The “Vis Saint-Gilles”, Symbol of Compromise between Practice and Science

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> I have seen in my youth that whoever knew the way to make the layout of the aforementioned vis Saint-Gilles (Saint-Gilles’ winding stairway) and was quite acquainted with it was highly esteemed among the workers.
>
> (Delorme, 1567, p. 123 reverse side)

INTRODUCTION

The difficult learning of the drawing techniques which permit stone-carving for the annular winding vault remained reserved for centuries for the elite of the construction corporation. It is still nowadays a respectful knowledge within the stone cutters’ corporation in France. Our study does not seek to unveil his secret forgotten by everybody: we simply want to show the intellectual research conducted by the constructors in order to be able to succeed to define traits for the vault cutting they imagined.

Thanks to a selection of the most interesting diagrams of this vault, subject of various treatises of stone cutting, we will understand that the first goal of the “art du trait” (trait art) was to build. The method developed was above all useful and rarely perfect in the geometrical sense. In the stereotomic works, the respect of geometrical volumes like spheres, cones, etc, was a permanent objective in the history of the trait. However, the application depends on the competences, the geometrical culture and the will of the persons charged to find new ideas as related to the trait method. The solution for the vis Saint-Gilles (Saint-Gilles’ winding stairway) has only came tardily, this vault was not really defined geometrically until the beginning of the nineteenth century, thanks to the work of Gaspar Monge.

HISTORICAL ASPECT

Helicoid vaults appear very early in the history of construction. The way of carrying them out does not necessarily involve a very advanced geometrical culture. We see the helicoid vault which allows access to the catacombs of Kom al shuqafa in Alexandria, Egypt, second century. Out of stone it makes a revolution around a large well of 3 m diameter. Thus the “voussoirs” (wedge-shaped stones forming the curved parts of an arch or a vaulted ceiling) have little curve and their external face is flat. In spite of regular joints and a vault prepared according to an ideal geometrical model, there is actually nothing that prompts us to suppose that the builders had recourse to a method of trait (layout), the stones having been well able to be adjusted on site.

This is why our study will involve the helicoid vaults with interior radius of small diameter, smaller than 2 m. They are of large dimension: the voussoirs were cut from blocks of cutting stones rather than from cinder-blocks of masonry. Finally their dimension imitates the generations of the helicoid's geometrical model. Nevertheless, the helicoid vaults generated around a small diameter do not allow upon request cutting. Indeed, the stones placed against the centre are too deformed to allow cutting them without a prior layout.

The oldest known models are the two helicoid vaults built in the wall of the Bab el Nasr gate of the Fatimid walls of Al Qaira (a part of Cairo); accomplished between 1087 and 1092, the construction of this door formed part of the project of fortifications entrusted by vizier Badr Al-Djamali to Armenian architects of Urfa (Edesse) who had stereotomic knowledge of their region.

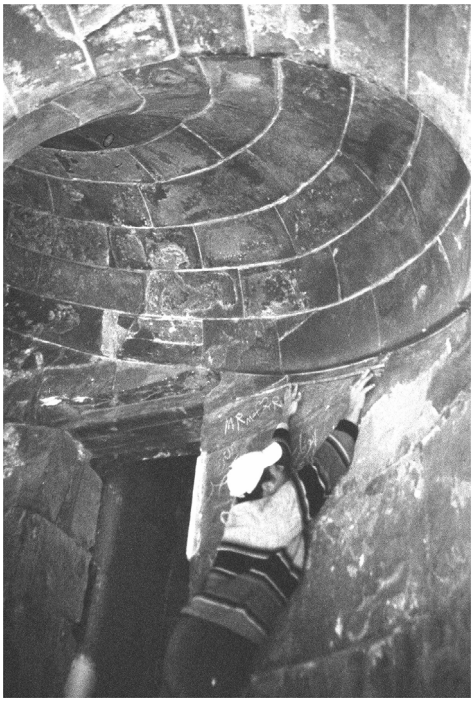

Figure 1. Bab el Nasr, first staircase vault, Egypt (Tamborero, L, 2002).

