

Some Notes on Gothic Building Processes: the Expertises of Segovia Cathedral

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Gothic architecture has aroused the interest of architects, engineers and historians for centuries (Frankl 1960). The technical point of view has also received attention; in particular, there is an abundant literature on gothic vault construction and structural behaviour. The rational approach of Viollet-le-Duc (1854), followed by Choisy (1899) and many others, was subsequently criticized, mainly by Pol Abraham in the 1930s (for an excellent résumé of the debate, see Kubler 1944, pp. 135-7; see also Mark, 1977). From a structural point of view the discussion focused on the actual functioning of the different elements of the vault (the ribs, webs and bosses) and the debate was actually closed by Heyman (1966, 1968) with the application of the ideas of modern limit analysis to masonry structures. However, the deep meaning and the practical consequences of Heyman's discoveries have not yet been fully understood by many architects and engineers, who are still using sophisticated computer programs to try and obtain the actual state of internal stresses in masonry.

There is another aspect that has been rarely considered: the cathedral must also have been in equilibrium during the building process. In any of the intermediates phases, the sequence of the operations, the dispositions of scaffoldings, materials, etc., must have assured a safe state of equilibrium. This consideration implies some order in the erection procedures. The only author who has tried to answer these kinds of questions is Fitchen in his book *The construction of Gothic Cathedrals: A Study of Medieval Vault Erection* (1961). After four decades, Fitchen's book is still the main reference on gothic building processes and is a mine of scholarly information. However, in his discussion of these matters, Fitchen uses a building commonsense approach, trying to deduce the possible gothic processes from the nature of the problems involved, which he studied thoroughly. He assumed explicitly that the scarce gothic original sources could give no information about building processes. In fact, this is not the case. Since the 1960s, the work of Shelby (1977, 1979), Müller (1990), Coenen (1990), Binding (1993), etc., has unearthed a remarkable amount of gothic technical literature on building.

More concrete information can be found in expertises. During the construction of a cathedral, sometimes, the Chapter considered it necessary to call in a foreign expert to assess the state of the work or to discuss erection problems. This was the case in Segovia Cathedral, where several expertises from the beginning of the sixteenth century have been preserved. One of the authors (Ruiz Hernando 2003) has recently published a transcription of these expertises. The texts are extremely difficult to interpret: They refer to a concrete phase of the construction of the cathedral,

which must be identified, and the vocabulary is obscure, both because of the use of old Castilian words and for the complexity of the technical matters involved. What is most interesting is that some of the expertises make direct reference to the kind of questions listed above: the order and sequence of construction of the flying buttresses, the lateral vaults and the walls of the main nave. This paper is concerned with this problem and should be considered as a kind of appendix or a series of footnotes to Fitchen's book.

