) : 40-55; Robert Branner, *Burgundian Gothic*, 107; Harry Titus "The Auxerre Cathedral Chevet and Burgundian Gothic Architecture," *Journal of the Society of Architectural Historians* 47/1 (Mar., 1988): 45-56.

Figure 11 Vézelay, La Madeleine, chevet, hemicycle, column at I 3-4. Photo: author.

Figure 12 Auxerre Cathedral, Saint-Etienne, nave (left) and hemicycle (right). Photo: author.

of the church, which follows the disposition of the Romanesque crypt, includes a hemicycle arcade with six huge monolithic columns **(fig. 13)**.

As noted, the abaci on which the arches are seated have eight sides (or are octagonal). In a regular geometric octagon, all eight sides would be the same length and the internal angles would be identical. This is not true in the hemicycle at Auxerre Cathedral.[45] The irregular octagonal sides are not equal in length on each abacus, nor are the angles the same at each vertex; instead, each side was modified to conform to the needs of the hemicycle arcade and the structural elements that the columns support.[46]

Similar to Chablis, the tops of the abaci blocks are crowded and numerous items fall on each abacus for support. At Auxerre Cathedral, the abacus supports even more elements: two arches, two ambulatory ribs, an ambulatory transverse rib, and a thin column or respond (support) to the hemicycle vault rib.[47] The final abacus is awkwardly shaped; even so, the asymmetrical design is not really noticeable to the casual viewer especially because these capitals are so high—over six meters from the floor.

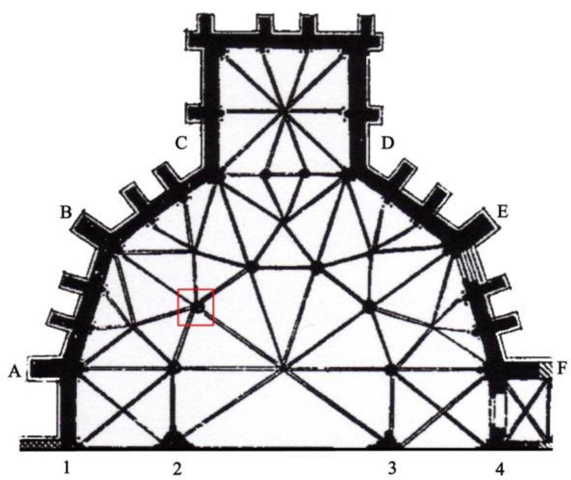


Figure 13 Auxerre Cathedral, Saint-Etienne, chevet, hemicycle, plan. Photo: author.

[45]While the irregular shape of the octagonal abaci was noted by Porée ("Auxerre," 174), he did not discuss the reasoning behind the design.
[46] In a regular octagon, the opposite sides are parallel. In the case of these abaci, only two sides seem parallel to each other.
[47] The profile of the hemicycle arch is the common one with angle rolls and a flat intrados similar to the one at Chablis.

One side of the abacus in the column capital[48] **(fig. 14, left, in red)** is much shorter than the length of either adjacent side **(fig. 14, left, in bright green)**. In this five-segment hemicycle, not only do the arches have simple intradoses that are parallel to each other, but also the abaci on which these arches land, have sides that parallel each other. Similar to Chablis, the hemicycle arches are not skewed. Here it is not necessary to adjust the arches since the octagonal capital abaci have been altered instead into irregular polygonal shapes that accommodate the arch and other supported elements.

Figure 14 Auxerre Cathedral, Saint-Etienne, chevet, monolithic column at B 2-3. Photo: author.

This type of capital with a shaped abacus also exists at the Cistercian abbey church of Ourscamp, founded in 1129 (Oise) **(fig. 15)**. The two-story Gothic chevet with a five-segment hemicycle was probably begun around 1232.[49] Today, the ruins of the church include a skeletal

---

[48] See fig. 13, B 2-3. This plan was modified from that of Charles Porée, "Auxerre," 175.

[49] See Caroline Bruzelius, “The Twelfth-Century Church at Ourscamp,” *Speculum* 56/1 (1980): 28-40, here 39. E. Lefèvre-Pontalis, "Ourscamp," 167, dated the rebuilding of the chevet with ambulatory to *c*. 1280. P. Héliot, "Le choeur gothique de l'abbaye d'Ourscamp et le groupe de Longpont dans l'architecture cistercienne," *Bulletin de la Société nationale des Antiquaires de France* (1957): 146-162, here 150, did not accept the dates of Lefèvre-Pontalis (noting that Lefèvre-Pontalis based his dates on style, not on documents), but instead suggested that the building campaign was begun around 1235-1255 under Abbot Guillaume.

chevet hemicycle sporting capitals with 13th-century crockets. With a design similar to capitals at Auxerre, the sides of the abaci at Ourscamp are not equal (and so do not form regular octagons) **(fig. 15, right)**. As at Auxerre, the abaci were designed to accommodate production requirements; at this church, the Cistercians were using an existing solution to meet the practical demands of constructing a hemicycle arch. In each case (Auxerre, Ourscamp, and Vézelay), the modifications do not follow from a desire to change the overall appearance of the hemicycle arcade, rather they relate to construction demands. Each builder has gone out of his way not to change the visual impression.

Figure 15 The third group, Shaped Abaci: Cistercian abbey church of Ourscamp, plan (left), hemicycle view (center), hemicycle capital (right). Photo: plan, after Lefevre-Pontalis, "Ourscamp," *Congrès archéologique* (Beauvais, 1905): 165-169 and photos, author.

The Fourth Group: Complex Axial Skew Arch (Designed Using Unequal Arches)

The fourth group, Complex Axial Skew Arch (Designed Using Unequal Arches), is found in the chevet of the Cistercian church of Notre Dame and Saint Edme at Pontigny (Yonne).[50] The

[50] Cîteaux, the mother-house, and her four daughters governed the Cistercian Order. Pontigny was the second daughter. Jean-Luc Benoit, "Pontigny, saint Edme, les moines et leurs voisins: L'abbaye cistercienne pendant la première moitie du XIII^{e} siècle,"*Mémoire de D.E.A sous la direction de Mme. P. L'hermite-Leclercq* (Paris IV-Sorbonne, 1997); Monique Peyrafort-Huin, Patricia Danz Stirnemann, and Jean-Luc Benoit, *La bibliothèque médiévale de l'abbaye de Pontigny* (Paris, CNRS Éditions, 2001).

new chevet of the church at Pontigny was probably begun in the 1180s **(fig. 16)**,[51] specifically, the hemicycle arcade seems to date to 1185-1190.[52] This seven-part, slender graceful hemicycle at Pontigny, derived from a heptagonal layout, has been discussed as “one of the apparently most enigmatic geometric figures particularly if we take into account that it is the basic layout for the apses of some Gothic cathedrals. The medieval architect therefore had to consider the problem of how to lay out seven chapels around the arc of a semicircle.”[53] The seven-part vault, as half of a fourteen-part circle, shows the knowledge of the geometrical layout available in the Middle Ages.

