Toward a Stereotomic Design: Experimental Constructions and Didactic Experiences

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ABSTRACT: The present study explores the possibility of tying up again the broken thread of research on stone-cutting construction following in the wake of the discontinued weave of stereotomic culture, aiming at applying its innate creative momentum to the education of engineers and architects and to contemporary architecture.

STEREOTOMY AND DIDACTIC EDUCATION

Speculations about architectural form based on the use of stereotomy marked a historically relevant peak between the sixteenth through the eighteenth centuries, followed by a sudden break at the beginning of the nineteenth century. From the half of the eighteenth century, as a result of a changed Weltanschauung, classical stereotomy began to show undeniable signs of weakness; it was considered unable to produce anything but superfluous formal structures, which failed to meet required needs.

Abbot Laugier's *Essai sur l'architecture* reflects the fierce criticism against the pompous eccentricity of the stereotomic manner of stone construction.

Abbot Laugier's voice was not the only one to tarnish the reputation of stereotomy; amongst many others, J.-F. Blondel asserted that a good architect had to prefer likelihood/naturalism to the pretentious arrogance of stereotomy. Furthermore, a destruction of all most renowned archetypes of stereotomic construction takes place from 1770 onward, in keeping with the tenets of the Revolution and its detraction of the lavishness of the *Ancien Régime*.

On the other hand, it is worth mentioning that, in those very years, stereotomy was turned into a school subject, thus reinventing itself. This structuring was performed at the time in the Ecole du Génie de Mézières, one of the first military engineering schools of Europe. From its establishment in 1748 (before the coming of Monge), the teaching of stereotomy went beyond the sheer utilitarian aspect of a declining technique. The founders of the Ecole du Génie du Mézières explicitely stated: "These arts provide such an exact and accurate knowledge of the drawing of planes and surfaces, and of the way of expressing the relief they purport to represent, to be considered by the same standards as Euclid's Elements." The scientific interrelationships of the polytechnical fields of teaching in the first teaching program of 1794, according to d'Alembert and Diderot's encyclopedic model, was divided in two greats categories: mathematics and physics. In the first one there was stereotomy, along with architecture and fortifications, as sciences susceptible to exact definitions, including the comprehension and description of the geometric objects.

The *Ecole des Beaux-Arts* and the *Ecole Polytechnique*, representative of the fields of architecture and engineering respectively, share from the beginning of the nineteenth century, the common teaching of the subject of stereotomy, although they have specific curricula and teaching programmes. This subject was regarded as the most appropriate in encouraging students to "build space" and stimulate creativity. In those years stereotomy became the pivotal subject in the first years of education of both the students of the *Ecole des Beaux-Arts* and the *Polytechniciéns*.

Stereotomy has nowadays no place whatsoever in both new building practice and education, the subject being merely the result of partial and isolated research in the riverbed of the history of construction.

Is it possible to think that the marvels of French and Spanish stereotomic construction between the sixteenth and nineteenth centuries are only tied to historical memory? Is it possible that the secrets hidden within the magical vault of the City Hall of Arles are no longer applicable to architecture today? Is it possible to believe that the technical knowledge of such vaulted spaces has been lost to us? Is it possible to believe that the language of stone architecture has been divorced from modern structural systems and methods of construction?

I believe not! I believe, to the contrary, that the need to return to the construction of stereotomic vaults, renewed by a modern architectural vocabulary that celebrates the materiality of stone, is of extreme importance today.

The present paper basically wonders about the possibility of tying up again the broken thread of the research on stone-cutting construction following in the wake of the discontinued weave of the stereotomic culture, aiming at applying its innate creative momentum in contemporary architecture planning.