CHOISY 1899 AND FITCHEN 1961

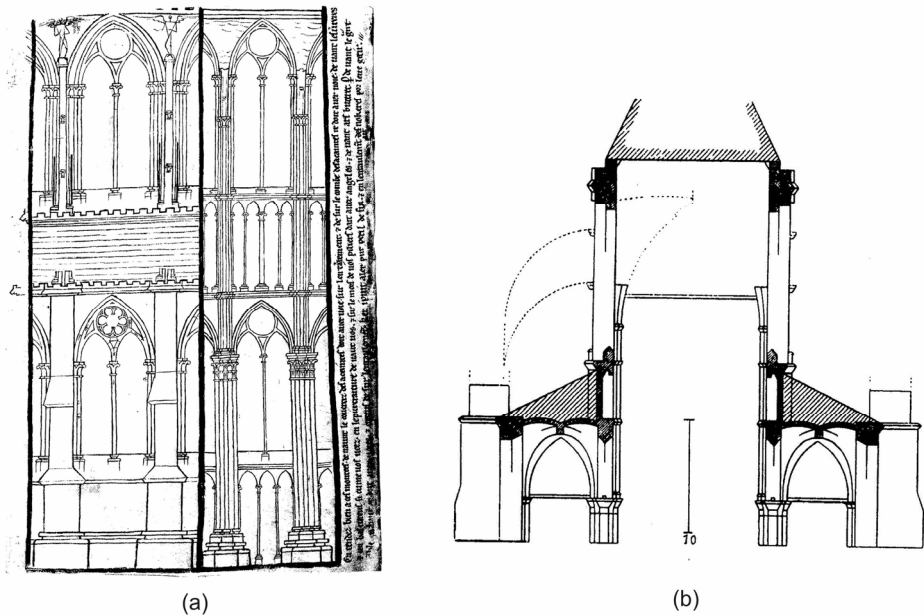


Figure 1. (a) Villard de Honnecourt's drawings of the nave of Reims under construction (Villard de Honnecourt f. 31, v°). (b) Choisy's hypothetical reconstruction of the process of building after Villard (Choisy 1899, 2, p. 338)

The first author to address the matter of gothic building processes is Auguste Choisy in a brief comment in his *Histoire de l'architecture* of 1899 (pp. 337-9), *Aperçu de la marche générale d'un chantier gothique* (General process of the construction of a gothic church). Choisy bases his argument on the interpretation of one of the drawings contained in Villard de Honnecourt's sketch-book (fol. 31, vE, **Fig. 1 (a)**). The drawing contains an elevation from outside and a cross longitudinal section of the main nave of Reims cathedral during construction (Choisy 1899, p. 337; Hahnloser 1972, p. 387). In the elevation the buttresses appear unfinished, reaching only a few feet above the roof of the lateral nave. The capitals to receive the heads of the flying buttresses are in the wall. In the sections it is possible to see, at the level of the *tas-de-charge*, a rectangle with a cross

inside which Choisy interprets as a wooden horizontal tie (in this Choisy is following Viollet-le-Duc's interpretation of the Chainages found in several French gothic Cathedrals; see **Fig. 2**); the vaults have not yet been built. Choisy explains the processes thus (**Fig. 1 (b)**):

From this authentic document it turns out that the sequence of construction was as follows: they raised the piers of the high vaults; they erected the roof; and it is under its protection that they built the high vaults. The flying buttresses were built at the same time as the vaults, and the tie rods resisted the consequent thrusts while awaiting the completion of the final decisive abutment. The roof itself, during this period of the work, was a valuable feature of consolidation. Not only did it add to the stability of the piers by its own weight, but its ties above the vault added a role equivalent to that fulfilled by the tie rods at the springings [...].

(translation by Fitchen 1961, 124)

Fitchen cites this analysis of Choisy and criticizes it. To him the ties are not working in tension, but are struts working in compression. Besides, Villard's drawing is not conclusive and he says that Choisy made an interpretation of some rather obscure marks in the drawing. Finally, the evidence of the existence of these ties was found by Viollet-le-Duc not in the high vaults, but in the lower side-aisle vaults (in Amiens and Reims, **Fig. 2**). Fitchen cites also Viollet-le-Duc's (Viollet-le-Duc 1854, vol. 2, pp. 398, 403) interpretation of the function of these ties:

They were placed during the course of erection and were left in place until the building was completed; that is to say until the moment where the interior piers were charged to the point where the builders no longer needed to fear any buckling produced by the thrust of the side-aisle vaults.

(Fitchen 1961, p. 125)

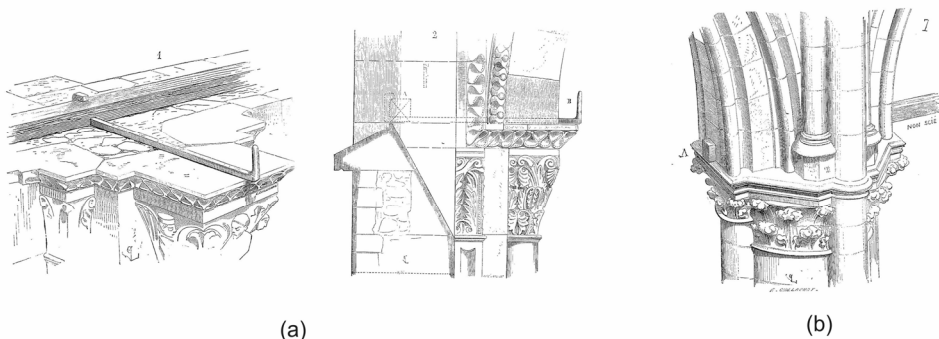


Figure 2. Viollet-le-Duc's drawings of chainages (ties) found in existing buildings:

- (a) Iron anchors for ties in Vezeley; (b) Wooden ties over the capitals of the side-aisles in Reims.
- (b) (Viollet-le-Duc 1854, vol. 2, pp. 398, 403)

Fitchen then goes on to explain his own theory of the process of building, which he illustrates in one of his excellent drawings (**Fig. 3**). Fitchen attributes to the centrings of the flying-buttresses a fundamental function in stabilizing the high wall against any movement inwards or outwards. As always, his explanation is full of detail and ingenuity. The main difference with Choisy's drawing is the absence of any horizontal tie or strut at the level of the tas-de-charge.

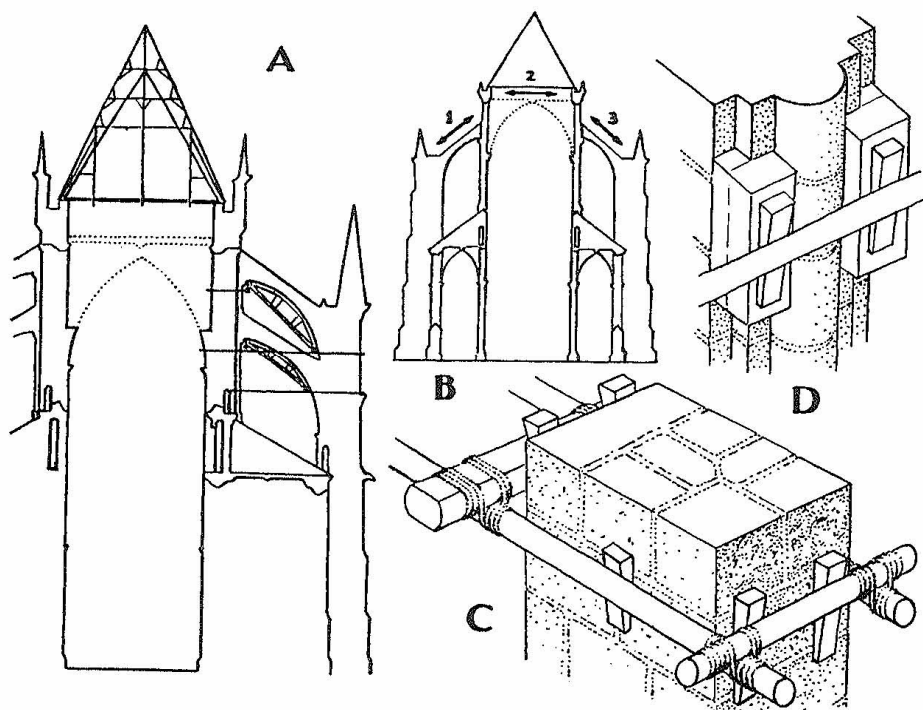


Figure 3. Fitchen's explanation of the equilibration of the main walls and flying buttresses during construction (Fitchen 1981, p. 127)

DOCUMENTS ON THE CONSTRUCTION OF SEGOVIA CATHEDRAL

The above discussion may serve to put in context some documentary evidence of late-gothic building processes in Segovia Cathedral. The first is Rodrigo Gil de Hontañón's description of the process of building of a gothic vault contained in his treatise. Rodrigo Gil was architect of Segovia Cathedral and he was probably describing the method he followed to build his vaults. The second and third documents are expertises written on the building of the cathedral by two foreign architects: Enrique Egas and Francisco de Colonia. In **Figure 4** the different phases of the construction of the Cathedral are shown.

