

E.E. Viollet-le-Duc: Innovation and Tradition in Architecture: Language of Form and Structure in the Conception of Polyhedral Vaults

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Abstract: The experiments carried out in the last few decades on reinforced or pre-stressed stone continue to conceal, like the Eighteenth century architecture, the metal *inside* the stone. In the Nineteenth century, Viollet-le-Duc warns of the limits and proposes a way to cross, although without having the tools to verify its validity, therefore he merely gives *suggestions* for a good design. These suggestions contained in some pages of the *Entretiens sur l'architecture* and *L' Art Russe* are the subject of this study that analyzes projects carried out by Viollet-le-Duc in terms of form and structure. Works in which the stone assembled in accordance with the stereotomic principles dear to French tradition, interacts and cooperates with the metal (cast or laminated iron, depending on the role that it is due to perform) creating new forms using principles and rules of compositional tradition. Artworks that can be a resource for the design of large contemporary buildings if appropriately updated and discussed.

PREAMBLE

This proposal is based on the conviction that can be developed on an entirely original line of investigation identifying its expression in the *built form* by a result of a method of design and composition achieved through clearly defined rules and codes.

For a long time the stone has been the only material able to cover and protect spaces on a permanent basis. Since the Eighteenth and Nineteenth century, however, new artificial materials and consequently new techniques have gradually replaced it. However these new techniques have impeded the development of the studies on structural behaviour of stone elements and vaulted systems, stopping research at the level of intuition or empirical experimentation of the reactions of stone structures.

It should be noted that a recent *reversal of trend* in the Mediterranean area identifies a possible answer to the question on shape and the identity of the contemporary architectural space from a *rational* use of materials and conscious updating of construction techniques resulting from tradition, by sifting through the media vanguard. Researches on pre-stressed stone by Peter Rice, Ove Arup, Renzo Piano, Buro Happold until the experiments carried out at the ICAr Department of the Politecnico di Bari emphasized the need to restore, in the field of contemporary design, the right space for stone construction, often in association with other materials, drawing important signs of scientific experimentation from traditional architecture of the past.

Starting from these principles and, indeed, putting them as their direct derivation, this work investigates the vaults proposed by *Viollet-le-Duc* (1814-1879) in *Entretiens* and *L' Art Russe* identifying solutions in them congruent with those forementioned.

These projects were never realized and were presented almost as visions comparable, we might say, to Boullée's ones. Assembled in accordance with the stereotomic principles of the French tradition the stone interacts and cooperates with the metal (cast or laminate iron, depending on the role that it is due to perform) creating new forms but also using principles and rules of traditional composition.

INFLUENCES

In relation to Viollet-le-Duc the theme of influences is still considered a highly topical subject. Much of the criticism does not consider original its proposals as others before him had already placed metallic materials in the construction industry, such as the famously known Louis Auguste Boileau with the Church of Saint-Eugène (Paris).

