The Windows of Perrault's Observatory in Paris (1667-1683): The Legacy of a proto-modern Architectural Inventor.

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Introduction:

When, during the reign of Louis XVI, the famous Royal Observatory in Paris - built a century earlier after the designs of the scientist/architect, Claude Perrault (1613-1688) - was threatening to collapse, two factors were identified as being the principal causes for its dilapidation: First, water penetration from the observation platform that served as its roof was undermining the stability of the supporting stone vaulting and structural walls below it. Second, the ruinous state of the large iron windows on the south side had rendered important sections of the building unfit for occupation and use[1]. The subsequent restoration of the building (1780-5) removed all traces of the original windows installed under Perrault and, apart from fragmentary, and somewhat contradictory contemporary contract documents, a few engraved views from the period prior to the renovation, and the abovementioned reports by the incumbent astronomer-royal, J-D Cassini (Cassini IV) on the condition of the building in 1775- 7[2], nothing is known about what these windows looked like, how they operated and what materials they were made of.

It is a question that seems to merit further exploration for a number of reasons: Claude Perrault was a pivotal figure on the late-17th architectural scene, whose theories and building projects had a considerable influence on how French classical architecture developed subsequently. The Paris Observatory (1667 – 1683) - one of only two surviving buildings by him (and, the only one of undisputed authorship) – thus has iconic status. Moreover, the project is of interest from more than just the architectural and construction historical perspective. As arguably the first building ever to be devoted entirely to scientific research (it was meant to function simultaneously as a working observatory and as the seat of new Academy of Science, established 1666) the Observatory has significance to the historian of science as well.

While the only prior purpose-built observatory, the so-called Uranienburg, near Copenhagen – erected 1576-81 to serve simultaneously as a royal residence and an observational base for the Danish astronomer, Tycho Brahe – still had a residential aspect, with its architectural components designed to a residential scale[3], the Paris Observatory was singularly focused on its scientific purpose. In his *Claude Perrault, 1613-1688, ou la curiosité d'un classique* (1988), Antoine Picon argues that Perrault's design was conceived of essentially as a scientific instrument in itself - a proto-modern *édifice-machine*[4]. This aspect of the building became even more pronounced as the architect, prompted by the intended user, the astronomer-royal, Giovanni Domenico Cassini (1625 - 1712), struggled throughout the construction period to find new ways of adapting the structure so that the building could respond more effectively to the increasingly sophisticated demands of the new science, astronomy[5]. It is therefore of some importance to know exactly how the technical complexities of a novel type of architectural agenda were resolved, including the way in which the building was fenestrated. Over and above the self-evident potential of the window as a location for astronomical observation the new brief called for a rethinking of both the traditional role of window openings within a building and their functional format. Architectural precedent in fenestration had evolved largely according to residential and ecclesiastical norms and neither model quite suited the new building type. In other words, the Paris Observatory project revealed that traditional practice could no longer be relied upon to provide all the answers in architecture – a new approach was called for.

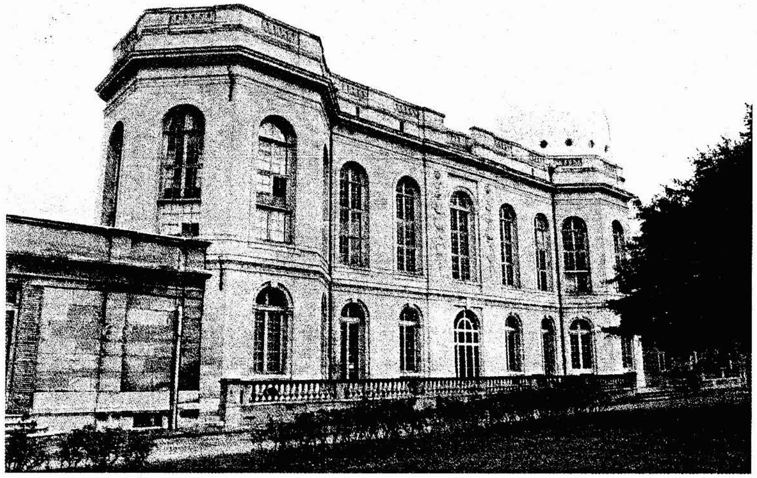


Figure 1. The south front of the Observatory, Paris, 1667 – 1683. (Author)

