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

The vault of Arles City Hall: A carpentry outline for a stone vault?

Luc Tamboréro
Jöel Sakarovitch

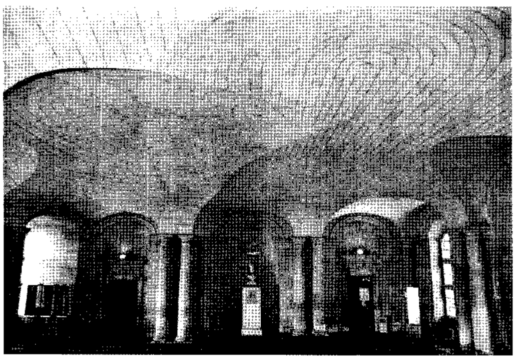
«Masterpiece of French stone-cutting» according to Pérouse de Montclos,[1] the vault covering the entrance hall of the City Hall of Arles is a true directory of the stereotomic virtuosity of the 17[th] century.

Yet the building work did not get off to a good start. When it had been underway for 6 and a half years, the defects left by the first contractors led to the decision on October 27[th] 1667 to demolish the building down to its foundations. But on August 7[th] 1672, the City Council decided « . . . *que l'hostel de ville de cette cité qui à esté demolly, comancé à estre rebasty et ensuitte redemolly sera incessamment rebasty jusques a son entiere perfection* . . . » The first foundation stone was laid on June 22[nd] 1673. The same day, Jules Hardouin-Mansart (1646–1708) arrived in Arles, on the invitation of the coadjutor to the City Archbishop's Palace, in order to give his opinion on the drawings prepared by Dominique Pilleporte, Master Stonemason, and Jacques Peytret, Master Painter.

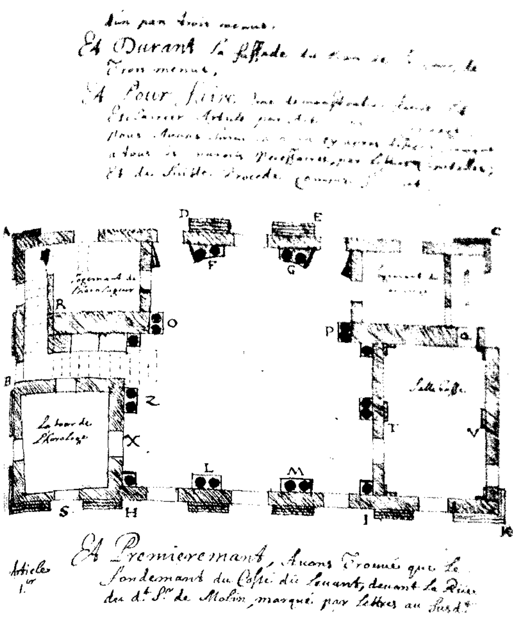
The Royal Architecture Academy was then two years old and Hardouin-Mansart 27 years old. For 6 years, he had been managing a small team which Jean Boyer called the «Mansart Agency».[2] The team included, among others, his brother, Michel Hardouin-Mansart, who accompanied and assisted him in Arles, and his brother-in-law, Robert de Cotte. It was on the occasion of the June 1673 visit that Hardouin-Mansart drew a sketch (which has disappeared today) in which he erased the intermediary pillars of the Hall vault. He invited Peytret to accompany him to Beziers where he gave him « all the instructions, models and panels for the building and vault in order for the work to be done whilst he was away».[3]

Two and a half years later, the vault was finished and its construction will probably not have taken more than 18 months. It resembles nothing previously known. Covering a square of approximately 16 meters, its arrow is only 2,40 meters high. At first glance, it can be described as being composed of two oval vaults penetrating each other crosswise and sustained by lunettes (photographs 1 and 2, and figure 5).

Whilst the vault of Arles has been studied frequently, it seems that no study precisely accounts for its shape



Photograph 1



Photographs 2

nor for its construction. The rapidity with which it was built plus the apparent complexity of the penetrations and the subjacent line seem inconsistent with the shortness of the presence of Mansart on site. Mansart taught Peytret in less than a month how to conduct the work. We can question how a man, originally a painter, and although he had some knowledge of the geometrical needs of his trade, could claim in such a short period of time to be able to manage the drawing, the manufacturing and the construction of such a complex vault. The answers to these questions lie in the analysis of the construction and in the reconstruction of the steps from the design stage to the cpmpleted vault.