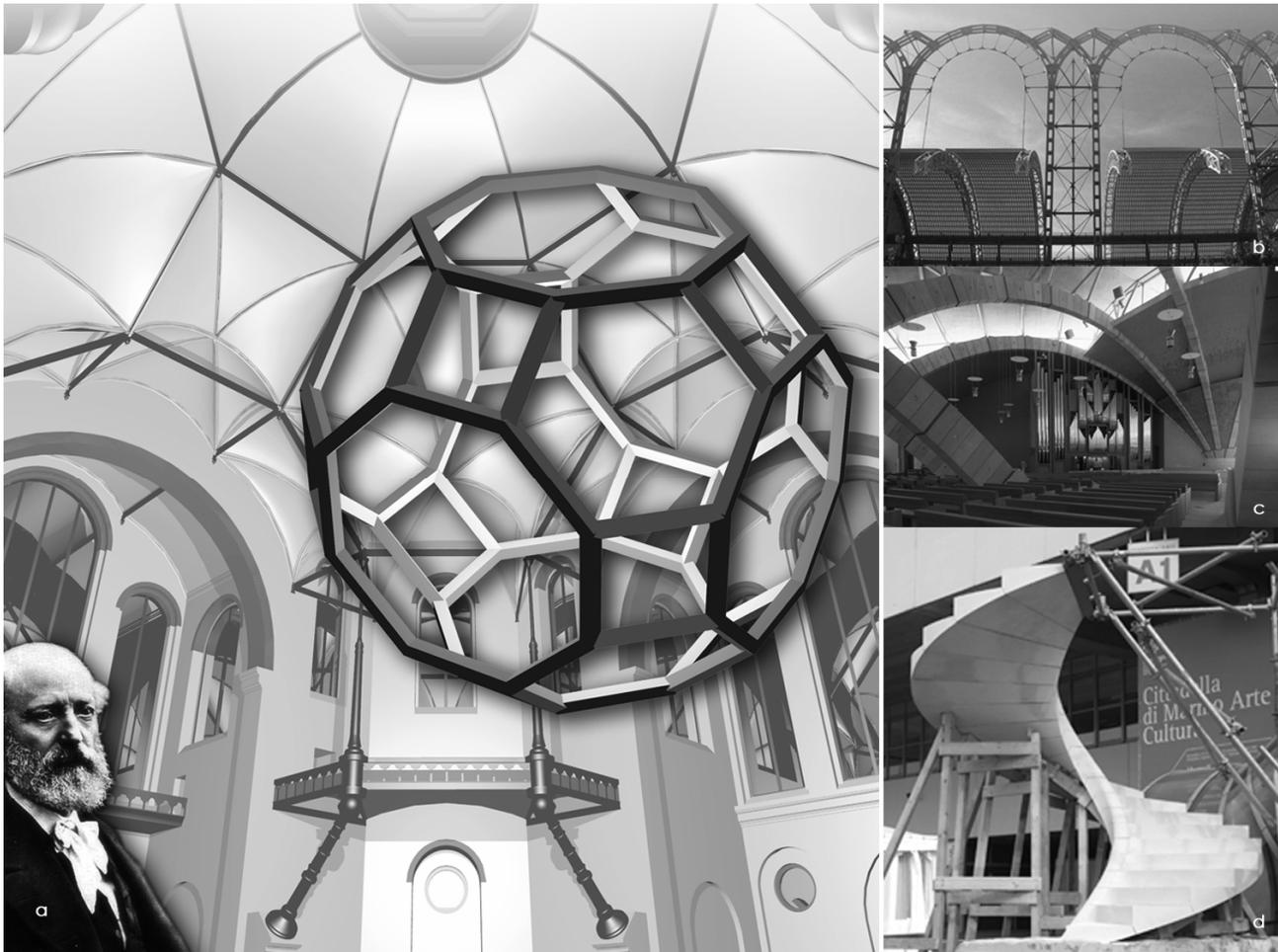


Figure 1: Stone and iron – form and structure: from Viollet-le-Duc to the contemporary architecture. (a) Viollet-le-Duc concert hall (1863–1872); (b) P. Rice Pavilion (Seville Expo 1992); (c) R. Piano church; (S. Giovanni 2004); (d) C. D'Amato, G. Fallacara Escalier Ridolfi; (Verona 2005)

E.E. Viollet-le-Duc VS L.A. Boileau

Without doubt the construction of this church in 1854–55 preceded the writing of *Entretiens* which dates back to 1863–72, as well as the Bibliothèque Sainte-Geneviève and the reading room at the Bibliothèque National of Labrouste, the Halles Centrales or Crystal Palace. However, what distinguishes these projects from all other works that combine stone and metal is the formal language adopted, the rational and innovative way of using two materials no longer in accordance with traditional forms but making new ones.

As Viollet-le-Duc says it is not an innovation to replace the corresponding elements in a stone cathedral which still incorporate Gothic forms with arches and columns of cast iron, as it is not the aim of architecture to achieve monuments such as bridges or hangars but rather rooms for ceremonies: monuments that will remain standing for centuries and witness the history of that particular period when the new society seeks new building structures. Combining instead traditional materials with those of more recent design according to new forms in order to harness the capabilities of both, is to make innovation in design.

It is therefore architectural and formal language, not primacy in the use of a particular material.

The difference between the two concepts is evident if we take, for example, the case of cover for the concert hall of Viollet-le-Duc and compare it to the church of Boileau. The latter is just a serial overlay of stone vaults contained and supported by metal arches that have practically the sole purpose of alleviating the structure: the result is a gothic church *modernized* thanks to an innovative material. The concert hall, on the other hand, is an organic composition of stone vaults also contained by arches in stone discharged on a metal structure that follows another logic that is suitable for the material which it is made for, arising from solid geometry, in particular polyhedra.

E.E. Viollet-le-Duc VS Leonardo da Vinci

The presence in the library of Viollet-le-Duc of some texts on Leonardo da Vinci and the castles of Blois and Chambord, as well as several passages of his *Histoire d'un dessinateur* allow us to assume the possibility of veiled references to theories concerning Leonardo's architecture.

Leonardo's research on the octagonal shape and its countless applications remind us of the reflections that Viollet-le-Duc relates to issues directly linked to them.

