Late XVII\textsuperscript{th} century practice of stereotomy prior to the establishment of Engineering Schools in France\textsuperscript{1}

Randy S. Swanson

This paper explores the practice of French stereotomy in the late XVII\textsuperscript{th} century through the field study of the l’Observatoire de Paris, (1667–1672), designed by Dr. Claude Perrault (1613–88). This effort seeks to present modest evidence to the base line of performance in the practice of stereotomy prior to the establishment of engineering schools in France.\textsuperscript{2} The l’Observatoire presents a unique case because substantial changes to the design of the Main Salon and Grand Escalier occurred after the construction was begun. It is suggested here that the detailed response to these changes offers a view of the empirical knowledge and capabilities that existed in that era. On-site research in Paris involving both field and archival efforts took place during the summers of 1997 and 1999.\textsuperscript{3} The examination revealed a construction that was rationally systematized, generally of high precision, and employed a consistent patterning of joint-work to provide a significant contribution to the architectural effect of the project.

The establishment of the l’Observatoire represents a turning point for the development of modern science and this importance was appreciated by the members of the Academy from the outset. The l’Observatoire is a three story facility placed into the northern face of a small hillside that today, lies just to the south of the heart of Paris, Figure 1. The original intention of Jean Baptiste Colbert (1619–1683) Intendant of France, was to have a facility to house the core of all scientific activities in France. The new facility was expected to be the center for astronomical observations, provide a chemistry laboratory, permit the display of new inventions, mechanical models and machines, provide laboratories for anatomical dissections, as well as house the royal collections of natural history objects.\textsuperscript{4} Permanent construction was employed to insure a consistent reference point for the measurement of astrological events over the next several centuries and to fix the location of the French prime meridian from which the most exacting measurements were to be made of Paris, France, and the earth.\textsuperscript{5}

The pursuit of astronomy and geography became
the primary activities in this facility shortly after the arrival of Head Astronomer, M. Cassini (1625–1712), in the spring of 1669. Upon review of the design, Cassini argued before Louis XIV, for a list of changes to insure that the l'Observatoire would serve as a perfect instrument. These included, the removal of a northern roof-access tower to have the night sky observable from any point of the roof; to change the octagonal towers to rectangular forms to ease observations; to insert a vertical solar observation port cut directly through the work that extended far below the foundations; the elimination of all reference to astrological symbols as ornamentation on the facade since they were non-scientific; and, to enlarge the main salon on the upper floor to accommodate academy meetings (Wolf 1902, 1–18). Dr. Perrault argued against the changes claiming the design was already perfect. Nearly all the changes requested were accommodated however. Of particular importance to this paper was the demand for a larger salon and its impact, Figure 2. The resulting «Cassini Salon» was a 15.5 meter wide clear span segmented vault replacing two intersecting cloistered vaults of 6.9 meters each. The increase of the salon also produced a fifty percent reduction of the area for a grand stair hall and a 90 degree shift of the stair. Climbing the same height in a reduced area required an increase in the slope of riser and tread and a corresponding need to reduce the width of the stairs resulting in a wonderful stereometric achievement of a cantilevered elliptically vaulted semi-helical stairwell.

**GENERAL CONSTRUCTION**

Before examining the grand escalier, it may be helpful to address the general state of the building construction. The facility is completely of stone. The work was supervised by Antoine Foucault of Saint-Marie and the quality of finish and jointing is consistently superior (Picon 1988, 212). Several construction strategies are revealed from a careful examination of the exterior northeast and south elevations. The walling is of coursed ashler in a running bond with a constant height within each course. Measurement of the wall coursing at grade level on the northeast elevation revealed that the first course above the watertable is 55.5 cm in height with all other coursing above this alternating between 44 and 41 cm. The exception to this is the course which contains the arch spring-line for the window apertures that has a height of 55 cm and corresponds to the spring-line of the interior vault. Coursing above this point returns to the smaller dimension of 44 and 41 cm. This technique where increased course heights are strategically located in the walling, was observed at the entry level of the southern elevation as well, where the common coursing height was modestly reduced (first floor of construction) and varies between 40 and 42 cm, with the more substantial coursing measuring 52 cm in height. The increased height of the coursing appears intentionally placed to provide greater resistance to the thrust of the interior vaults as well as stabilize the plane of the wall to restrain the thrust of the aperture arches.
At all apertures a round stepped arch construction can be observed. The purpose was to insure a maximum stability for the arch and wall. The method was more expensive than others because more surfaces had to be cut, but doing so prevented the slippage of stones over time. The transition of the arched window opening to the interior vault, as handled on the first floor, results in an intersection between two cylindrical surfaces and a visibly skewed ellipse. The masonry jointing in the soffit of the window vault demonstrates that the exterior and the interior stonework flow directly from one to the other. At the top of the salon vault is a keystone that interlocks the two salon vaults. Its surface is shaped as a «T», following the pattern of the vaults in plan. This shape, traditional to gothic masonry design and construction, is the geometrical resultant of dividing the vault surface with a series of radial lines to define the voussoirs for construction. An examination of the earliest detailed sectional drawing (dates from 1692+/-), reflects the heavy masonry construction of substantial wall thickness to restrain the vaults proposed for the facility. What is not reflected is that each room varies modestly so that it’s likely that a vault would have been laid out directly on a newly constructed floor or wall to find the final dimensions. The result is remarkably harmonious effect of construction and a fluidity of space. The fundamental construction strategies of massed simple coursed construction,7 interlocking prisms, and a continuity of construction geometry from exterior to interior constitutes the basis of the observatory construction.8