The 17th century saw the first tentative moves towards applying scientific methods to building technology, and Claude Perrault was one of a trio of brilliant scientists, or natural philosophers, who devoted a considerable amount of their time and energy to solving architectural problems (the other two being the Englishmen, Christopher Wren, 1632 –1723, and Robert Hooke, 1635 – 1703[6]). Like them Perrault demonstrated a talent for technical invention equal to his formal design and organizational skills and it is known that he too had experimented with the design of architectural components. The emphasis on rational experiment, based on direct observation and reasoning from first principles, that characterized the new scientific movement was also brought to bear on topical architectural issues. Foremost amongst these was the quest of Northern European nations to develop a classical language of architecture that would emulate that of Renaissance and Baroque Italy, but answered to local conditions. Under Jean-Baptiste Colbert, Louis XIV's first minister and director of the royal building programme from 1664 onwards, France had taken the lead in this development.

The window was one of the defining features of the new French classical style of architecture that reached maturity during the reign of Louis XIV and the Royal Observatory, so ostensibly devoted to all things experimental, provided the ideal opportunity for Claude Perrault - the leading French architectural theorist of the era, and a member of Colbert's select professional team spearheading this state-sponsored cultural revolution – to explore innovatory ideas in this regard as well. In attempting to determine the nature of the original fenestration of the Paris Observatory this paper will therefore also seek to place Perrault's contribution to window design in a broader socio-technological context. In the process we hope to throw some light on the elusive concept of innovation in the architectural domain, during one of the most inventive periods in architectural history.

Part One: Reviewing the Evidence:

Works on the site of the Royal Observatory in the Faubourg St. Jacques district of Paris began within a year of the foundation of the Académie des Sciences, in June 1667 and, for all practical purposes, the building was complete by the time that Louis XIV visited there on the first of May 1682. Although comparatively small by the Sun King's extravagant standards, the contract had turned out to be both more costly and time-consuming than anticipated. One reason for this was

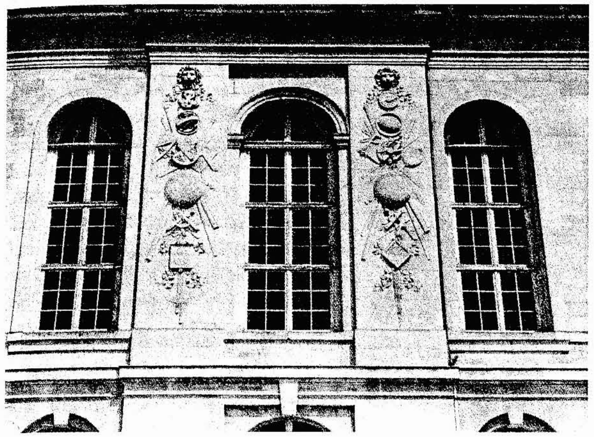


Figure 2. Central windows on the top floor, south front, showing late-18th century replacements of the original iron windows. (Author)

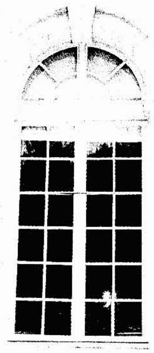


Figure 3. Window on the bottom floor, south front. Later replacement of the original leaded wooden casements. (Author)

probably the poor subsoil conditions – the site was riddled with ancient mining works – which led to the unusually massive masonry vaulted structure that gives the building its fortress-like appearance and accounts for much of the expenditure (about 88% of the 714,000 livres spent by 1683 went on the stonework alone, compared with 2.75% on joinery and 5.5% on locksmithery respectively[7]). Another probable cause was the extra cost incurred due to a series of alterations made to the design during the construction phase at the request of the astronomer-royal, J-D Cassini, since his appointment in 1669. Some of these, as will be seen later, had direct implications for the development of a fenestration scheme for the building.

Considering the complicated nature of the evidence available for this attempt at reconstructing a plausible scenario for the event, it is important that the reader is thoroughly familiar with the premises upon which the argument is based, hence the decision to begin with a detailed analysis of the existing source material. In presenting this material a distinction is drawn between the following two categories of evidence: factual evidence, i.e. primary information, either contemporary or of a later date, that has been specifically linked with the Observatory project and its outcome; circumstantial evidence, i.e. attendant facts or, as the dictionary describes it, 'the logical surroundings of an action' – in other words, information the relevance of which to the case is established through substantiated argument.

