

Gothic vaults: A rationalist or a tectonic track for the role of the ribs?

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TO VISIT AN ANCIENT DEBATE AGAIN

The construction history is also the history of the great constructive debates. The world of architecture knew very famous of them: from the Milano Duomo to the quarrel about Sainte Genevieve church in Paris, going through the project of Firenze Duomo cupola. In these occasions, to observe the confrontation of the doctrines and the knowledges is very interesting.

In France, a continuing historical constructive argument is especially adapted as concernings the thematic of this meeting: the question of the debated role of the arches, particularly the intersecting ribs, in the mechanical behaviour of a Gothic vault. This question is not new but it seems interesting to me to mention it at the occasion of the First international Congress of Construction History for at least three reasons. Firstly, it is a typical example of a constructive question: in the meaning of building (*mise en œuvre*) and in the meaning of calculation, it will allow us to touch on the development of the sciences of construction and their supply for architecture: each time new scientific models appears (like graphic analysis, photoelastic models, FEM calculation, . . .), the question of the ribs is asked again. Secondly, it is an exemplary debate with a mixing of doctrine and objective science and it illustrates the influence of the theories of the second half of the 19th century on the development of Modern architecture. Lastly this question has been studied in plural disciplines: history, architecture, engineering

and even semiology, that makes this argument particularly interesting from the constructive history point of view.

The problem is not to know whether the system of ribs hold up the ceiling of the vaults as Viollet-le-Duc believed it. I don't want me to decide between the «combattants» and establish who is wrong and who is right, even if we have studied the case of Auxerre cathedral with a Finite Element Method approach, pointed out the fact that the ribs didn't held up the vaults but created troubles into the piers of the ceiling (tension area at the level of the haunches for instance). We purpose instead looking at the development of this controversy: how did it begin, how did it become impassioned, who took part in it, and how did it evolve with the progress of constructive science and new scientific models; how finally, a theory which has been built in another academic discipline came and gave help to a new «constructive truth».

Henri Focillon already showed the real historical impact of the question:¹ «(le problème) de l'ogive est d'une particulière importance parce qu'il intéresse les méthodes de la recherche et, par ces méthodes mêmes, la conduite et les disciplines de l'esprit. Il ne s'agit pas seulement pour nous, malgré l'intérêt fondamental de la critique instituée sur ce point, de savoir s'il faut abandonner ou sauver tout ou partie de l'admirable édifice archéologique de Viollet-le-Duc, mais de mesurer avec justesse les rapports de nos coordonnées, technique, plastique, vie des formes dans le temps» (Focillon 1945, 110).

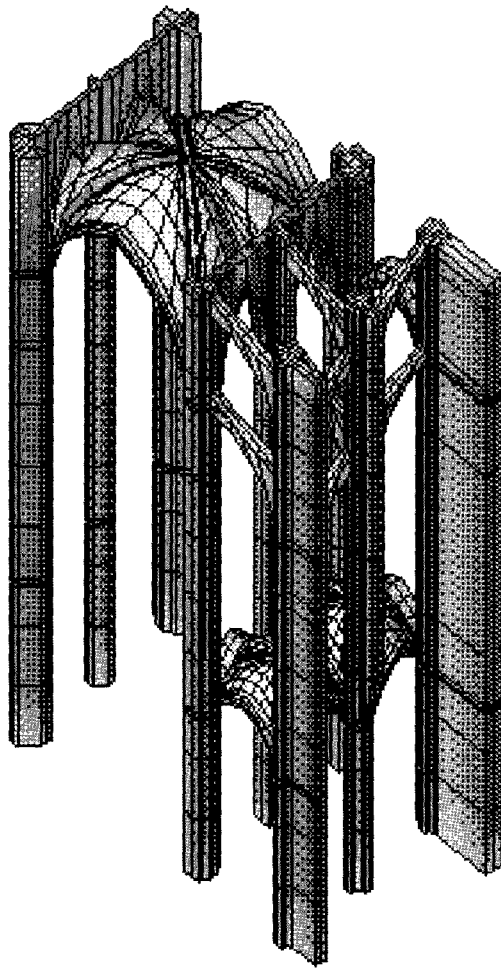


Figure 1
Modélisation for a Finite Element Method calculation
(document : Anne Coste)

Nowadays we can read once again this debate clearing it up with Kenneth Frampton theory about the tectonic or the «poetics of construction» (Frampton 1996): if the Viollet-le-Duc's theory can be ranked in the side of a pure constructive determinism, the concept of tectonic allows us to establish, with Frampton, a continuity between form and construction and to give a real place to the relationship between constructive choices and spatial quality.