Our working method

The working method which has been followed is based on historic study principally of the archives, a precise record and the creation of a model on a scale of 1/5.

Thanks to the numerous accounting archives of the City Hall, we were lucky to be able to piece together with considerable precision the progress of the work. Purchase orders,[4] as well as documents discussing the resistance of the building were kept. It is important to note that the lack of reference to reinforcement or the purchasing of iron enables us to eliminate the presence of iron ties inside the vault. Part of the archives was published by Jean Boyer in 1969.[5] Furthermore, the vault has been the subject matter of various unpublished studies by Emile Fassin, at the end of the 19th century,[6] and numerous publications during the 19th as well as 20th centuries.[7]

The precise and complete survey of the volume and of each soffit which was carried out in 2001 has been cross-checked with the photogrammetric survey implemented for the Regional Board for Cultural Affairs and the Regional Council for Inventory. This survey confirmed that « La Canne d'Arles», which was a measurement unit at the time, was 204,6 cm.[8] The «Canne» was divided into 8 «pans» of 25,6 cm which were divided into 8 «menus» of 3,2 cm divided in turn into 8 «lignes» of 0,4 cm. The fact that the vault had been rigorously built according to a module is confirmed by the survey of the columns. Indeed, the vault rests on 20 Roman Doric columns without pedestals. The module of the columns is of 1 pan. A column is divided into 16 modules of 1 pan of the height which is 2 «cannes» high that is 409,25 cm.[9] Given the exactness of the dimensions measured in 2001, it seems that the decisions taken by the Council regarding the requirement of high quality work had been respected during the construction.[10]

As is the case for the vault, the model, made by Luc Tamborero for his Masterpiece for the Stonecarvers Corporation[11], has been made in Fontvieille stone.[12] Its construction, step by step, was the best way to test the efficiency of the various hypotheses of how work was carried out.

The construction of the vault

We believe that the construction of the vault was based on 3 points:

— the regulatory lay out
— the double role of the plan view
— the stereotomy and its methods

The regulatory lay out

Two interpretative frameworks are superimposed on the setting up of the vault. The first one is linked to the module of the «canne». For instance (Fig. 1), the base square is 8 «cannes» (16,37 m) long on the side, and the columns for the north and south walls are regularly spaced with regard to this unit of measurement (Fig. 2). The second framework concerns the construction of the regular pentagon, which does not touch the circle, given by Dürer[13] (fig. 1 to 4).[14] It enables one to determine the position of the east and west columns, of the key stones and of the centering point, as well as the posotion of the penetrations and even the arrows of the arches as we will demonstrate below. The second implementations are of course incommensurate with the «canne».

The drawing of the North-East and North-West twin lunettes clearly confirms the existence of these two frameworks. Indeed, the axial edge, for example, of the North-East lunette joins the middle 2 of the penetration edge with point 1 (Fig. 5). The drawing of this edge, which rests partly on the modular drawing and partly on the pentagonal drawing, is therefore not orthogonal to the penetration edge. This remark proves that the regulatory drawing has been scrupulously followed.

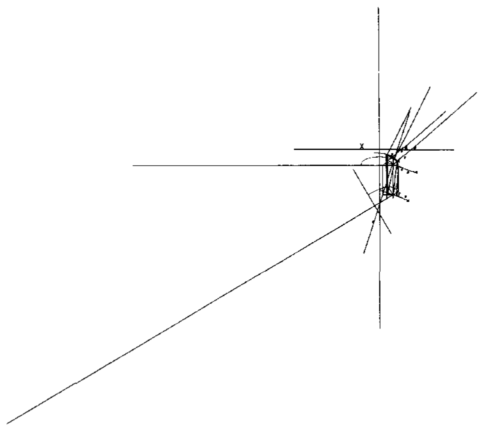


Figure 1
Drawing of a circle and semi-circle, intersecting according to a bowstring equal to their common radius. The point A and A′ will be the horizontal projections of the keys of the large vault semidomes

