Constructive experimentalism and innovation technique in the 18th century French treatises.
The discovery of Félix François d’Espie

Riccardo Gulli

Monsignor, a constructive treatise about a new type of roof, it may appear not worthy to be offered at your attention. Perhaps I could be blamed for the initiative in submitting it at your attention, but your acceptance will justify my act. I hope you will approve it since I trust my discovery to be useful: great men appreciate objects for their utility and not for their magnificent.

In this manner, with a dedication to the Duke of Bellisle, begins the treatise The way to render any type of buildings fireproof or adjusted for the construction of tiles and plaster vaults, commonly defined flat vaults; and about brick roof, without wood, called tile roofs published in Paris by Félix Francoise d’Espie in 1754.

These first introducing words, clearly state the author’s concern to give to print a strictly applicative contents work. A superior reason research, which could justify the interest for the description of a technical procedure, is as a matter of fact easily understandable if related with the specific theoretical futures which identifies the treatises concerning the building vaults construction during the XVII century and in the first part of the XVIII century in France.

The birth of new disciplinary branches, as for example the sterotomia, means in this sense the direct and tangible evidence of a progressive specialization process oriented towards an always stronger separation among the different knowledge and competences which belong to the area of project design and architectural construction.

Starting from the forties of the XVII century and through the studies of M. Jousse (1642), of G. Desargues (1640), F. Derand (1643) up to A. F. Frézier (1737–1739) about a century later, the interest on the vault building, it appears to be almost exclusively oriented towards setting up of suitable instruments for scientific description able to give an exact geometrical description.

Through the project of the Encyclopedia, the boarders of knowledge in architecture and construction are ridiscussed and repositioned: a new sensitivity oriented towards the complexity arising from the variety of knowledge takes place instead of the research of indubitable truth and therefore a tendency to a requalification of trade.

To this respect d’Espie’s treatise, represents a specific and relevant editorial phase, which unable to determine a focal point on the terms of this transition.

The attention given to the study of a construction system, as a consequence of an unlearned knowledge of the skilled workers, finds its own way of legitimation to obtain the approval by the Institutional figures, the Academies, in charge to evaluate the scientific validity requirements.

The innovative value arising from technique, considered as a discovery, together with its instrumental and utilitarian target, symbolizes for d’Espie the categories and conceptual instruments through which it appears to be possible to give new relevance and dignity to a study regarding construction.
In the introducing section it is written:

Many people are reluctant and sometime they are right, to accept new discoveries. However, I hope that when they will have evaluated with care this proposal of mine, they will understand the advantages and the importance . . . I refer to a new type of roof which I executed for a house in Toulouse three years ago. This roof is made exclusively with bricks, plaster and lime; neither wood nor iron are used. This is the reason why I called it bricken roof. It is sustained by flat vaults, which represents an admirable and singular technique which many people do not approve only for the fact of not knowing it, and which has a very antique use in the Roussillon, and more recently in Languedoc and in other neighbouring provinces. The Duke of Belleisle has given to this country the first example of this type of vaults. He has used some carpenters from Perpignan, the most expert for this type of work, to build such vaults in his castle in Bîzy (d’Espie 1754, 7–9).

Therefore, a very ancient practice but at the same time, very innovative. The potential contradiction which apparently raises from such an association actually means an important indication which refers to a different way of considering the notion of «progress», intended as upgrading of knowledge in the relationship created with the values of Tradition and History.

The discovery about which d’Espie refers to us is not describable in terms of «scientific innovation», or better in terms of a progressive exceeding of the last obtained result, of the last invention.

In parallel with this attitude, which however remains and informs the scientific cultural background of that period, a new approach to knowledge comes up which looks with a renewed interest and on a different point of view to the historical experience, in its different articulations from the theoretical ones to the applicative ones, restitutes as feedback.

The d’Espie’s notion of discovery should therefore be considered as belonging more to the category of recognition than to the one of invention.

To this extent is possible to find common aspects with the contemporary research promoted by the encyclopedists in the attempt to make a complete rewriting of knowledge and in this way rearing even what it remains hidden, for its specific nature, in the dark folds of the practice.
Constructive experimentalism and innovation technique

In the project design and architectural construction section the *functionality* concept is often linked with the one of *rationality*, branching off on two parallel paths: on one side the research moves on the field of natural phenomena understanding through elaborating scientific theories and models of explanation, the first steps on the way of a future development of Construction Science; on the other side, as already mentioned, it is enhanced the trial to gather *reason and work, science and technique* through reevaluating the minor arts and a reapproaching between *conceiving and practice*.