GRAND ESCALIER ANALYSIS:

Perrault clearly did not surrender his integrity under the impact of the changes forced upon his design, as the choice to replace the original semi-circular half-turn stair, was an escalier a jour ou vis suspendu (a suspended daylit elliptical stair), see Figure 3. This type of stair has been credited to Girard Desargues (1591–1662), the geometer, inventor, and architect, where it was installed at the l’Hotel de Ville de Lyon, in 1646 (Chaboud 1996). This staircase appeared as a seamless plastic form defying gravity, an effect of growing fascination since Philibert de l’Orme invented the trompe de Montpellier at the Hotel Bullioud in 1536 (Pottie 1996, 92–103). Desargues’ influence seems limited however since his own projective methods appeared too complex and the illustrations of his work failed to provide convincing details of interlocking masonry construction.10

To convey the impact of this decision, Figure 4 presents two schematic sectional views of the semi-helicoidal stone stair hall. The total height of the stair-hall from the floor of the side entry to the rooftop terrace is 25.6 meters. This analysis is confined to the elements of the first floor vault-work at 4.96 meter elevation, and which occurs directly in line with the entry from the Grand Terrace on the south. A dimensional and unit/design analysis of the second floor suspended vaults of the stair-hall has been published elsewhere (Swanson 2002, 273–251). The piercing of the upper vault to permit the passage to the roof terrace offers an equally fascinating condition to examine, but presents a special case.
Figure 5, describes in parital plan and section the measured profile of the suspended horizontal groin vault of the landing and the inclined suspended vault of the rear stairwell. (To simplify further descriptions, the term 'suspended' will be understood when any vault of the stairwell is discussed.) The recorded field dimensions for both vaults are found in Tables 1 & 2. The profile of the vaults from the ground, first and second floors remain constant, given the minor variations of having been worked by hand. The concealed supporting structure of the vault presented the most curious portion of the problem overall. An insight as to how this may be constructed is provided by a close examination of the soffit for the interlocking voussoirs in the arched window openings. The internal jointing pattern and vertical dimensions of the voussoirs in section are an abstraction by the author based upon the joint spacing in this portion of the stair-hall and the graphically determined thickness of the vault in section. The solution presented here, is suggested by visualizing a window arch as a section through the cantilever stairwell, which would result in producing interlocking prisms whose center’s of gravity would fall behind the edge of the stone beneath it, thereby permitting each stone to be put in place without the workman’s fear that it would fall from the vault. Of course, there is the added complexity that the stairwell is inclined and curving in three dimensions. Such an approach however is not convincingly represented until Frezier’s work nearly seventy years later (Frezier 1737, IV), or with certainty in the work of Rondolet. (Rondolet 1817, IV: Pl. LXIV). The quality of construction that this demands certainly falls within the exponential shift of increased precision that is being experienced in science in general, and particularly in surveying and astronomy.

It may be helpful to consider the face of the stringer conceptually as a soffit of an inclined splayed arch ring that has been rotated to a horizontal position to explain the stability of the inner ring of voussoirs 7, 6, and 5. That these prisms are acting in true arch form is suggested by the joint angle of each prism which is perpendicular to the angle of inclination of the vault, and not vertical to the horizon, which would require the insertion of iron cramps between the
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Late XVIIth century practice of stereotomy

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prisms (Frezier 1737, III, 306-07). While this is of modest conceptual help in understanding how the voussoirs of the stringer may work, it does not address the process of assembly since the complex warped stringer prism at mid-point can not act as a keystone.