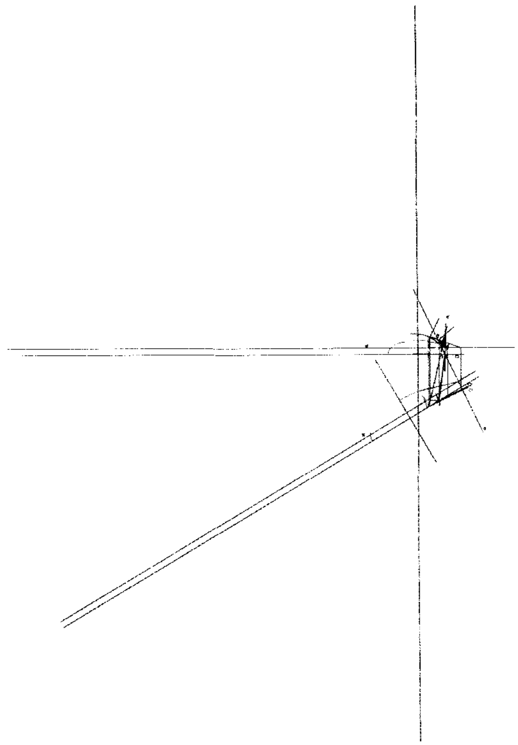


Figure 2
Construction of the regular pentagon which does not touch the circle, given by Dürer, construction referred to as «with constant opening» (the side of the pentagon is the radius of the circle of figure 1)

The double role of the plan view and the volume defined according to the penetrations

One of the principles of constructing the drawing apparently lies in the establishment of the horizontal projections of the penetrations. The penetrations of the large and small vault with the twin lunettes are flat; that of the two main vaults is partially flat; those of the entrance lunettes with the principal vaults are circular (horizontal projection).

We have chosen to work on the small vault, the construction principle being identical to the large one.

Once the plan implementation had been determined, the penetration edges between the vault and the lunettes were drawn on this very same projection. These edges, which are basket-handles with 5 centers whose span is

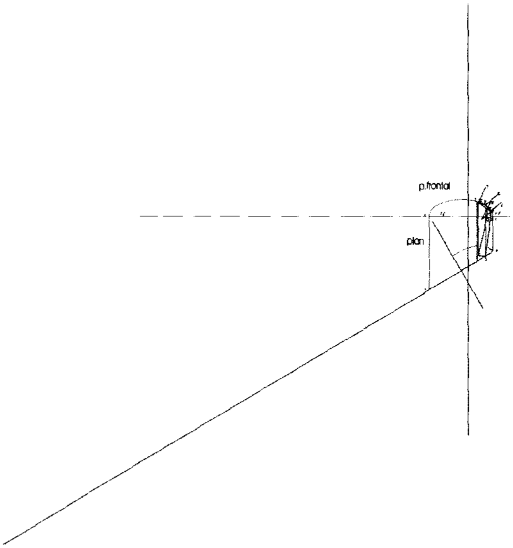


Figure 3
The two segments [x,y] and [x′,y′] are the layout of the penetrations of the two twin lunettes in the half semidomes of the small vault. This drawing was obtained from a modular North-South layout and of a pentagonal East-West layout

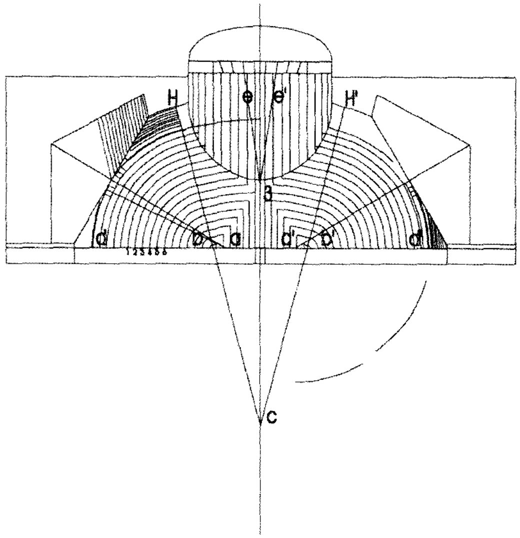


Figure 4
The axes of the twin lunettes are extended until they intersect (a and a′) with the straight line of the top B and B' of the pentagon.
The sides B• and B′• cut C and C' the spacing AA′.. The segment CC′ is located at 10 cm above the base square according to the regulator drawing, 3 cm according to the tracing; taking into account the encounter angle and the number of previous operations, the mistake is minor. From c, in the middle of AA′, we draw cC and cC′ which cut BB′ respectively at b and b′. The points a and b will be the centering points of future drawings (fig 6 and after). The point 0, which positions a couple of columns, is the middle of segment 1,1′ and does not belong to the straight line AA′.