A first winding stairway allows access to the first floor of the tower, its large spacing makes it possible for two persons to cross, one second winding stairway of small diameter connects the first stage to a terrace. These two winding stairways, made out of firm stone, are of an exceptional quality. The key bricks are of big length, between 60 and 80 cm. Several details are immediately appreciable: their external face was not cut on the spot and the head joints are perpendicular to the platform, which makes us suppose that initially the finished pieces were installed, then an elaborate

layout was made which makes it possible to define them. Finally, the joints, rarely exceeding 3 mm of width, give to the work a remarkable execution quality. However, in the history of the construction of the Cairo walls, there exists a particular episode in which it is possible to imagine an original means of transmission of knowledge from the Eastern builders to the Western builders.

In the twelfth century, under the reign of Saladin, Ayyûbid Sultan of Egypt and Syria (the Ayyoubids succeeded the Fatimides under the reign of Saladin in 1173), unwillingly, the Sicilian Normans will discover the Fatimid Gates of Cairo. In July 1174, the Sicilian fleet arrived with 284 ships in Alexandria to attack Saladin who surprises them and returns victorious to Cairo with a great number of Norman prisoners reduced to slavery. The prisoners were employed for the works of restoration and prolongation of the walls built by Fatimids as well as the construction of the citadel. If we have a description of the cortege of Saladin, however, little information is available as to the treatment of these slave masons (André 1993). The prisoners have forcibly borrowed the vaulted passages during the restoration of the Fatimid walls: the winding stairways of Bâb el Nasr must have astonished them as they still astonish us today. The quality of construction of the Ayyoubid wall being of a poor level as compared to the older part of Fatimid walls, makes us believe that stereotomic knowledge has not been shared between the Eastern and Western masons during the construction of the walls. However, the typology of the vaults can find here a passage from the East to the West. Illustrated stereotomic research in France in respect of the first helicoid vaults generated by a semicircular arch (Uzès winding stairways, the first to be built, from 1060, were half vaults clearly made of cut cinder blocks upon request and without particular drawing or worry to follow a generatrix; it was not before 1170 that the helicoïdal vaults were generated by a full curve) is of a great chronological mixture with the forced training of Cairo, and in fact, one can see a causal link between them. In fact, the principle of the helicoid winding stairways extends in all France, from the twelfth to the thirteenth centuries: at the Saint Victor abbatial of Marseilles in the second half of the twelfth century, at the Notre-dame Collegial at Mantes-la-Jolie where the building site was started in 1170 , at Saint Etienne de Sens Cathedral in about 1200, or also at the Collegial of Notre-dame de Saint-Laurent d'Eu in Normandie after 1186, which possesses two vaults made of small cinder blocks.

The quality of building of the helicoid vaults in France is very variable. Evolution or imitation, the French helicoid winding stairways, comparable with those in Cairo from a typological point of view insofar as to their origins, however, they are different from a stereotomic and qualitative point of view unless for the helicoid vault of the Abbatial of Saint-Gilles du Gard built in the thirteenth century.

As if it was to underline the importance of the work it contains, only the tower which supports the helicoid winding stairway was preserved at the time of the destruction of the heart of the abbatial. The quality of this work has made a typical example in the treatise of stone-carving where the helicoid vaults are generally called "the Saint-Gilles' winding stairways". To the best of our

knowledge, no other exemple exists of this stereotomic vault prior to the end of the fifteenth century, at that time the Saint-Gilles' winding stairways multiplied in the cathedrals of France, thanks to the knowledge of the master builders as Martin Chambiges (1460-1532) who was the chief of many building sites like the Saint-Gervais church in Paris, the cathedral of Sens and the cathedral of Senlis.

Figure 2. Vis Saint-Gilles du Gard, France (Fallacara, G, 2000).

At that period, the knowledge of the layout was a symbol of power between the members of the same corporation. It is this knowledge which Philibert Delorme (1510-70), endeavoured to diffuse to impose the architect's profession and role. In his second treatise, "Le premier tome de l'Architecture" published in 1567 (Delorme 1567), he gives the first diagrams of the Saint-Gilles' winding stairway by two distinct methods, the first simplistic one while the second is accompanied by the following instructions:

> In case some wish to know how to put it in use, and do not have the brain to understand it, and in case they can not find another more knowledgeable person than me, then they may come and see me, I would voluntarily tell them what, by the grace of God, I knew.
>
> (Delorme 1567, p. 126)