THE ORIGIN OF THE CONTROVERSY

The Viollet-le-Duc's rationalist theory described the ribs as a member canalising the load of the vault on the four angles in order to «transmit» it to the piers and to the pier buttresses through the flying buttresses. The main discussed point of this theory is the famous definition of the ribbed vault: «... suite de panneaux à surfaces courbes, libres, reposant sur des arcs flexibles...» (Viollet-le-Duc 1854–1868, vol. 4: 21). This definition poses two problems: the reality of the fact that the ribs held up the portions of the vault and their supposed «elasticity». I will go back over the tools used by Viollet-le-Duc in order to explain the behaviour of the vaults.

The first contradictors

The best known contributions to this argument are the thesis about «Viollet-le-Duc et le rationalisme médiéval» (edited in 1933) by the French architect Pol Abraham, and the engineer Victor Sabouret's article who asserted approximately the same thing a few years ago. In fact, the polemic started from 1900 with Brutaills'book: he already wondered about the role of the intersecting ribs, bearing arch or cover-fillet?² He described the ribbed vaults of Morienvall as a solution to a problem of masonry bond rather than a structural equilibrium problem. Somewhere, he noted that the diagonal ribs were thinner than the main arches of the vault and he found that the section of the nave's diagonal arches was identical to the one of the ambulatory in spite of the difference of their chord.

After that, A.Vaillant casted doubt on Viollet-le-Duc's theory: «... (il) n'a d'entendement qu'au service de son œil, que sa passion moyenâgeuse a déformé...» (Vaillant 1919, 89). Vaillant asserted that the Greek temple was the archetype of the whole of architecture, included Gothic cathedrals. This assertion is open to criticism as Brutaills answered (Brutaills 1920, 15), but he also introduced the doubt about the role of the intersecting ribs, as later Abraham theory: the first, Vaillant told that the ribs played only a role of masonry formwork during the mortar prism. It was Julien Guadet advice too (Guadet 1901, 323).

What did Viollet-le-Duc write about medieval methods ? «Il est probable que les architectes

gothiques primitifs s'étaient fait des règles très simples pour les cas ordinaires; mais il est certain qu'ils s'en rapportaient à leur seul jugement toutes les fois qu'ils avaient quelque difficulté nouvelle à résoudre. Comme s'ils eussent défini les lois des pressions des arcs, ils s'arrangèrent pour concentrer sur le parcours de ces lignes de pression les matériaux résistants, et, conduisant ainsi les poussées du sommet des voûtes sur le sol, ils arrivèrent successivement à considérer tout ce qui était en dehors comme inutile et à le supprimer» (Viollet-le-Duc 1854–1868, 64).

Viollet-le-Duc also thought that the method of dimensioning for the piers of a vault described by Derand in the 17th century was already known by the medieval builders. Their knowledge about structure and mechanics is still mysterious: the architects didn't know the notion of vector as a representation of a strength but they had a clear physical perception of strength, and they also knew about the qualities of materials before the science of Strength of Material was invented several centuries later.

Numerous authors have studied this question, with different trainings and functions: engineers, architects, historians of Art, all of them modified the knowledge of the gothic structural system during the 20th century. Because of the limited place in this paper, I will only skim over each contribution: for a deeper analysis, see Coste (1997).

I have to begin with Paul Planat's work. In the *Encyclopédie de l'Architecture*, he gave a personal interpretation of a gothic vault but the historians were not interested in this study. E. Rümpler quoted it in his introduction of Pol Abraham's book: «Toutefois, il y aura demain cinquante ans, un savant et un vulgarisateur, P. Planat, cherchait à voir clair dans la structure compliquée de nos cathédrales, et le Dictionnaire d'Architecture de Viollet-le-Duc en main, il comparait les réalités que la science lui révélait, avec les théories trop souvent fantaisistes de l'auteur».³