given, have been drawn following the method of C Huygens (1629–1695). But contrary to Huygens who considers that the arrow is given and chooses the first centering point, Mansart gave himself the two centering points (one of which is point a) and deduced the arrow from those[15] (Fig. 6). All plan, penetrations or outline arches are basket-handles with 5 centers, drawn according to the same method. Only the large arch which supports the partition wall and on which the two vaults rest, is a connection arch with 3 centers. Moreover, the global drawing is based on a template shape arch included in the vertical plan bH. The distance bH being unequal to the distance bK, the two arches are different. But whereas a regular distortion from bK to bH would have produced horizontal joints, Mansart chose two different connection curves which generate the bending of the intrados.

The order of the drawing and of the construction is therefore as follows:

— the periphery arches and the twin lunettes
— the large arch
— the small vault with the large entrance lunette
— the large vault

The archives also confirm this order.[16]

The rest of the drawing (Figs. 7 to 10) will be obtained by permanent back and forth between the horizontal projection and the beads, on this view of the different arches. As the Penetration arches for the vault and the lunettes have alreadsy been determined, the drawing of the large arch and the drawing of the template shape arch bH are deduced from them (and not the contrary). The five centering points a, a′, b, b′,c, enable one first of all to draw the curve (d-d′), tangential to the lunettes (Fig. 7). The center «a» is used for transporting the shape of arch I to the cross

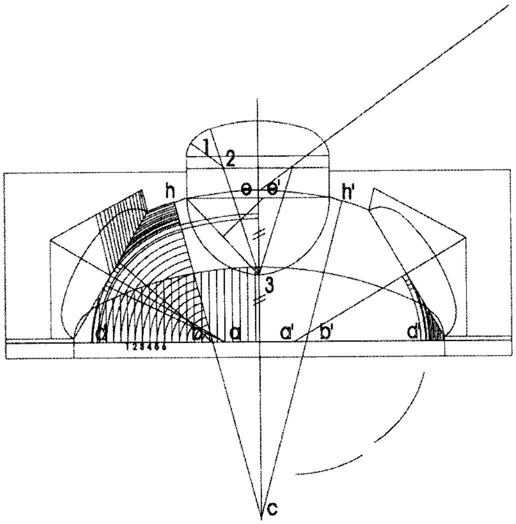


Figure 5
The plan view with its six centering points which will be used both for the horizontal projection and for the elevation of the arches

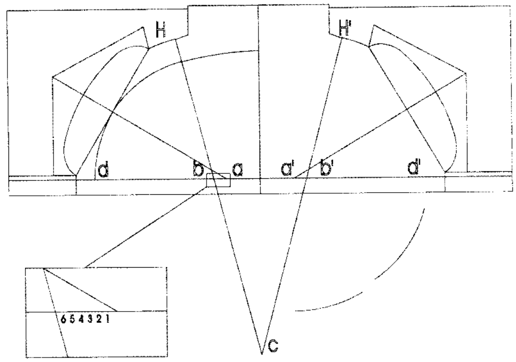


Figure 7
The curve (d-d′) created by the five centering points a, a′,b,b′, tangent to the lunettes, is a curve of rotation; the joint curves distort themselves into curves with three centers b,b′,c. For a five-centers-curve to evolve into a three-center-curve, the angular part which will disappear has to be fragmented into several centering points, in this case into 7 parts

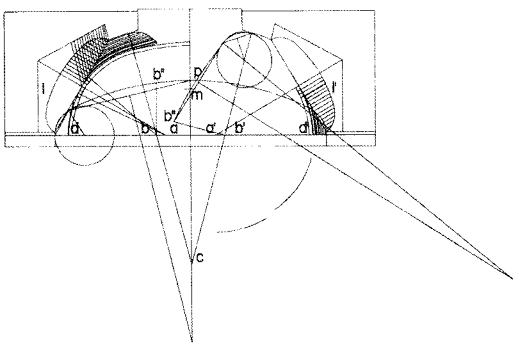


Figure 6
The centering points a and a′ are two of the centres of the basket-handles with 5 centres. The first centre (i) has been made by a transfer of dimensions with a compass, the last centering point is (a), the second centering point (j) is deduced from it

wall, the center «b» is used for transporting the shape of arch I to the template arch bH (Fig. 8). It is the distortion of the crosswall springing curves which confirms that the order which is followed is indeed the one which has been described. This arch is composed of two distortion curves and a connection arch which is the only one to be divided regularly into 45 modules. These modules will generate the disposition of the joints on the small and the large arch.

