Proceedings of the First International Congress on Construction History, Madrid, 20th-24th January 2003, ed. S. Huerta, Madrid: I. Juan de Herrera, SEdHC, ETSAM, A. E. Benvenuto, COAM, F. Dragados, 2003.

Stereotomy, a multifaceted technique

Joël Sakarovitch

The meaning of the word stereotomy, the etymology of which broadly designates the art of cutting three-dimensional solids into shapes to be assembled, is restricted in architecture to designate more specifically the art of stone carving for the purpose of constructing vaults, squinches, cupolas or flights of stairs . . . Although universal dictionaries mention «wood stereotomy» as involving the assembly of timber pieces, it is noteworthy that this meaning generally disappears from architecture dictionaries. The shift in meaning is of course not fortuitous and this will be discussed further below. *Vocabulaire de l'Architecture,*[1] defines stereotomy as being «l'art de tracer les formes à donner aux pierres (et aux briques) en vue de leur assemblage», in other words «the art of drawing the shapes to be given to stones (and bricks) for future assembly». Hence it adopts once more the definition given in Aviler's dictionary of 1691, which was considered the authority in the 18th century, and echoes the French expression «art du trait» or art of line drawing. Thus reduced to the «art of line drawing», stereotomy would appear to be solely concerned with the art of drawing lines in preparation for the future assembly of carved stones. In that sense, stereotomy would not be as such a construction technique but merely a preliminary step in stone vault construction. I cast my preference here on a definition attributed to Claude Perrault, a fine expert on the subject, according to whom stereotomy is «the art of using the weight of stone against itself so as to hold it up thanks to the very weight that pulls it down».[2] Being a broader definition than the one in which it is seen merely as the art of line drawing, it seems to me to be more in accordance with the majority of contributions that have been classified in the section on stereotomy in this conference. This implies viewing stereotomy as part and parcel of the construction technique itself, and specifically in the domain of stone construction. I shall therefore talk only about what is directly relevant to stereotomy as such —insofar as the distinction can be made— and not about stone carving in general, the material itself, the different qualities of stone, the various tools, etc.[3] Furthermore, the fact that Perrault's definition identifies the arch as the origin of stereotomy gives a historical depth of 23 or 24 centuries, which is quite an advantage for the historian.

Fundamentally, the problem of constructing a stone vault or any building with stone arches is first and foremost one of statics. The major objective is to resolve a problem of spanning or covering. Now Perrault's definition is indeed formulated in terms of vault mechanics. At the same time, the shape of voussoirs is essential to this art. The underlying geometry is subservient to vault statics and is therefore constructional in the full sense of the word. From this fundamental, intrinsic and consubstantial overlap emerges a polymorphy of stereotomy, a multitude of possible approaches, a variety of ways in which it can be viewed, studied and therefore historicised.

Rather than presenting a panorama of more or less recent research on the subject,[4] I have chosen to try and present the different approaches proposed by the researchers who decided to climb this great mountain —which is noteworthy for both its height and antiquity (a rare occurrence in geology). My intention is also to analyse the relationship between different approaches and the perspectives they offer and reveal. Cross-examination allows one to show the importance of stereotomy in the history of construction and I think it can contribute to defining the specificity of the history of construction.

Stereotomy can be studied from the standpoint of its relationship to the history of architecture, the applied geometry used by the stone cutter, the erudite geometry of the mathematician, studies in the field of mechanics, and the history of crafts and their emergence.

STEREOTOMY, ARCHITECTURE AND CONSTRUCTION

As a construction technique, stereotomy allows the creation of architectural forms. A taxonomy of forms and their evolution in time and space, as well as a comparative study of national characteristics have produced some of the most beautiful studies on the subject. The use of stone vault construction over a long historical period opens a field —one might even say an ocean— of possible research avenues. Indeed from the emergence of stone vault construction and its spread in Antiquity right through to its golden age and ultimate decline, there have been noteworthy topics available for study. The more readily identifiable are: the birth of complex stereotomy in paleochristian Syria, the development of European stereotomy after the return of crusaders, the comparison between Roman and Gothic stereotomy and how they answered different needs and demands[5] . . . Half historian of construction and half historian of architecture, the researcher must follow the evolution of stereotomy in space and time, with all the difficulties that entails including the precise dating of constructions. Naturally, the evolution in the construction of particular shapes and vaults is linked to the development in the techniques of stone cutting such as repointing, squaring, half squaring, or cutting with a template. Which method was used and when? Which practical and theoretical tools were used and with what result in mind? Etc. And of course the motors for improvement or the reasons for a loss in know-how are also of interest for historians of other construction techniques.

A great number of studies are actually case studies: studies of particular buildings, specific vaulted constructions, or buildings designed by particular architects. Philibert de l'Orme, for instance, remains one of the architects who has been most written about. Even though stereotomy is not the only reason for this, it is nevertheless responsible for a good part of the interest the community of historians has shown in Henry II's architect. The numerous studies dedicated solely to the squinch of the castle at Anet would suffice to show the different possible approaches to vaulted construction.[6] It is true that the destruction of this masterpiece of stereotomy during the French Revolution has contributed somewhat to elevating it to the rank of architectural myth and this squinch is now to stereotomy what Mies van der Rohe's pavillion in Barcelona is to Modern architecture.