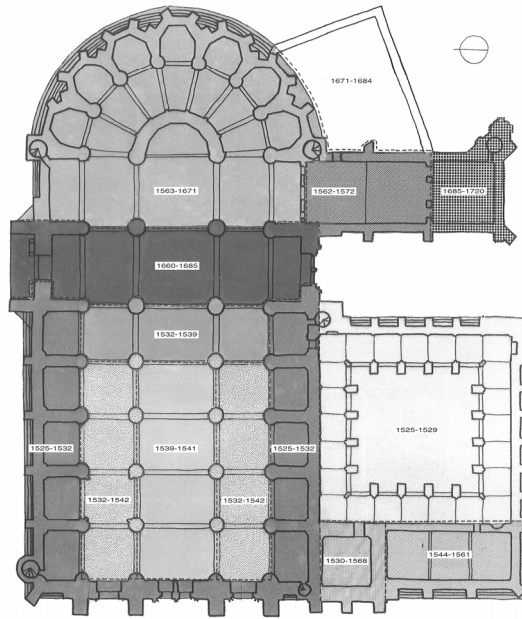


Figure 4. Phases of construction of Segovia Cathedral (drawing of A. M. Beloqui in Cortón de las Heras 1997, p. 275).

Rodrigo Gil de Hontañón ca. 1540

The architectural treatise of Rodrigo Gil de Hontañón (1500-1577) is well known to any scholar involved in the study of gothic design techniques. The original is lost but Simón García copied most of it in his treatise of 1681. The treatise of Rodrigo Gil is full of interest, though so far no critical edition has been published (Sanabria 1984, published an English translation with many notes; in what follows, all the English citations of Rodrigo Gil are from Sanabria's translation).

In the context of this contribution his description of the building of a gothic vault is relevant, **Figure 6 (a)**, García (1681, fols. 24r-25v). First, a platform is built at the level of the tas-de-charge (a little above of the springings). There the plan of the vault is drawn over it and the bosses are placed in position above wooden struts. Next centrings between the bosses were constructed, the ribs were built and finally the masonry web between the ribs was laid. The rib skeleton functions as a permanent centering and ribs and bossess should have certain dimensions so that this skeleton would be in equilibrium, not only at the end, but during the whole building process. The process may seem simple but Rodrigo Gil notes that: Athese things may be difficult to understand if one lacks experience and practice, or if one is not a stone mason, or has never been present at the closing of a rib vault.

The sizing of ribs and bosses is treated considered in detail by Rodrigo. He stresses the importance of the problem:

It is good to know the correct size and thickness of the ribs and bosses of rib vaults, since we have seen many ruined either because their bosses were too heavy and thus much larger than what the ribs could hold, or else much too light so that the weight of the ribs lift them causing cracks to open in the walls.

(García 1681, fol. 22v)

Rodrigo alludes, probably, not only to the completed vault but, also, to the vault under construction. The skeleton of ribs must be stable during construction. Web construction would have progressed from the perimeter to the centre of the bay. In this situation it is possible that the skeleton of ribs, loaded mainly on the haunches, could collapse by rising of the central boss. The bosses placed on top of wooden struts were a passive weight, which was used, if necessary, to stabilize the rib skeleton during construction. The statics are evident and are explained in **Figure 6 (b)** (the ribs are supposed weightless). The dotted line, completely outside the ribs, represents the situation without a boss, and the ribs will collapse inwards so raising the boss; some part of the total weight permits the line of thrust to be constructed within the cross ribs (Huerta 2004, p. 475).

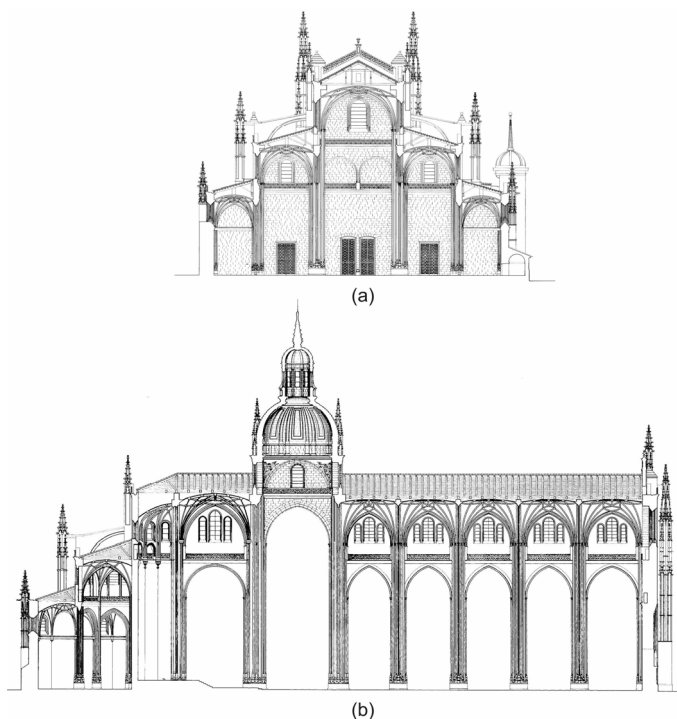


Figure 5. Transversal and longitudinal section of Segovia Cathedral (drawings by J M Merino de Cáceres)