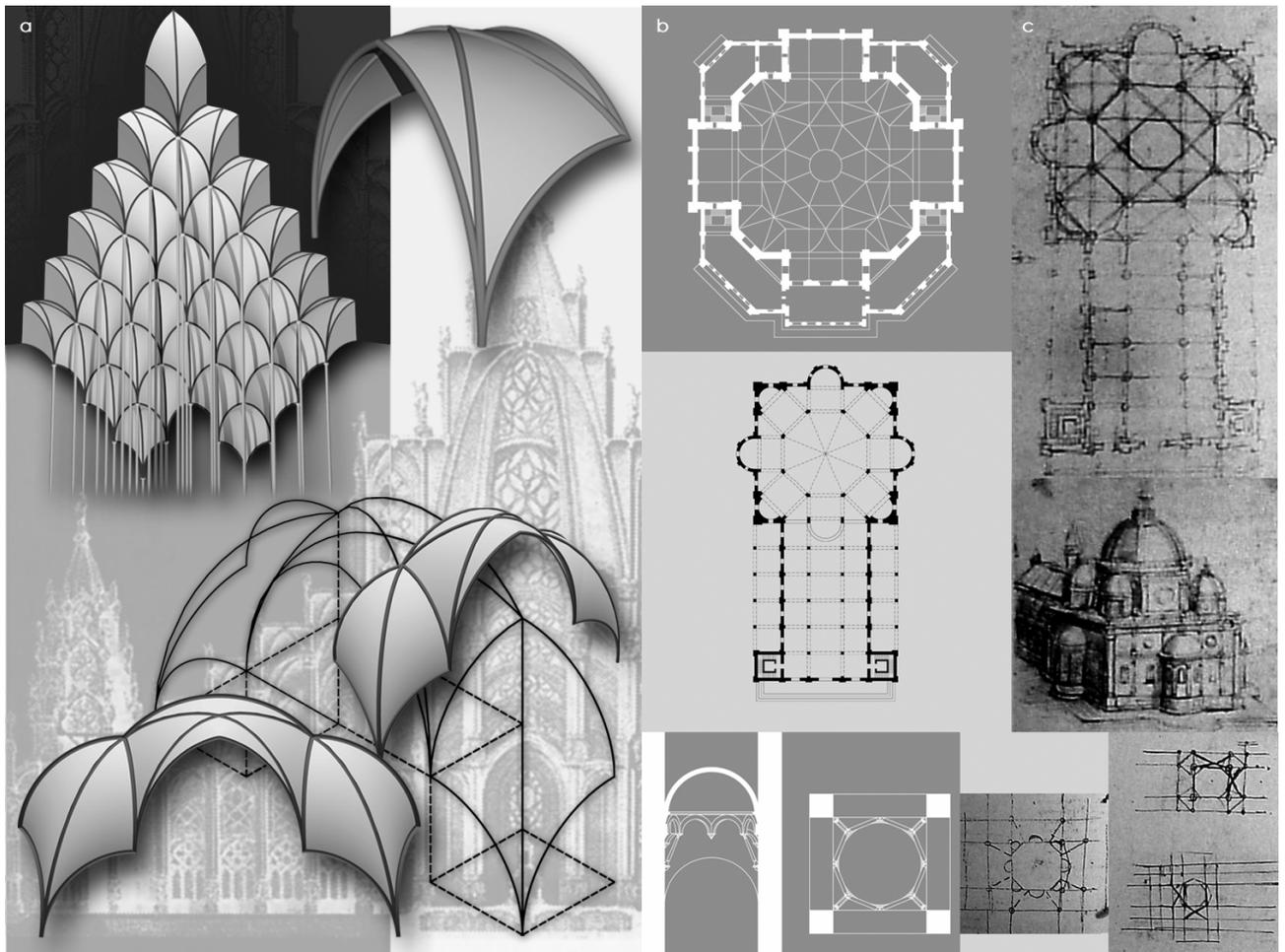


Figure 2: (a) Boileau system vault (1853); (b) Viollet-le-Duc's concert hall and Russian cathedral (1872); (c) Leonardo's drawings; (Manuscript B, 1490)

Sheet N. 24r of Manuscript B of Paris, for example, depicting a hypothetical plan of a church with alternately semi-circular and rectangular chapels, has a strong resemblance to the concert hall for 3000 people that *Viollet-le-Duc* describes in the *xii Entretien sur l'architecture* although it takes on a very different shape than that of its space design.

The analogy that perhaps more surprising than any other is the one between figure N. 78 of *L'Art Russe* by *Viollet-le-Duc* and a drawing at the 12r sheet of the *Codex Trivulzianus* by Leonardo.

The first illustrates a trick that *Viollet-le-Duc* implements to achieve a vaulted structure combining the Russian method with the advantages that the inclusion of metallic elements can offer. The second study deals with a solution designed by Leonardo to ensure horizontal stability between tiburium and aisles in the Cathedral of Milan through metal ties.