Compared to other more recent construction techniques, such as the use of iron and concrete, which were international from the onset, stereotomy has long remained strongly marked by specifically regional and national characteristics.[7] The work of Pérouse de Montclos provides a remarkable repertoire of stereotomic buildings, principally in France but also in the rest of Europe. By presenting stereotomy as the touchstone of French-styled architecture, Pérouse de Montclos proves —if that were at all necessary— that the history of architecture cannot be conceived independently of the history of construction.[8]

These studies usually sing the praise of stereotomy. However, in relation to the history of construction in general, one cannot glide over the fact that architects overconfident in the novel possibilities offered by a new technique or too focused on its (immense) possibilities, could sometimes forget or neglect other parts of a building. As Jean-Louis Taupin put it, they occasionally succumbed to the «the rapture of stereotomy».[9]

STEREOTOMY AND GEOMETRY

One of the more specific aspects of stereotomy is the fact that it is a technique that is deeply rooted in geometry. Unlike the carpenter who makes the skeleton of a particular volume or the ironsmith who determines the envelope, the stone cutter works directly into the mass of the material, which can be given any shape. Concretely, materially, the stone cutter has in front of him a solid piece of three-dimensional space. It follows that stereotomy involves varied surfaces (usually ruled or revolution surfaces) as well as surface intersections.

Because of this complexity, stereotomy generates situations where a preliminary drawing is indispensable. This situation is neither very frequent nor very old. The history of architectural drawing shows that, up to the Renaissance at any rate, the tendency was for builders to avoid preliminary drawings before starting construction since drawings were made only when deemed absolutely necessary. It is more thanks to the stone cutters than the architects themselves that geometral representation was literally «constructed». This occurred by a slow back and forth process between different cutting techniques, which were long used in parallel and in time, constituted a base of «pre-geometric experience».[10] It is from such experience that stone cutting treatises emerged in the first instance and descriptive geometry later on. In addition, stereotomy —unlike masonry— requires a precision of execution, which further pushes the tendency towards making a preliminary drawing.

Since the preliminary drawing is the crux of the 2D/3D transformation, of the conversion of a two-dimensional explicative drawing into a three-dimensional construct, stereotomy is the starting point of the fully-fledged construction site drawing. And the problems linked to projection and the changing of co-ordinates imply very much more subtle geometric reasoning than those involving planar geometry.[11]

It is for this reason that stereotomy is linked to both applied geometry —practised by building guilds— as well as erudite geometry, which is the domain of mathematicians.

Stereotomy, applied geometry and stone cutting treatises

The elaboration of an applied geometry, which lies at the heart of the transformation from planar to three-dimensional geometry, turns out to be sufficiently complex to have sustained the «secrecy» of the stone cutting guild for centuries. This delayed the formulation of the underlying geometrical theory until relatively recent times in comparison with the progress made in other branches of mathematics. To understand how this step was resolved is therefore the focus of numerous studies referring to stereotomy, particularly during the Middle Ages.[12] The stone cutter statutes —promulgated in Ratisbona in 1459— forbade the disclosure of the «guild's ways and practices», which certainly included the way to «draw» the elevation from the plan. These statutes are therefore an integral part of the history of stereotomy in the Middle Ages. Such geometrical knowledge, wrapped in a halo of secrecy, contributed to the «secret of cathedral builders», which, like the secret of the pyramids or the secret of Roman concrete, has always stimulated the curiosity of scholars and potential readers. It is not impossible in my view that, partly for this reason, the so-called secret surrounding such issues has been somewhat exaggerated in a good number of commentaries.

In any case, it is striking to note that the «mystery» surrounding the working drawings of fitters and carpenters is to be found again when descriptive geometry was created. According to Dupin, Monge supposedly declared, when he was teaching at the Louvre in the 1780's, that «Everything I achieve with calculations, I could also achieve with a ruler and compass, but I may not reveal such secrets».[13] Théodore Olivier also recounts an anecdote according to which a civil engineer had had his notes from Monge's course stolen by artillery officers. It turns out the thieves failed miserably in their attempt to «decipher the hieroglyphics» of the Mézières School.[14] The fact that an atmosphere of mystery still hovered when descriptive geometry was being invented is proof of the real difficulty involved in reading and interpreting the drawings that were the key to the 2D/3D transformation. It is indeed a language —and Monge does define descriptive geometry in such terms— a language that needs to be learned. Thus the reference to hieroglyphics is hardly fortuitous but Champollion's talent is not given to everyone.