It is suggested here that the assembly of the inclined vault probably proceeded in the following manner. Voussoirs 1–4, were put in place as the wailing rose with the benefit of offering a narrow passage from level to level. The soffit joint pattern also suggests that these prisms were layed-up in a concentric ring in stair-step fashion. The landing and supporting horizontal vaulting could then put in place when that level of construction was reached. The remaining inclined vaulting, voussoirs 5–7, could then be cut and assembled with the certainty given the location of the lower and upper groined thrust blocks being in place.

In this approach, the keystone of the stringer would be the uppermost inclined block that abuts the upper groined thrust block since it would have been the last stone to be put in place. The upper groined thrust block ties constitutes the intersection of the three vaults and was probably too complex a prism to have been fitted into place last, see Figure 6. Support of this approach is provided by the presence of a square faced infill block at the rear wall of the stairwell, that coincides with the elevation of the landing floor, and probably fills a socket used to hold the centering for the completion of the vault assembly.

As the wailing and vault merge into a formal system, a special concern was anticipated at the window aperture of the stairwell. At this point the continuity of that system was interrupted and required a special response to insure stability. At the window head, a transfer and a keystone prism —double the standard prism height, were put in place. The interlocking form of the keystone to insure a smooth transmission of upper vault forces can be viewed in Figure 7, where the joint patterns have been outlined. This is the only visible alteration of prism size within the design and from the minor fissures that have appeared directly above this point, where another window aperture for the second floor is located, the
concern and response seems justified. For the sake of clarity, the voussoirs of the vault are also numbered in this figure, and the lower groined thrust block for the second floor vaulting is also outlined.

This notion of providing interlocking construction at points of concern can also be observed where the stair treads meet the sidewall. As the stairs run down from each landing, the treads interlock with the sidewall throughout the semi-circular rear wall to insure that all the surface work would remain fixed in place. The wall appears to have been cut after having been put in place since the joint dimension is substantially larger than elsewhere. In this manner the treads would have been placed last in the construction and although seemingly minor, and perhaps even an afterthought, the detail helps to reinforce that the method of assembly well thought-through.

The empirical and informed intuitive nature of the constructive/structural knowledge demonstrated in the stairwell is considerable and could be argued as systemic, where all the prisms rely upon one another to permit the successful resolution of the form. And it is not just in the stairwell where this was found, but also in the relationship between the interior vaults and the exterior wall construction. In this manner, the entire form, and by necessity the conceptual approach, has an organic sensibility that could be thought of as advanced Gothic design & construction.

The sense of craft, the fitting and finish of the stonework, speaks for itself. No where is this quality more evident than in the rear mid-point stringer prism with a complex warped surface. It is not just a geometric achievement but creates the impression of a sculptural effect throughout. The considerable
amount of stone that had to be removed to form this prism alone should not be lost on us. The sizing of this prism, and hence the sizing of the entire stairwell system presents a turning point for this discussion that must (somehow) address the presence of rules governing the execution of the project, or theoretical knowledge (Picon 1992, 11).

Two elements will be explored in the stair-hall, first the size of the stringer and then the inflection point at the intersection of the spiral and inclined arches. In this stair system three different cloistered vault types are connected, a half spiral, an inclined, and horizontal vaults. The first floor landing width is 1.6m and the depth of the landing face is 80 cm, presenting the simple proportion of 2 to 1. At the inclined portion of the stringer, the dimension across the face of the stringer perpendicular to the angle of inclination is 84.5 cm and the width of the stair is 1.96 m. (see, Figure 5). The depth of the face is approximately equal to the inside radius of the stair in plan, (166 cm diameter/2 = 83 cm). When considered in section, minimizing the face dimension of voussoir #7 would seem to have been important. However, the elliptical profile of the vault soffit does not seem to significantly minimize the weight of the stairs as much as it provides a daring sense of suspension. The elliptical section could have been generated from joining the arcs of two circles, each based upon a stairwell dimension in plan, suggesting that the form in section, was ultimately derived using simple methods of geometrical proportioning. It cannot be determined which ratio may have been the determining factor for the dimension of the stair structure, where the platform face thickness is 1/2 the landing width or where the stringer face depth is 1/2 the radius of the inside curve of the stair. Both together however, allow a smooth transition to occur between the face of the inclined vault and the cloistered vault of the stairwell. At the transition point between the rear spiral and inclined vaults an inflection appears. This is noticeable only from a specific angle Figure 8. This inflection has been graphically reproduced when the geometry of the stair is laid out on an incremental basis of plotting the rise over run for each step from landing to landing. Whether drawn by hand or by computer the inflection arises with this approach. It is suggested then that this was the method of layout for this stairwell and presents the limit of geometrical knowledge being brought to bear upon this general problem. This type of problem may have been observable with geometrical methods of Frezier, or Rondlet, and then possibly resolved.