The coincidence of themes between Leonardo and *Viollet-le-Duc* is almost as worrying as it is suspicious. The reading of *Histoire d'un dessinateur*, real testament of *Viollet-le-Duc*, the consultation of his drawings and the contents of his library reveal the same themes, the same interests: from perspective to medicine, from anatomy to static. Although not comparable to that of Leonardo, his scientific culture is remarkable and has never ceased to expand and innovate. He was in contact with many scholars of the time thanks to his uncle *Delécluze's* constant help, and this undoubtedly played in his favour but we must recognise his outstanding ability, his *genius*.

STUDY CASES

To extract a *method for well built* from the lessons given by *Viollet-le-Duc* we have analysed the vaults he has designed identifying the geometric and technical structure characters in relation to the use of different materials placed side by side consistently that have allowed their conception and that can be a resource for the contemporary design of large spaces when appropriately updated and discussed.

The undisputed merit of *Viollet-le-Duc* is to have systematized through a theoretical definition in his writings the process of renewal of the techniques and language of architecture, although it had already started in his time and even before.

The aims of this research are: the understanding of formal geometry; the identification of technical and structural model of functionality in the subject of analysis; constructive awareness on shares and the

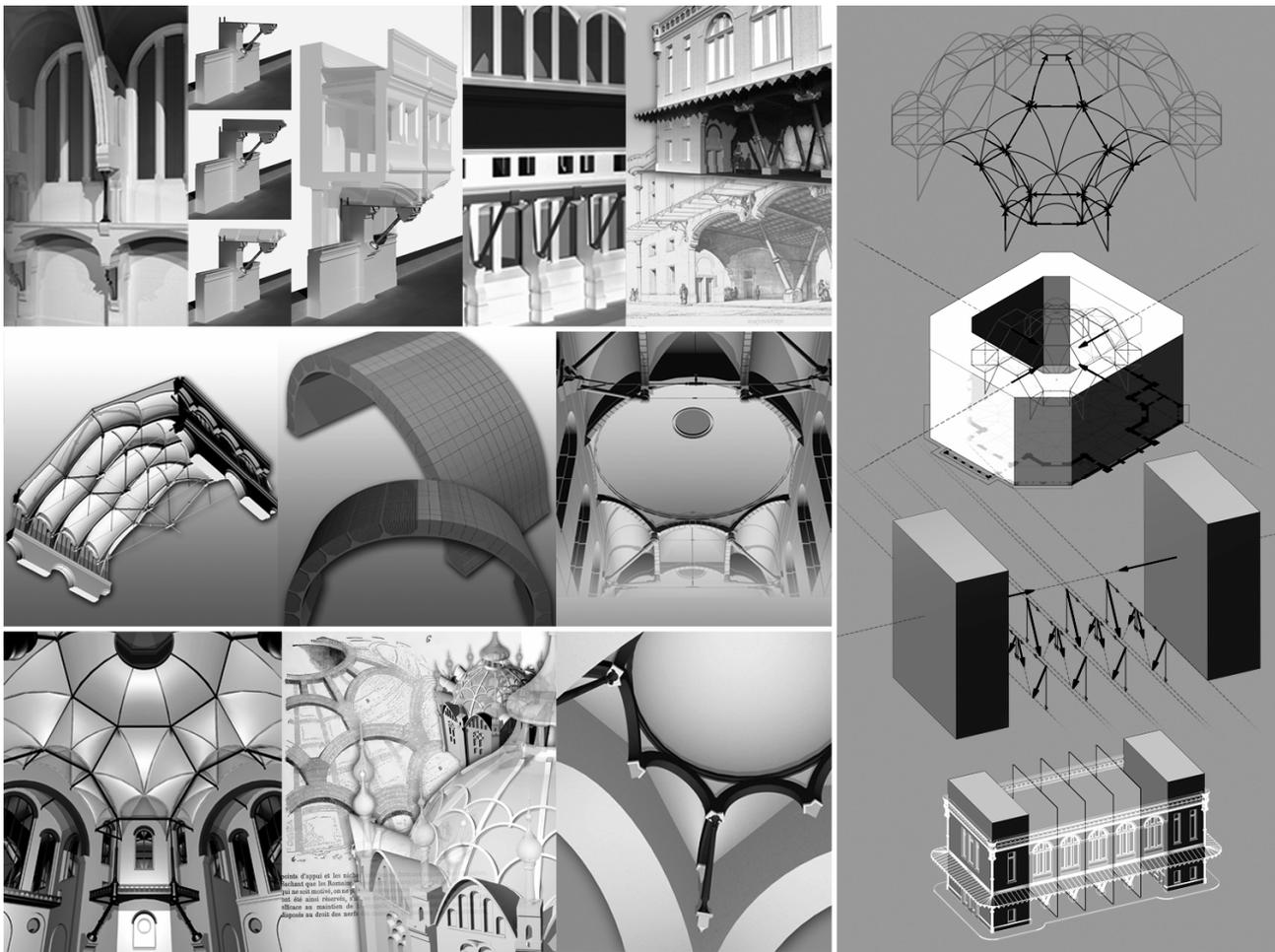


Figure 3: Ten study cases (Viollet-le-Duc 1863–1872) and analysis of the relation between form and structure for the concert hall and the meeting room above the covered market

method of equipping and assembling of the elements; critical interpretation of the research work done by the architect in relation to the technical and formal culture of the time; the critical updating of formal and constructive model to propose prospects in architectural projects in the Mediterranean area.