As José Carlos Palacios observed (Etlin, Fallacara, Tamboréro, 2008, pp. 12-13), "in the nineteenth century, when this development had reached its very summit, stereotomy collapses and falls into oblivion; the massive masonries of traditional architecture succumbs to give way to a new architecture based on a structural set up never imagined before. Nevertheless, there is still some hope. New geometrical skills gave way to new developments in stereotomy. Digital monitoring allows expansion of the limits of geometry. These new tools, as in the past, enable us to explore new fields previously unattainable in stereotomy [and offer promise] for a great revival: the beauty of its proposals allows us to foresee a future, maybe elitist and sophisticated, but real and possible, for this discipline of architecture which we dreaded obsolete." Yet, the ecological qualities of stone are compelling: unparalleled durability, natural cooling, lack of pollution by toxic waste. The use of stone can reinforce the genius of the place by providing new buildings, however modern in form, that blend with the colour, texture, and materiality of the past. Once a slow and painstaking process of cutting each stone by hand, now stone masonry can proceed rapidly with computer–guided cutters that can fashion more complex shapes than a person working manually with hand–held tools. And computer graphics enable architects to explore sophisticated forms, while subjecting them to static analysis for safety (Etlin, Fallacara, Tamboréro, 2008, p. 17).

Let us reflect upon the potentialities of a union between stereotomy and three-dimensional computer modeling techniques in relation to topological transformations and deformations. This kind of modeling allows very complex stereotomic shapes to be controlled and built by using elaborate notions but very easy actions. The geometrical conformation of every single ashlar of a specific vaulted system is the result of an appropriate series of simple solid geometrical transformations, producing a topological correspondence. Topological geometry can provide a new universal method for stereotomic design. The method takes advantage of the possibility for transforming simple topological forms into various architectonic configurations. Whereas, from the perspective of topology, there is no difference between a plane or a cylinder, in stereotomy the stones will have different shapes in each of these and other forms. In classical stereotomy, the determination of the exact angles between the surfaces of various vaults and domes constituted a problem to be resolved. For topological stereotomy on the computer, the determination of the angles is resolved automatically as a consequence of the deformation of the initial shape. Through a virtual deformation, each ashlar of a vault is a numerical entity whose value is transferred automatically to the cutter. To optimize the assemblage of the vault, the designer should aim for the least possible number of different shapes for the individual stones.

The practical and constructive outcome of this speculation comes from the investigation about the relationship between stereotomy and topology presented by the author in an article published in the congress proceedings Second International Congress on Construction History. The results of this study contributed to the production of the Stereotomic Architecture section of the *Città di Pietra* (Cities of Stone), an exhibition curated by Claudio D'Amato Guerrieri for the Tenth International Architecture Exhibition held at the Venice Biennale in 2006; and on 9-20 July 2007 in the CEU Universidad San Pablo in Madrid within the Summer School named The Art of Stone Theory and Practice of Masonry directed by José Carlos Palacios Gonzalo and Alberto Sanjurjo Alvarez.

These experimental constructions involve some topological changes of the famous stereotomic system known as "flat vault" as found in the patents by the engineer Joseph Abeille and Father Sébastien Truchet respectively. In 1699, each of these two Frenchmen proposed his own design for a flat vault using only one shape of stone. These projects were then popularized by the military engineer Amédée–François Frézier, director of fortifications for Louis XV, who offered his own variants, in an extensive treatise on stereotomy (1737–39, 1754 second edition). Several flat vaults were constructed in Spain over the course of the next century after these models. The flat vaults envisaged by Abeille and Truchet presented the advantage of a thin stone ceiling and floor that could not warp, was free of rot, mold, and insects, and could be constructed of identical stone pieces with an inherent decorative pattern. The Abeille vault came first, its interlocking stones leaving small, square voids on the underside that could be filled either with mortar or with a stone of different colour so as to create a decorative pattern. Father Truchet developed his design as an improvement on the Abeille vault, since its interlocking shapes left no void at all on either surface. Yet, as the initial report published by the French Royal Academy of Sciences explained, the Truchet vault would be difficult to build: «This invention is truly ingenious, but it would perhaps be difficult to execute, because of the need to have the concave and convex