Cassini Salon vault analysis: (1672-1777)

The original design by Perrault for the main floor salon space is indicated in Figure 2. The plan essentially mirrored the first floor layout, having two intersecting cloistered vaults with a width of roughly 6.9 meters each. Replacing these vaults with a wider vault of 15.5 meters would accommodate the existing foundations, the spacing of the planned south elevation window piers, and the necessity to maintain the plan symmetry, which was an accepted strategy to assure structural stability. The intersection of the new vault with the south wall would have presented a serious problem to the elevation design if it remained a cloister vault. To retain the exterior elevation and the height of the building, a segmented barrel vault construction was required. This approach minimized the connection between the vault and the south wall. The remaining space in plan was covered by two narrower barrel vaults placed on each side of the southern portion of the main vault. This solution however, shifted the weight of the vault to the interior walls, increased the weight of the vaulting, reduced
the area of bearing by one third, and resulted in a loss to the constructive bond between wall and vault achieved in the rest of the design. Given these conditions, it is reasonable to think that the objective for the vault design was to keep its weight to a minimum by limiting its thickness so as to reduce the thrust on the abutments.

The first published drawings for the l’Observatoire appear in Claude Perrault’s Vitruvius of 1673. The illustrations were prepared by LeClerc and present plan, section and elevations. While no construction is indicated in section, the suggested vault thickness is approximately 1.8m (5 ft. 11 inches). Two undated drawings of the Cassini Salon vault, longitudinal section H79534, and transverse section H79536, indicate stone construction details and fissures suggesting as-built accuracy. At the crown of the vault the construction is shown in both drawings as being comprised of a single voussoir in thickness covered by a thin plane of masonry to provide weather protection. The depth of the key stone, averaged from these two drawings and arrived at through interpolation by using field dimensions, is estimated as being 1.02 m (3 ft. 4 inches) in depth—a little more than half the depth suggest in Perrault’s illustrations. Why a difference of this magnitude exists remains to be learned. The final dimension appears to have been close to the following, a one meter deep arch ring, with voussoirs of 4 degrees of thickness, for a desired clear span of fifteen meters. Using a late nineteenth century approach based upon empirical methods, an arch ring of 0.65m (2.12ft) would have been sufficient for cut stone construction. Depending on the accuracy of these drawings, this would mean that the depth is more than sufficient.

In the Cassini Salon the radius of the vault near the crown was made as large as necessary to clear the flanking windows of the south elevation. The vault could not have had a much greater rise without also causing the re-design of the south elevation as well. At this point the vault thickness appears to have been a result of the availability of space as defined by the limits of the other elements of the design. The thickness and depth of the voussoirs shown are more or less consistent throughout the section, regardless of the dimension of the span, so no simple proportional relationship between span, radius, and thickness seems immediately apparent. A more practical approach is to examine the relationship between the soffit (exposed face) of the keystone and its depth. This relationship of the height to width when examined across the voussoirs as shown in H79536 varies, but the extreme heights—both low and high, are shown as being 1.6 to 2.0 times the width of the face. Clearly the quality of construction played the crucial role in the stability of masonry vault construction. How the actual thickness was determined remains to be learned for this clearly was not an easy problem to resolve. As has been shown elsewhere, the concern to determine vault thrust was the focus of analytical attention from the 1690’s through the end of the eighteenth century (Heyman 1996, 116–18).

CONCLUSIONS:

At the highly skilled end of the craft of building within the masonry tradition there is very little evidence that these masters had more to rely upon than a hard-won empirical knowledge and an informed intuition. And yet, in the presence of the work, there is a demonstrated sense of understanding, of a highly rationalized logic, that runs to the core of the material, to the form it was given, to the intersection and interdependence of elements, and the flow of space. It is difficult to argue in the presence of this form, or the shaping of the prisms, that analysis did not occur here.