This is the first group where the hemicycle arch has a particularly complicated design. The designer and/or builder went to a great deal of trouble to keep the abacus block edge parallel to the lower block (impost) of the arch (where the capital abacus is set perpendicular to ribs in the clerestory hemicycle in the standard method radiating from the center) requiring the hemicycle arch to be adjusted or skewed along the face of the intrados **(figs. 17, left, 18)**. As noted earlier for complex construction, the curve of the intrados is constantly changing as the

[51] George Fontaine, *Pontigny, abbaye cistercienne* (Paris: E. Leroux, 1928), 33 and Terryl Kinder, “Clay and What They Did with It: Medieval Tiles and Bricks at Pontigny,” *Studies in Cistercian Art and Architecture* 4 (Kalamazoo: Cistercian Publications, 1993): 15-44, 198-219, esp. 34, dated the commencement of the chevet to *c*.1180. Frédéric Van der Meer, *Atlas de l’ordre cistercien* (Paris: Editions Sequoia, 1965), 292, and Anselme Dimier, *L'art cistercien, France* (La Pierre-qui-Vire (Yonne): Zodiaque, 1962), 304 suggested *c*. 1185.The right to unregulated use of stone at a Saint Bris quarry is often used to mark the first campaign of the chevet (Archives Départementales de l’Yonne, ADY H1518). Marcel Aubert, “Abbaye de Pontigny,” *Congrès archéologique* (1958): 163-168, esp. 164, dated it1185, mentioning this donation as proof. Jean Vallery-Radot, “Aspects et tendances de l’architecture religieuse dans les pays de l’Yonne jusqu-au début du XVIIe siècle,” *Congrès archéologique* (1958): 8-25, here 10, 19, claimed that Pontigny was built of stone from this quarry. André Philippe, “Pontigny, église abbatiale,” *Congrès archéologique* (1907): 199-204, noted the donation of the quarry in 1186; but speculated that the chevet was initiated, after 1170. Robert Branner, *Burgundian Gothic*, 163, dated the beginning of the chevet after 1186, “when a quarry is mentioned.”
[52] See the most recent dates suggested by Canejo, “Transforming Early Gothic Form,” 30-65.
[53] Josep Lluis i Ginovart, *et al*, “Gothic Construction and the *Traça* of a Heptagonal Apse: The Problem of the Heptagon,” *Nexus Network Journal* 15/2 (August 2013): 325-348, here 327. Lon R. Shelby, *Gothic Design Techniques: The Fifteenth-Century Design Booklets of Mathes Roriczer and Hanns Schmuttermayer* (Carbondale: University of Southern Illinois Press, 1977), 118-119; Peter Kidson, “Roriczer's Iceberg,” *Journal of the Warburg and Courtauld Institutes* 71 (2008): 1-20.

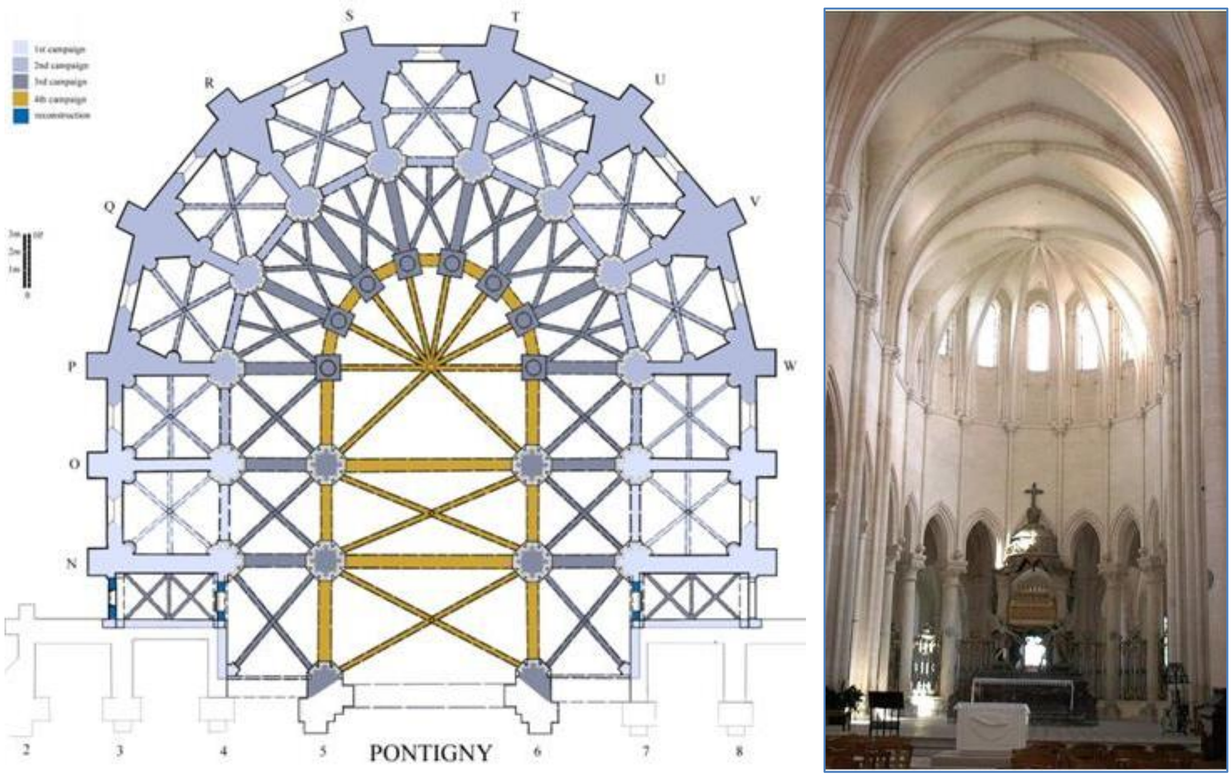


Figure 16 Cistercian church of Notre Dame and Saint Edme at Pontigny, plan (left) and chevet (right). Photo: author.

blocks are laid vertically (skewed inward in order to meet the other side of the arch smoothly at the apex); consequently, each voussoir would require a separate template.[54] Extensive pre-planning is necessary to make sure that the arch voussoirs meet at the top pair of keystones.[55]

On the plan at the right in **fig. 17**, the location of the arch and two columns, T5-6 and U5-6, are clarified in a red box.[56] Three reconstruction views of the arch at TU 5-6 **(figs. 18, 19)**

[54] For templates used as guides or patterns to cut profiles of sculpted architectonic elements in medieval construction, see Shelby, "Mediaeval Mason's Templates," 140-154; John James, *The Template-Makers of the Paris Basin: Toichological Techniques for Identifying the Pioneers of the Gothic Movement with an Examination of Art-Historical Methodology* (Leura, Australia: West Grinstead Press, 1989), esp. 33-36, 119-120; Richard Morris, "Mouldings and the Analysis of Medieval Style," in *Medieval Architecture and its Intellectual Content: Studies in Honour of Peter Kidson*., ed. Eric Fernie and Paul Crossley (Hambledon Press, 1990), 245); José Calvo-López, "From Mediaeval Stonecutting to Projective Geometry," *Nexus Network Journal* 13 (2011): 503-533, esp. 507, 514.
[55] Note that, rather than a single keystone, the design at Pontigny includes two keystone blocks at the apex (one on either side of the arch point).
[56] The plan of Pontigny's chevet is based on the plan by Bernard Collette, Architect of the Monuments Historiques from 1995. Collette's plan was drafted after the 1950 plan by Jean Trouvelot, Architect of the Monuments Historiques and adjusted following close observation and meticulously obtained on-site measurements.