As the first element of the vault to be constructed, the works for the partition arch began on October 24th 1674; the key of this arch is located at the same level as the top of the large vault. The arch is already built, with an arrow whose length is one «canne» and one «pan» and a half. (243 cm, point p on fig 8) when the model is received at the beginning of November from Paris[17]. Mansart wanted the height of the arrow to be one « pan» and a half less (204,6cms, point m on Fig. 8). After a quick discussion, it was decided to leave the arch as it was and to carry on the works.[18]

The construction of the arch of the main entrance and of its penetration in the small oval vault, which had been drawn with ruler and compass, followed the same procedure described above (Figs. 9 and 10). It is important to note that the joint lines do not turn back on the penetration edge.

This fact shows that the respect of the module on the lunette, as well as the esthetic concern about the

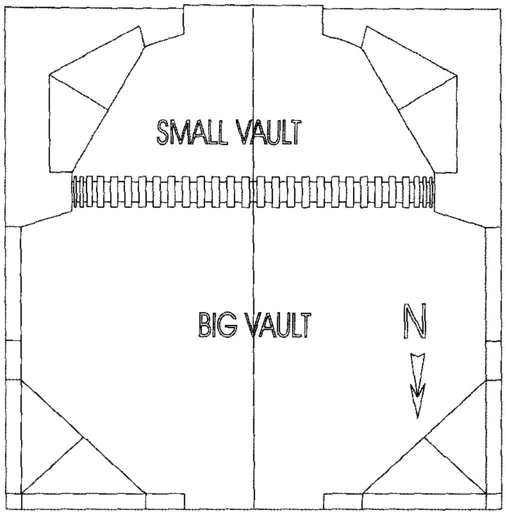


Figure 8
From the starting point of the arches (I-I′) to the curve (d-d′), the centers a,a′,b,b′ generate the distortion. It is the volume of the vault and not the volume of the lunettes which is defined. The connection, from the top of the distortion to the chosen height of the large arch, is done through the tangency to the nearer circle and the connection whose top is located at b″ is drawn the same way. On the large arch, the connection curve is divided into 45 modules. We can already begin to understand the magnitude of the difficulty. First of all, the modules are future arch stones burred on the segment crossing through aa′.
With plan view, the models represent the soffits and joint lines determined by their rotation according to their respective evolutive centering points (fig. 7) which therefore creates 8 irregular soffits. Secondly, the connection curves previously drawn not being identical, the soffits are not on the same level; there is a 5 cm difference for a rotation of 4 meters. Thirdly, the stones of the penetration arches have a soffit in the direction of the lunettes, the other one in the direction of the ray of the vault

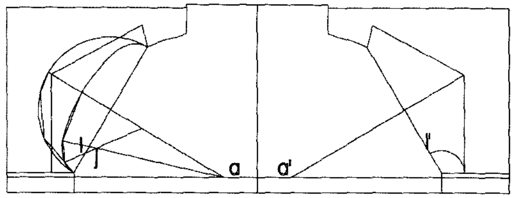


Figure 9
The construction of the arch of the main entrance and of the penetration of the small vault.
The penetration is drawn from the two centering point e and e′. The soffits, in plan view, starting from [c-h], [c-h′] extended by the center c and made to encounter the soffits of the lunette. In the aim of having a module almost regular on the penetration surface and constrained by the forms and penetrations drawn using ruler and compass, the draughtsman has chosen to skip some rows. two lunettes rows penetrate twice on the row into one vault row. Along the same joint, approximately 2 meters, the level difference is 7 cm maximum

penetration curve, outweighed the definition of the volume. This was therefore apparently not defined.

The compliance of this drawing with the survey is also proof of the previous hypothesis.

The stereotomy and its methods

A number of different cutting techniques were certainly used for the construction of this vault.

The first two rows, which are part of the outside wall (and which therefore would have been construcred first) are corbelled and therefore have been square cut. The two semidomes of the large vault, which follow surfaces of revolution, were probably cut by panel according to the truncated cones method which was very classic at the time. However, on the small vault, the semidomes are not regular as mentioned earlier.