surfaces touch at all points, the curves being entirely different in profile along the entire joint» (Etlin, Fallacara, Tamboréro, 2008, p. 30).
In our constructive speculation, as the images shows (Figs. 1-5), each flat vault, with its particular pattern of interlocking stones, has been converted into a stone ceremonial entrance arch in order to demonstrate the possibility and the robustness of the specific three-dimensional modeling system. On the first occasion the "Abeille" vault was erected with hand-cut stones as an entry gate to the *Città di Pietra* (Cities of Stone) exhibition at the *Artiglierie dell'Arsenale* in Venice; on the second one the oblique vault building, realised during the Summer School in Madrid with students, was entirely designed and produced with CAD/CAM systems, thereby serving as an exemplar of contemporary virtuosity in stereotomy. Today, with computer–guided cutters, the difficulty noted by the Royal Academy of Sciences has been eliminated. In effect, such mechanized tools make the preparation of stone for either vault a relatively easy process, assuring the requisite precision of fit.
These experimentations lead us to the formulation of a new and specific disciplinary realm within architectural design that can be called stereotomic design based on a specific geometric methodology applied to the study of the vaulted space. They also display the vitality of the stereotomic lesson, maybe as a leap into a new future (Fig. 6).

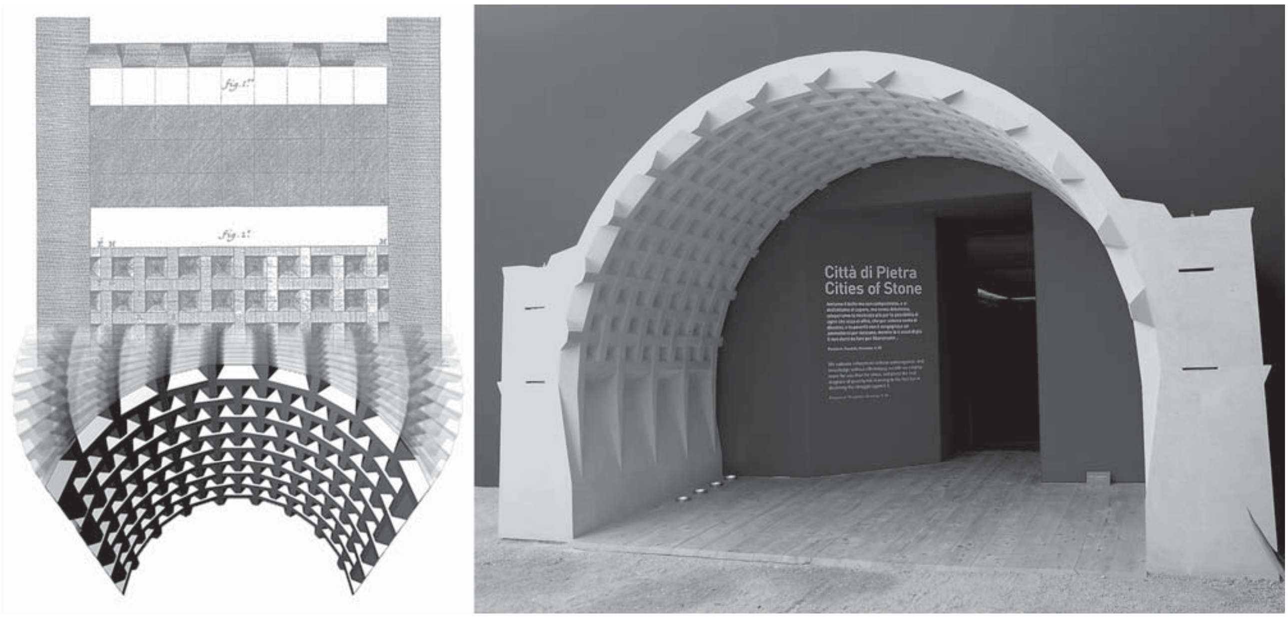

Figure 1: Abeille vault, ceremonial arch at the Città di Pietra (Cities of Stone), for the Tenth International Architecture Exhibition held at the Venice Biennale 2006