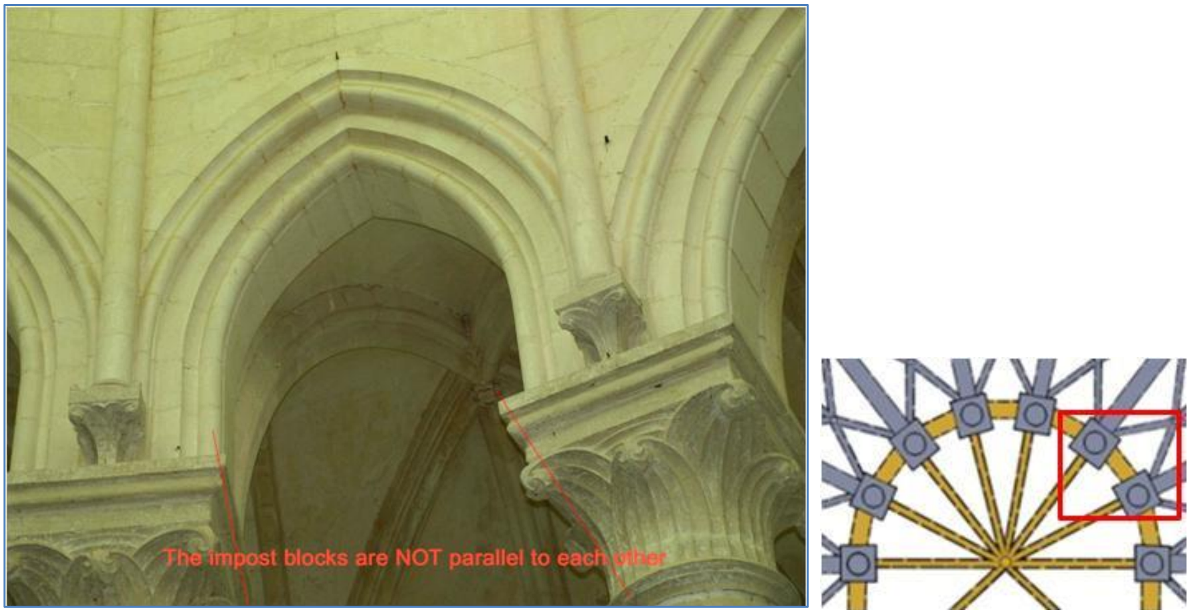


Figure 17 Pontigny, chevet, hemicycle arch (left) and hemicycle plan with TU 5-6 (right). Photo: author.

were created using the PhotoModeler 3-D photogrammetry software.[57] A series of photographs taken on-site at various predetermined angles in relation to the arch were uploaded to the Photomodeler program. Three-dimensional wireframe models were then generated after marking each photograph with hundreds of corresponding reference points.

Notably, the hemicycle arches are stilted **(fig. 19)**; the springer has been raised above the two lowest squared blocks directly atop the abacus of the capital. The shape of these arches above the stilted blocks is very close to an equilateral pointed arch or "a two-centered arch in which the chords of the curves just equal the span of the arch."[58] This is a good choice for a seven-segment hemicycle since this arch configuration would be narrower than either a third-point (*tiers-point*) or a fourth-point (*quint-point*) arch given the same height and, as a result,

[57] The use of the three-dimensional PhotoModeler photogrammetry program with a limited number of calculated photos has been successful for one of the more difficult arches to visualize in the chevet of the abbey church of Pontigny. Even with the aid of three-dimensional models created by the PhotoModeler program and photographs, not all aspects are apparent; thus, drawn schematics, plans, and profiles as well as photographs were added to clarify the differences between individual cases.
[58] Harris, *Dictionary of Architecture and Construction*, 372.

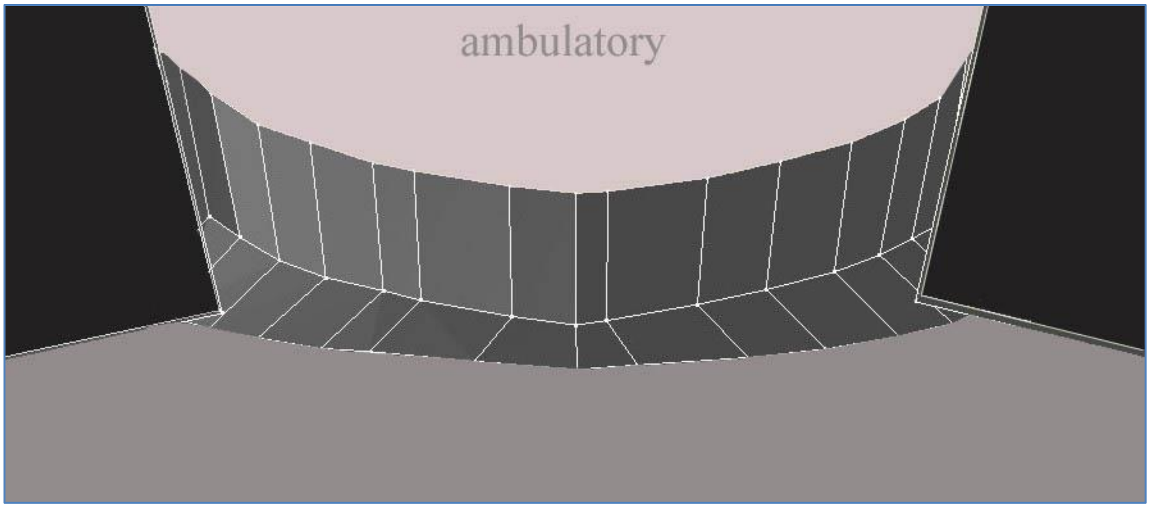


Figure 18 Pontigny, chevet, hemicycle, PhotoModeler reconstruction of the arch at TU 5-6, perspective view from below the arch. Photo: author.

the final arcade would appear taller as well as more slender and elegant.[59] With the addition of stilting, height would be further accentuated.