It is likely that the arch stones of the 6 rows of evolution were square cut.

It is also probable that, in view of the good implementation of the joint curves, the vault was constructed on a «veau», the curve of an arch with a plastered surface where the joint curves were reported.

However, as far as the arch stones of the lunettes are concerned, a square cut seems impossible for the following reasons:

— the archives mention the fact that Mansart *« baillera le trait à celui qui le conduira»* (will teach to whoever carries out the work) and Peytret spent approximately one month to receive *« les instructions modèles et panneaux pour lesdits bâtiment et voûtes»*[19] (the model instructions and panels for the building and

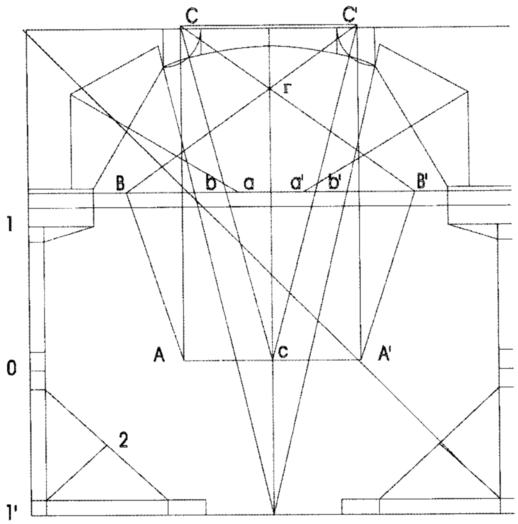


Figure 10
We can observe that the platband is treated separately from the vault drawing: the centering point is located at a distance of three alf span under the springing of the arch. Although this point is located at approximately 10 cm from point 3, the draughtsman did not get them mixed up

Example of a drawing on a twin lunette

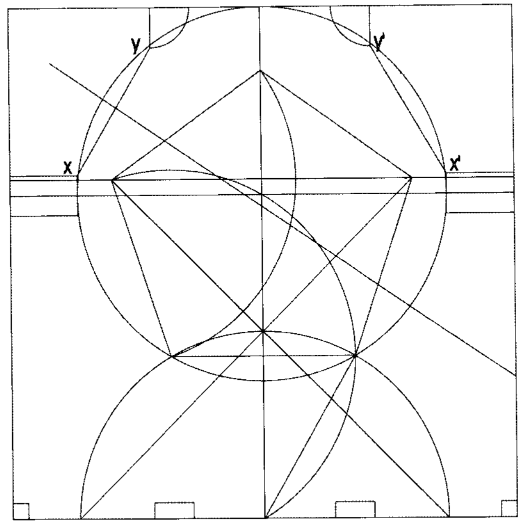


Figure 11
Head angles
The lunette is defined by the arches xy and zt whose elevations are turned down on the plan. The arch xy projects itself into frontal x′y′. Any soffit is given through its plan 1–2–3–4. In terms of carpentry, the frontal plan is «la herse» and the horizontal plan is «le plan». The segment [3c] is a borrowed chevron, that is a construction line which is not the outline of the piece but a marker for manufacturing. It is parallel to the frontal plan. The straight line 6′–4′ goes through one of the centers of arch zt. It enables the definition of the joint plan of the arch stone: it is enough to consider a parallel line 3′–5′ through the frontal plan 3c . In the same way, we can define the other side of the joint 8′–2′–1′–7′. The angles which are necessary for the cutting appear on the frontal projection and will be transfered through the bevel square.

vaults). It is sure that Peytret did not need a month of apprenticeship with the master in order to use the square cut technique.

— a model was made out of wood for the large lunette, thereby also suggesting the use of a more complex method than the square cut.
— we know that the square cut was not the method advocated by the Academy and Mansart, less than any other, would have pushed for its use.
— and last but not least, square cut consumes a huge quantity of stone at the level of the reins of the vault, especially with the curved penetrations and for a vault of at least 50 cm thick.

The square cut is therefore excluded for the lunettes. But a traditional cutting by panel does not seem appropriate either. Indeed all the intrados are warped, which eliminates the (numerous) drawings out of a flat intrados panel.