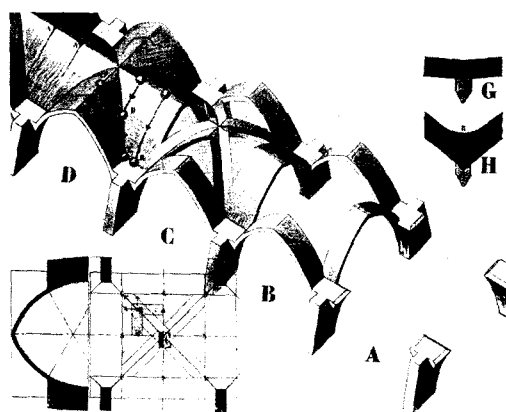
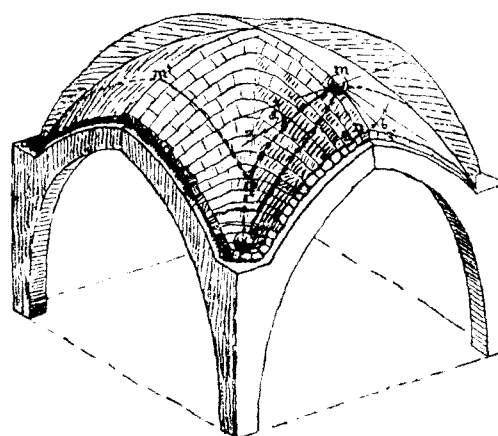
Pol Abraham himself, in the first part of his thesis (Abraham 1934a), cited the different archeologists and historians which have kept their distance from the Viollet-le-Duc's thesis. Firstly, he quoted the Anthyme Saint-Paul, J. A. Brutails and Marcel Aubert's work. All these studies are critical but very respectful reviews of the great architect Viollet-le-Duc's work.

Abraham also quoted the work of engineers Paul Planat and Victor Sabouret, and René Schneider too (Schneider 1928).

POL ABRAHAM: «L'ÉQUILIBRE PLASTIQUE N'EST PAS L'ÉQUILIBRE STATIQUE»

Sabouret and Abraham's studies

Victor Sabouret published an article entitled «Les voûtes d'arêtes nervurées. Rôle simplement décoratif des nervures» in *Le Génie Civil* of March 1928. As



Figures 2 and 3

To understand the behaviour of a vault after Abraham (*Viollet-le-Duc ou le rationalisme médiéval*)

far as he's concerned, Pol Abraham had brought in the subject for his thesis from 1923 (Very 1989).

In the book *Viollet-le-Duc et le rationalisme médiéval*, Pol Abraham reproached Viollet for cheating over gothic architecture. After him, Gothic architecture was the contrary of rationalist: it was only an illusion, the diagonal ribs, the double walls and the colonnettes were an artificial system which concealed the real massive structure. «Aucune (architecture) n'a porté plus loin . . . l'illusion d'une structure idéalisée, à la base d'éléments linéaires adventices dépourvus de toute utilité matérielle. L'architecture gothique est donc, essentiellement, *une plastique*, et Viollet-le-Duc n'a soutenu, en conséquence, qu'un brillant paradoxe» (P. Abraham 1934a, 115).

But Abraham also made a distinction between a structural and a constructive role of the ribs. He denied the structural aim of the ribs but he thought that the constructive role was real: the diagonal ribs didn't hold up the ceiling but they were useful for the building of the vault and they may have also contributed to the general equilibrium during the mortar prism. The rare medieval texts concerning the constructive aspect of the Gothic architecture confirmed this analysis: they described intersecting ribs «to built vaults on» (Aubert 1934, 213).

The polemic was also about Viollet-le-Duc's knowledge in the field of Mechanics. Strangely, Abraham accused Viollet-le-Duc of not knowing the method that Mery (1840) had developed a few years ago (P Abraham 1934a, 10). Viollet-le-Duc used the concept of «courbe des pressions», that seems to prove that he knew Mery's method (Viollet-le-Duc 1864–1868, vol. 4: 62–64), but his calculation included a lot of errors. So, his technical analysis of the mechanical behaviour of a Gothic cathedral was incorrect and Pol Abraham accused him of using mathematical tools in a erroneous way in the service of his doctrine.

It is interesting to look for this Abraham's remark concerning Mery's graphic method: «Elle est si simple et si satisfaisante qu'elle est encore employée aujourd'hui, concurremment avec les méthodes plus précises, basée sur les déformations élastiques, pour l'étude des ponts en maçonnerie», and in a note: «Les expériences de la Commission autrichienne pour l'essai comparatif des voûtes en matériaux divers, faites en 1891, ont démontré en effet que les voûtes

en maçonnerie se comportaient sensiblement, *sous certaines conditions*, comme des arcs élastiques» (Abraham 1934a, 10, note 6): it reminds us the notion of «flexible arches» that Viollet-le-Duc gave in the *Dictionary*. But Abraham himself pointed the mistake in «elasticity» and «plasticity» made by Viollet-le-Duc (Abraham 1934b, 254). Nevertheless, Abraham wasn't either a specialist of Mechanics and his own inconsistencies will be noted later by other authors (Mark 1982, 13).