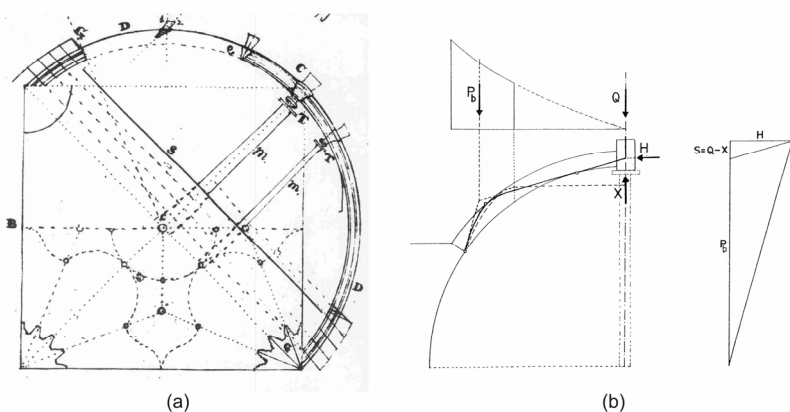


Figure 6. (a) Process of construction of a gothic rib vault by Rodrigo Gil (García 1681, fol. 25r). (b) Static equilibrium of the cross ribs under construction (Huerta 2004, p. 475).

The platform must be supported by some kind of scaffold, perhaps strong beams crossing the span with a system of diagonal struts to obtain a more rigid and strong support. The horizontal struts may, then, have a double function: to support the building platform of the vault and, as remarked by Choisy and Fitchen, to stabilize the high walls.

The method described by Rodrigo Gil is much more rational than the employment of trusses covering the whole span of the vault. In fact, it was used to reconstruct some late-gothic vaults in Germany, as may be seen in the photograph (**Fig. 7**); no doubt the contractor used this system for economy and ease of construction. Furthermore, the only surviving scaffolding of a gothic vault, **Figure 8**, from the 14th century (tower of the church of Lärbro in Sweden, Svanberg 1983), represents a procedure similar to that described by Rodrigo Gil. Finally, one of the authors (Huerta 2001) had to rebuild a collapsed barrel vault in north Spain. He designed a conventional scaffold with steel trusses covering the whole span; the master mason Mr. Ricardo Blanco, suggested the construction of a platform at the level of the springings, and the scaffold was of the same type as that of Lärbro and much more rational and economical than the original design.

Enrique Egas 1532

The report of Enrique Egas, architect of Toledo Cathedral describes the state of the work at the date of the visit and, then, he discusses the plans (traças) to continue the work. Only the first eight lateral chapels and the entrance wall (with the gates up to the height of the chapels) were built at this time; therefore the expertise is centred in commenting on the plans (see **Fig. 4** above). His opinion is completely positive:

[...]vistas todas las particularidades de todo lo que esta fecho la obra es buena y muy cuerdamente labrada con todas sus fuerças bastantes como se requiere para la tal obra esta

la obra muy bien tratada conforme a la traça que para ella esta fecha esto es lo que me paresçe en Dios y en mi conçiencia.

(having considered all the details of what has been built, the work is good and very well done with all the elements of enough dimension, as the work requires, and the work is made following the plans made for it, and this is my opinion before God and my own conscience).