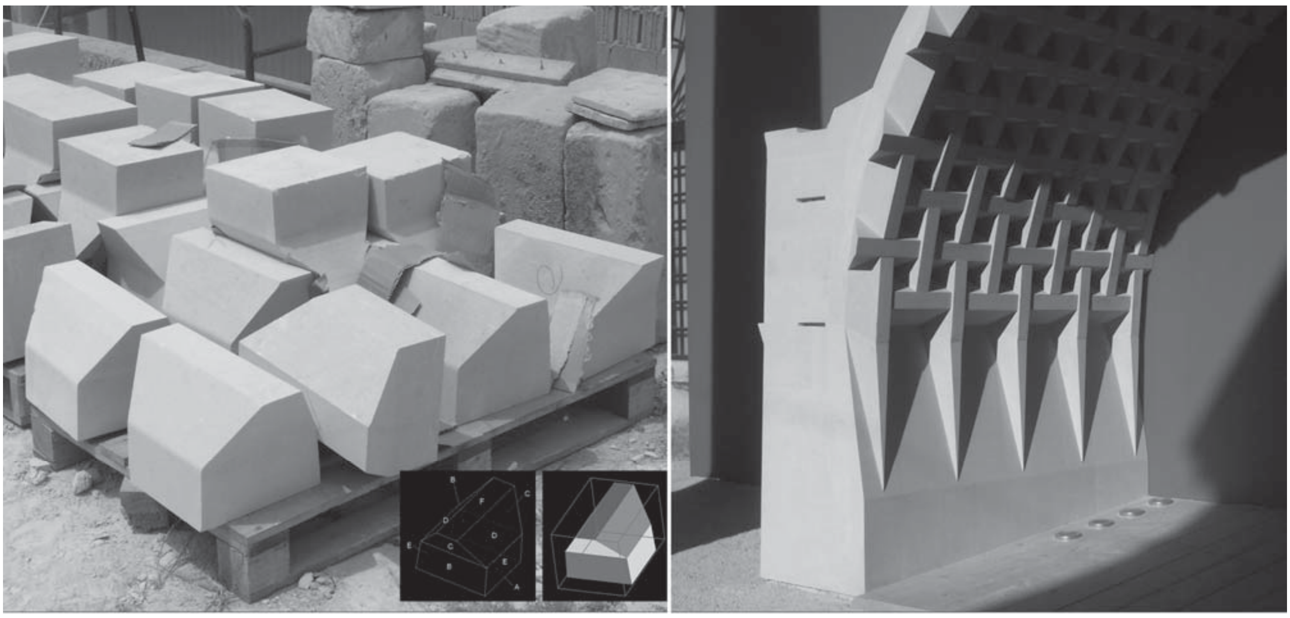
Figure 2: Abeille vault, construction

Figure 3: Abeille and Truchet vaulted patterns

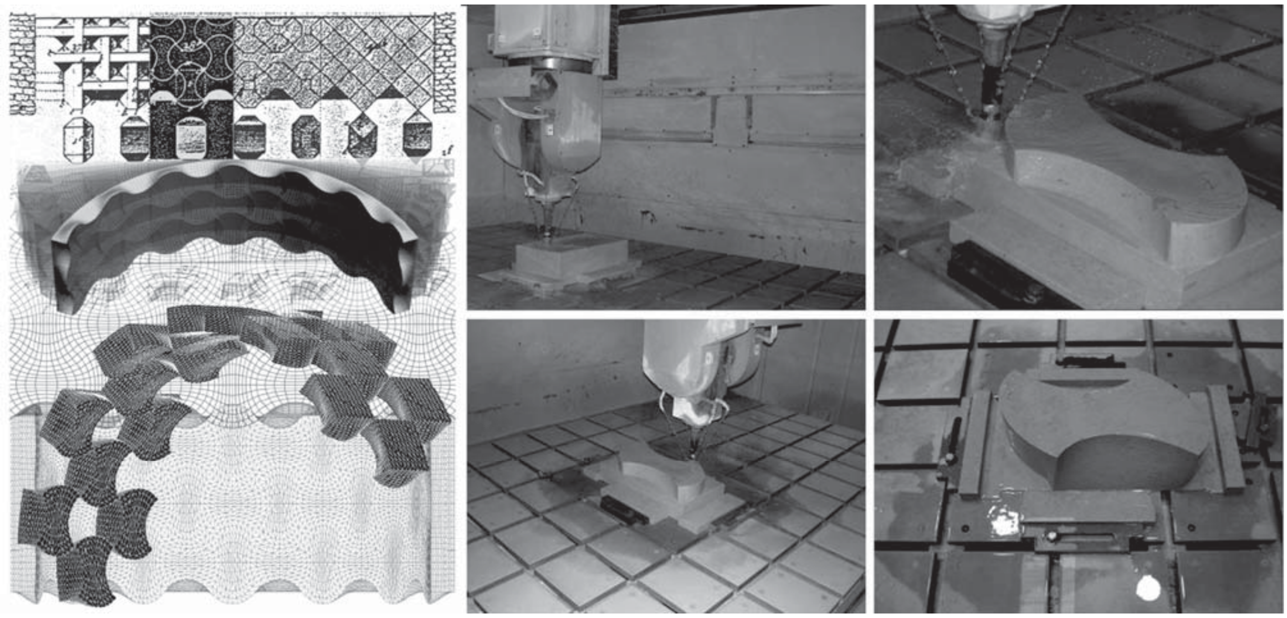

Figure 4: Truchet vault, CEU Universidad San Pablo in Madrid, Summer School, 2007

TOWARD A STEREOTOMIC DESIGN

To speak of stereotomic design requires both a theorical and a practical paradigm whereby discrete elements, joined by dray construction, are made to fit together to form a vault. Such a paradigm is based on traditional building techniques, specifically in stone and wood, where the concept of the joint of the constituent parts of the fabric represents the distinctive figure of the character and the architectural expressiveness.

It is possible, therefore, to speak of stereotomic architecture when there exists an application of rules of geometric statics based on historical precedents that yield the construction of vaulted spaces.