D’Espie treatise condensade and exemplifies both orientations showing in the same time the contrattidions of a new and different knowledge approach. The theory supported by d’Espie is focused on the performance requirements offered by this type of construction, both in terms of structural behaviour and in order to the house functionality.

Let us stop on the first matter. The arguments developed on the statical working principles applied on the vaults executed with this technique, called *flat Vaults or imperial vaults*, is set up starting from the exact understanding description of the constructive nature of this type of vaults through a detailed exposition of the technical process and of the needed rules for a correct execution.

In one section of the treatise it is said:

The bricks used in Perpignan to build these vaults, and which have been used by myself, measure 10 fingers, 5 width and 1 thickness . . . Other centring have not be prepared since they are not needed to form the imperial or any other geometry which will be given to the vaults: they are quite light and can be built with discarded wood from our construction: therefore a minimum cost is foreseen. These centring are not made to support the vault, but only to give a guideline to the carpenter. These vaults can be executed on old walls, provided that they are solid enough, and also on new walls, provided that they are let consolidate for six months before building up the vaults, so that a natural settling is granted. This is an essential caution which I myself found very useful. To guarantee that these vaults will be solid enough and will not cause any thrust on the walls, it has to be made during the construction process a recess (niche) of 3-4 fingers along the room’s perimeter, in the point where the vault has to be built, in a way that the first brick can be set on the side and almost vertically on this recess (making and angle of about 80°) . . . These vaults may be simple or double: the first type are used when the upper floor should be
inhabited, or in those cases they do not have to sustain other loading apart from their own. The double vaults result to be in any case more stable; this is obtained laying down a second layer of bricks covering the first one and paying attention that the joints of this brick layer never match with the first one (d’Espie 1754, 19-25).

The process described by d’Espie strictly reposes such a practice whose presence and diffusion cannot actually be constrained only to the French regions of Languedoc and Roussillon, but to the whole territory consisting of Catalogna and the other northern regions of Spain. The most directly and truthful evidence of the belonging of this technique, called tabicada, to the ancient constructive Spanish tradition, it will be offered by Fray Lorenzo de San Nicolás treatise (1633), which comprehends a detailed description of the rules that consents an exactly bovedas tabicadas’s construction, or on the other hand of tile vaults that presents two or more layers (Gulli and Mochi 1995).

But independently from the questions about cultural and geographic paternity of the technique, which appears meaningful regards the important rule shows by the comprehension of the exactly constructive procediment at the ratio of the correspondence with the structural working hypothesis about this kind of vaults.

D’Espie says:

People could say of the existence, in others places, of collapsed flat vaults; centerly I will agree with them and answer that these one were construe by bad masons which hadn’t respected the exactly construction rules, or that had used shoddy materials. But, otherwise they couldn’t present any example of flat vaults that had upset walls. I know the some are collapsed because they will be too much flat, but these, with the collapsed, didn’t origined orizontal forces against walls (d’Espie 1754, 56).

This is therefore the fondamental passage of d’Espie thesis which consents to recognize the pecularity and in consequence the innovative value, that marks these constructions. Vaults carried out by this technique and belonging to this typology don’t generate orizontal forces to the supports. A such assertion, reconsidered through light of knowledge and theorical hypotesis about the static of arches formulated by scientific culture of that time, from De la Hire (1666; 1712) to Belidor (1729) and Couplet (1731–1732), appears indeed extremely surprising. The comparision with traditional brick or stone vaults is discussed in a treatise’s chapter:

Traditional brick or stone vaults in voussoir manner with lime mortar, required particolar attentions and the application of principles and art’s rules that couldn’t be neglected . . . Monsignor Belidor, in the treatise dedicated at ingener’s science, did demonstrated by geometrical way these principles. It might be desiderable that who is interested on construction building knows that very well and that do not make the mistake to follow a fallacious procedure based on a practice which foundations will be everytime fallacious if not confirmity by theory’s laws . . . Instead for flat vaults, belonging to another nature, is not necessary that during construction same rules and principles of traditional vaults are followed (d’Espie, 1754, 40–44).