A. Factual Evidence:

Built Fabric: Judging from the surviving design and survey drawings, the Observatory building that one sees today [Figure 1] is in essence that which was built in the seventeenth century. There are some obvious additions like the observation domes on the southeast and southwest towers, and it is known that the building received a new roof as well as having part of the top floor vaults renewed during the 18th century restoration, but this did not affect the rest of the structure. Unfortunately it has not proved possible to carry out a thorough inspection of the fabric, but a few spot checks confirmed that, while the window openings themselves are unchanged, none of the original window frames survived the late-18th century renovation programme. As shall be seen later, there are good reasons for that. However, the existing wooden window frames (and some of the glass) almost certainly date from the latter period. [Figures 2-3].

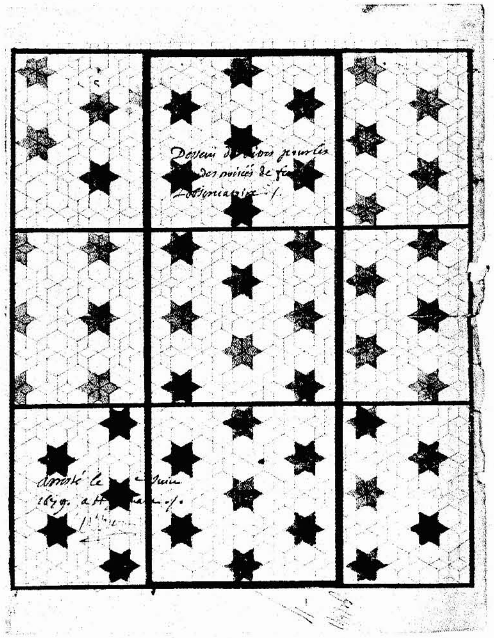


Figure 4. Contract design of 1679 for glazing seventeen iron windows on the top floor of the Royal Observatory, Paris, showing the arrangement for the bottom half of the window only. (Centre Historique des Archives nationale, Paris. Cat. O/1/1691/p.15)

Design and Survey Drawings: Although a significant part of Claude Perrault's architectural drawings' archive was destroyed in a fire in the Louvre Library in 1871, two important sets of original drawings for the Observatory survived and are kept in the *Département des Estampes, Bibliothèque Nationale,* Paris[8]: a) Various sketch designs and other drawings by Perrault, dating from the period c.1667 to c.1671 (These include several that were included as engravings in the first two editions of his translation of Vitruvius, 1673/ 1684); b) Survey drawings of the building made by the royal architect, François d'Orbay in 1692-4. This material has been the subject of serious academic research and the basic chronology for the design and construction phases seems established, as is Claude Perrault's claim to being the architect of the building[9]. Unfortunately, none of the extant drawings mentioned above give any indication of the configuration of the windows in the main building, other than the general disposition and dimensions of the structural openings.

Contract Documents: The most important new material that came to light during this investigation is the glazier's contract, dated 29 July 1679, for glazing seventeen large iron windows in the Observatory[10]. In it Antoine Charles de Janson (d.1689), *maître des oeuvres de vitrerie des Bâtiments du Roy*, was commissioned to provide each of the 21ft high by 7 ft wide iron frames, with 21 leaded glass 'panes' or panels (*panneaux*) of *gros verre double de France* (i.e. pieces of thick Normandy glass[11]). For the layout of the glazing pattern he was to follow a drawing of a contract that had been stopped earlier, and which provided for the inclusion of stars of yellow stained glass. The contract stipulated that the glass for the windows had to be clear and set in heavy lead cames, as was the practice in stained glass windows in churches; that the work had to be ready very shortly, and upon request by the locksmith transported safely and installed as soon as the windows were finished. For this job Janson was promised the sum of 165 livres per window. A note at the bottom, dated 28 March 1686, recorded that the document was returned to the royal notaries for checking. Another of the same date, in a different hand and signed by Claude Antoine Couplet, Treasurer of the Academy (who became the Observatory's first concierge and keeper of the instruments), confirmed that the work on the seventeen windows mentioned in the contract, was in place. By good fortune the design referred to in the contract has also survived [12] [Figure 4]. It shows a glazing pattern consisting of overlapping hexagons with coloured six-pointed stars in between, all set in a nine-panel structural frame (evidently part of a larger framework). The drawing carries two separate inscriptions, written in free hand over the design: At the top: '*Dessin de vitres pour les grandes croisées de fer de l'Observatoire*' ; at the bottom, in the same hand: '*arresté le 25 Juin 1679 a St Germain*', signed, 'Colbert'.