The relationship between stereotomy and applied geometry also explains the large number of stone cutting treatises written right through into the 19th century, either edited or in manuscript form. Thus the analysis of original treatises and their reedited copies with commentaries, as well as edited manuscripts are, together with the study of stone vault constructions, an invaluable tool in the study of stereotomy.[15] There again the approach may be architectural, through a comparison of the guilds presented in the various treatises. It can be geometric, through the study of the graphic methods presented and the analysis of the applied geometry used, which may (or may not) brings solutions yet does not provide answers to fundamental questions.

Finally, one ought to mention that, given the quasi desert of sources on technical drawing during the Roman and Gothic architectural periods, Villard de Honnecourt's *Carnet* seems like an oasis of untold riches. The two drawings about stereotomy in this *Carnet* are truly precious corner stones enabling one to appreciate the evolution of graphic methods applied to stone cutting.[16]

Because they are basically dealing with the problem of transposing 2D into 3D, stereotomy treatises also offer one of the most complete examples of the evolution of representational modes in space. For this reason, stone cutting drawings have been one of the motors of the evolution of space representation techniques.

Stereotomy and erudite geometry

While stereotomy, together with carpentry, provides one of the richest examples of the uses of applied geometry, it is also at the root of a branch of erudite geometry, namely descriptive geometry. To sum up the situation, one might say that stereotomy is to descriptive geometry what perspective is to projective geometry.

The parallel between the evolution of stereotomy and perspective is indeed striking. Both practices developed during the Gothic period —whether on stone cutting work sites or in painters' workshops. The first treatises were edited during the Renaissance and the mathematicians of the «Monge School» explicitly theorised stereotomy and perspective at the end of the 18th and beginning of the 19th century. In a letter addressed to the minister of war, the director of the Ecole du Génie de Mézières writes that Monge «has demonstrated the theory of stone cutting»,[17] an expression which successfully expresses where the matrix of the Monge theory lies. Numerous studies, past and present, have focused on the deep, old and complex ties that exist between stereotomy and descriptive geometry.[18] It is worth noting the specific role played by «squaring» in the emergence of a type of geometric thinking that was to generate descriptive geometry. Stone cutting by squaring, which does not have its equivalent in carpentry, has the advantage over the template method of providing an algorithmic process of form discovery. This explains why this method, though more time-consuming and more expensive, has never been totally abandoned in practice. Just like graphical techniques used in cutting with templates, descriptive geometry theorises this algorithmic procedure as well as the definition of surfaces associated with it.

Showing that descriptive geometry was in fact born of the heaviest of all the techniques it more or less theorised, namely stereotomy, weighs it down forever. «Let Descartes intervene, then Monge and many others, they still work as always from the applied as well as the representational standpoint, perpetuating the cleverness of engineers, inducing the survival of archaic, pre-mathematical practice and thus blocking the emergence of science in all its purity. And this science is born precisely when this cleverness dies: not very long ago».[19] Thus Michel Serres makes of Monge the last «harpedonapt». Yet, in the wake of Chasles, no science historian describing the origins of modern geometry would refuse to see Monge as Poncelet's teacher. None would refuse to find in *Leçons de géométrie descriptive* the starting point of a rebirth in geometric studies at the beginning of the 19th century and the beginning of the ensuing profound upheaval in mathematics. Thus, in spite of Michel Serres' assertion, geometry «in all its purity» —that is to say freed of Euclidean metric— was launched in a drawing course for engineers and it would seem that science in all its purity was born of this cleverness.

The German mathematician Felix Klein who claimed «to have been educated . . . thanks to [his] teacher Plücker in the Monge tradition», considered the «application of geometric intuition to analysis» to be one of the major contributions of this tradition.[20] In the *Erlangen Programme*, which is considered to be the foundation of modern mathematics, Felix Klein explicitly refers to this tradition. This is not to suggest that modern mathematics are a direct result of the spiral staircase of Saint-Gilles. But it means that descriptive geometry, which belongs to the history of techniques through its origins and that of mathematics through its development, establishes a link between the stone cutting tradition and the history of science. And this does confer to stereotomy a rather original position.

Stereotomy and vault mechanics

Vitruve believed that geometry provided simpler rules than did statics for the construction of arches. And until Galileo, it was thought that «geometry —and not mechanics— [was] the true guardian of stability».[21] The «Firmitas» thus mainly belongs to the field of geometry. The new Galilean line of thought imposed itself rather slowly and one cannot fail but notice the total absence of knowledge Guarini, Blondel and Fontana, for instance, had of statics and material resistance. Before the 18th century, builders only had extremely simple, purely geometric and (at best) empirical «rules» at their disposal to size the buildings under construction. One of the most famous rules is the «Leonardo rule», which says the arch will not break if the chord of the outer arc does not touch the inner arc.[22] Another is «Derand's rule», which gives the sizing for the piers of a vault, the size of which is by the way independent of their height. In spite of this construction aberration, the Derand rule —like the Leonardo rule— was still extolled throughout the 17th century and to a large extent during the 18th century.

This state of mind explains why stereotomy has come to be perceived in some ways as what I would call «twice over geometrical». Because, in addition to having a situation objectively requiring an extensive knowledge of geometry —as mentioned above, problems of statics are approached from a geometrical standpoint. This is why stereotomy treatises essentially deem themselves to be books on applied geometry.