It is evident that the second makes it possible to carry out a work comparable with the model of the winding stairway Saint Gilles of Gard. With the said Delorme's text, it would have been very

difficult to understand the elements contained in said diagram, it is only thanks to the treatise of Mathurin Jousse "le secret d'Architecture" (Mathurin 1641) published in 1641 that it was possible to draw the conclusions. Generally difficult to read, the explanations of Jousse are not less comprehensible but the Saint Gilles' winding stairway is differently described: Jousse seems to have voluntarily dissimulated his explanations by additions of letters, non-existent references on the figures to prevent a person not initiated with stereotomic knowledge finding the elevation of the diagram. On the seventeenth century, the knowledge of the layout within the corporation of the masons and particularly the helicoids' layout are still of major importance as Desargues (1593-1662) underlines it:

> And to discourage the beginners they speak incontinently to cut one of the most difficult parts of the layout, like where the curved surfaces are in surbased vault, winding and whirling in shell or snail form, and similar.
>
> (Desargues 1640, Post Scriptum of the Brouillon project)

It is by the end of the seventeenth century that the Saint-Gilles' winding stairways will be apprehended from a new point of view thanks to the work of Philippe De la Hire (1640-1718), who implemented an original technique of tracery. Technically, the tracery falls under the very particular logic of De la Hire treatise (ENPC Ms 228, Hire 1688-1690) which seeks to obtain the useful angles to directly cut the stones of the vaults without passing to the preliminaries through a precise definition of the volume's surfaces. This new model of layout was taught exclusively in the courses of the Royal Academy of Architecture in which De la Hire's treatise is the support. The purpose of teaching these techniques was to allow the architects a big freedom of expression: since the layout does not depend any more on a regular geometrical volume like a cone or a cylinder, the architect is not forced any more to the use of a defined volume, he may also decide on the shape of the edges between two contiguous vaults, which is the case of the vault of Arles city hall (Tamborero 2003). Finally, the first layout which makes it possible to make a helicoid vault, respecting the geometrical model, was not finally made before 1799 by Gaspar Monge (1746-1818) in his course of descriptive geometry (Monge 1799).

THE SAINT-GILLES' WINDING STAIRWAY IN THE STONE-CARVING TREATISE

The Saint Gilles' winding stairway is certainly the only case of vault which has such a variety in the possibilities of execution. Each method requires different knowledge: it is not a question of evolutions brought to the figure layout made by the successive authors, but rather it is the question of creation of new geometrical conceptions which brings big changes in the diagram layout.

We have been able to differentiate five methods of layout implemented during the course of stone-carving history. We have selected four authors who best present the various diagram layouts. Philibert Delorme and Mathurin Jousse for the first three which are the methods by *équarrissement*,

panneaux and *beuveaux et sauterelles*. Philippe de la Hire for the fourth method which we will call the method by the angle of douelle and Gaspar Monge for the last method which is the helicoid geometrical layout.

Philibert Delorme and Mathurin Jousse:

Delorme gives a first diagram which he names:

> Another kind of winding stairway which can be vaulted between the centre and the walls which close the winding stairway: it will be a straight vault, like we make the vault on the centre, at the highest point of the winding stairway, or crawling to carry the steps, like the saint Gilles winding stairway.
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> (Delorme 1567, p. 123 reverse side)

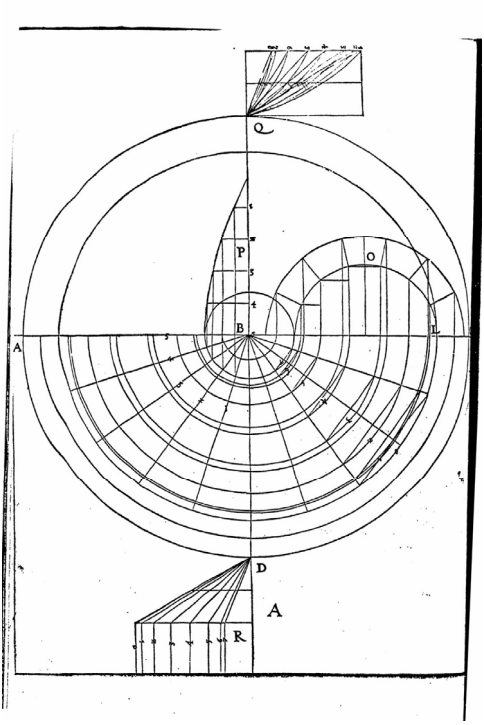

Figure 3. (Delorme 1567, p. 125 reverse side).