To encourage a faithful understanding of theoretical thinking design by the architect and come naturally to deduct a “method to well compose”, works have been studied in the same order they were presented by the author. In other words: the meeting room of XI Entretien, the primordial question Viollet-le-Duc deals with and from which springs the whole series of arguments around the theme of large roofing; the first project of a gallery out of a building with which the author suggests an alternative use of “new material” available to the modern society; the second project of a gallery out of a building, formal and technical evolution of the first model for which he hazards a static study of the acting forces; the meeting room above the covered market, natural consequence of reasoning developed for projects of tunnels; the “voute très-plate et d’une grande largeur”, first real symptom of the acquired confidence with the theme of great coverage; the armed stone arch, precursor, certainly unaware, of the extensive research and trials still underway; the vault for a 20 metres wide room, as variation on the theme of coverage planned, in this case, for a longitudinal space; the concert hall, the most famous project where speculation on polyhedra takes its greatest development; the Russian cathedral where Viollet-le-Duc combines an innovative use of sloping metal pillars to traditional Roman and Byzantine techniques of overlaying of brick arches (the system of the “crossed arches” used, after the Romans, in the construction of the Pantheon by the Byzantines and the Russians according to a description by Piranesi used by Viollet-le-Duc); the octagonal vault, silent tribute to the geometric shape subject of numerous studies of Leonardo da Vinci, reinterpreted here by the placement of supports tilted in two diagonal directions. Similarity is not limited to architectural composition but it is also noted in the area on the principle that characterizes both static structures, that is the discharge of the vault balanced by a strut system.

Analysis method

The *instruments* through which this survey was conducted are those specifically used by the architect–designer. According to the teaching of the same Viollet-le-Duc we used design (through the use of computer systems) for understanding and reworking critical architectures studied “because designing means learning to see and to see means to gain knowledge.”

Through the analysis process we want to achieve a perfect reconstruction of the theoretical trail made in the work of the architect resulting in a method capable of generating new architectures through logical propositions that constitute it and that, in Viollet-le-Duc for the first time and knowingly, pervasive: the shape of space and its Euclidean geometric generation on the one hand, while the structure and technique through which the form and its static conduct is built on the other.

The wording of global model for each project has resulted in a sequence of operations summed up in:

- identification of space primary geometries;
- determination of primary solid figures;
- minimum element of symmetry in composition;
- division system based on the solid material represented: metal, stone, brick;
- identification of profiles of stone mouldings according to the corresponding study on the *Dictionnaire raisonné* and works made by the same author;
- identification of the elements making up the construction and their mutual influences;
- analysis of the load paths and structural diagram;
- stone and metal structure;
- comparison of the structure identified with the edges describing Euclidean solids.

The result from the reconstruction work is a compendium of *rules* underlying the design which will aim to clarify the relationship and mutual influence between shapes, building materials and construction techniques to vary the architectural composition through a theoretical operation redesigning the entire work and each part, from the point of view of the methods of tracing and assembly.

While reconstruction, on one hand, refers to the generative property of form, through the interpretation of its underlying geometry, on the other presents a discussion of building techniques used and property of behaviour to which ultimate goal is the encoding of a set of rules universally valid in the field of contemporary design of large roofing vaults.

Study profiles of stone mouldings

The work of infographic modeling is not a mere exercise of redesigning but a criticism of the manner in which Viollet-le-Duc approaches architectural design. Retracing the compositional process of every work analyzed and assuming its construction even if only *virtual*.