Towards the end of the 17th century, the problem of arches and vaults was approached by the European erudite world from a mechanical standpoint. Following this evolution, numerous studies focused on the slow evolution of mentalities on the subject, the difficult switch of thinking in mechanical rather geometrical terms. In other words, they focused on what Eduardo Benvenuto describes exquisitely as the study of how vaults, for which we previously only had solutions, are going to become a problem.

What shape should an arch be? How wide, how thick, how high should the piers of a vault be? One of the earliest answers to this mechanical approach of the problem is Philippe de la Hire's memoir. It deals with the application of lever theory to vault mechanics and has been one of the most extensively studied. The analysis of arch and vault statics is important because it is one of the first examples where infinitesimal calculus was used for practical purposes. The demonstration of Catenary properties by David Gregory or Jacob Bernoulli, Coulomb's memoir on the method of maximis and minimis, the taking into account of material resistance and friction at the end of the 18th century and of the theory of elasticity during the 19th century, constitute an entire chapter in the history of construction and the evolution of thinking in terms of mechanics with respect to the rest of knowledge.[23]

The succession of treatises and memoirs on the subject allows one to study the to-and-fro between the idealisation necessary for mathematisation and the appraisal of the full complexity of phenomena. For instance, how do we go from an infinitely thin to a thick and heavy vault? Since these studies belong to applied or «mixed» mathematics —according to the 18th century French expression— the problem arises as to how to propagate them both amongst the erudite community and the building community. Though generally hostile, sarcastic or ironical, the latter cannot help but show a certain admiration. The subject is therefore an ideal observation point to reveal the quarrels and debates that opposed advocates of practice or theory throughout the 18th and the first half of the 19th century in Europe. The Tredgold aphorism according to which «The stability of a building is inversely proportional to the science of the builder»[24] is a good gauge of the manner in which the first essays on the mathematics of statics were perceived. The title of Charles-François Viel's memoir, entitled *De l'impuissance des mathématiques pour assurer la solidité des batimens*[25] *(Of the powerlessness of mathematics to ensure the solidity of a building)* is another.

While the theory on the mechanics of vaults progressed, stereotomy disappeared almost totally from architectural construction, mainly because of the arrival of new materials such as iron and concrete. But the building of railways in Europe was to bring about the construction of relatively specific civil engineering structures, namely «oblique bridges» or bridges the deck of which is not perpendicular to the railway line. Such bridges have to withstand overloads and strong vibrations produced by the passage of trains whilst being —sometimes quite substantially— skewed. Their construction in stone therefore requires the resolution of delicate installation problems in order to reduce the outward thrust. Much has been written about oblique stone bridges. This literature is particularly interesting in that the civil engineering constructions concerned require that the problem be mastered both from the point of view of geometry and statics. In addition these writings are significant because they deal with an issue which needed to be addressed almost simultaneously all over Europe thus allowing a comparison of national characteristics.[26]

Stereotomy occupies a strategic position between geometry and mechanics. This explains on the one hand why it became a power stake and therefore a source of conflict between the different building guilds and, on the other hand the reason it played — and possibly still plays— a role in the formation of the various building trades.

STEREOTOMY AS THE SCENE OF SOCIAL CONFLICT

Being the favourite scene of the practical versus theoretical debate, stereotomy has been from the Middle Ages right through to the 19th century the main stake in the rivalries between master mason architects and engineers.[27] This is so even though the terms of the practical/theoretical debate evolved considerably over such a long period of time.

It is to enable the architect to «direct and train master masons and their workers rather than be trained and led by them»,[28] that Philibert de l'Orme inserted the first treatise of stereotomy in a treatise on architecture. The Desargues-Curabelle quarrel, which opposed in the 1640's one of the most famous fitters with the best geometer of the time, is also a symptom of the tensions that existed. The essence of the Desargues-Curabelle quarrel bore on the manner in which one might ascertain that the lines of a drawing are legitimate. For Curabelle, the criterion was feasibility whereas Desargues only counted on whether the geometrical reasoning was correct. Now in this opposition, it is the entire status of the working drawing that is being questioned. If one admits along with Curabelle that the legitimacy of the drawing can only be validated by its execution, the master mason remains the keystone on the construction site. If, on the other hand, a drawing can, as Desargues claims, find legitimacy in itself, if its correctness can be shown purely on theoretical grounds and independently of any concrete execution, if optimal lines are found solely on the basis of geometric reasoning rather than experience, then the very status of the drawing becomes modified and hence that of its author and executant. Like de l'Orme, Desargues explained what is at stake in these conflicts: «just as Doctors of Medicine neither attend the schools or lessons of Apothecaries . . . neither should geometers attend the schools and lessons of Masons but, on the contrary, Masons should attend the schools and lessons of geometers, which is to say that Geometers are the masters and Masons the disciples».[29] Thus the salient feature in Desargues polemical writing is the assertion that theory takes precedence over practice.