The title emphasizes the spirit of the layout: the subject is to consider the saint Gilles winding stairway as an annular vault which one stretches upwards. Delorme thus treats the diagram by presenting the layout of an annular vault which must be cut by équarrissement. He adds to this base a layout of the slopes and of the cerces rallongées.

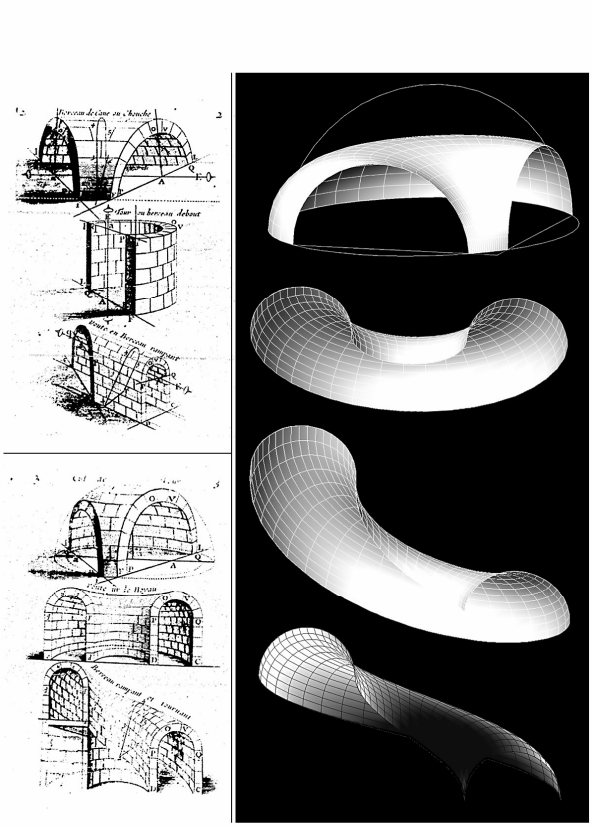

Figure 4. From annular vault to the saint Gilles winding stairway (Fallacara, G, 2004).

From this simplistic diagram, the stone cutter will carry out the helicoid archstones but the archstone head joints will be vertical, which is problematic for the very inclined stones which are close to the centre of the winding stairway. It indeed appears at this place acuteness which makes the edges too fragile and do not allow a work of a good quality. The explanations of the diagram layout which Delorme gives are not detailed and solicit the reader's knowledge. On the other hand, its text delivers information on the various execution practices of the Saint-Gilles' winding stairway:

> The workmen worked hard and mainly to do it *par panneaux*, [...]. We would meet some of them which did it *par équarrissement*, but in that, there is no spirit nor industry, and it is necessary to lose many stones [...] it is also extremely easy to make it with the *beuveaux et sauterelles*.
>
> (Delorme 1567, p. 123 reverse side)

What are the characteristics of each those three methods for carrying out the Saint-Gilles' winding stairway?

The *par équarrissement* method in which the diagram is limited to the layout of the vault with elevation and sight according to the plan. The carving method of an archstone consists of reproducing contours of the sight in plan on the stone, to carve them in the block with the square and at the given heights elevation and sight according to the plan.

The *par panneaux* method (board of chapter XIX) necessitates in addition to elevation and sight according to the plan, the layouts of slopes and cerces rallongées. The method of carving an archstone makes it possible to save more material than in the par équarrissement method. They start this time by reproducing the voussoir elevation on the face of the stone, thanks to the edge angles, then the depths are carved thanks to the cerces rallongées, and we finish by giving the shape of the archstone using the arc profile.

The *beuveaux et sauterelles* method: We suppose that this involves the diagram which Delorme presents in chapter XX of his treatise "the trait of another kind of winding stairway and creeping rise as the Saint-Gilles' winding stairway" (Delorme1567, chapter XX).