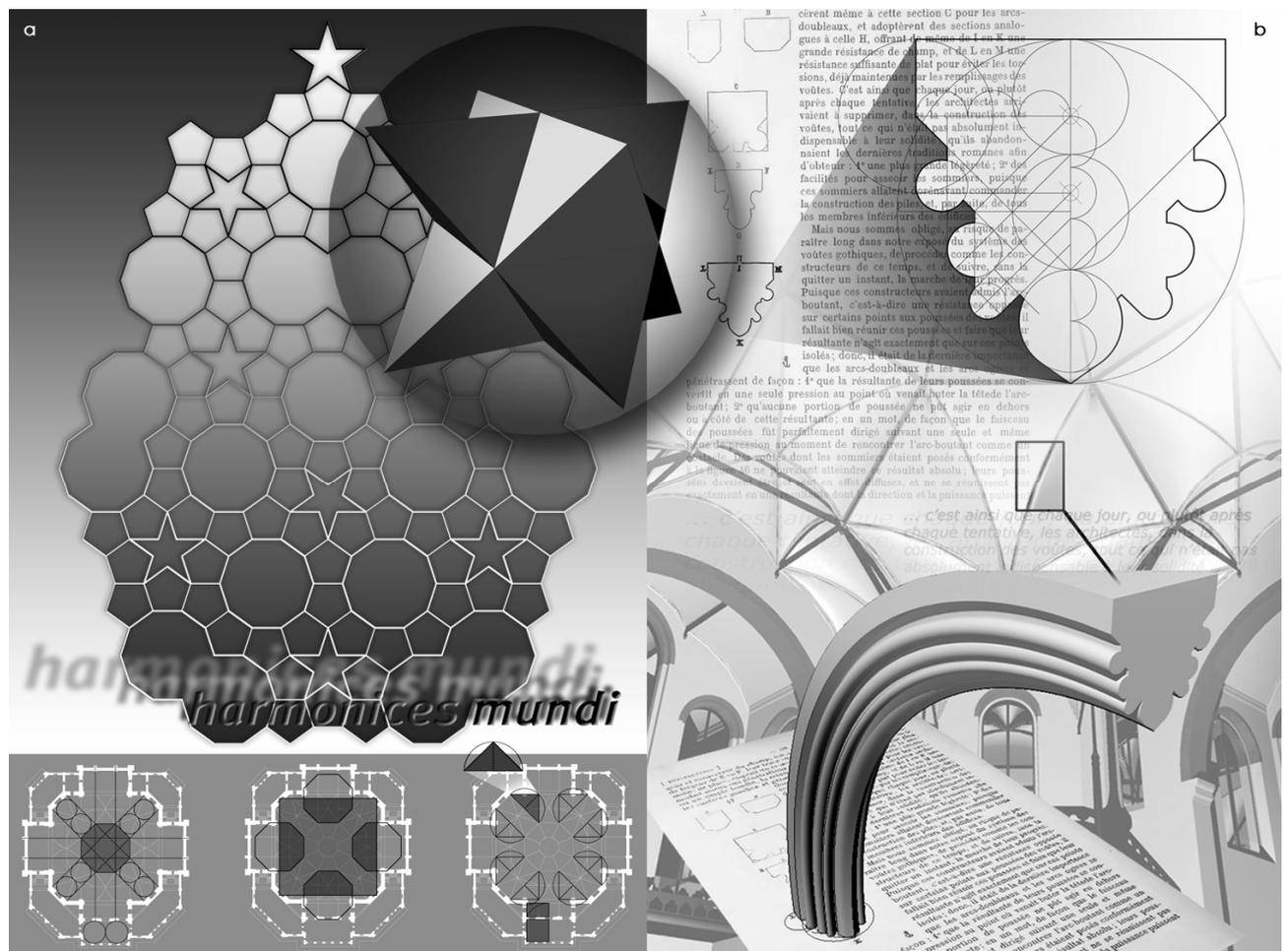


Figure 4: Analysis of proportions, Euclidean solids composing structures (a), profiles of stone mouldings (b)

In doing so, we are very often faced with questions regarding both the size of certain elements of construction and in the forms they take in space depending on the function assigned to them within the structure. One of these questions which Viollet-le-Duc has often devoted almost maniacal attention, is represented by the shape and size of the profiles taking stone elements in the construction industry. By taking any profile as a component of the outer decor of buildings into consideration, specifying proportions and their size, where not only Viollet-le-Duc's theory has been constantly used but also what he designed and built with a series of constant references and mutual comparisons.

Analysis of proportions

The virtual *dissection* of the monument in architectural elements included in the specific generative geometry and then "reassembled" through the recognition and intuition of the rules of proportional composition, has enabled us to reach the formal identification of the formal continuous model.

Each solid model has been the subject of further breakdown operations which have affected not the architectural elements but the individual components of the stone structure, on the one hand, and the metal structure on the other, in the significant ties of the construction.

This is because, as Viollet-le-Duc says: "we will be a witness to a good architecture when it manages to combine harmoniously form and structure."

The key to his thought is probably to be found in the message that large reticular structures, by then already greatly developed both in France and elsewhere, sent into the eyes of connoisseurs. For the first time and so manifest structure and construction coincided perfectly.