With the emergence of the architects' guild and later on the guild of engineers, this current aims at increasing task specialisation. This clearly goes against the will of the stone cutters' guild that wanted to keep full mastery of the entire production process in complex vault construction. Thus, as the history of stereotomy unfolds, so does the history of the emergence of the different construction guilds and the way the territory was eventually to be shared between them.[30]

However, one can also have a differential reading of this history and try to understand how the actors are going to reappropriate their own history. We are now talking about the history of the history of techniques. For the history of techniques plays a social role and, in the conquest of professional hegemony, it is possible to find arguments in favour of the social division of labour and the means of legitimising its foundation. Rather than perceiving the tradition of guilds as resulting necessarily in routine behaviour that the use of geometric and statics theory might be susceptible of breaking (as argued by Desargues, Frézier and other engineers of the 19th century), the stone cutters' guild is seen as having a tradition which, far from being synonymous with refusing change or observing stupid and immutable rules, represents the conscience of being a structured entity.[31]

Didactic Stereotomy, Theoretical Stereotomy

One last consequence —fundamental for its evolution in the 19th century— of the narrow and specific links binding stereotomy and geometry, is the transformation of stereotomy into a school discipline. It is of course not fortuitous that such a shift should occur at the time of creation of the Ecole du Génie de Mézières, one of the first engineering schools in Europe. Right from its creation in 1748 (thus before the arrival of Monge), the teaching of stereotomy in the school went beyond the strict utilitarian aspect of an already declining construction technique. The major objective of the course was to provide training in geometry and the art of visualisation in space. The founders of the Ecole du Génie de Mézières formulated this idea quite explicitly: «these arts offer such exact and precise knowledge for the drawing of plans and profiles, and the manner in which to express the relief they are to represent, that they may be regarded on the same level as the Elements (of Euclid)».[32]

This situation therefore opens a new area of research: stereotomy as a school discipline. What was its role in the training of engineers in Europe from the middle of the 18th to the end of the 19th century, how was it was taught and how did this teaching evolve . . . Since the history of learning institutions is dependent upon the history of the disciplines that are taught in them, the teaching of stereotomy becomes one of the possible markers for comparing institutions. Finally and for the same reasons, stereotomy also became part of the training imparted to workers and craftsmen, there again to a much larger extent than its strictly practical aspect would lead one to suppose. Indeed this is still so today if we consider the overemphasis of stereotomy in the training of the Compagnons de France (highly skilled craftsmen).

The fact that Monge, when an Ancien Régime engineering school was being transformed into an engineering school of the Republic, tried to transfer to descriptive geometry the didactic function previously assigned to stereotomy offers another reading of the relationship between the two disciplines.

Projective geometry, which decisively broke away from the graphical techniques out of which it was born, differs fundamentally from descriptive geometry, which remained linked to them body and soul. Poncelet did not propose a new form of pictorial art, give advice to painters or have artistic pretensions. Monge, in his courses at the Ecole Polytechnique, developed a stone vault construction theory based on curvature lines. This theory is extremely elegant from a geometrical point of view and is supposed to answer a relatively simple question: how can we generalise to any intrados surface starting from the case of the hemispherical vault? Yet one cannot but recognise that Monge's theory, which is based on curvature lines, is in fact for him a means of teaching the concepts of curvature lines and normal surfaces rather than teaching stereotomy. In any case, Monge finished off at the Ecole Polytechnique what the founders of the Ecole de Mézières had undertaken, by establishing what one might call «theoretical stereotomy», detached from its original function as a technique of construction and in radical opposition to the stereotomy of the work site.[33]

Conclusion

It appears to me the diversity of possible approaches is what gives stereotomy its specificity and importance as an object in the history of construction. Studies on stereotomy have successively been conducted by historians of architecture, historians of science and technology, and historians of education, and have benefited from the development of each of these particular points of view. But the true riches of stereotomy come from its intrinsic complexity and the constant interactions between historians from different fields. Therefore, the primary aim of studies on the history of construction today is more to decipher specific histories which interact at any given time, and put the pieces of a multi-faceted history together rather than explore a previously identified niche or other. The number and diversity of communications that follow under the heading *stereotomy* illustrates this wealth and polysemy.

I should like to conclude in a more personal way.

Like many other researchers present here today, I teach in a School of architecture. Now I do not perceive my activities as teacher and researcher as fundamentally separate. This is so not only because I teach history of construction but also because the history of construction in itself is for me a tool to vitalise teaching in schools of architecture. Stereotomy is a means —as I have just attempted to demonstrate— of approaching the history of architecture, understanding the mechanics of natural phenomena and learning geometry. Because of this and because its virtues as a school discipline do not appear to me to have entirely disappeared, I have given my students exercises in stereotomy for a number of years. The opening of the «Grands Ateliers de l'Isle d'Abeau» (near Lyon) in December 2001 allowed me to propose for the first time last year a stereotomy experiment on a large scale. I constructed with a group of some fifteen students and with the help of a professional stone cutter a planar vault of about 2.5 by 2.5 metres (see figure below).