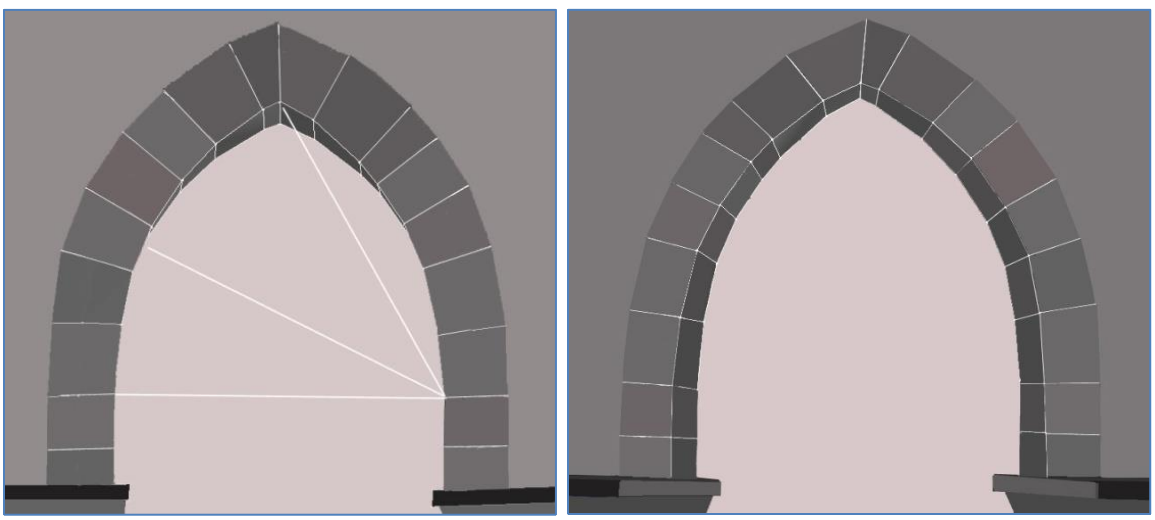


Figure 19 Pontigny, PhotoModeler reconstruction of the arch at TU 5-6, perspective view from the hemicycle (left) and ambulatory (right). Photo: author.

At Pontigny, the hemicycle arch blocks have a rather unusual profile **(fig. 20, left)**. While generally following the arch profile common for the period, one of the corners lacks an angle roll (i.e., angle E was left uncut). The asymmetry of this design is often found in openings

[59] On pointed arches, see Shelby, "Setting Out the Keystones of Pointed Arches," 540.

(such as gallery arches) where the squared side (an undecorated edge of the block) would not be visible.[60] The pure circular form of the upper torus flanked by a cavetto at Pontigny follows the pattern of the arch profile that was common during the late 12th and early 13th centuries as apparent in the comparison with Chablis **(fig. 20, right)**. The lower block molding profile at Pontigny, however, is an “S” curve or a cyma reversa rather than the circular design widespread in the period (shown in the upper block of the molding at Pontigny).[61]

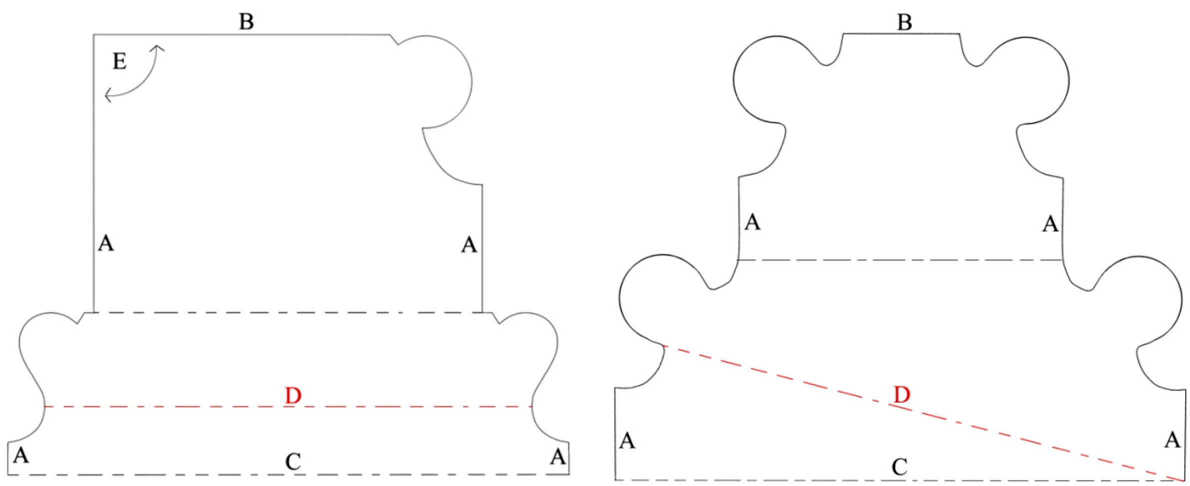


Figure 20 Pontigny, hemicycle arcade, arch profile (left) and Chablis, Saint-Martin, hemicycle arcade, chevet, arch profile (right). Photo: author.

Fig. 21 presents the layout of two hemicycle arch blocks on the abaci in a polygonal bay. Note that, similar to Chablis, each arch block profile has been reduced in size in order to merge two arch blocks closer on one abacus and tighten the arcade making it as tall, thin, and stylish as possible **(figs. 20, cutline D in red, 21, arrows)**. At Pontigny it was not necessary to cut the block diagonally (as at Chablis), since the skewed arch had already compensated for the turn of the arcade.

[60]The use of this squared profile in the hemicycle arcade may reflect a desire for homogeneity since the transverse arch in the ambulatory has a simple rectangular profile (i.e., the square-edged transverse visually links the Early Gothic ambulatory with the Romanesque nave aisle). It is also possible that those blocks were left undecorated due to the complicated template required by the skewed arch.

[61] It is conceivable that a number of these blocks with the cyma reversa were reused from the Romanesque chevet that was destroyed before building the Gothic one and the profile was continued for new blocks added.

