The relationship between scientific knowledge and the building achievements. The evolution of stereotomry in the eighteenth and nineteenth centuries

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*Geometria plura praesidia prestat Architectura.*

These words, taken from Vitruvius work and assumed as a motto by Frezier in the frontispiece of his famous book, can synthetically explain which was the position of the scholars in stereotomy in the period that runs from the appearance of Delorme’s «Le premier tome de Architecture» (1567) to the publishing of Frezier’s «Traité de stéréotomie à l’usage de l’architecture» (1737-39) which concludes the first and fertile season of treatises on stone building. More strenuously than in preceding works on the subject, Frezier, in this book, supported the idea of the usefulness of mathematics in the development and progress of architecture. The search for the rational foundations of architecture which characterized a good deal of the French treatises on stereotomy and theoretical studies on architecture starting from Delorme and Perrault, seems to stop with Frezier’s *Traité de stéréotomie* where the geometrical rigour of building problems reached its highest peak.

The author was convinced that, a scientific knowledge was necessary for the development of architecture and that such a knowledge could give the opportunity to satisfy new demands without waiting for the consolidation of practical solutions.

Such a conviction, clearly stated in the *Epitre* of his work, clashed with the emerging ideas which tended to go beyond the doctrinal separation between theory and technique. The will to demonstrate the usefulness of reasoning applied to building represents one of the topics of an open debate between the supporters of the necessity of a scientific foundation in architecture and those who wanted to revalue technique and knowledge acquired through experience.

Against the theses of the stereotomists and especially against Frezier’s ideas expressed in the first volume of his treatise in 1737 set Cartaud’s *Pensées critiques sur le mathematiques* published in Paris in 1734 where the author stated the uselessness of mathematics for the progress and improving of the Beaux Arts.
The controversy spread and went beyond the theoretical debate: Frezier’s work was harshly criticized by constructors because he wasn’t able to meet the necessities of the building process.

Frezier’s aim was to demonstrate how every situation dealing with the definition of stone structures could be solved by use of geometry but not a word came from the author to explain how his complex geometrical constructions could be of any help to the practical needs of a building site. Criticism from experts led Frezier to publish a compendium of his work whose title was *Elements de stéréotomie a l’usage de l’architecture*, in 1760 but, like his master Desargues, he didn’t succeed in elaborating a synthesis of the stereotomic problem.

The study of the evolution of stereotomy proceeds side by side with the study of how the problem of free stone building is dealt with by the different authors.

During the first period of stereotomy running, as we have already said, from Delorme to Frézier and the works of M. Jousse, G. Desargues, F. Derand and J. B. de la Rue, such a problem coincided with the elaboration of the rules which enabled to determine univocally the form of the voussoirs of a vault. Such rules are of a geometric type but seems to originate from some building considerations deriving from the age-long experience of gothic constructors. These considerations, never expressed in the works of the above-mentioned authors, will clearly appear about a century after Frézier’s *traité* in Adhemar treatise when the transformation of stereotomy had already taken place.

The stereotomists’ goal was to find a rational solution, I mean in geometric terms, in order to obtain a building that was comme une seule pièce. Their interest was to elaborate rules by which it would be possible to obtain a structure which worked as a voussoir arch; that meant to define voussoirs with joints in radial sequence through univocal geometric construction.

As a matter of fact the acquired experience suggested the best form for every building problem requiring a vaulting. The relationships between the span and thickness of a vault were defined by rules handed on orally inside the various guilds of constructors. In order to determine the thickness of piers, some empirical geometric constructions were used on the basis of the form and size of the vault. These considerations are not dealt with in treatises of stereotomy. In that context they usually debated on the geometrical definition of the voussoirs. Such a result was achieved by geometrical constructions based on the intersection between the intrados surface and the system of surfaces that included the voussoirs’ joints.

Frézier was the first to arrange in a system the pieces of information about geometry applied to stone cutting. If we exclude some little investigated works by Hero of Alexandria and Anthemius of Tralles, such a topic had only been treated, mostly with poor scientific rigour, for the last two hundred years.

Frézier deemed it necessary to start his study on stereotomy from the intersection between solids and surfaces and the study of the resulting curves passing on to the description of the methods for representing solids and their sections on a plane. Then he dedicated two of three volumes of his work to the discussion of
various examples of vaulting and to the definition of their respective voussoirs.

His intention to demonstrate the usefulness of a rational process applied to architecture resulted in harsh criticism from those who had to cope with everyday difficulties in a building site.