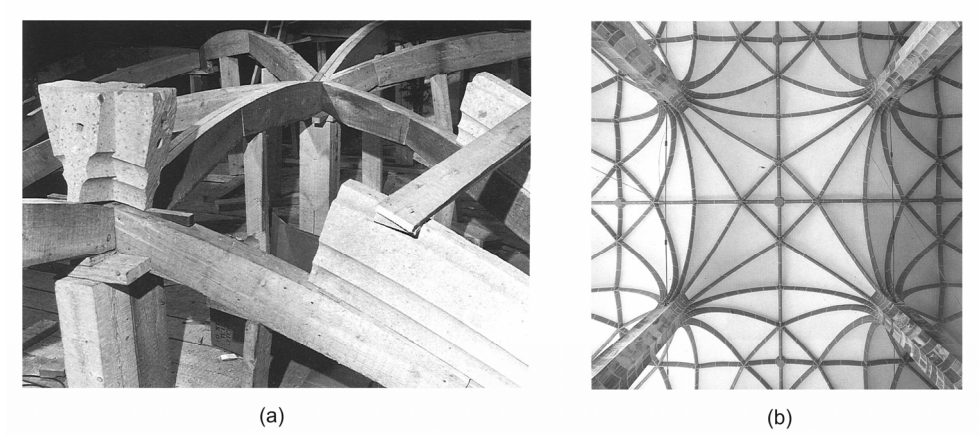


Figure 7. Rebuilding of the vaults of the church of St. Maria and St. Wolfgang in Schneeberg destroyed in 1945 (Conrad 1990, p. 260)

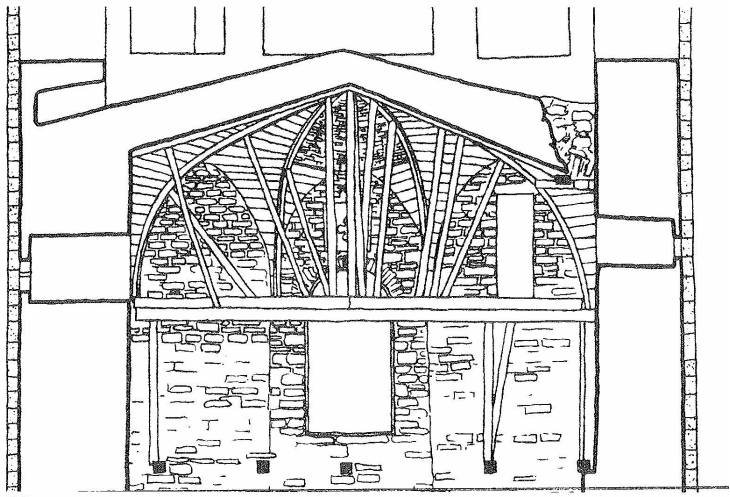


Figure 8. Medieval scaffolding of the vault of the fourteenth century tower of the church in Lärbro (Svanberg 1983, p. 65)

For the purposes of the present contribution the most interesting part is his response to a question posed by Juan Rodríguez, the fabriquero of the cathedral (the man named by the Chapter to direct the construction):

Iten para çerrar la nave mayor y las dos colaterales que juntan con ella pregunto el dicho señor Juan Rodríguez qual de sus tres naves se çerrara primero pues son las unas estribos de las otras y tienen dificultad en el çerrarse digo que enjarjadas las dos naves colaterales en los pilares torales en sus altos y enjarjadas las capillas de la nave mayor en los dichos pilares en sus altos que estando las jarjas en sus lugares antes que se çierre ninguno de los arcos en las dos colaterales ni en la mayor se han de hechar unas entivas de madera de vigas bastantes de pilar a pilar sobre sus pies en el alto donde an de estribar los terçios de los arcos de las dos naves colaterales y asy echadas las entivas a muy buen recabdo se pueden çerrar los arcos y capillas de las naves colaterales y quando sean çerradas estas dos naves colaterales se pueden çerrar las capillas de la nave mayor teniendo miramiento que los arbotantes se çierren en su rason y que no les quiten las çinbrias fasta que las capillas de la nave mayor sean çerradas.

(To build the vaults of the nave and of the two side-aisles which are together, I asked the above-cited Mr. Juan Rodríguez which of the three vaults should be built first, as they buttress each other and it is difficult to build them. I said that once the tas-de-charge of the two side-aisle vaults has been built, and built the main pillars of the central nave up to the tas-de-charge, also, and the stones of these tas-de-charge being in place, before the building of any of the ribs of the side and main vaults, it is necessary to place some horizontal struts of sufficient cross-section between the pillars on their feet at the height where the thirds of the ribs of side vaults thrust, and in this way, having put the struts well, it is possible to build the vaults of the side-aisles, and once they have been finished, you can build the vaults of the main nave, taking care that the flying buttresses are well designed and that their centrings are not removed until the vault of the main nave is finished.)