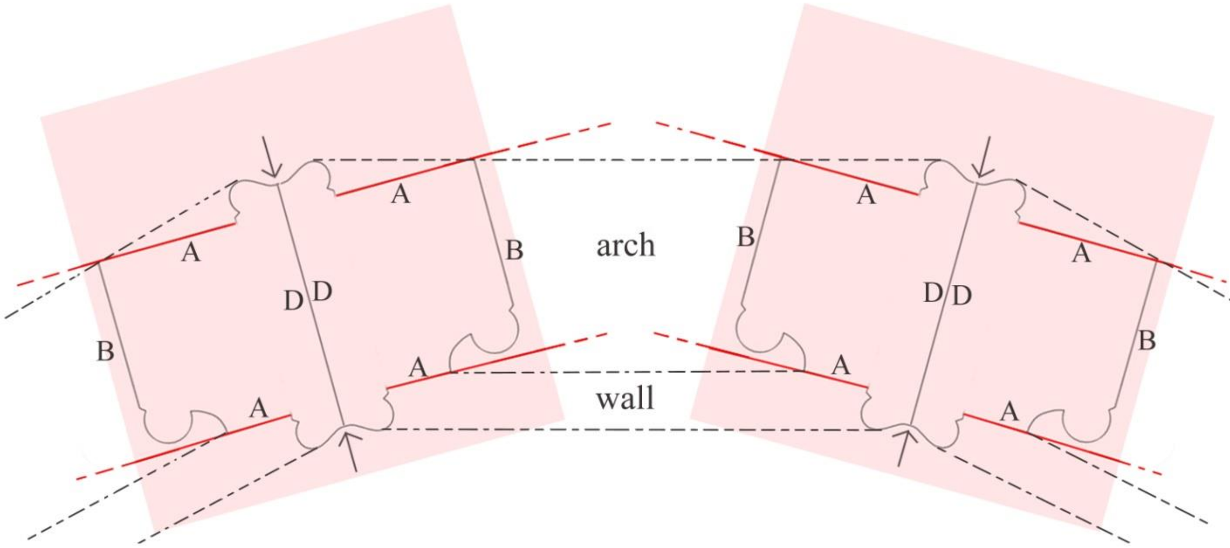


Figure 21 Pontigny, hemicycle arcade, general abaci layout of the arcade for polygonal bays. Photo: author.

This type of complex axial skew arch at Pontigny, designed using unequal arch patterns, is found at both Cistercian and non-Cistercian sites. Considering that the Pontigny hemicycle arch was difficult to design and construct, it would make sense that builders, such as the one at Chablis, may have wished to avoid this effort-laden solution.

The Fifth Group: Advanced Arch Construction

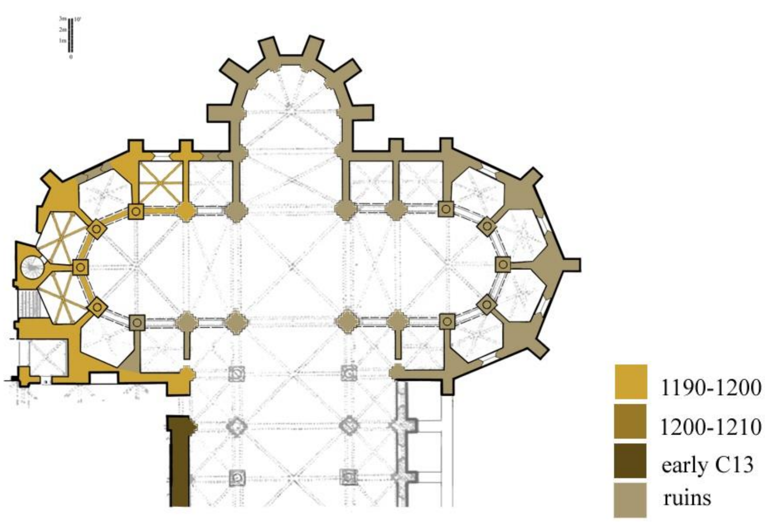


Figure 22 Cistercian church of Notre Dame at Châalis, north transept (left) and plan (right). Photo: author.

The fifth group, Advanced Arch Construction, includes only one building—the Cistercian church of Notre Dame at Châalis (Oise). The Royal Cistercian Abbey of Châalis is in ruins, yet, enough bays remain of the church transept to indicate the design of the original construction, dating the east end to between 1190 and 1210.[62] At Châalis, each transept arm is closed by a four-segment hemicycle **(figs. 22, 23)**. This unusual design with a polygonal hemicycle in the transept is found at a limited number of churches.[63]

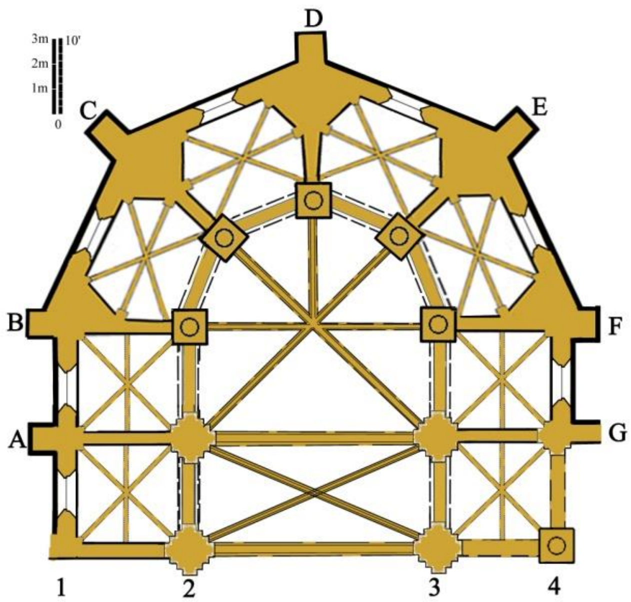


Figure 23 Châalis, north transept, hemicycle, plan. Photo: author.

In the north transept, three vaulted chapels and the upper hemicycle wall still stand **(fig. 22)**. The hemicycle arches are stilted with tall thin nearly equilateral arches similar to those in

[62]The church at Châalis could have been under construction as early as 1190, Canejo, "The Yonne Valley Builder," 19-65. For past scholarship on Châalis, see Eugène Amédée Lefèvre-Pontalis, "Chaalis." *Bulletin monumental 66* (1902): 449-487, here 451-452, placed the beginning of the east end of Châalis before 1202; Frédéric Van der Meer, *Atlas de l'Ordre cistercien* (Paris: Editions Sequoia, 1965), 275) first pointed out that Châalis was probably begun at the same time as the new Gothic chevet at Pontigny was being completed. Caroline A. Bruzelius, "The Transept of the Abbey Church of Châalis and the Filiation of Pontigny," *Mélanges à la mémoire du père Anselme Dimier*, vol. 6, (Arbois: Pupillin, 1982), 447-455, here 451, concluded that Châalis "is securely dated between *c*. 1200 and 1219."
[63]A similar design is found in one transept at Soissons Cathedral and once existed at the Cistercian church of Quincy (now destroyed).

the hemicycle at Pontigny. The resemblance of the transept design to the chevet at Pontigny — noted by Fontaine, Bruzelius, and Canejo—may reflect that Châalis was founded by Pontigny.[64]

Figure 24 Châalis, transept hemicycle, column at D 2-3. Photo: author.

The transept hemicycle has a deceptive design; from a distance the arcade initially appears to utilize monolithic columns, nonetheless, the columns are actually engaged to the chapel walls. The style of the arch profile—in two orders with angle rolls at the corners (flanked by cavetos) and a flat intrados **(figs. 24, B, 25, B)**—is similar to a number of buildings already discussed (Chablis and Pontigny) and typical for the period. The arch profile at Châalis diverges from the other churches by using an angled face fillet on the outer block **(figs. 24, 25, left, A)**. This allows the arch (and the wall above) to be built following angle A and conforms not only to

[64]Fontaine, *Pontigny, abbaye cistercienne*, 34; Bruzelius, "The Transept of the Abbey Church of Châalis," 450; Canejo, "The Yonne Valley Builder," 50.

the plan of the hemicycle, but also to the requirements for the engaged columns (i.e., the block profile is not symmetrical; rather one side was left open to attach to the chapel wall).