To bend a surface means to make it welcoming and in this way to form a habitable inside space. Such a concavity of the form, whether vaulted and domed, evokes the sense of reception and protection and hence refers to the primordial residence: the cavern. The exterior, for vaulted architecture, is of a less significant value. It represents the place of the affirmation or dissimulation of the volumetric composition of the interior space: the intrados of a vault is always visible from the interior of the room, where, in its geometric completeness, it individualizes the moulded material; whereas the extrados of a vault is the place of the concentration of the loads, of the reinforcement, and is partially visible only in the cases of vaulted roofs with canted surface. To design with vaulted systems means, therefore, to characterize a cavity, an excavation, to give quality to the cavern, through two possible, interrelated:

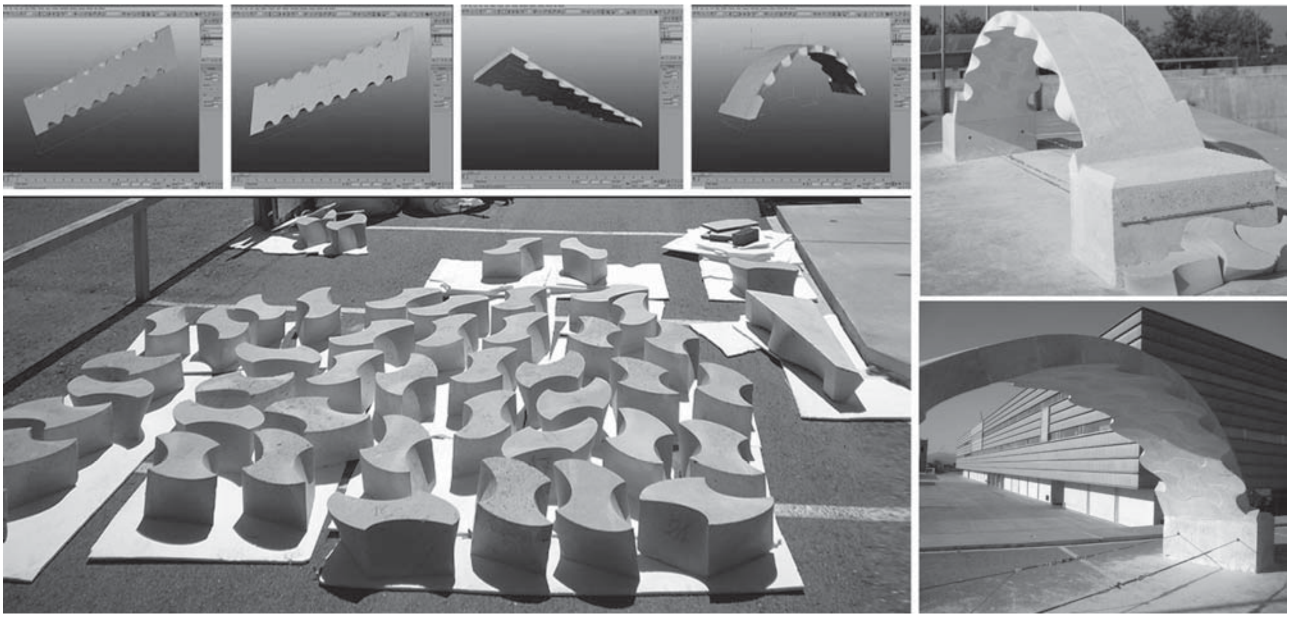

Figure 5: Truchet vault, CEU Universidad San Pablo in Madrid, Summer School, 2007