Before proceeding with the building of the vaults of the side-aisles it is necessary to construct the wall of the main nave and prepare the springings of the main vaults up to the tas-de-charge. Then, thick horizontal struts should be placed between the opposite pillars at the height of one third of the height of the transverse arches (marked A in **Fig. 9**; diagonal bracing conjectural). After this, the lateral vaults may be built and, finally, the main vault. The construction of both vaults will follow a procedure as described by Rodrigo Gil de Hontañón in his treatise (see above). The exterior buttresses will be built at the same time of the wall and the flying buttresses will be set on centrings (B in **Fig. 9**; centring conjectural). These centrings will not be removed until the main vault is closed.

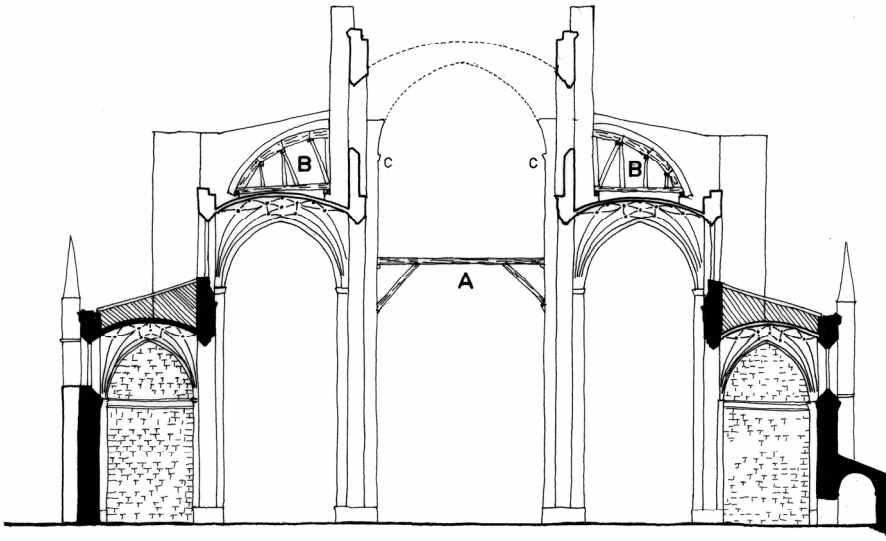


Figure 9. Process of building suggested by Enrique Egas in 1532: A horizontal strut; B flying buttresses (centring hypothetical). (drawing by Huerta, after Merino de Cáceres cross-section)

Francisco de Colonia 1536

Three years later Francisco de Colonia, architect of Burgos Cathedral continued the work. At this time, the ten lateral chapels, up to the crossing and the exterior buttresses on top of the walls between the chapels were commenced, and the pillars of the main nave were also built up to the level of the tas-de-charge of the lateral aisles. Therefore, everything was prepared to continue the work and to vault the lateral and main aisles. Francisco de Colonia describes the form and heights of the ribs, and comments on many details of the construction. As for the order of building, the same question which was answered by Egas, he remarks:

Iten digo, que me paresçe que las dos naves laterales se pueden çerrar antes que la nave principal, con tal condiçion que despues de çerrados los arcos que van sobre los pilares torales y subidas las paredes que han de yr sobre ellos fasta donde han de començar las ventanas de la nave mayor, se çierren las dichas naves colaterales y no antes porque el peso de las paredes que van sobre los arcos bastan para estribo para poderse çerrar las dichas capillas sin daño de los pilares torales.

(I say that in my opinion the vaults of the two side-aisles may be built before the vault of the main nave, with the condition that after building the arches between the nave pillars, the wall resting on them should be built up to the level of the base of the windows, and not before because the weight of the walls over the arches is sufficient as a buttress to build the lateral vaults, without causing damage to the nave pillars.)