Marcel Aubert's great contribution

«Il m'a semblé que le moment était venu de reprendre le sujet dans son ensemble et de rechercher ce qui, dans les théories anciennes, peut être modifié et ce qui doit être conserve»: in 1934, Marcel Aubert published an answer to Abraham and Sabouret's thesis in the *Bulletin Monumental* retracing the history of the ribbed vaults: he explained that some roman vaults built during the 2nd and 3rd centuries were equipped with reinforcements which looked like the future gothic ribs. Nevertheless, Marcel Aubert opted for the «canalising» role of the ribs: «(Les architectes Lombards) n'ont pas connu la véritable voûte sur croisée d'ogives dont les arcs, ogives, doubleaux, formerets, composés de claveaux et indépendants de la voûte qu'ils renforcent et dont ils ont facilité la construction, ont leur clef sensiblement sur le même plan, ce qui ramène aux quatre points de retombée les pressions que l'on pourra facilement épauler par des contreforts, des murs-boutants et des arcs-boutants, et permet, par conséquent, d'ouvrir de vastes intervalles entre les supports» (Aubert 1934, 12–13).

The author added a precious note in order to sum up the situation of the articles about this matter. In addition to Brutails' work (*Précis d'archéologie du moyen-âge*, 2e édition, 1924, pp. 133–134, et *Pour comprendre les monuments de la France*, 1922, p. 42), he quoted Clarence Ward (*Medieval church vaulting*, Princeton, 1915): «il ne considère guère les voûtes que du point de vue de leur aspect extérieur et attribue leur origine et leur évolution surtout à des raisons d'ordre décoratif», A.K. Porter (*The Construction of Lombard and Gothic Vaults*); M. Roger Gilman, which had studied the Reims and Soissons gothic churches after the air-raids, he had noted the amazing strength of certain vaults after the collapse of the intersecting ribs and he concluded that

these members were only an aesthetic system («The Theory of Gothic Architecture and the Effect of Shellfire at Reims and Soissons», in *American Journal of Archeology*, t.XXIV, 1920)» (Aubert 1934, 205 note 2). Marcel Aubert also related the German archeologists Gall et K.H. Clasen's work (*Baukunst des Mittelalters, die gotische Baukunst*, 1932), «ne voyant trop souvent dans l'architecture que des combinaisons de volumes et de proportions, en dehors de toute nécessité de construction, (ils) supposent que les maîtres d'œuvre du moyen-âge ont seulement voulu prolonger sous les voûtes l'élancement des lignes verticales et se sont aperçu ensuite des avantages constructifs de la voûte d'ogives» (Aubert 1934, 206 end of the note 2). M. W. Van der Pluym (*Oudheidkundig Jaarboek*, 1932) denounced the untrue rationalism of the medieval architecture too.

At the end, Marcel Aubert didn't settle, he concluded his study about the role of the rib as following:

«Elle facilite d'abord le montage de la voûte et donne une sécurité certaine au constructeur pendant le tassement des mortiers. Elle renforce ensuite la voûte sur ses points faibles, le long des arêtes et sur le plan des sommets, et cela d'autant plus que les compartiments sont construits légèrement ou en matériaux médiocres». (Aubert 1934, 234).

A controversy which mobilized numerous authors

One year later, R. Doré resumed this controversy once again in the *Gazette des Beaux Arts*: «M. Abraham nous rappelle que les dégâts causés par la guerre ont montré qu'une voûte d'ogives ne tombait pas nécessairement lorsque ses nervures étaient rompues . . . Mais les surplombs considérables qu'on put constater dans les voûtes crevées semblent bien étayer, c'est le cas de le dire, la théorie de la voûte couvercle, étant entendu que l'homogénéité de la voûte a pu exiger de très longs délais. Ne voit-on pas même assez souvent les murs gouttereaux se déverser sans que la voûte d'ogives se lézarde, la fissure s'ouvrant le long des formerets ?» (Doré 1935, 122). Doré's analysis of the gothic vault is a little different: «Le génie des maîtres d'œuvre fut de tirer, après coup, d'une «commodité de chantier», un nouveau style d'architecture pour lequel nous professons tous une commune admiration» (Doré 1935, 125).