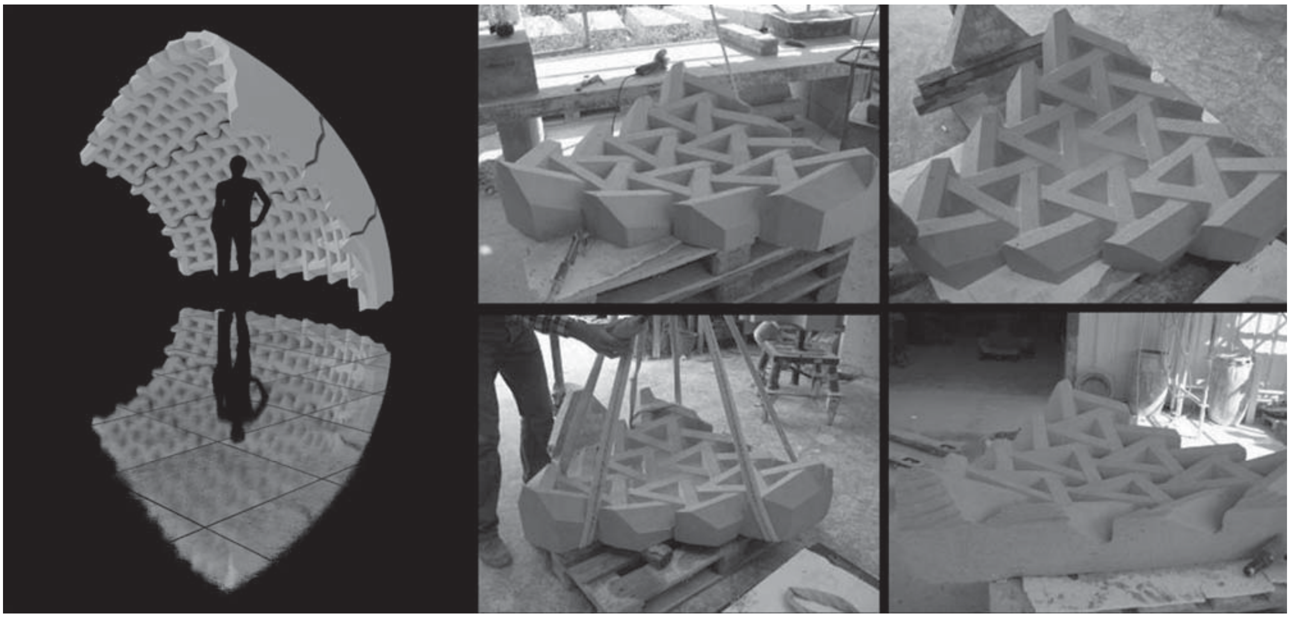

Figure 6: Plaited Stereotomy, Marmomacc, International marble exhibition, Verona, 2008

- To proportion the volumes that defines the interior space;
- To qualify the surface that envelops the volumes.

In the first case the attention is set on the modeling of the vaulted spaces in their totality and in the interaction between the geometric parameters that determine the volumetric spaces: the dimensions and the form of the room to be covered, the height of the impost of the vaulted system in respect to the dimensions of the plan, chose of the vaults, individualization of the openings as a solution of continuity of the vaulted system, etc. In the direction of the specific projective choices, in conformity with the diverse symbolic and functional necessities of the building, the character of its space can oscillate between the fullness and absoluteness proper to the family of forms deriving from the semicircular arch to the tension and structural boldness of the depressed arch; from the silence of the simple vault to the vibration of the composite vaults with multiple spatial intersections. Such intentions still require the reasoning of the aesthetical definition of the arches, related to the construction of the vaulted spaces, in the dialectics among visual proportionality, geometric exactness, and structural calculation.
In the second case the attention focused on the aesthetic projection of the intrados surface of the vaulted space or on the possibility to conceive the bonding of the vault as an adornment frame that transforms the static/constructive application of the proportions of the blocks in spatial adornment. Through the endless possible set of configurations, it is always understood according to the logic of the connection of the figures that