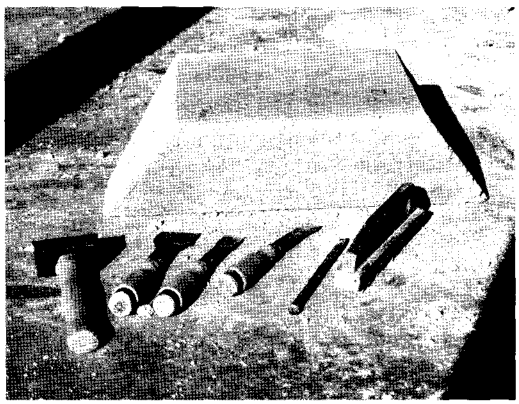
Leroi-Gourhan has written: «it would be of little importance that this organ of fortune that we call the hand disappear where it not for the fact that everything points to its activity being closely bound with the equilibrium of cerebral territories associated with it . . . to not have to think with all of one's fingers is equivalent to missing part of one's normally phylogenetically human thinking ability. There exists therefore as of now and at the individual level, if not at the level of the species, a hand regression problem».[34]

In carrying out stereotomy experiments on a large scale, the idea is to sensitise students to the complexity of the building endeavour. Given the relationship between stereotomy and the different branches of architecture I have just described, such experimentation is a means of learning «to think with all of one's fingers» about the history of architecture, construction, geometry and statics. In a time when the Internet imposes a rhythm of exchange on the order of immediacy, the practice of stereotomy, a hymn to slow motion, is I believe indispensable in teaching. It can renew the ways in which to apprehend fundamental disciplines in the teaching of architecture and to understand the relationships between them.

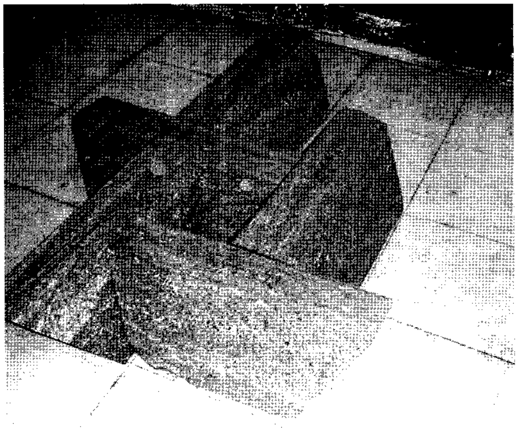
Construction of a mortarless keystone planar vault in the Grands Ateliers de l'Isle d'Abeau (Isère, France) from 4th to 8th February 2002

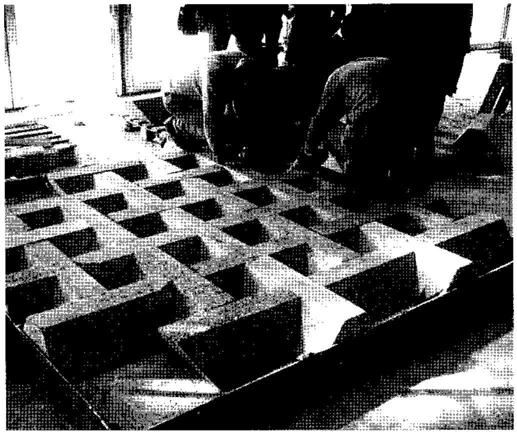
Under the direction of Joël Sakarovitch, Jean-Paul Laurent (structural engineer) Jean-Paul Foucher, (stone cutter).

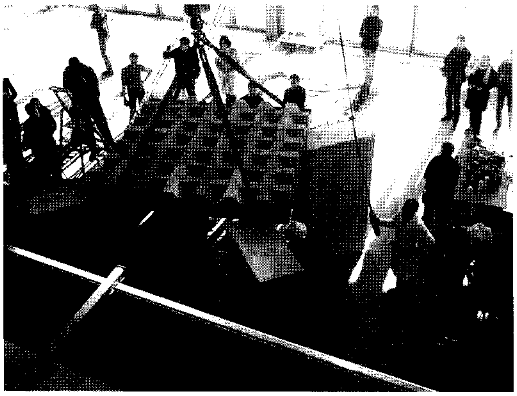
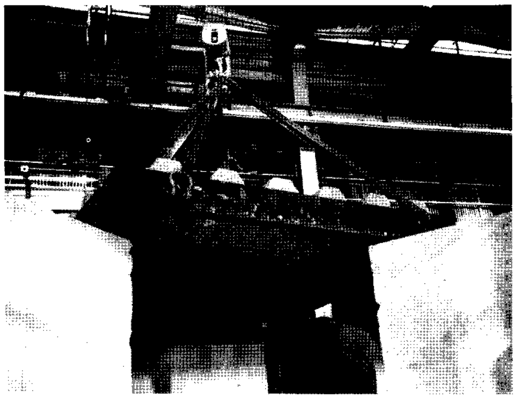
Cutting of voussoirs