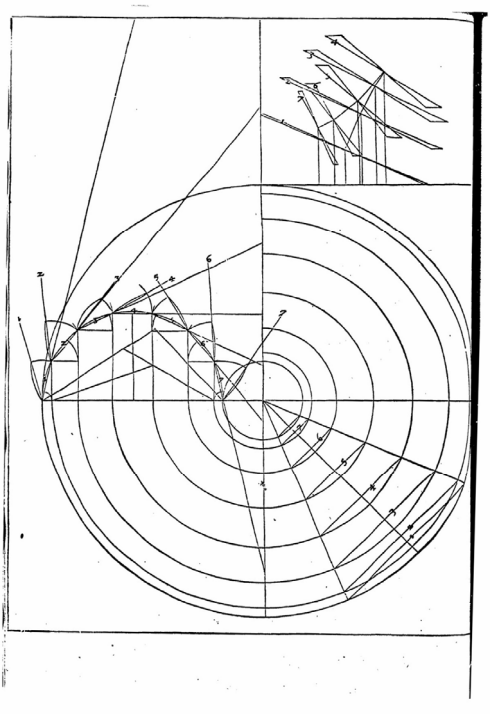

Figure 5. (Delorme 1567, p. 126 reverse side).

The diagram is not explained by Delorme, the few text extracts which accompany this chapter allow us to understand that he voluntarily remained discrete on the layout of this figure. He indicates its complexity in his words:

> I wish still to show the trait of another kind of winding stairway which can be made like the way of the Saint-Gilles' winding stairway, [...], the truth is that this layout here would be quite sufficient to do one or two big chapters out of them, even three or four, in order to specify and declare all parts, but insofar as it is almost the same thing as what you have seen in front, [...].In case some wish to know how to put it in use and do not have the brain to understand it, and in case they can not find another more knowledgeable person than me, than they may come and see me, I would voluntarily tell them what, by the grace of God, I knew.
>
> (Delorme1567, p. 126).

This figure is actually the skeleton of a diagram, Philibert gives here the indispensable elements for establishment of the layout, but if he wants to point out that he knows this layout, his goal is not to divulge it.

It is thanks to the Mathurin Jousse's treatise, and despite the text being discouraging due to the confusion which reigns there, that we could comment on the Delorme's diagram and to determine the various principles out of them. For that, we have divided it in three parts: the first to the left side of the vertical axis, the second in the bottom to the right side of the axis where the chords are seen, the third at the top to the right of the axis where the slopes are seen.

In the first part, only the intrados of the vault is represented, the joints do not appear. The intrados is divided into seven flat douelles numbered from 1 to 7 and prolonged up to over the axis. These prolongations make it possible to establish a connection between the diagram with those which are traced to cut the revolution vaults through their flat douelle. The flat douelles being in this case cone trunks, obtained by development, the prolongations represent the directrix line of the various cones. It is based on this detail that we have been able to establish the reciprocities with the Jousse's diagram which functions applying the same principles.

In the second part, the chords numbered from 1 to 7 are represented as in the par panneaux method: the chords are used to reform the spaces which make it possible to trace the cerces rallongées.

The third part content the slopes table. The disposition representation of these slopes is done in pair at the crossing of a same douelle with the axis. Each pair of slopes is distant from the following one by the height which separates them on the elevation in the first part of the diagram. This height is orthogonally brought back to the slope that the superior and inferior pairs have in common. This douelle heights' layout shows the means for defining the normal head joints to the slope, which

already meets one of the particularities of the winding stairways of Bab el Nasr and the Saint-Gilles du Gard's winding stairways. The other particularity which this table informs us is that the vertical section of the winding stairway thus produced is not half cylindrical. This is one other point in common with the winding stairways of Bab el Nasr. We could not check this on the Saint Gilles winding stairway. The vertical section is thus almost oval: we therefore understand that the first part of the diagram is not an elevation. We will remark that the slopes table is wrong for the pairs 5 to 7, because the heights are reported in an inverse direction. We believe that this is an error on the part of the carver. The act of joining a same douelle's slopes in pair should draw attention, since it is only the concerned slope which will be used to bring back the height which separates it from the following slope. We will learn from Jousse information that these pairs of slopes are used to adjust the carving gaps of a helicoid flat douelle. This diagram indeed makes it possible to carve a helicoid winding stairway directly from the douelle.

However despite Jousse's work, several points of Delorme's diagram are unclear to us: on the first part, we know that the figure represented is not the elevation and that it is used for various operations, out of which the douelle panels layout. However we have no explanation for the cerces and the angles which are traced out of the half circle: sections of the intrados are moved at an angle which position we did not understand.