explains, in geometric abstraction, the sense of the joint or the interlacement between the parts, as well as the structural relationship. This concept allows us to refer to the textile origin of the architecture, where the knot of fabrics represents a first form of serial adornment, as well as a constructive valence, and to conceive what G. Semper defined as wall decoration. The translation into an aesthetic valence of the connection of the blocks of a vault is therefore the assignment of the spatial adornment that, through the concept of the bonding of separate elements, resituates a sense of structural and visual firmness. Stereotomic design, therefore, on the basis of what has been explained, is finalized as the celebration of vaulted spaces. It fashions the interior of the building through the conformity of surface and volume through the art of the cutting of solid bodies (στρο' = solid and τομη' = cut). The origin of the word stereotomy, as it is said, does not contemplate explicit references to the materials of the construction even if is the term has been coined by stone–cutters and stone–dressers who entrusted to it a scientific meaning of the proper work founded on the rules of the geometry applied to the cut of stone or wood. According to stereotomy, a vaulted space can only make itself as coherent sum of so many separate elements; likewise, these elements complete the creation of a vaulted space only if guided by the stereotomy. This consideration automatically excludes the use of the materials and the constructive techniques which presuppose, for the creation of structural elements, the continuity of material, for example, such as reinforced concrete and the like. The shapeless material is destined to lose something of itself to become material for construction, therefore a constructive element and then a form of architecture. Stone and wood represent the materials of the construction for antonomasia, and they can represent the materials of the future, as they are "manufactured" from the earth, easily perfectible, and capable of reutilization without waste of energy. The conceptual exercise connected to the design of architectural organisms constituted of the encasing of single parts pushes the reflection on the close relationship which exists between the particular and the general, the elementary unity, represented by the worked block, is the synecdoche of the project, the part that contains the whole because it possesses in nuce its final spatial configuration. Stereotomic design is realized therefore with her "spatial resolution" of vaulted systems and with the subdivision in parts of the same: an individual block can be produced successively to the spatial conformation of the whole, to which is also tied up in the processes of geometric transformation; or vice versa it can generate a spatial whole of which it preserves the constitutive geometric rules. The part is described not in itself, extrapolated by the context of affiliation, but dependent strongly upon the configuration of the whole from which it cannot be separated.

A possible renewal of such arguments, as developed in this study, presupposes a methodological and instrumental updating always constant and innovative of the stereotomic discipline, so as to facilitate the operations, either conceptual or practical, connected with the management of the multifarious problem: geometric/formal, static/mechanic and constructive. We have seen how, thanks to the strong conceptual affinity with stereotomy, the technological updating through three–dimensional graphical modeling, joined to the principles of typological variation, have paved the way for a new research on vaulted space. The syncretic nature of the computerized processes, assured by the merging in the geometric modeling of different analytical–cognitive forms, contributes to the unification of the knowledge (geometrical, formal, mathematical, structural, mechanical, constructive, etc.) typical of the architect, both ancient and pre–modern. The "genetic outfit" of the solid info–graphical model offers an analytical approach, variegated and punctual, which has the tendency to carry over the stereotomic speculation toward the unity of the disciplinary knowledge, historically united, today unfortunately broken down into sections. The idea is one which would build a method, a way (*hodós*) able to go over (*metà*) the contradiction that characterizes the manner of contemporary architectural in which the projective routine is continually "interrupted" and submitted to the professional specialties that inevitably corrupt the unity of the design thought. In an info–graphical environment, it is possible to easily transfer the project's geometries to other environments of analysis: either of structural calculation or mechanized production of the blocks.