The l’Observatoire de Paris exemplifies a coherence of design, of structural conception and a system of construction. Neither admiration nor fascination for this work has weakened its grip on this
author, or for any first class 17th century French masonry construction. Antoine Picon clearly responds to the Observatoire, and the stairwell in particular, as a remarkable product of the collaboration between its architect Claude Perrault and the master masons (Picon 1988, 212–19). These sentiments are said to be broadly shared by those who are knowledgeable when shown this work.17

Is it possible that the principals inherent with the conceptualization and resolution of the l'Observatoire demonstrate an attitude that lies at the core of design in all admirable technological efforts? Perhaps the l'Observatoire could have been modestly refined, to be lighter, stronger, more amenable, or socially graceful. It is difficult to conceive however, that a significant improvement could be achieved without a significant change. In this sense, the design and fabric constitutes a seminal system that was the product of a special kind of thinking or attitude that is still prized today. What does this mean? The study of stereotomy may have done more than was originally expected in the XVIIIth century schools of engineering, beyond the development of a refined sense of spatial or even constructive logic, but to help convey an attitude as well.

The l'Observatoire de Paris was one of a handful of projects to achieve this degree of sophistication in the latter part of the XVIIth century. That this class of work might be thought of as seminal would mean that they contributed to the dispersion of an attitude as to how work should be conceptualized and conducted. This attitude goes beyond the general notion of excellence, and perhaps comes closer to a sense of teleological participation of all the elements that contribute to the making of a system. This can be observed in other scales of endeavor, whether for mechanical toys at French court, the precision clock, other buildings, or even in the massing of one's armies. In the wonderful work of Antoine Picon, there is a clear analysis of the transformation of how thinking changed from a classical to analytical rationality during the XVIIIth century in France (Picon 1992, Chapters 2 and 5). Because the l'Observatoire still commands admiration however, there appears to be a significant element of continuity from the classical or Vitruvian period of rationality that remains at the core of our own ideals in an era of analytical rationality.

NOTES

1. This research was supported by the University of North Carolina Charlotte.
2. Ecole des Ponts et Chaussées 1747, based upon the introduction of scholastic training with the customary approach of apprenticeship based upon on the job training. (Sakarovitch 1995, 205–27). The Académie royale d'architecture (1671) began instruction to apprentice architects in «applied mechanics, hydraulics, stone cutting, and civil and military engineering» within a few years of its founding. This institution is credited as «the first higher technical school in France.» (Arzt 1966, 29–34), (Picon, 1992, Ch.1).
3. I would like to thank Madame Danielle Michoud, le Service des Relations Extérieures of the Observatoire de Paris, and Madame Claudine Laurente, Astronomer, also of the Observatoire de Paris, as well as the Office of Herve Baptiste, Architect en chef des Monuments historiques, Paris, for their generous gift of time and interest.
4. Cassini IV, 1810, Ch. 1. See also, Hahn 1971, Chapter I.
5. The lifetime's work of Tycho Brahe, a record of thousands of star positions in the night sky on the island of Hvene, was proving to be highly resistant to conversion to Parisian coordinates for confirmation of their accuracy or further practical utility. Johannes Kepler's conjecture that Mars moved in an elliptical orbit (1610) based upon Brahe's data, could not be verified conclusively and continued to be hotly debated. It was reluctantly decided among Academy members that recording astronomical data would have to begin from scratch (1673).
6. The south facade is a generous two stories in height and the general siting can be understood from the site and sectional drawings. The unadorned north facade presents a stern attitude due in part, to the vertical scale of the massing. The south face however, appears very well proportioned and approachable.
7. A corresponding detail from the frontispiece of Perrault's Histoire des Animaux prepared by Sebastien Leclerc, also suggests the construction proceeded layer by layer, evenly throughout construction. (Sebastien Leclerc. «Louis XIV being shown round the Academy of Science by Colbert», 1671).
8. The methods of construction used here could have suited a generally unskilled work force with a minimum number of skilled masons (3 or 4), on site at most times. The methods would have permitted one master mason to have been in control of the work without being overwhelmed and yet maintain high standards of precision through the use of templates or jigs, simplifying the ordering of materials from the quarry, and insuring a consistency of effect from the exterior to
the interior. These methods would have allowed the workers to address tasks systematically, being confronted by only one or two tasks of construction at a time. The tasks could be as repetitious as the stone from the quarry would permit. The implication is that the master mason and his principal assistants had to have a good understanding of the total project for this to occur, which means that careful drawings for the general construction would have had to have been prepared.

9. His mathematical work initiated a century of development on conic sections among French savants. His method of projective geometry was rejected by the professors at the Academie Royale and masons alike, for different reasons, despite the concerted efforts of Abraham Bose. (Schneider 1983).