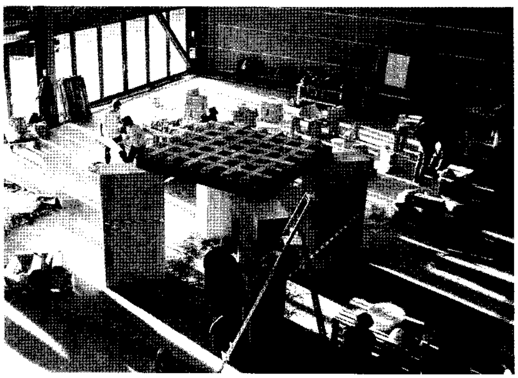


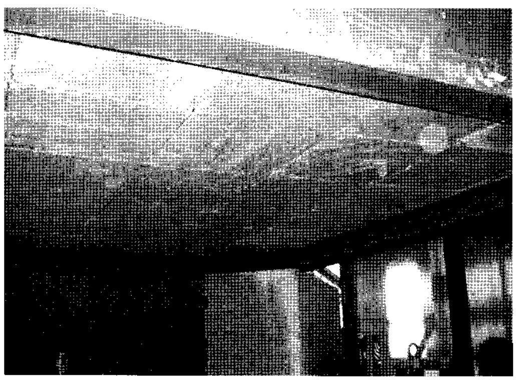
Voussoir and cutting tools

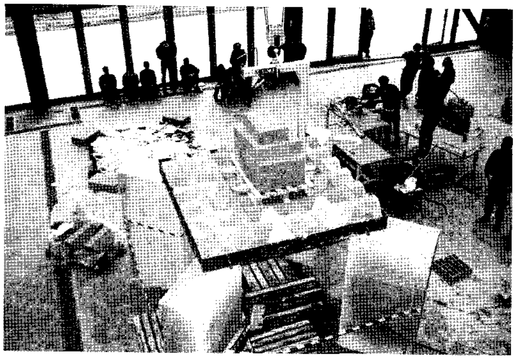
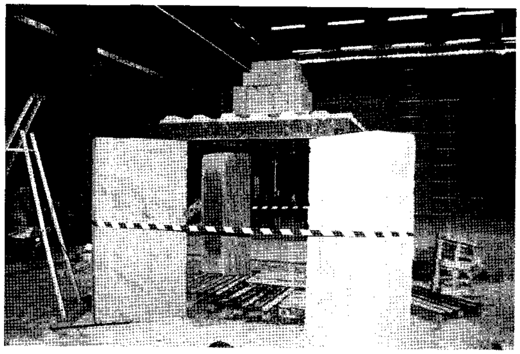

Assembly of first voussoirs


Voussoirs in their metallic frame



Positionning on piers


The planar vault


The underside

Load testing

Notes

1. J.-M. Pérouse de Montclos, Ministère des affaires culturelles, Paris, 1972.
2. This definition is attributed to Claude Perrault by J.-M. Pérouse de Montclos in *L'architecture à la Française, XVIe, XVIIe, XVIIIe siècle*, Paris, Picard, 1982, p. 85.
3. On the subject, the following works are of interest: l'*Encyclopédie des métiers, La maçonnerie et la taille des pierres*, edited by l'Association Ouvrière des Compagnons du Devoir du Tour de France, volume 5, *Les outils* ; volume 6, *Le savoir faire (De la carrière au chantier)*, Paris, 1991–2000.
4. For a compete bibliography see A. Becchi et F. Foce, *Degli archi e delle volte. Arte del costruire tra meccanica e stereotomia*, Marsilio, Venezia, 2002.
5. See in particular Adam, J.-P., *La construction romaine, matériaux et techniques*, Paris, Picard, 1984 ; Ward-Perkins, J. B., *Roman architecture*, Electa, Milano, 1974; Kubach, H. E., *Architecture romane*, Electa, Milano, 1972.
6. One of the last is from Trevisan, C., «Sulla stereotomia, il CAD e le varie trompe d'Anet», in Migliari, R. ed., *Il designo e la pietra*, Gangemi, Roma, 2000, pp. 27–53.
7. On Spanish stereotomy, see Rabasa Díaz, E., *Forma y construcción en piedra. De la cantería medieval a la estereotomía del siglo XIX*, Akal, Madrid, 2000 or Palacios J.C., *La estereotomia en las construcciones abovedadas*, Instituto Juan de Herrera, Madrid, 1999.
8. Pérouse de Montclos J.-M., *L'architecture à la Française*, op. cit.
9. The serious foundation problems of the Maulnes pentagonal castle in Tonnerrois are probably an example of this rapture affecting Philibert de l'Orme
10. I'm borrowing this formula from Hubert Damisch, who used it concerning *L'origine de la perspective*, Paris, Flammarion, 1987, p. 86.
11. See Evans R., *The projective cast ; architecture and its three geometries*, MIT Press, Cambridge (Mass), 1995 or R. Migliari, op. cit.
12. See Shelby, L. R., «The Geometric Knowledge of the Medieval Master Masons», *Speculum* 47, 1972, pp. 395–421 or Recht, R., ed., *Les bâtisseurs des cathédrales gothiques*, catalogue of the Strasbourg exhibition, Strasbourg, 1989 and in particular the article by Müller, W., «Le dessin technique à l'époque gothique», pp. 237–254.
13. Dupin, Ch., *Eloge historique sur les services et les travaux scientifiques de Gaspard Monge*, Paris, 1819, pp. 20–21.
14. Olivier, Th., *Traité de géométrie descriptive, théorique et appliquée,* Paris, 1843, p. VII. However, in 1771, Tinseau presented a memoir to the Academy, published in 1780, where he clearly uses a descriptive geometry drawing.
15. See for example, the reedition of Philibert de l'Orme by Perouse de Montclos, of Vandelvira by Barbé-Coquelin, of Martinez de Aranda in the Biblioteca CEHOPU, the works of Müller, W., «Guarini e la Stereotomia», in *Guarini e l'Internazionalità del Barocco —Atti del Convegno*, Turin, 1970, vol. 1, pp. 531–556, the book by Bonet Correa A., *Figuras, modelos e imagenes en los tratadistas espagnoles*, Alianza, Madrid, 1993 or the article by Calvo Lopez J. and Rabasa Diaz E., «La coupe des pierres dans l'Espagne du XVIe siècle : le manuscrit de Gines Martinez de Aranda» in Becchi A., Corradi M., Foce F., Pedemonte O. (eds), *Towards a history of construction. Dedicated to Edoardo Benvenuto*, Birkhäuser, Basel, 2002 . . .
16. Lalbat, C., Margueritte, G., Martin, J., «De la