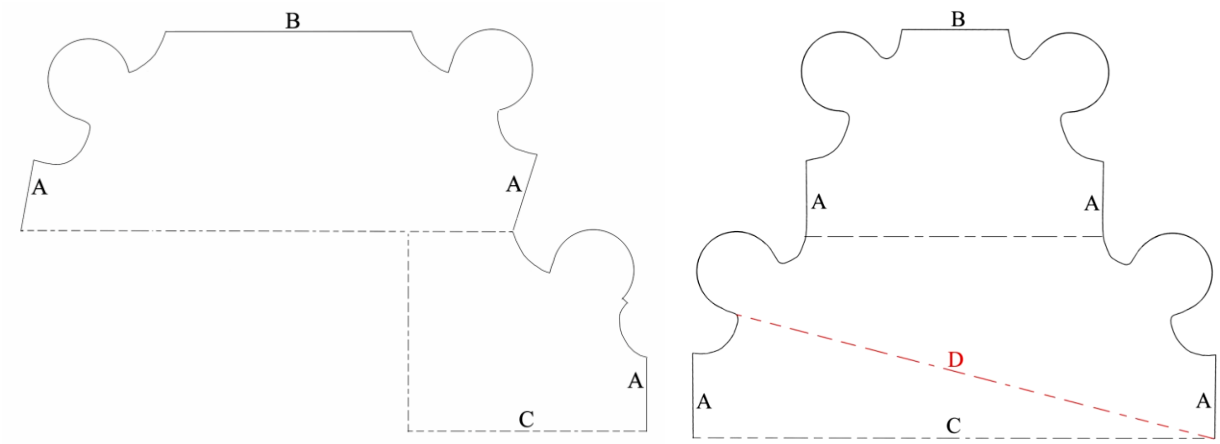


Figure 25 Châalis, Notre Dame, abaci layout (left) and Chablis, Saint-Martin, abaci layout (right). Photo: author.

The layout in **fig. 26** shows the setup of the hemicycle arch profiles on the abaci at Châalis. This multifaceted design allows the intrados (B) to remain parallel to the abacus beneath it without the need for complex adjustments for a skew arch. Each voussoir has been planned in advance and cut so that the intrados follows the edge of the abacus block. This design is remarkably well-thought and complex. Its clever arrangement demonstrates the intelligence of the medieval designer as well as the skill of the medieval mason. That Châalis was a royal abbey may be significant; as a royal construction,[65] the church would have received sufficient funding to hire a highly skilled builder and his workers as well as to allow for costly enhancements.[66] Visually, this arcade does not vary significantly from others, especially Pontigny, yet in the

[65]This Benedictine priory was originally a dependency of the abbey of Vézelay. King Louis le Gros converted the priory into a Cistercian monastery in the name of his brother, Charles le Bon, Count of Flanders, who died at Bruges in 1127. The abbey of Vézelay allowed the move under the house of Pontigny. The Cistercian foundation dates officially to June 10, 1136 (*Cartulaire Châalis*, eighteenth century). The foundation was reconfirmed by Louis VII in 1138 (Paris: BN, ms latin 17113, fol.11).
[66]Michael T. Davis, "On the Threshold of the Flamboyant: The Second Campaign of Construction of Saint-Urbain, Troyes," *Speculum* 59/4 (1984): 847-884, here 850, noted similar endowments for Saint-Urbain, Troyes, and Sainte-Chapelle, Paris.

complexity of the modifications of the hemicycle arch, the design responds directly to production requirements.

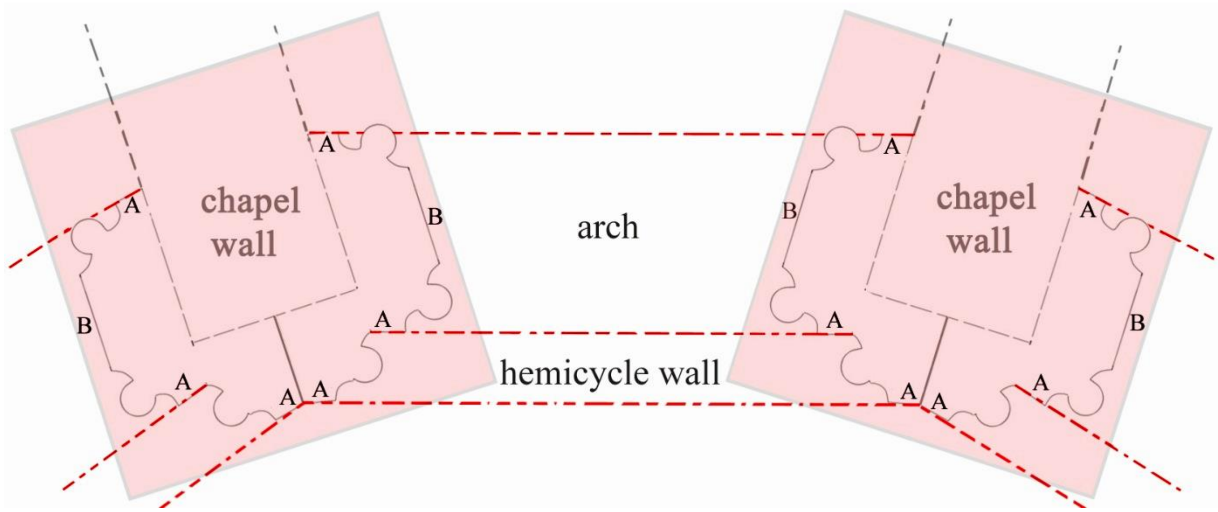


Figure 26 Châalis, chevet, hemicycle, layout. Photo: author.

The Sixth Group: Rayonnant Forms and the Continuous Molded Arch and Support

The sixth and final group includes buildings with a Continuous Molded Arch and Support typical of Rayonnant style, appearing in the13th-century hemicycle chevet at the Abbaye Saint-Germain d'Auxerre (Yonne) **(fig. 27)**. The former Benedictine abbey is positioned alongside Auxerre Cathedral on the hill above the banks of the Yonne River. With a five-segment hemicycle following the layout of the Carolingian crypt, the chevet is believed to have been erected after the old east end was destroyed in 1277.[67]

---

[67]According to Charles Porée, "Saint-Germain," *Congrès archéologique* (Avalon, 1907, Avalon): 182-188, the church was begun at the east during the end of the 13th century. Jules Tillet,,"L'abbaye de Saint-Germain d'Auxerre," *Congrès archéologique* (Avalon, 1907): 627-653, here 629, and Jean Vallery-Radot, "Saint-Germain d'Auxerre. Le eglise haute," *Congrès archéologique* 118 (1958): 26-39) suggested 1277. Robert Branner, *Burgundian Gothic*, 108, reaffirmed this date for the beginning of work "under Abbot Jean de Joceval, who seems to have constructed most of the ambulatory." Hermann Arnhold, "Le chœur de Saint-Germain d'Auxerre et l'architecture du gothique Rayonnant," in *Archéologie et architecture d'un site monastique, Ve-XXe siècles: dix ans de recherche à l'abbaye Saint-Germain d'Auxerre*, ed. Christian Sapin (Auxerre: Editions du CTHS, 2000), 158-163, clarified that the Gothic chevet was based on the layout of the crypt and dated the choir pillars and grand arcades to a second campaign between 1309 and 1334. Alexandra Gajewski sets the debut of construction at 1277 following the *Gesta abbatum sancti Germani Autissiodorensis* in "Saint-Germain d'Auxerre: une abbatiale rayonnante des

Figure 27 Abbaye Saint-Germain d'Auxerre, chevet, hemicycle. Photo: author.