The art of building, with its rules and its own principles, is therefore subject to the verified by theory. But the recognition of the pre-eminence assigned to the scientific demostration in convalidating figures coming out from experience opens up to formulate new ones just it is declared the discordance existing between theory and practice, between conceptual models and phisical phenomena. In other terms, the theoretical hypothesis concerning the fact that the flat vaults do not push, while being evaluated by the scientific truth to be recognized as worthy, strictly required the identification of scientific instruments and methods able to describe it. The lack of a general theory which would at that time unable to explain the static function of the vaults operating out of the field of the studies based on the «wedge» model, obliged therefore d’Espie to go through the experimental evalutation way. D’Espie says:

There are finally the proofs which I have done myself and which will not give minor confirmation of their solidity. I had made built an imperial vault in carriage, in a squared room with more than 4 and half testo for side; but even before having it completed, I made it load with 1,750 bricks layed on the extrados, each of them weighting 25 pounds, which was corresponding to 4,375 pounds load that I left on the vault for two days, making the carpenters from Perpignan which built it treble . . . I made then discarge it with the result that not withstanding the enormous load and right often the lightness, no alteration
occurred... In consequence of this experiment, what could reply whom declared that flat vaults aren't solid, that generate horizontal forces against walls and that occurred a great thickness of these ones to be sustained? All examples I has already referred would make them thinking about their prejudices (d’Espie, 1754, 52–56).

The polemic vein that coulors d’Espie words to declare the truthfulness of experimental’s procediment as a thesis’s confirmity, reproduces the terms of famous ideologic’s quarrel which accompanies, in the first part of century, the wellknown of the San Pietro’s dome riability by Giovanni Poleni e Luigi Vanvitelli. Poleni himself will state in a passage of the Memories that his knowledge analysis «does not accept the sublime and abstacte calculations and that it wants real proofs for itself: to these therefore in the intend to better discover the truth, we must go through. These notions have to be clarey up with the experiments to be able not to use abstracted doctrins which could in this way denicted» (Ramazzotti 1984, 28).

The attempt promoted by the illuministic research to reduce the space will separate the forms of an ideal language, the matematical analysis and the Rational Mechanic, from the phisical reality of constructions, finds as a matter of fact in the laboratory research an important mean able to provide a scientific description of the phisical phenomena through the experimental figures interpretation. Such an orientation is well translated in the Académie Royale des Sciences acts, in which are preserved the results of numberless experiments carried out by the experts of that time, as for example those onemade by H. L. Du Hamel about the wood mechanical properties, which as feedback and under a different historical prospective, contains common elements of interests with d’Espie studies. The conclusions to which Du Hamel come to with reference to the behaviour of a wooden beam laying on the medium point and loaded at the extreme, concerns the importance asumed by the cohesion force of the wooden fibres guarantee a high value of resistance «such as that wooden beam costituted by very strongwood fibres, that are not stricked one to the other, it might break under the weight which another beam but with weaker and closer fibres would sustain» (Du Hamel 1742, 340).

Du Hamel intuition, which he is not able to translate in scientific terms, it is the support given by the side adherence between one fibre to the other or in other words the existence of tangential tensions which raise up in case the bending stress is followed by shear. It is only after the development of Charles Coulomb (Coulomb 1776), which the first mathematical formulation in terms of adherence and cohesion concepts was obtained with the following use in the statitical theory of arch stone. From the theoretical stand point the qualitative evaluation of the phenomena described by Du Hamel, appears however important since it represents the first contribution to the further studies concerning the elastical futures of the materials and on the applicative methods which will come in use in the nineteen century. At the same time, d’Espie percives that the structural behaviour of the bricken layer vaults differs from the hypothesis of the «wedge model» and this comes out from the different constituent relationship which results from the material depending on the peculiar constructive organisation which marks out this type of vaults.

In the following d’Espie statement that these kind of vaults «do not originate thrusts like the other vaults, and this can be as the plaster, when is well linked with the single brick, determines the vaults to be a sole body which do not have any specific role playing with the single parts: they will never push each other, since their assembly make them as a solid mass which will self contain without ever splitting, even if lighly supported» (d’Espie 1754, 57), it is in fact contained an important observation which anticipates, even if only from qualitative point of view, the following difference made between the structures describable through the theory of the stiff body and those to which the mechanic of continuos is applicable.

The intuition of d’Espie will find as a matter of fact confirmation only later on, with the experimental study carried out by Raphael Guastavino (Guastavino 1893), in the last decades of 19th century and with the hypothessys on the elastical characteristics of the materials and therefore on the capacity of the bricken layer vaults to sustain the tensile tensions induced by the shearing and bending stress, elaborated by some spanish experts in the first part of the 20th century (Bayó 1910).

But the experimental texts which d’Espie gave to support his own theory were not sufficient to obtain the official approval by Académie Royale de Architecture.
On August the 19th 1754, Michel Toannevot introduced the treatise to the Academy members for their judgement; in the last of the five sessions dedicated to the matter evaluation, on April the 28th 1755, the council, unanimously gave its evaluation (Lemmonnier 1915, 6: 222–225, 228, 234).