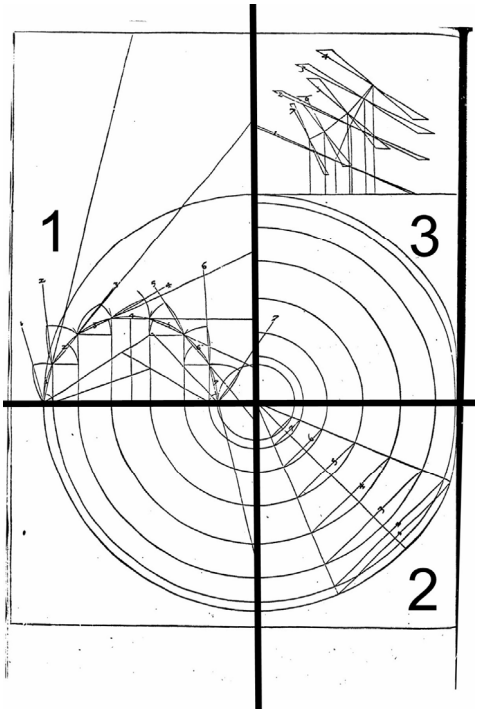

Figure 6. Délimitation of the Figure 5 (Tamborero, L).

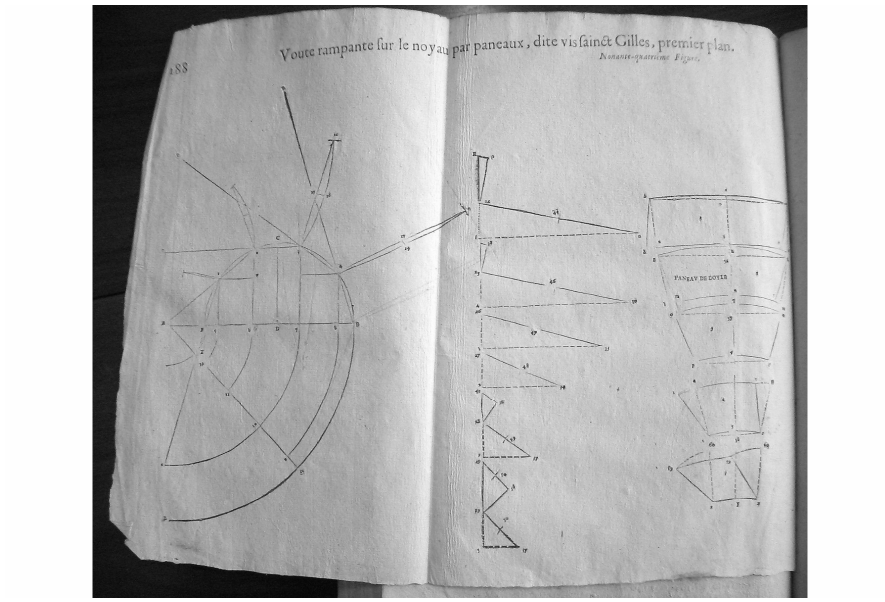

Figure 7. (Jousse 1641, p. 188).

Neither Delorme nor Jousse give an explanation for the carving method, we simply know that the carving is done by the douelle. We can however understand that this diagram combines two totally different layout principles: the first is the layout by the conical directrix of a vault of revolution, here an annular vault. While the second is that of the slopes layout of an in descent vault, this thus involves the fusion of two different layouts.

De la Hire

The De la Hire method is totally original, and is tackled in a different way: De la Hire traces initially the sight in plan with the generator arc (generatrix) turned down on the same plan. There is no elevation. All the height check marks (indicators) are produced separately, in separate diagrams which is very similar to the Delorme's layout by beuvaux et sauterelle. De la Hire does not define the surface in a precise manner, and never does it in his treatise. His choices are directly connected to the carving technique: like Delorme and Jousse, he proposes to directly carve the most difficult surface to define in a helicoid vault: the intrados.

He decides to determine in the first instance an angle very far from the finished surface. To obtain it, he uses the dihedral angle layout. He thus defines a third level plan attached to the flat douelle's lowest point with two inclinations and takes off from this plan the dihedral angle which he seeks to obtain, as it is possible to do it for a simple groined vault or for a hip rafter framework. This technique, unknown up to that point, uses the intersection angle of the dihedron formed by two adjacent triangles which bases are the chords of the archstone at its ends.