The hemicycle piers at Saint-Germain were designed to allow for an arch that is integrated (using the same profile) with the pier responds below **(fig. 27)**. Since monolithic columns with capitals are not used in the hemicycle, the resulting seamless continuous molding runs up and down—from one side of the arch to the other—without a break in uniformity. In other words, by avoiding the use of capitals (which would interrupt the flow), there is a "fluid transition between support and load."[68]

années 1300," *L'Architecture gothique à Auxerre et dans sa région (XIIe-XIXe siècles). Naissance, transformations et pérennité* (Actes de la Journée d'études —7 mai 2008—Abbaye Saint-Germain d'Auxerre), *Bulletin de la Société des Fouilles Archéologiques et des Monuments Historiques de l'Yonne* 26-27 (2009-2010), 42-65;Anne Heath dates the abbey between 1277 and 1398, "Elevating Saint Germanus of Auxerre: Architecture, Politics, and Liturgy in the Reclaiming of Monastic Identity," *Speculum* 90/1 (January 2011): 60-113.

[68] Michael T. Davis for the choir at Saint-Urbain, Troyes, "On the Threshold of Flamboyant: The Second Campaign of Construction at Saint-Urbain, Troyes," *Speculum* 59 (1984): 850.

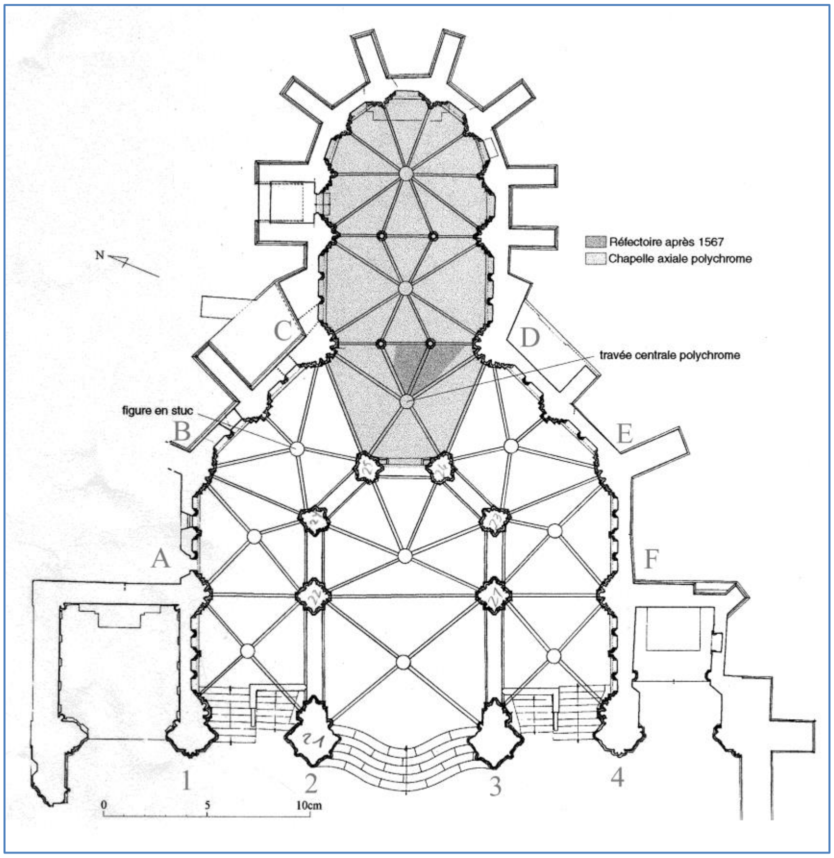


Figure 28 Abbaye Saint-Germain d'Auxerre, plan. Photo: Courtesy Gilles Févre, Centre d'Études Médiévales (CEM)

Around the year 1300, changes were made as "the result of a new way of conceiving the entire structural system."[69] The modifications include designing with fewer profiles and using forms that are standardized (arches, ribs, and their supports are based on a single profile).[70] Within the unity of this system, the pier is no longer autonomous but becomes a "logical extension" of the system.[71] Efficiency is increased due to the integration of the pier design with the arch supports; using standardized profiles in the new system would mean a smaller number

[69] Freigang, "Changes in Vaulting, Changes in Drawing," 67.
[70] On standardization and the connection between production, form, and aesthetics, see the well-known studies of Dieter Kimpel and Robert Suckale, "Le développement de la taille en série dans l'architecture médiévale et son role dans l'histoire économique," *Bulletin monumental*, 135 (1977), 195-222; Kimpel, "Ökonomie, Technik und Form in der hochgotischen Architektur," *Bauwerk und Bildwerk im Hochmittelalter*, eds. K. Clausberg *et al*. (Giessen: Anabas, 1981); Kimpel and Suckale, *Die gotische Architektur in Frankreich, 1130-1270* (Munich: Hirmer, 1985).
[71] Freigang, "Changes in Vaulting, Changes in Drawing," 67.

of templates are needed overall. This design involved the transformation of "the column and arch from individual distinguishable elements into a continuously molded wall-framework structure."[72]