The system approval was constrained to the observance of primary condition: instead of tiles, ordinary bricks 2 3 6 3 12 inches should have been used and laid down on edge as obtain resistant section of 6 inches. In a few words a bricken vault layed down as for the traditional system.

The inability shown by the Institution to understand and consequently to give legitimation to a rule which did not correspond to the canons and precepts fixed by the construction habit, is indicative of the difficulty expressed by the scientific community of that time to promote innovative methods and systems buildings techniques.

As very clearly observed by Luigi Ramazzotti, while moving inside a not scientific techniques world, to evaluate them with a systematic and severe approach, the Illuminism goes through the way of the precise knowledge of the traditional building procedures and of the expertise transmitted in the building techniques. Viceversa in the operational side there are any records in terms of innovative building techniques. In this field the real impact of Ecletism can be evaluated better on the methodological side then in terms of innovation (Ramazzotti 1984, 30).

In such a way, if on one side d'Espie system will acquire a relevant editorial fame, appearing as a costant reference also in the following manuals and treaties in the end of 18th century and at the beginning of the 19th century, on the operational side the applicative examples of this technique will be constrained inside single and isolated experiences, without carrying on a relevant change in the building attitudes of that time.

The reasons of the disparity between the considerable editorial diffusion of this technique towards d'Espie treatise —with English (London, 1756), german (Frankfurt and Leipzig, 1760) and Spanish (Madrid, 1776) versions— and the failure on the side of constructive practise, belongs to the complexity that characterize every historic event, not describable through deterministic interpretations. Therefore, only a few hypothesis will be explained.

First issue, about which it exists a wide agreement in historical analysis, concerns the self-referring which can be found in the 19th treatises, as for the continuous elaboration and re-writing of information previously published.

The case of Toulouse tile roof, was variously described by M. A. Laugier (1755, 2° ed.), by D. G. Shebers (1761), by Joaquin de Sotomayor (1776) as a critic version of d’Espie treatise, by P. Patte (Blondel 1777), by J. B. Rondelet (1802), by J. N. L. Durand (1802–1805), by Pasley (1826), by U. Vitry (1827).

Therefore, considering the following editions and translations published in the course of 19th century, is possible to notice that the Toulouse experience will be alive and wellknown for about one hundred years.

In the other hand, in the field of constructive practice, the employment of this technique, out of the original context, was conditioned by the pre-scientific world that characterize the d’Espie experimental approach and the entire illuministic experience.

The failure of the experiment leaded inside the War School of Paris (Bauchal 1887, 238; Blomfield 1921, 2: 126–127), at the presence of the First Royal architect, A. J. Gabriel, will be recorded and annotated by Patte (Blondel 1777, 6: 116). The employment of Paris’s plaster, which offered a different behaviour in terms of resistance and shrinkage compared with which was in use in Toulouse, summed to the unskilfulness of skilled workers on leading the constructive process, were be, according to author, the main causes of the unforeseen vault’s collapse, as soon as constructed. To these reasons, for Patte, «this kind of construction have had a modest success in Paris».

The uncertainty showed by Royal Architecture Academy commission on attesting the scientific validity of the d’Espie constructive system, reinforced by the failure of War School experiment, will be assumed as two significant moments that had conditioned the employment of this technique in the building practice of that time, bordered inside the «cultured» dimension of the editorial project but devoid as an effective presence in the habit of erecting yard.

Only one building, from whose related in Blondel’s treatise, that represents an application of d’Espie solution for the house of Toulouse, is Palais Bourbon, where, in occasion of the riability in 1764 for Prince Conde account, as new proprietary, was foreseen the
Besides, on extrados, there are tie-beams with bolts; a significant warning, in spite of d’Espie thesis, of the presence of thrusts along the vault’s imposts.

In this case too, before the beginning of the construction, was requested to execute a prototype for a text, in the sight of a Royal Architecture Academy commission (Croÿ 1906–1907, 2: 320). The good result of the text, executed checking the vault’s resistance under a load uniformly distributed, allowed the continuation of the brickwork, but at the same time, declared the mistrust in d’Espie theoria about the missing of thrusts: in fact, the response marked that the good outcome was in consequence of the employment of tie-beams; an opinion originated from the observation of a vertical displacement, about two inches, suffered by one of the four walls as soon as constructed.