Moreover, the panel method requires different panels for each arch stone, given the irregularity of the arch stones on a same row and in between rows. This time consuming drawing does not seem to be compatible with the swiftness of the work nor with the archives which state a limited number of patterns for the panels.[20]

This is the reason why we think that the «méthode à la sauterelle»(bevel square method) cutting method was used. Used in carpentry, this was a quick method for cutting arch stones, using simple angle transfers and without the need for drawing all the panels. The principle is as follows: to determine a polyhedron with 6 sides, it is necessary, for each crown, to know the angles of the edges which converge to it. Here one of the sides is warped but the knowledge of those angles is sufficient for the cutting. Starting from one of the joint plans, two segments of straight lines of the intrados (or «soffit») —non coplanar segments— will enable the «adjustment», during the cutting, of the intrados surface. Figures 11, 12, and 13 show respectively the drawing of the angles needed for the construction.

For the penetration arch stones, the X plan is used (Figure 12) on which the panel of the horizontal projection is applied. The penetration can be square cut since the radial joints of the small vault are vertical.

Conclusion

«We must hear that architecture will come out soon, as we say, from the trowel and the rubbish of bad interest, and that working only for glory, it will create works which will make most of the works created in the past unbearable to be seen».[21] The vault of the City of Hall of Arles is certainly an illustration of this quotation from Blondel. «Working only for glory», Mansart did not ask for any money for his own work and it was on his initiative that the City of Arles paid the architect.[22] As for the « trowel architecture», the vault surely works on it. We perceive the penetrations and the geometrical volumes to be regular whereas there is a profusion of warped surfaces. Mansart's constructive willingness is based on reversing the usual order of choices. He first decided on the drawing of the penetration edges which are to the eyes more pregnant than the shape of the volume themselves. We could conclude that his esthetic choices took priority over his constructive choices. But the strength of Mansart in this work was to offer simultaneously a cutting method which would allow the execution.

He therefore became the best representative of the young Architecture Royal Academy by breaking away from the usual models, linking technique innovation and formal imagination.[23]

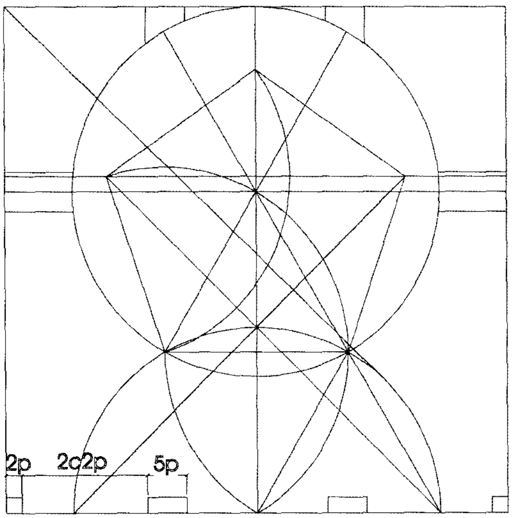


Figure 12
Joint angles
One can burr down on the horizontal plan the joint panel (6′–4′–3′– 5′) and deduct from it the joint angles.
On the figure, the horizontal plan X is also mentioned; the distance report 3′–x2 and 4'–x1 allows to find the X plan on the stone and to square cut the penetration.

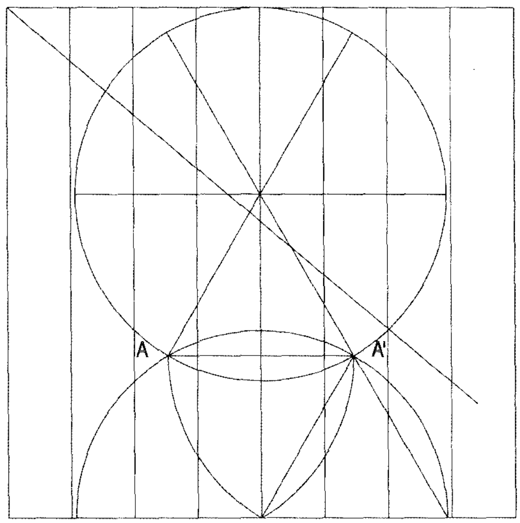


Figure 13
Soffit angles.
One can burr down around the horizontal hinge (for instance the one which goes through point 3) the plan defined by the two straight lines 3–4 and 3–c to obtain the real size of this angle. In the same way, we can determine the angle for the two straight lines 3–4 and 2–4 thanks to a hinge going by 4. A distance report on segments 3–c and 2–4 determine the second edge of the soffit.