Frézier’s work appeared incomprehensible to them and not even its figures were of any help because their abstract geometric constructions didn’t provide, unless, very rarely, with form and size of the voussoirs.

This event showed two important problems: the inexistence of a common language shared by both stereotomists and constructors which allowed the transmission and diffusion of the geometric processes.

The second problem consisted in the inefficiency of the two-dimensional representation system of geometric constructions that proved to be inadequate to convey information graphically.

Frézier, together with Monge’s predecessors, used mainly representations through plan and elevation. Only in very few cases he introduced the double orthogonal projection which made the spatial comprehension of the whole construction more precise and complete.

The double orthogonal projection, in fact, would represent one of the basic elements in the maturity of stereotomy.

The distance between Frézier’s work together with those scholars who maintained the necessity of a theoretical foundation for architecture and those who emphasized the importance of an empirical knowledge seems even wider if we compare the theoretical examples taken into consideration in Frézier’s treatise to the level of practical experience.

The superficial analysis of the compound vaulting especially cross vaulting contrasts with the wonderful stone building showing virtuosic skill that flourished in various areas of France in the XVIIIth century.

Around the middle of the 18th century, as a result of a changed cultural attitude, unquestionable signs of crisis in classic stereotomy started to be evident. The age of Encyclopédie (1751–1772) marked this period of transformation and reconciliation between theory and practice.

At the same time the publication of Abbot Laugier’s Essay sur l’architecture (1753) represented a harsh criticism against the excessive oddity of stone buildings.

On the other hands on page XIV of his discours préliminaire Frézier himself exhorted architects to ostentate knowledge and show indifference towards any kind of restraints.

Abbot Langier’s voice wasn’t the only one to hurl against stereotomy: J.F. Blondel, too, maintained that a good architect should prefer verisimilitude to the presumptuous arrogance of stereotomy.

The apparence of Diderot and D’Alambert’s Encyclopédie started a new attitude as regards the transmission of ideas in architecture and especially the arts related to building. Any aspiration of theoretical foundation was abandoned and there was a simple record of what had already been acquired. Within the detailed classification of sciences and arts Diderot and D’Alambert’s work included also their traditional and empirical aspects. Diderot believed that progress and research could develop only by free diffusion of
Figure 4
Concise treatment of stereotomy in «Encyclopédie» (Diderot and D’Alambert 1751–1772)

However, it’s in the set of figures included in the volume that we can realize that the stereotomists’ studies were completed disregarded. As a matter of fact in the illustrations dedicated to stone building, they hardly examined some kinds of vaulting and as far as voussoirs’ form and size are concerned only flat arches and flat floors were dealt with. There was a conscious refusal to treat stone building in the stereotomist’s fashion, as if their intention was to deprive it of any importance. If we compare the attention dedicated to wooden ceilings with that dedicated to stone building its evident a clear partiality in favour of first technique. As regards wooden ceilings the difficulties of the geometric treatment is certainly comparable to that which characterized the works on stereotomy. This can

Figure 5
Geometric explanation of wooden ceilings in «Encyclopédie» (Diderot and D’alambert 1751–1772)
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be seen both in figures and in their relative explanations. In Frezier’s works the results of stereotomic constructions had been elaborated for both stone building and wooden ceilings as the title itself expressed. On the contrary in the Encyclopedie only the interior carpentry, called *menusier en bâtiments* seems to keep a close connection with geometry. In the text, even less impotence is given to the problems of statics, in fact, one single figure and very little explanation are dedicated to the problems of equilibrium of arches. Probably no editor was able to give, in the little space available, any explanation about subjects being animatedly dealt with in the academies in those years.

In Frezier’s treatise a whole part had been devoted to the statics of vaulting with the intention to define what the thickness of piers, necessary to carry the thrust of vaults, should be. In doing that the author used the already known conclusions reached by De la Hire and Belidor.

The publication of the volumes of the Encyclopedie, as we have already said, marked the crisis of classic stereotomy and led to a general reflection about stone building which, in the dawning of the XIX century, was heading for a deeper awareness of its nature. Gaspard Monge gave the necessary stimulus; in his work he succeeded in collecting all the conclusions and demonstrations already elaborated by mathematicians. In 1800 descriptive geometry developed and proposed the double orthogonal projection, which permitted an exact knowledge of the three-dimensional space and its correct representation on a two-dimensional plane. All that meant the end of the difficulties related to the explanation and representation of stereotomic constructions.

The first author who could take advantage of such conclusions was J. B. Rondelet whose works (1802–1817) have been widely studied.