Pol Abraham and Victor Sabouret's theories were criticized as soon as 1935 by another Ingénieur en chef des Ponts et Chaussées, Henri Masson. He disapproved on the hypothesis of the absence of tensile strength of the masonry and he thought that Abraham's method of calculation was out-moded (Masson 1935).

In 1939, the review entitled *Recherche* gathered new contributions. Henri Focillon, Pol Abraham, Walter H. Godfrey, Elie Lambert, Gurgis Baltrusaitis et Marcel Aubert examined the problem of the ribs once again (Very 1989, 25).

After that, we find again this question at Princeton University with the famous study of Robert Mark, in about 1970. Mark used photoelastic models in order to solve the historical polemic about the role of the ribs and also the role of flying buttresses and pinnacles. He sided with Pol Abraham and asserted in conclusion that ribs are more decorative than structural (Mark 1982).

Then, Roland Bechmann purposed a complementary hypothesis (Bechmann 1981). The Suger's description of the building of Saint-Denis allowed him to develop an economist explanation for the role of the ribs: he thought that the invention of the rib was in fact the substitution of a stoned arch to the wood centring due to the lack of trees at this moment in the place where the ribbed vaults saw the light.⁴

THE OTHER WAYS

We have just seen the arbitration of the argument about the ribs from the Mechanics' point of view, by several authors (our presentation is not exhaustive). The problem was to understand whether ribs held up the ceiling, or whether they were decorative members. Now, we are going to explore new ways with authors who look for a more philosophic and maybe more architectural explanation of the use of the ribs.

A philosophic approach

After Erwin Panofsky, we can find the materialisation of the *Summa Theologiae* by Thomas d'Aquin into a gothic cathedral. In his book *Architecture gothique et pensée scolastique*, (1951) he compared the gothic space with the regulator principles of the philosophy

of the Middle Age. Panofsky alluded to the controversy: «S'agissant de l'architecture des XII^e et XIII^e siècles, l'alternative «tout est fonction, tout est illusion» est aussi peu pertinente que l'alternative «tout est recherche de la vérité, tout est gymnastique intellectuelle et oratoire» s'agissant de la philosophie de la même époque. Les ogives qui ne sont pas encore *singulariter voluti* ont commencé par dire quelque chose avant d'être capable de le faire. Les volées des arcs-boutants de Caen et de Durham, encore dissimulées sous le toit des collatéraux (frontispice), ont commencé par faire quelque chose avant d'être autorisées à le dire» (Panofsky [1951] 1970, 111). Panofsky developed the concept of «visual logic» about the gothic architecture.

A semiologic approach

Umberto Eco gave us a new key in order to understand this viewpoint: the concept of prime function and second function applied to the the ribbed vaults. He cited the debated problem of the role of the rib that he perfectly knew, introducing the three hypothesis we have already seen: the rib holds up the ceiling, the rib doesn't hold up anything, the rib holds up the ceiling during the building as a temporary formwork. «Quelle que soit l'interprétation admise, personne n'a jamais mis en doute que la croisée d'ogives dénotait une fonction de soutien réduite au seul jeu des poussées et contre-poussées entre éléments nerveux et subtiles. La polémique concerne plutôt le référent de cette dénotation; la fonction dénotée existe-t-elle ? Si elle n'existe pas, la valeur communicative de la croisée d'ogives reste toutefois certaine et d'autant plus intentionnelle, voulue et valable qu'elle aurait été articulée seulement pour communiquer une fonction, non pour la permettre . . .» (Eco 1972, 276–277).

This very important remark reveals the real architectural quality of the gothic cathedrals. The rationalist theory of Viollet-le-Duc, as the most efficient numerical tools, are unable to give us an idea of the conceptual richness of that architecture. This is the new way that Kenneth Frampton follows in his recent book about the «Poetics of Construction». He also refers to Eco, quoting his theory of denoted function: « . . . One may also add that building, unlike fine art, is as much an everyday experience as it is a representation and that the built is a thing rather than

a sign, even if, as Umberto Eco once remarked, as soon as one has an object of «use» one necessarily has a sign that is indicative of this use.» (Frampton 1996, 2). But the problem of the ribbed vaults in the Gothic architecture is more complicated because the denoted function of the rib doesn't fit a real structural function. Nevertheless, Frampton will allow us to introduce the last part of this paper with the importance of spatiality in Gothic architecture and the influence of Viollet-le-Duc's doctrine on the Modern Architecture.