FORM AND STRUCTURE FOR VIOLLET-LE-DUC

While in setting out the first study cases Viollet-le-Duc uses only elementary solids as he proceeds in exposure and thus in the creation, he takes a certain mastery in using not only materials but also forms to which subordinate them. Whether regular or semi-regular polyhedra, the used forms allow us to guess about his deep knowledge of Euclidean geometry.

The tetrahedron, the cube and their combinations are the basis of the *organism* used in the vault for the twenty meter large room; the truncated cuboctahedron permits him to implement the concert hall for 3000 people; the geosphere is the basis of the Russian cathedral.

Therefore, while Viollet-le-Duc uses flat geometry in the design of structural models (an operation sufficiently evolved for its time) such as the equilateral triangle, the hexagon and finally the octagon, contrarily he uses the solid geometry, namely space geometry, in the design of forms that characterize the vaults as often carried out using stone and metal in a synergetic manner.

It is probable that we need to recall to memory studies of Leonardo da Vinci, especially those around the theme of *tiburium*, to trace the references which Viollet-le-Duc could have drawn for this formidable intuition that allows him to associate the theme of large buildings that are free from intermediate support to those of geometric shapes defined as regular and semi-regular solid; anything like the work which Henry Labrouste and Victor Baltard were preparing to carry out or were already in the process of carrying out in the National Library and Halles in Paris; polyhedra and crystals, however, were the reference around the middle of the twentieth century for all researches on large space structures. His reference to polyhedra to configure the structure of the architectural space of the great concert hall marks a turning point in the history of architecture: until then the search for a concrete viable form had never been attempted at least not in accordance with the rules and forms of tradition. There also had never been proposed in such clear terms the role that the construction, becoming structure, was called upon to perform in the new historical social and political context determined by the industrial revolution and its enormous consequences.

The reticular structures probably constituted the arrival point, although not considered *architecture* but *engineering works*, of his research aimed at maximum economy of materials: within them nothing is actually superfluous because the material is prepared exactly where it should be namely around the long lines which transmit actions and reactions between the ties and bars.

The vast and ancient experience in the construction of wooden carpentry had as a constant reference to the primordial model of the truss placed in support of roofing. To propose as a model for the hemispherical dome a form derived from regular or semi-regular polyhedra indicated the overcoming of the classical types on which the reticular structures had attested and the opening of new horizons for architecture seeking new solutions to solve old problems.

He would certainly have a rudimentary knowledge of the rules of composition and decomposition of forces until the construction of the funicular polygon. However, although Viollet-le-Duc explicitly recognizes the importance of the latter as an essential tool for understanding a structure, it does not appear particularly accomplished in the occasions when he uses it; only some strokes of pen mark the features, functional to the demonstration of the thesis that he is supporting during treatment.

The sense of innovation

Perhaps in a not entirely conscious manner Viollet-le-Duc started the line of research about structural forms according to the properties of matter. Here, therefore, to the great resistance to compression that stone possesses, he has associated the tensile strength of metal resulting in composite structures.