In the light of today’s knowledge on structural analysis, the d’Espie thesis about the lack of thrusts, appears, under a strict theoretical point of view, incorrect; or better, is possible to assert that the multi-

employment of flat vaults for middle floors and of a barrel vault for roof.

Omitting the case of the roof, not belonging to the category of flat vaults and for this substantially different, instead of particular interest is the case of the vault described in Figure 4.

The vault, on square base and with profile section generated from a circle and not from ellipse, shows some particularities compared with the one of Toulouse. The first regards the employment of briques sillonnées, or tiles with drills on the plane faces in according to have best proprieties in terms of strong adherence between plaster and brick.

A clearly clue of the consciousness of the importance assumed by «cohesion» force, as well as defined by Du Hamel, on conferring the capacity on resistance to shearing stress of multi-layers structures.

Figure 4
Drawing of Palais Bourbon’s vault by P. Patte. (Blondel 1777). Panche 97

Figure 5
Experimental prototype. Plan and prospect
layers vault's structures are more rigid compared with traditional vaults of similar thickness, but this is not sufficient to consider any presence of actions along the vault's imposts.

This issue is widely confirmed by a sequence of experimentations leaded on constructive prototypes executed in laboratory (Gulli and Mochi 1995); in particular, the good response in terms of little deformation for original mono-layer tiles scheet vaults afterwards reinforced by two more layer on the extrados, was been in evidence in the experimentation regarding a cross-vault of 3,00 m side and in the ratio of one to eight between rise and span.

The main objectives of this experimentation were to put in evidence the way to employ the tabicado system as a restoration technique for mono-layer tiles scheet vaults; in addition to this aim, there was the exigence to realize the constructive procedures, in the passage between theoretical explanation of a constructive rule and its translation in operative manner.

For example, d'Espie's hint on how do not tighten the vault against the perimetrical structure, in order to allow the horizontal shiftings following from the strains generated by loads, has been an important constructive device to guarantee a correct working of vault's structure.

Figure 6
Experimental prototype. Axonometric of multi-layers vault

Figure 7
Experimental prototype. Construction of mono-layer tiles scheet vault

Figure 8
Experimental prototype. Laying of first layer's tiles on arch's extrados. On the left, is present the void space in order to allow the horizontal shiftings following from the strains generated by loads

Figure 9
Experimental prototype. Construction of mono-layer tiles scheet vault
In the matter of structural working, the analysis of the tension stress under load, attest a remarkable increase in terms of stiffness of multi-layers vault compared with the original one (Fig. 12). An increase, however not sufficient to eliminate the thrusts. At the end of ripening, was gradually released the hooping tie-beams disposed along the line of the impost. Progressively and inexorably, the vault’s prototype collapsed following the typical kinematical situation with the rotation of the four supports (Fig. 13).

Figure 12
Graphic in which is represented a synthesis of experimental results. Relative values of vault’s vertical translations (ordinate) related to the phases of loading (abscissa). The blank line indicated the condition of multi-layer vault, while the other, the state of original mono-layer tiles scheet vault. It is clear the remarkable increase in terms of stiffness of multi-layers vault compared with the original one.
The experimental way followed by d'Espie, as the subsequence Guastavino’s one, represents, for that time as today, an essential instrument to approach the comprehension of the peculiar structural working of this constructive system.

In fact, the refined numerical models for structural’s analysis today in use, show margin of doubt, when the factors connected to the sensibility of artisan’s action and the presence of different materials combined in heterogenetic manner, play an important roll.

In consequence, it is easy to comprehend the explanation given by Patte in order to the premature collapse of War School’s vault, belonging to the use of Paris’s plaster.

Under the hidden folds of a kind of learning that swings between the theoretical speculation and the empiric data of experience, between theory and practice, rise and consolidate, rules, principles, technical procedures that declared themselves valid in the act of construction; at this dimension belongs the entire experience of tabicado system, of which, the d’Espie vicissitude, represents only a partial contribute.

As Patte said «the construction of tile’s roofs has not reached the auspicate point of perfection and will be considered a very useful discovery if will be found a new system of doing it, that is light, solid and lasting at the same time» (Blondel, 6: 159).

An auspice and a forewarning, of what will be about a century later, when, on the hands of the Catalan Modernistic Movement’ Magisters, will flower the extraordinary architecture vault’s examples, characterized by a diversity and surprising employment of multi-layers vault’s system.

Also in this case, not as an expression of logic originated from mathematic comprehension of physic phenomena, at that time still uncertain, but as an epilogue of a kind of knowledge, that rises slowly inside the empiric data of experience.

**REFERENCE LIST**