BEYOND THE ARGUMENT

The debate concerning the Viollet-le-Duc's rationalist doctrine is not closed, as Jean-Michel Leniaud's book shows it (Leniaud 1994), but we are going to explore another way in order to understand all the symbolic importance of the ribbed vaults system. Umberto Eco gave us an important contribution with the notion of denoted function but we can continue this reflexion about the ribs, wondering about their influence on the perception of the space.

The tectonic nature of Gothic architecture

Frampton noted that the notion of space, which is very significant in the theory of Modern architecture, was absent from the Viollet-le-Duc's pieces of writing. Yet spaciality is fundamental in the architecture of the great Gothic cathedrals. And I think that the system piers / arches, with little colonnettes starting from the soil and going to the ceiling with the ribs, is a very important member of this spatial quality. In order to define the role of the ribs, I wouldn't speak about «structural» members but «structuring» members. These arches structure the space of the cathedral and, in the same time, they give us an illusion of a line of load, as Abraham said.

Viollet-le-Duc described the gothic architecture as a kind of ideal and operational model, projecting the leanings of his own time on the Middle Age and the possibilities of new materials on Gothic cathedrals in order to produce a doctrine which will be fruitful for the future (Bekaert 1980). Indeed, Viollet-le-Duc was a precursor of Modern architecture (Revel 1964): his work had hugely influenced the next generation of

architects, i.e. the generation of the Modern Movement. Pol Abraham himself detected this influence: «Viollet-le-Duc qui n'eut pas d'originalité plastique et dont l'imagination artistique était, en dehors du pastiche, d'une attristante pauvreté, trop intelligent pour ne pas sentir ses faiblesses, trouva sa voie dans une pure construction de l'esprit, paradoxale mais prophétique, celle d'une architecture qui, soumises aux plus étroites nécessités matérielles, en ferait, cependant, la substance même de la beauté. Admirable idée, puissante et féconde, et dont l'architecture internationale du XX^e siècle est, en grande partie, sortie. Mais, aussi, attitude de combat, machine de guerre contre l'Académie, dans une lutte où il fera figure de héros de l'art national et moderne contre la tradition gréco-romaine moribonde» (P. Abraham 1934a, 102).

This Viollet-le-Duc's influence on international modern architecture is very significant. Le Corbusier was one of the heirs of Viollet-le-Duc's theory. With the title of his book «Quand les cathédrales étaient blanches», he symbolically referred to the Middle Age as a time of revival but he didn't admit the gothic architecture as an ideal model. We know that Le Corbusier didn't like Gothic architecture much. And we find Pol Abraham once again on this subject with his sharp critic of *Vers une architecture*: «Enfin, M. Le Corbusier paraît tenir essentiellement à opposer l'art de bâtir, qui est fait "pour tenir" à l'architecture qui est faite "pour émouvoir". . . . Ce contraste n'est-il pas surtout théorique et n'est-ce pas, au contraire, de ce trop rare équilibre entre l'intelligence constructive et le sentiment plastique que sont nées les belles œuvres?» (Abraham 1924). We can notice that Pol Abraham was already sensible to the «Poetics of construction», i.e. the expressive potential of construction which seems to be the alternative way to the rationalist stand.

Let us Bruno Zevi bring the conclusion of this paper: «Ho rivisitato alcune cattedrali inglesi dopo che le bombe ne avevano infranto le vetrate e fatto cadere i riempimenti tra le costole delle volte: ebbene, quelle strutture, svincolate ormai perfino dalla trasparente cartilagine che le univa, sembravano aver realizzato a pieno il sogno degli architetti gotici: creare lo spazio, scandirlo, elevarlo, dargli forma senza interromperne la continuità» (Zevi [1959] 2000, 71).



Figure 4
Ribs of a vault after the collapse of the compartments
(document : Anne Coste)

NOTES

1. Focillon: the chapter VI «Le problème de l'ogive» was published a first time in *Bulletin de l'Office des Instituts d'Archéologie et d'Histoire de l'Art* in 1935 and, later, in a collective book, collection «Recherches», in 1939.
2. The author quoted Anthyme Saint-Paul: «L'arc-boutant est un peu à l'extérieur de l'église ce que la nervure est à l'intérieur; celle-ci est un cintrage permanent, celui-là un étai permanent» (Saint-Paul A. *La Transition*: 7).
3. Presentation by E. Rümmler of Pol Abraham's book «Une thèse sur Viollet-le-Duc et le rationalisme médiéval». *La Construction Moderne*, 14 janvier 1934: 253.
4. This explanation was also used from 1911 by Arthur Kingsley Porter in his book *The construction of Lombard and gothic vaults*, New Haven: Yale University Press.

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