Nevertheless the last stereotomist gave a better systematization of the knowledge about stone building and made its intrinsical problems evident. Around 1750 the crisis of stereotomy involved not only its theoretical aspects but the whole practice of

Figure 6
Study on different stone barrel vault in Rondelet (1802–1817)
stone building declined also as a consequence of a change in taste. The popularity that Roussillon’s vaulting enjoyed in those times thanks to the diffusion of Abbot Laugier’s work, contributed a lot to the falling out of grace of stone building.

During XIX century these structures were still used for infrastructural works such as railway oblique bridges. These buildings had to follow the layout of the railway line so they might either cross a river obliquely or have a curvilinear tracing. The acquired experience of constructors, more than innovated techniques, could be profitable in these situations where a technical skill was required.

In 1870 the sixth edition of J. A. Adhémar’s work *Traite de la coupe des pierres*, included in a wider

*Figure 7*
Roussillon’s vault in Blondel (1675)

*Figure 8*
Oblique running bridge’s example with orthogonal device (Adhémar [1850?] 1870)

*Cours de Mathematiques à l’usage de l’architectes* was published. Unfortunately I’m not able to give you the exact date of the first edition but I think it must not be prior to 1850.

Almost half of this work is dedicated to the discussion of several problems related to the building of an oblique-running bridge. One of the major problems of such structures is the necessity to prearrange a building device in order to avoid the risk of a void-thrust. The difficulties is brilliantly faced by the authors who shows the studies of a helicoidal device and of an orthogonal one, both are adequately supported by a set of figures which provide the reader with much graphic information. Adhémar’s work is carried out with lucidity and coherence, his prose is fluent and effective, free from Frezier’s bombastic and dogmatic tone. No demonstrations, lemmas or postulates are proposed and basic notions of descriptive geometry are necessary to understand his constructions.

This treatise witnesses that stereotomy reached its full maturity just when it was headding for its complete disappearance from the European architectural scene. Finally the most important problem of the stone building appears in all its aspects and complexity. During the XVII and XVIII century classic stereotomist had had an unrealizable dream about the possibility of giving scientific foundation to the problem of stone building and of elaborating a single solution which could satisfy any request concerning formal, building or static aspects.
On the contrary, in his work, Adhemar pointed out, more than once, that stereotomy couldn’t be considered as an exact science. It must be intended as a series of both scientific and empirical notions: a fascinating mixture of abstract concepts and references to the physical reality of the building problem. In the proposition 844 the author clearly stated that the difficulties dealt with in the study of a complex situation such as the building of an oblique-running bridge, derived from the incompatibility of the limitations and considerations of mechanical, building and geometric nature. As a matter of fact, as regards the main geometric conditions, that is the absence of acute-angle voussoir which had represented an implicit rule also in classic stereotomy, it was possible to obtain either voussoir with double-curved joints but their cutting proved difficult or joints with inclination contrary to the theories of the mechanics of arches but that led to a subsequent rotations and to the appearance of dangerous void-thrusts.

On the other hand the existence of acute angles could cause a localized breaking of same voussoirs’ edges while, wanting to privilege the setting of the voussoirs, that could lead to an unacceptable formal solution. Previously, in proposition 373, Adhemar had explicitedly introduced the structure of stereotomic problem; according to him, it is composed of five faces: 1) the choice of projection plans; 2) the choice of the thickness of vaults and piers’, and then of the
whole device; 3) the definition of the joints surfaces; 4) capsizing and development of the surfaces of the different joints faces and 5) the tracing of the joints on the voussoirs and their cutting. As we can see, vaults thickness and building device were quantitative and qualitative variables that constructors had to fix in advance.

The continuous references to mechanical, geometric and building problems is emphasized, in some cases, by the personal intervention of some constructions who the author appeals to for empirical help when explanation of geometric constructions and static reasonings are not sufficient. That is the case of the directions about stone cutting and about the form to give to some very complicated voussoir. Adhemar's reader seems to be already dealing with the carrying out the building of a stone vaulting. He is probably an expert who looks for suggestions when he lacks the consolidated experience of generations of constructors.

The battle of the supporters of classicism against the use of stereotomy in the Architecture didn't prevent stone building from resisting even if in rather different form up to the end of the XIX century. When the theories of eclectic architecture flourished and the traditional architectural inheritance of the different countries revived, stereotomy enjoyed some moderate fame again. By that time, being the world of building technologically changed, every theoretical speculation on the subject had come to a dead end proving to be devoid of any sense and aim.

Figure 13
Antoni Gaudi. Milà’s house in Barcelona (1906–1910). The stone covering of the facade
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