10. Desargues countered that he was not a craftsman and that his intention was to improve the methods of geometric projection and not necessarily improve the craft of construction. (Schneider 1983. Ch. II).

11. The traditional methods for cutting stonework with warped surfaces and compound curvatures appear embarrassingly simple when described in 19th century texts. A method of «parallel rules» for cutting plane surfaces: Two drafts or channels are cut as close as possible to the same plane into the rough surface of a stone. Into each grove is placed a wooden rule of constant dimension so that its lower and upper edges are parallel to one another. A level is placed across both rules and sighted across the length of each to insure that the drafts are perfectly level with one another. Two additional drafts are cut to the same plane and then if no additional drafts are needed, the remaining stone between the drafts can be removed to produce a plane surface. To cut a warped surface, a method of «twisting rules» was employed. In this approach one rule has a constant dimension along its length while the other starts out at the same dimension at one end but then increases along its length. Again, drafts are cut into a coarse stone face and the rules inserted. This time one draft will have an increase of depth along its length so that the exposed edge of each rule will be in plane with one another and confirmed by testing with a level. To insure that the warping of a surface is constant from stone to stone through a course or across several courses, the drafts must be sunk and rules maintained at a constant distance apart from one another as applied from stone to stone. This distance was maintained by simply boring two holes through each rule and stringing a knotted a piece of twine through each to maintain a constant distance between each rule where ever they were applied. A stone with compound curvatures would have several rules applied to it during cutting. The trick is determining the angle at which the twisting rule to be cut at and the distance at which the rules are to be kept apart. However, this problem is not overly difficult when the problem is being solved at full scale either graphically or on site. These techniques were probably employed across each surface of the stones, the facings, sides and backing as needed. (French, 1902, 26–34).

12. This approach of producing an inclined helical prism with vertical joints requiring cramps for support can be found in Frezier (1980) Figure 193, Plate 106, page 306–7.

13. Dimensions of the vaults in the stairwell were determined with the use of a pulse laser ranger finder, on site, during June of 1999. The vault dimensions show the curvature to be an ellipse whose arc falls outside the dimensional of the stairwell. The ellipse may have been generated by using two circles placed with their arcs tangent to the spring line of the vault, one whose diameter is 1/2 the width of the stair and the other whose diameter is the full width of the stair, which fall upon most of the points of the arc of the vault. The form was more likely the result of structural necessity than formal desire, as the suspended edge of the stairwell would have been kept as narrow and therefore as light a weight as possible. These lines could have been drawn within the limits of the stairwell construction, probably on the landings. This form has the pleasant effect of capturing and reflecting daylight better than a singular circular arc form would have permitted.

14. A recent investigation by Robin Evans of Philbert Delorme’s 1550 method of preparing traits suggests that a graphic method may have existed that would have had sufficient accuracy to permit an approximate dimension of prisms to have been found, but was incapable of preparing descriptive forms. For a description of Philbert Delorme’s method of producing traits, see, Evans 1995, ch 5). On the advise of Mr. A. W. French, a late 19th century expert in stereotomy; if the form is too difficult to be defined by calculation then the approximate solution must be arrived at by drawing alone —and the accuracy of drawing alone was not sufficient for good masonry construction. No finish dimensions should be taken from the projections since the reduced scale of the drawings would not allow a sufficient accuracy nor account for the changes that creep into a project due to the necessities of construction. The final responsibility for accuracy of construction must be the stonemason’s, who is expected to make full scale working drawings and then find the finish dimension of each prism in situ. (French 1911, Ch. 2).

15. Archival drawings listed in Bibliotheque Nationale, film Va 3041/1, longitudinal section H79534, and transverse section H79536. H79536 may be viewed in Picon, 1988, ill. 179, page 215.

16. Trautwine’s formula is used here since it is empirically
Late XVIIth century practice of stereotomy based. With an interpolated dimension of the upper vault radius of 10.38 m (34.05'), and 7.75 m (25.42') for one half the vault span suggests that the keystone depth for cut stone construction should be about 0.65 m and for first class late 19th construction, the depth could be as little as 0.61 m (2'). Snelling, 1952, 319-329.

17. In conversation with Madame Claudine Laurente, Astronomer, and Observatoire Historian who has provided tours to numerous architectural groups through the building.

REFERENCE LIST


Schneider, Mark. 1983. *Girard Desargues, the Architectural and Perspective Geometry: A Study in the Rationalization of Figure*. Unpublished dissertation: Blacksburg, VPI and State University.