An abandoned project for an octagonal observation pavilion on top of the north tower of the Observatory, lodged in the archive of the Bibliothèque nationale, provides further material of relevance to this study. It is a hitherto unreported sketch design, probably by Perrault himself and entitled, '*Projet d'une tour au-dessus de la petite terrasse de l'Observatoire*'[13]. Amongst the drawings for this scheme there is a pencil sketch showing two tall wooden, glazed, compass headed windows of a type that became known as *porte-fenêtre*, or, *porte-croisée* (literally 'window-door') [14] [Figure 5]. One of these provided for small square panes of glass set in wooden bars (*petits- bois*), and the other for leaded glass panels (*panneaux*). The *petit observatoire*, upon whose roof this pavilion was to be erected, was executed during the building phase following Cassini's arrival, 1669 – 71 [15]. Perrault initially explored the possibility of adding an extra story to the north tower, which could serve as an additional observation room on the north/south axis, but eventually settled for a sunken space within the vaults devoted exclusively to zenithal observation [16]. The projected pavilion on top of this space would have combined the latter activity with a facility for all-round observation, something Cassini had demanded for the main hall on the floor below, but which could no be accommodated there due to constructional constraints (see below p29). It is known that Perrault was paid in March 1671 for design work done in 1669-70[17], which would suggest a date of c1670 for this project.

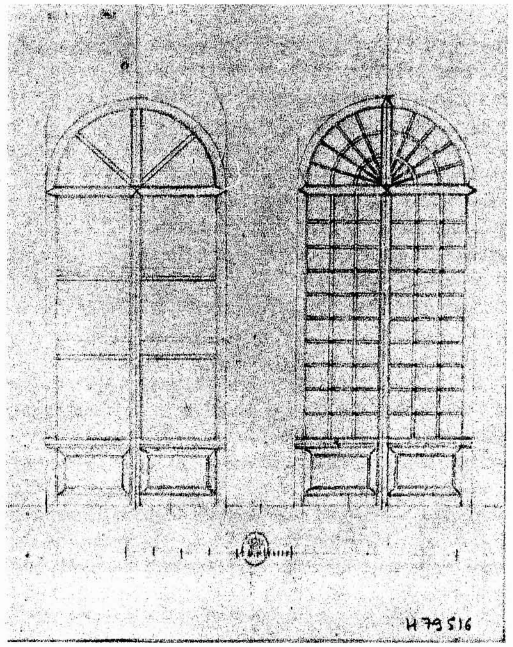


Figure 5. Claude Perrault. Design for two 'French windows' of an unexecuted observation pavilion on the roof terrace, Paris Observatory, c.1670/1. Pencil drawing. The window/door on the left was to be glazed in lead, the one on the right with square panes set in a wooden grid. (Bibliothéque nationale de France. Cat. BN. Va 304 t.1/ H79516)

Building Accounts: One advantage for the scholar researching the architecture produced by the *Surintendance des Bâtiments* during the reign of Louis XIV, especially the period under Colbert, is the meticulous care with which the official records were kept. The building accounts – made even more accessible by Jules Guiffrey's publication of the full set of records in five volumes (1881-1901)[18] - therefore offer an excellent framework against which the on-site progress of any of the royal building projects can be plotted. A drawback of the bureaucratic record keeping system that served the highly centralized management structure of the French court, however, is the loss of specificity in the recording of particular tasks. Specific references to aspects of the fenestration of the Observatory are rare in the accounts. There is, for example, no mention of windows under menuiserie (joiners' work), nor under peinture (paintwork). The only relevant entries are to be found under serrurerie (locksmithery) and vitrerie (glazing), which will be discussed later.