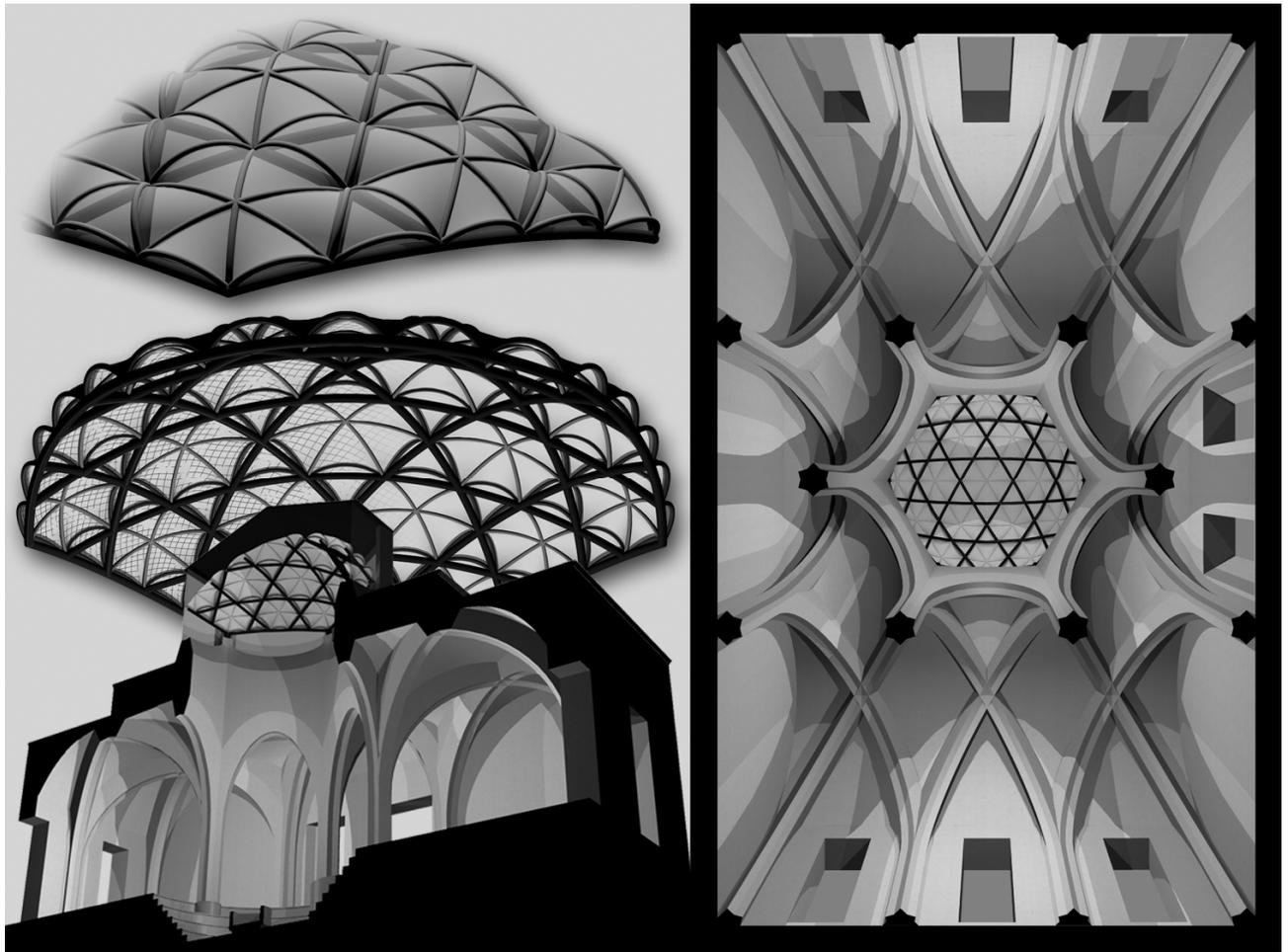


Figure 5: Study for a church with "crossed arches" under stone and iron vault; (Campa 2008)

The choice of referring to the profiles of Euclidean solids in the structural design of the metal system should thus be attributed to reasons of form: pure geometric shapes are surely able to resolve the static problems in a clear and simple way. The material also is used according to its specific characteristics.

Similarly the stone is called to play the role that is most appropriate. Consequently the vaults are wholly designed in stone or stone and brick and they are not in conflict with the metal structure but rather they work alongside each other. This is the substantial difference compared to the use of two similar materials in Boileau's theory.

This is the innovation that Viollet-le-Duc introduces to the system of mixed vaults.

CONCLUSIONS

At the beginning the experiences carried out in the last two decades on armed or pre-stressed stone were mentioned. The *limit* of these speculations and, consequently, of architectural design from which it arises, continues to conceal metal *inside* the stone like the eighteenth architects.

Viollet-le-Duc, in the Nineteenth century, realizes this limit and he proposes a way to overcome it but he does not have the tools to verify its validity. So he merely made some suggestions for a good design.

The advancement of knowledge in scientific building and skills acquired over time in the structural design allow today the reading and responding to questions on the *form* made by Viollet-le-Duc in its projects in a more conscious way thanks also to the help of contemporary tools of verification.

To know how to dominate shape through the understanding of structure and how to *combine* form and structure to obtain a reasoned architecture require a profound knowledge of materials and their capacity for resistance.

This study which is a short summary of the doctoral thesis carried out by the author at the Department ICAR of Politecnico di Bari (Italy) intends to offer its own modest contribution to contemporary design in the Mediterranean area using the *method* suggested by Viollet-le-Duc in the design of stone and steel new vaults and responding to some questions:

- how to use the stone today in accordance with the principles of its tectonics and not against them?
- how to enter immediately in the project and in its construction-implementation information technology?
- how to overcome the *aporia* more blatant in the use of stone, that of antagonism between structure and shell?

- how to overcome the outrage of *irresponsible* architectural form made possible by today's engineering project?

Moreover, Viollet-le-Duc offers examples not because they are taken as models to imitate but because they help to understand the reasoning, the method, the spirit in which they were conducted and urging young people to try new roofing in the composition of new forms.

So the chosen theme is that of sacred space. The hexagonal form–structure characterizes the central space. The composition on plan is consistent with theories of Viollet-le-Duc about proportions. The space, therefore, is entirely *tessellated* using equilateral triangles.

The crossed arches that characterize the aisle designed according to the stereotomic rules of stone cutting are arranged along each side of two consecutive triangles. Their section is then shaped to form six points pillars after being joined to another two arches.

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