stéréotomie médiévale, La coupe des pierres chez Villard de Honnecourt», *Bulletin Monumental*, vol. 145, IV, 1987, pp. 387–406 and vol. 147, 1989, pp. 11–34. or Bechmann, R., *Villard de Honnecourt. La pensée technique au XIII[e] siécle et sa communication*, Paris, Picard, 1991.
17. In Taton, R., «L'Ecole royale du génie de Mézières» in *Enseignement et diffusion des sciences en France au XVIII[e] siècle*, Paris, Hermann, , pp. 559–613, p. 595.
18. Loria,G. *Storia della geometria descrittiva delle origini, sino ai giorni nostri*, Milan, 1921 ; Sakarovitch, J., *Epures d'architecture, de la coupe des pierres à la géométrie descriptive, XVI[e]-XIX[e] siècles*, Birkhäuser, Basel, 1998.
19. Michel Serres uses this expression concerning the origins of Euclidian geometry in *Les origines de la géométrie*, Flammarion, Paris, 1993, p. 209.
20. Quoted in Taton, R., *L'Œuvre mathématique de G. Desargues*, Vrin, Paris, 1988 (2[e] éd.), p. 240.
21. Benvenuto, «Résistance des matériaux (histoire de la)», in *L'art de l'ingénieur*, A. Picon, dir., Paris, Le Moniteur, 1997, p. 409.
22. However we have to notice that Leonardo is one of the first to propose a mechanical approach of the problem.
23. Cf. for example Benvenuto, E., *An introduction to the History of Structural Mechanics*, Springer-Verlag, New-York, 1991 or the works of J. Heyman and in particular «The stone skeleton», *International Journal of Solids and Structures*, vol. 2, 1966, pp. 249–279 and *Coulomb's memoir on statics. An essay in the history of civil engineering*, Cambridge University Press, Cambridge, 1972.
24. Thomas Tredgold , *Practical Essay on the Strength of Cast Iron and other Metals*, 1822.
25. Published in 1805
26. See in particular A. Becchi et F. Foce, *Op. cit.*
27. See *Dessin-Chantier : Stéréotomie*, n°1, Grenoble, 1982.
28. L'Orme, Ph. de, *Nouvelles inventions pour bien batir à petits frais*, Paris, 1561, reed., L. Laget, Paris, 1988, p.38.
29. Desargues, «Reconnaissance de Monsieur Desargues» in Bosse, A., *Manière universelle de M. Desargues pour pratiquer la perspective par petit-pied, comme le géométral*, Paris, 1648.
30. On this subject see Potié, P., *Philibert de l'Orme, figures de la pensée constructive*, Marseille, Parenthèses, 1996.
31. See Assegond C., *Socialisation du savoir, socialisation du regard. Les usages sociaux du savoir géométriques et de la stéréotomie chez les compagnons tailleurs de pierre*, Université de Tours Thesis (France), nov. 2002.
32. Quoted in Belhoste, B., «Du dessin d'ingénieur à la géométrie descriptive», *In extenso*, n°13, juil. 1990, p. 111.
33. This work site stereotomy is very well described in Rabasa Díaz, E., *op.cit.*
34. Leroi-Gourhan, A., *Le geste et la parole*, t. II, Albin Michel, Paris, 1965 p. 61–62.