Descriptions of the Observatory prior to its restoration: In the absence of critical reviews of the building for this period, by professionals who might have commented knowledgeably about technical matters like window design, one is reliant on general commentaries in diaries, tourist guides and correspondence. There is a fair amount of such material available, because the Royal Observatory attracted visitors right from the beginning due to its connection with the crown, the novelty of the scientific activities it housed, as well as the fine views of Paris and its surroundings that its roof terrace offered. As the first building ever designed specifically to serve as a research institute it also excited the interest of the international scientific community. What seems to have impressed people most about the building itself was the general solidity of the structure, the scale and grandeur of the vaulted spaces and the quality of the masonry work, especially in the main staircase and the vaults. It is without question a stereotomic masterpiece and the overwhelming presence of the stonework soon gave rise to the popular belief that no other material but stone was used in the building. Dr Martin Lister, the noted English physician and member of the Royal Society of London, who, upon invitation from the Royal Astronomer, Cassini, visited the Observatory in 1698, for example noted: 'In all this Building there is neither Iron nor Wood, but all firmly covered with Stone, Vault upon Vault.'[19].

Lister, who, as his diary of his six month visit to Paris testifies, was normally observant in matters related to building as well as science, made no reference at all to the windows at the Observatory, which suggests that he observed nothing out of the ordinary – even that they were made of iron! The author of the popular guide to Paris, *Description nouvelle de ce qu'il y a de plus remarquable dans la ville de Paris* (first published in 1685), Germain Brice - and who probably coined the '*ni fer ni bois*' catchphrase that persists even to this day - at least noted that the windows had round or compass heads, still a novelty at the time for French secular architecture. However, none of the numerous editions of this work that were produced over the next century elaborates on this observation, nor are the engravings that accompany the entry on the Observatory from the 1705 edition onwards any more helpful[20].

The other written commentary on the building that survived comes mostly from the archives of contemporary scientists or natural philosophers. The Royal Society in London was keen to know about the Paris Observatory project right from its inception, so references to it featured frequently in the letters that passed between its members and those of the French Academy of Science. The most comprehensive record of this kind, the correspondence of Henry Oldenburg, secretary to the Royal Society, contains useful information on the building operations and the subsequent use of the site, but offer few specific clues on the fabric of the building itself. However, a document attached to a letter, sent to Oldenberg by one of his correspondents in August 1669, gives a rare contemporary insight into the thinking of the astronomers involved with the project at that stage. It is in the form of a rather crudely drawn schematic plan of the site indicating its scientifically most significant features. What is of special interest to this study is, the inclusion in this schedule of the 22 ft high windows of the second floor 'gallery' on the south facade giving on to the main observation hall or, as Cassini called it, '*la grande sala*'[21]. This would seem to suggest that, at that moment at least, these windows (drawn in elevation below the plan) were considered to be an integral part of how the building was meant to function as an aid to astronomical observations by those who were actually going to carry out the work.

The Restoration Archive: The only documentary evidence that survived from the restoration of the Royal Observatory in the 1780s are a series of mémoires on the dilapidated state of the building by the resident astronomer, J-D Cassini (Cassini IV), currently in the *Archives nationales*, Paris. These were compiled between 1775 and 1780, and record Cassini IV's desperate attempts to convince the authorities of the urgency of the situation[22]. The state of the roof and upper vaults had been a cause of concern ever since the mid-18th century[23], but this is the first evidence to suggest that the windows too were in general need of repair. From Cassini IV's account it is clear, though that they must also have been deteriorating over a long period of time - a fact which confirms that the windows in question were still the authentic late-17th century ones, and not replacements from earlier in the 18th century.

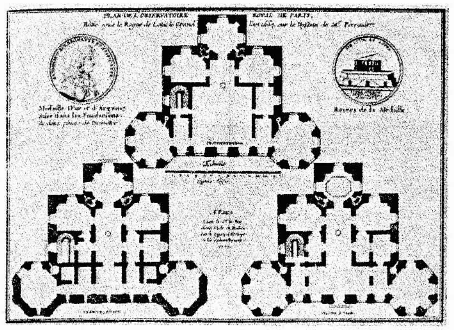


Figure 6. Commemorative sheet dated 1705, showing the floor plan of the Paris Observatory at all three levels. (Bibliothéque nationale de France. Cat. BN. Va 304 t.1 / H79505)