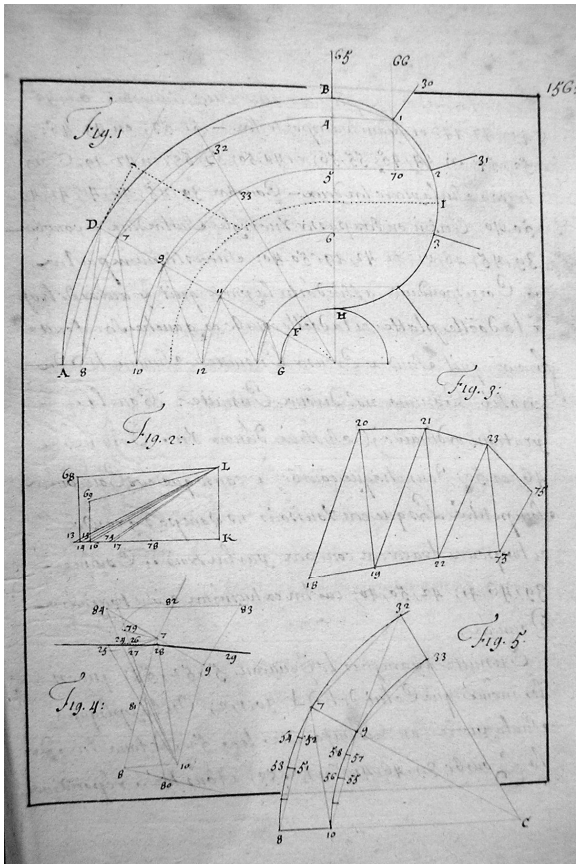

Figure 8. (ENPC Ms 228, De la Hire, p. 156).

De la Hire then carves this angle directly in the mass of the stone and thus reproduces a surface on which he traces the two adjacent triangles, their bases being the voussoir ends and their longitudinal edges being the chords extended between its ends. By applying a bevel-square on these two chords, he directly carves what he considers being the voussoir joint surfaces. Finally he reproduces a helicoid curve based onto the corde-douelle spacing measured on the sight in plan. Starting from this point, De la Hire traced a first helicoid curve, which enables him to carve the whole archstone.

De la Hire describes the voussoir carving. His texts are very detailed, and do not leave any doubt about the method. De la Hire's diagram thus have some points in common with those of Delorme's chapter XX, but uniquely in the organization of the diagram check marks (indicators). His layout is not geometrically ideal, but in no way is it a fusion of several layouts. Following De la Hire's indications, we carried out archstones, and have been able to observe that the result is satisfactory though relatively far from the helicoid ideal model.

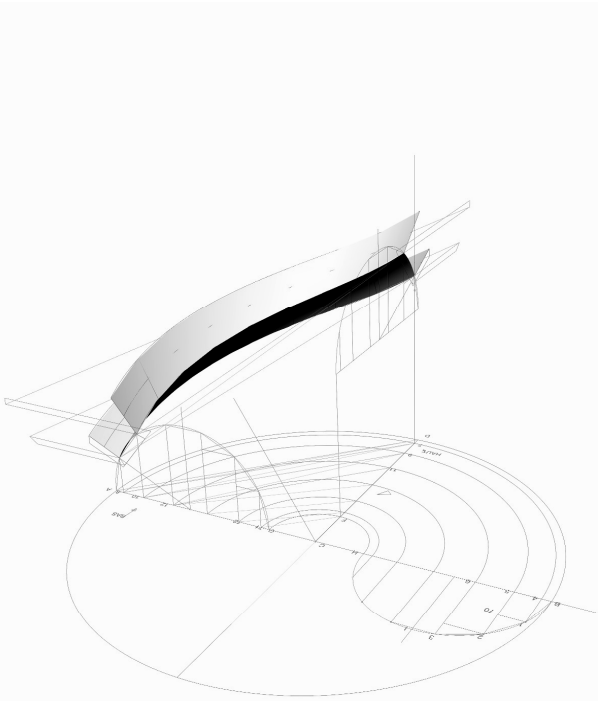

Figure 9. De la Hire method (Tamborero, L, 2005).

Gaspar Monge

Gaspar Monge is the first to have brought the necessary elements to the Saint Gilles winding stairway's layout perfectly respecting the ideal geometrical model, a helicoid needs only one sight in plan and an elevation in order to be perfectly described, the sight from the side not being of any use.