Constructed	Bridge	Location	Span l of the largest arch [m]	Rise h [m]	Rise ratio h/l 1 over
595–605	Zhaozhou Brücke (An Ji, Anji)	Provinz Hebei	37,02	7,23	5,12
1341–1345	Ponte Vecchio	Florenz	30	4,4	6,82
1499–1500	Ponte degli Alidosi	Castel del Rio	42,17	19	2,22
1556–1566	Stari Most	Mostar	28,69	12,02	2,39
1567–1569	Ponte Santa Trinita	Florenz	32	4,57	7,00
1588–1592	Ponte Rialto	Venedig	28,8	6,4	4,50
1595–1598	Fleischbrücke	Nürnberg	27	4,2	6,43

Rise-span ratios. Data from different sources vary, see also http://www.structurae.de

Notes

1. Pérouse DeMontclos, Jean-Marie (1983).
2. Boyer, Jean (1969).
3. Boyer, op. cit., p. 25.
4. The lines to draw the working drawing, the number of panels for cutting, the lead for the columns, etc. are clearly mentioned.
5. Boyer, Jean. Op. cit.
6. Fassin Fund, (ms2412).
7. Cf. in particular Pérouse de Montclos, Jean-Marie, op. cit.
8. According to Fassin , ms 2411, according to the index of ancient measurement units of the City of Arles dating from 1897, one canne d'Arles = 204.72 cm. In the ms 2412, « A qui revient l'honneur . . . », one canne d'Arles = 204.40 cm, p. 92.
9. Cf. archives in Jean Boyer, op. cit, p. 28. The current concrete ground diminishes slightly (approx. 1 cm) this dimension.
10. For instance the 128 cm-wide spring-mattresses correspond to 5 pans (5 pans = 127.89 cm), or the width of the 51,10 cm columns corresponds to 2 pans (2 pans = 51.15 cm).
11. Association Ouvrière des Compagnons du Devoir du Tour de France.
12. The stone was provided by Les Carrières de Provence at Fontvieille. Study time 1000h, Creation time 800h.
13. For this drawing, see : Peiffer, Jeanne (1995), pp. 208 and 369.
14. In order to facilitate the reading of the diagrams, the construction lines presented, to start with, as full lines will then be dotted and then eliminated in further figures if no longer needed.
15. *Encyclopédie des métiers, La maçonnerie et la taille de pierre*, Tome 3, fascicule 2, p. 61.
16. Jean Boyer, op. cit, p. 27.
17. Executed by the wood worker Fontvieille, according to Boyer, Jean, op. cit.
18. Debate related in the deliberations on November 3rd 1674, Boyer, Jean, op. cit. p. 30.
19. Jean Boyer, op. cit, p. 25 et 27.
20. 11 patterns for the whole vault . . .
21. Blondel (1673).
22. His payment was £500; his annual salary at the time was £6500, whereas Peytret was paid £135 for three months of wages.
23. Regarding the use of geometric knowledge in the setting up of the architect trade, see Christele Assegond.(2002).

Reference list

AOCDTF. *Encyclopédie des métiers, La maçonnerie et la taille de pierre*, 3 : fascicule 2.

Assegond, Christele 2002. *Socialisation du savoir, socialisation du regard et d'usages techniques et sociaux de la géométrie et de la stéréotomie chez les Compagnons tailleur de pierre.* Thèse de sociologie, Université François Rabelais. Tours.

Blondel 1673. *Architecture française des bâtiements particuliers.* Paris.

Boyer, Jean 1969. Jules Hardouin-Mansart et l'hôtel de ville d'Arles. *La gazette des Beaux-Arts*, 74 : 1–32.

Fassin, Emile. manuscrit 2411, Arles Media Library s.

Fassin, Emile. *A qui revient l'honneur d'avoir édifié notre hôtel de ville.* manuscrit 2412, Arles Media Library s

Peiffer, Jeanne 1995. Albrecht Dürer, Géométrie. Paris: Seuil.

Pérouse DeMontclos, Jean-Marie 1983. La voûte de l'hôtel de ville d'Arles est-elle le produit de la tradition locale ou une importation parisienne, *Travaux et colloque de l'institut d'art*, Publications de l'Université de Provence, 123–126.