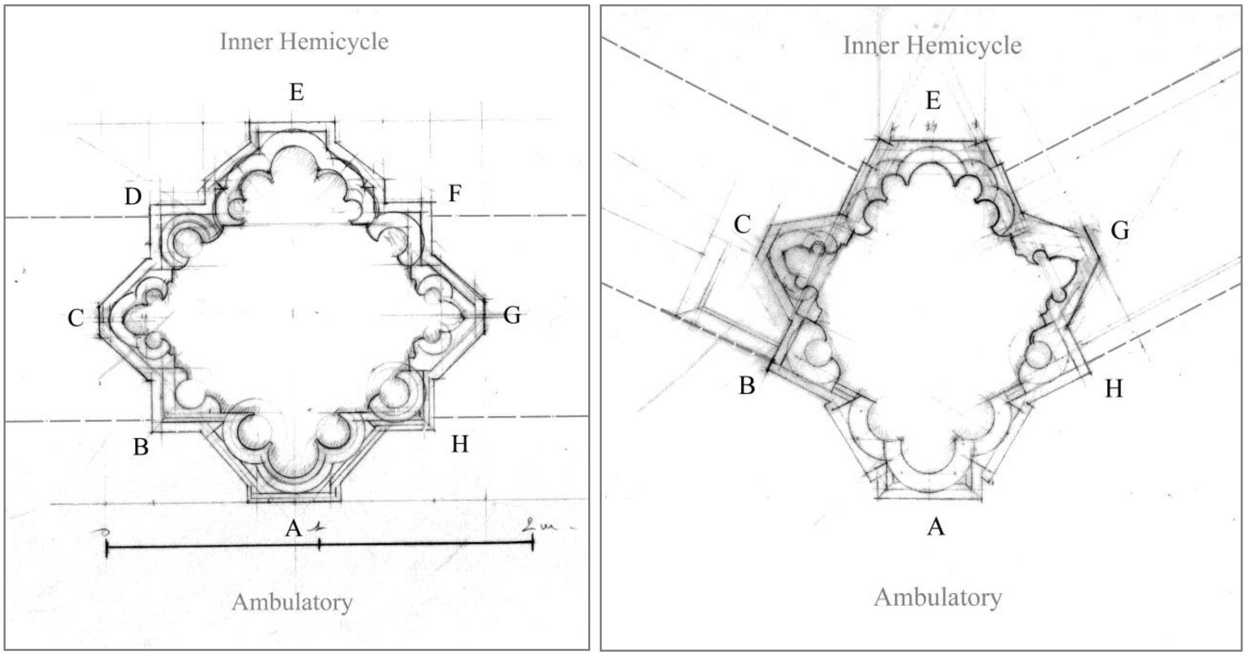


Figure 29 Abbaye Saint-Germain d'Auxerre, layout, arcade, pier 22 of the straight bay (left) and plan, arcade, pier 24 of the polygonal bay (right). Photo: Courtesy Gilles Févre, Centre d'Études Médiévales (CEM)

As can be observed in **fig. 29**, left, the piers of the straight bays have a socle layout with a rectangular shaped center (BDFH); whereas, the layout of the piers of the polygonal bays, has been altered slightly to incorporate the angle of the five-segment hemicycle. In the latter arrangement, the center becomes polygonal (BCGH) rather than rectangular and the pier appears more "V" shaped (CAG). In **fig. 29, right**, that two shafts (D and F) have been eliminated from the straight bay type socle (at the left, on the inner side of the hemicycle) in order to allow the

[72] Ibid, 68. Since Freigang focused on the year 1300, he traced the development of these forms back to earlier Gothic methods and did not address the continuous articulation used earlier in First Southern Romanesque buildings and visible at sites such as Cardona, Sant-Vicenç, in Spain. C. Edson Armi, "Orders and Continuous Orders in Romanesque Architecture," *Journal of the Society of Architectural Historians* 34/3 (Oct., 1975): 173-188.

side shafts to follow the turn of the polygonal hemicycle (specifically, BC and GH have been shifted toward E).

In this case, the use of the continuous molding for arches and their supports eliminates awkward or complicated arrangements found in the other five hemicycle arch construction categories discussed. By making the profile continuous (and eliminating the column with capital), the Rayonnant hemicycle arch is raised more efficiently (with the use of fewer templates). The aesthetic choices of this design seem to have followed from known practical needs; even so, this layout, initially chosen for reasons related to production, appears to have initiated a new style (i.e., practical demands had an impact on aesthetic change).

Significance of the Hemicycle Arch and its Fabrication

From the late-16th to the early-20th century, scholars have investigated the stereotomical arrangement of the stones in skew (or oblique) arches. Their treatises built a foundation which was enlarged (and complemented) by recent texts in engineering, architecture (practice and history), art history, and history. Even so, heretofore the specific requirements and modifications of the Romanesque and Gothic hemicycle arch design have not been explored.

Through this focused investigation, I have uncovered key aspects that will allow us to further understand the distinctive processes and choices of the medieval builder and/or mason in the construction of a chevet or an apse with an ambulatory and a hemicycle arcade. In a general sense, the information obtained will increase our knowledge of medieval construction and add to our understanding of construction techniques. More specifically, evidence indicates that the skills and methods of medieval workers varied. The recognition of this particular construction requirement of the hemicycle arch and its various solutions allows us to perceive the manner in

which a medieval builder or mason has dealt with a specific situation. That is to say, the personal inclinations of the builder may be apparent, for example, in whether or not he treated the situation as a complicated problem needing a simple solution or an intriguing puzzle to be solved in a more complex manner.[73]

In fact, at several Cistercian structures (such as the abbey churches of Pontigny and Ourscamp), the construction of the hemicycle arch parallels patterns found in both Cistercian and non-Cistercian neighboring works; however, a much more unusual and complex design—that does not seem to correlate with other sites—is found in a distinct building: the Cistercian abbey church at Châalis. In the majority of examples investigated, it seems that the Cistercian hemicycle arch configuration shows skills and planning that are comparable to non-Cistercian buildings; the exception is the case of Châalis wherein the design and workmanship indicate an exceptional designer and/or extraordinarily skilled laborers.[74]

The physical data shows that practical aspects of constructing a hemicycle arch go hand in hand with the aesthetic changes that take place in hemicycle arches by the 13th and 14th centuries. The style of continuous molded arches and supports developed from a need for an easier and more-economical way to construct the hemicycle arch. Freigang had suggested that the employment of a reduced number of molding templates in conjunction with their reuse in "re-combinable units" (standardization) not only led to a "much greater flexibility in planning than traditional construction methods," but also introduced greater efficiency in setup and

[73] If we are able to recognize the particular variations of the hemicycle arch as signs of individual designs or techniques, then a unique design may ultimately be useful in revealing the work of a specific atelier or even builder. Moreover, the consistency of the designs may eventually aid in estimating dates of construction.
[74] Since the quality of the unusual and innovative design indicates the work of a particularly inventive builder and shows the skills, creativity, and decision-making abilities, the identification of an individual design or designer may be informative, eventually, in helping to determine methods of design or construction that may be particular to the Cistercians.

created a specialized and desired aesthetic.[75] I agree with his conclusions, since indications in this study point toward builders searching for a method that is less complex and, ultimately, more adaptable to a range of building configurations. With standardized proportions, dimensions would have been easier for the builder to calculate.

With regard to the design of the hemicycle arch in the 12th century, experimentation with specific arrangements can be seen to have evolved from practical requirements. Even so, the choice of solution seems to depend on multiple factors including the skill, knowledge, ingenuity, and attitude of the builder. While aesthetic concerns were a consideration in the choice of hemicycle design and construction, they were not the sole driving force in the search for a solution.[76] ☙

[75] Freigang, "Changes in Vaulting, Changes in Drawing," 71-72.

[76] Less-significant aesthetic changes related to the hemicycle arch are apparent throughout the Romanesque and Gothic periods (an example is the "standard method" in which builders preferred square abaci aligned to hemicycle ribs).