The design becomes contextually either a verification of the formal qualities of the space or a dimensional calculation of the structures, followed by the possibility of a CAM mechanized realization of the constructive elements. To such an intention it is useful to observe another concept of high logical and precise rigor for the process of industrial production, i.e., the programmed modularity of the blocks, according to which in any vaulted system it is possible to optimize the least number of useful blocks to satisfy the whole construction of the vault. The idea of serial production, typical of the manufacturing industry, conjugates today with the notion of uniqueness of the architectural product, giving life to the concept of serial uniqueness of the manufactured article. It is a justifiable oxymoron, thanks to the advent of the parametrical–variational info–graphic era applied to the use of machines with numerical control for which every project is at once unique and also reproducible in series. The result is a sort of productive acceleration of the qualities of the handicraft product, that carries over the peculiarities of the traditional architecture to a level of best technical efficiency and performance.

CONCLUSIONS

To conclude, I believe, in line with the definition that Charles Perrault gave to stereotomy, that the art of the building in general has always responded to this aspiration for stereotomic architecture. This designates the constant challenge between the strength of gravity on bodies and the forms that, escaping such a condition, aspire to a dynamic ascension. A constant dialectics between heaviness (of the materials) and lightness (of the forms) that, if on one side it represents the common link between the work of the illustrious "stereotomists" of the French national way from Philibert de l'Orme to Jules Hardouin–Mansart, to J. P. Franque…, on the other it is handed over to us as central argument to rewrite and to re–design.

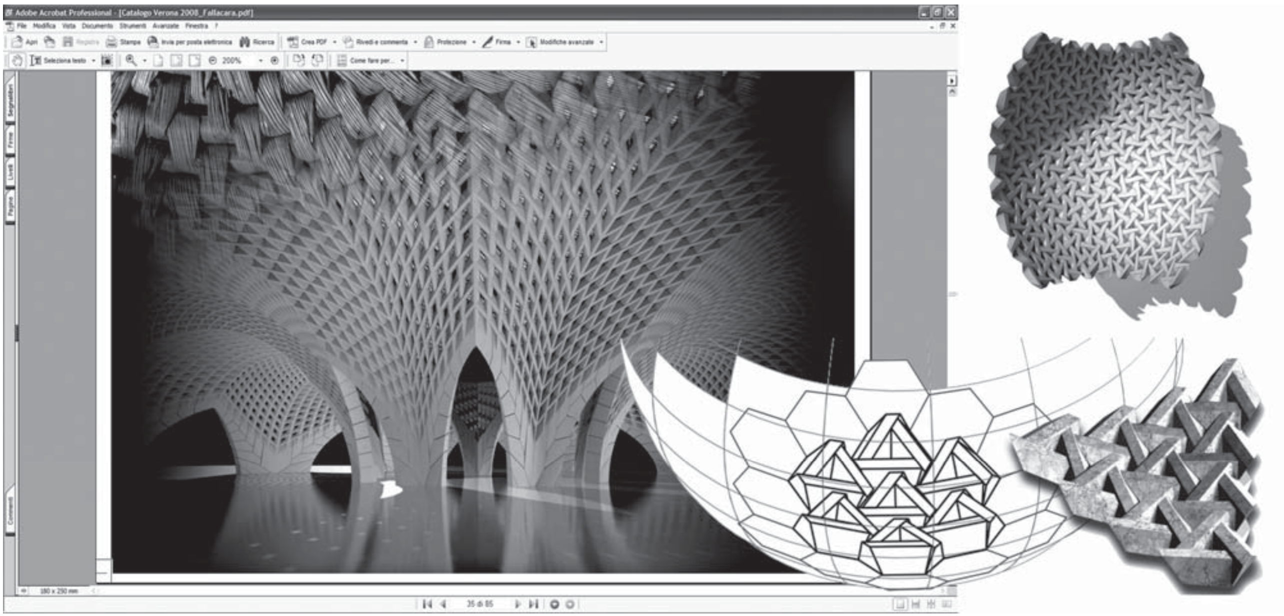

Figure 7: Plaited Stereotomy, *Sphera,* Marmomacc, International marble exhibition, Verona, 2008

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The arguments presented are a part of the books:

Fallacara G., 2007: Verso una progettazione stereotomica. Nozioni di stereotomia, stereotomia digitale e trasformazioni topologiche: ragionamenti intorno alla costruzione della forma. Roma: Arcane Editrice.

Etlin R., Fallacara G., Tamboréro L., 2008: Plaited Stereotomy. Stone Vault for the Modern World. Roma: Arcane Editrice.

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