Francisco de Colonia thinks that the wall of the nave should be built only up to the level of the windows (line C-C in **Fig. 9**), before de-centering the vaults of the side-aisles. His opinion is less conservative than that of Egas. But both use the same device to buttress the vaults: to increase the load upon the nave pillars.

BUTTRESSING BY LOADING

The device of buttressing the nave pillars by adding weight is cited also in manuals of the sixteenth century. For example, the Spanish engineer Cristóbal de Rojas in his *Tratado de fortificación* says that the buttress for a semicircular arch should be one third of the span, but he remarks that in some cases it is possible to reduce the buttress to one fourth of the span if the pillars are heavily loaded:

siendo un arco de medio punto, le bastara por estribo la tercia parte de su hueco: y algunas vezes bastara la quarta parte, quando cargasse mucho peso sobre los pilares.

(The arch being semicircular, it is enough one third of the span: and sometimes it will be enough one fourth, when a great weight is loading the pillars).

Christopher Wren explains in detail the device in his Report on Westminster Abbey (published in the *Parentalia*). With reference to **Figure 10**, the text of Wren constitutes the best explanation:

Let ABC be an Arch resting at C, against an immoveable Wall KM, but at A upon a pillar AD, so small as to be unable to a sufficient Butment to the Pressure of the Arch AB: what is the to be done? I cannot add FG to it to make it a Butment, but I build up E so high, as by Addition of Weight, to establish it so firm, as if I had annexed FG to it to make it a Butment: it need not be enquired how much E must be, since it cannot exceed, provided AD be sufficient to bear the Weight imposed on it [...]

(Wren Jr. 1750, 301)

In fact, Wren was concerned with securing the main pillars of the crossing by adding on them the weight of a tower, but he is explaining a gothic solution to the problem of buttressing a pillar of insufficient depth.

CONCLUSION

Villard's drawing of the nave of Reims during construction and the comments of both Enrique Egas and Francisco de Colonia are consistent. The vaults of the side aisles cannot be built (or de-centred) without providing some kind of buttressing. Viollet-le-Duc and Choisy suggested the use of wooden ties, based in some evidence found in some gothic churches and cathedrals. Fitchen devised complicated scaffoldings pursuing the same end. The recommendation of Egas are that wooden

elements working in compression rather than in tension are more simple and economical. But, of course, the most economical way is to avoid the use of either ties or struts, and this may be achieved by organizing the construction so that the permanent masonry elements act as buttresses due to their own weight: this is the objective of Egas and Colonia's condition of building the nave walls to a sufficient height before decentring the side-aisle vaults. If the essence of a gothic building is an economical and safe state of equilibrium obtained by means of a structure - a stone skeleton of an adequate form - then the essence of gothic construction is an equilibrated building.

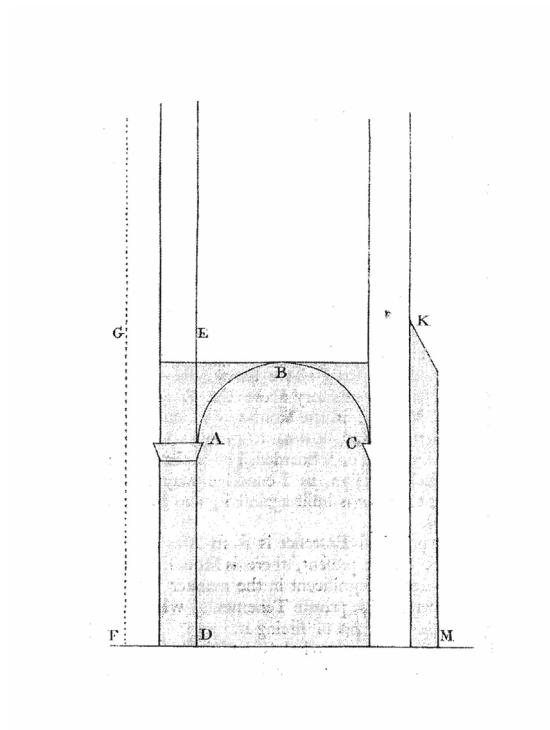


Figure 10. Buttressing of a pillar by adding weight (Wren Jr. 1750)

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