The contributions of Monge are consistent with the entirety of his synthesis and the invention of the descriptive geometry: during the layout, it is specially a question of using, a protocol perfectly respecting the helicoid geometrical model being the Saint-Gilles winding stairway's geometrical model. One cannot therefore completely disregard the constructive constraints of a vault as against the respect of a geometrical model. Thus, the voussoir head joints are plane in a descriptive geometry diagram applied to the stones carving, while they should have been ideally perpendicular to the helicoid and thus helicoidal.

These ambiguities will sometimes involve Monge's concern: thus, he was always very attached to carrying out a three axes' elliptic vault, respecting the ideal model of geometrical volume, the archstones of this very difficult to carve vault, requiring the development of a carving technique, thus allowing to respect all conical and elliptic surfaces. Traditionally this kind of vault is treated, like all vaults of revolution, with the technique of the development of the flat douelles by cone

trunks layout. In his courses given in the normales schools (Monge 1799), Monge underlines one of his synthesis work motivations.

> Thus, for example, when the surface of the vault was of revolution, whether it has been in spheroid, or in a revolving cradle, they divided its voussoirs by meridian lines and parallels, i.e. by the vault surface's curve lines. The joints which corresponded to the meridian lines were plans guided by the revolution axis; those which corresponded to the parallels, were conical surfaces with revolution around the same axis; and these two types of joints were rectangular between them, and perpendicular to the surface of the vault. However, when surfaces of the vaults do not swage such a simple generation, and when their curve lines were presented in such a marked manner, as in the lengthened spheroid vaults, and in a great number of others; the artists could not satisfy all points of suitability any more, and they sacrificed, in each particular case, those which presented to them the largest difficulties
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> (Monge 1799, p. 126-27).

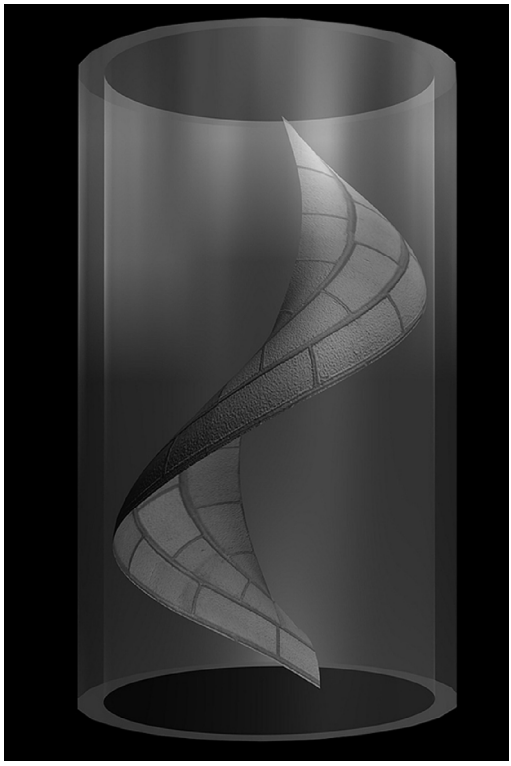

Figure 10. (Fallacara, G, 2004).

CONCLUSION

Certain vaults are far from being simple utility constructions: the winding stairway of the Saint-Gilles priory gave access to the bell tower, a helicoid staircase consisting of steps would have fulfilled the same function. These works, being the fruit of a social and community bond which had no other role but to pose the builders' social scale measurement, hidden behind their load-bearing walls, have sometimes received the marks of the companions who came to visit them as is the case with Saint-Gilles. Like the architect who models in his work the cultural and social conceptions of his time, the master masons formed in the stone what was their knowledge at the time of the building site, the construction of certain vaults is thus a humanity, which exceeds the simple mechanical aspect of the work.

Each method of the Saint-Gilles' winding stairway has a bond with the major changes in the builders' society, how would we then be satisfied to study them in just a typological respect? Apparently all being similar, they were however carried out based on completely different techniques. Observing or studying these works requires a knowledge of the geometrical concepts developed at a precise period: at the moment of their construction. The history of construction techniques is in the case of the stone vaults a unit which is not limited to the comparison of volumes, but takes into account the social and hierarchical aspects of the builders' community.

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