Cassini IV's first report, dated 31 January 1775, gives the most comprehensive and revealing description of the existing windows and the problems that they caused, with his suggestions as to the steps that need to be taken to rectify the situation . Speaking of the tall windows on the second floor of the south front Cassini speculates as to why the original builders would have adopted the structural solution that they did for some of the windows of the Observatory. He assumed that to them an iron frame might have appeared an economic and stable way of supporting the large panels made up of smaller squares with glass quarries held in position by lead cames, but points out that: 1) the heavy bars of iron and the innumerable quantity of lead strips resulted in windows that were extremely heavy, difficult to use and harmful during observations; 2) The size of these panels offered a large surface to the wind which, like a sail swept by the wind sooner or later would push in and a whole window would be smashed. Cassini observed that it ony took a moderately strong gust of wind to blow away some panels entirely from a window, and, as confirmation of his claim, pointed out that, at that very moment in time this was the case with eight such windows in the Observatory. He added that each time that the wind blows fairly strongly window glass and lead cames rained all around the Observatory, putting people entering and leaving the building at risk of injuries.

Cassini IV concluded that in its current state the maintenance of the Observatory windows was very extravagant, arguing that it would be more convenient and safe to construct the windows with wooden sash-bars holding squares of glass of 12 x 8 inches in size. He acknowledged that objections might be raised that the initial expense of installing new windows will be very high, but emphasized that in his calculations he drew a distinction between the windows on the first floor and those on the second, to the south side (i.e. second and third floors respectively on plan, due to the difference in site levels on the north/south axis) [See Figure 6]. Since the surviving old windows on the first floor already had wooden uprights, he claimed that it would not be difficult to put sash-bars in them, in order to divide each panel or casement into twelve panes - each window to have four casements and two transoms (i.e. apart from the compass head) [see below, Figure 14a]. Finally, he stressed that while it would be acceptable for the repair work on the windows to be done over several years, the windows on the first floor were the most urgent since they are the ones needed for their observations.

Despite further remonstrations by Cassini IV between 1775 and 1780 nothing was done to repair the windows of the Observatory, driving him to seek ever more radical solutions for resolving the crisis. Having concluded that the large windows on the second floor were essentially for show, with little practical use anymore to astronomers, he prepared his own scheme for replacing these with smaller, more utilitarian wooden ones. The drawing for this *Projet d'une Nouvelle Manière de Accommoder les croisées de l'Observatoire*, survived in the archives[24] [Figure 7]

The drawing, probably by Cassini IV himself and dating from 1780, shows the window openings partly filled in with a brick wall, reducing the 22'-0" x 7'-6" (7.15 x 2.43 metres) compass-headed window openings to oblong windows, 19'6" x 4'0" (7.15 x 1.3 metres). However, the striking thing about this scheme is not the attenuation of the windows, but the unusual way in which the windows were meant to operate. It proposes an eight-foot high glazed wooden casement at the bottom with

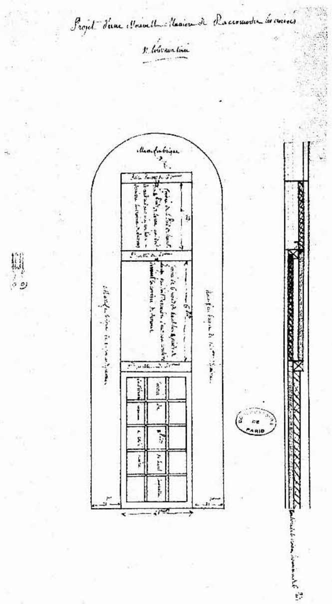


Figure 7. Cassini IV. Design for a three-tiered, combined sliding/casement window on the top floor, south front of the Observatory, 1780. (Observatoire de Paris. Cat.03/ 1286)

two sliding sashes over it, six foot by four foot high respectively and presumably also made of wood with square panes of glass. This is like nothing else in French architecture at the time, and the architects responsible for the restoration work carried out shortly after (1780-5) duly ignored this suggestion and, instead, adopted the traditional French wooden casement system that has survived to this day. How Cassini IV, who had no previous architectural training or experience, came upon the apparently unique configuration of his proposed solution for the Paris Observatory windows in 1780 is one of the questions this paper will have to address.

Topographical Illustrations of the Observatory prior to its restoration: Due to its prominence as a major public monument of the Louis XIV era the Paris Observatory was the object of pictorial representation from even before it was actually constructed and it remained a focus of attention until well into the 19th

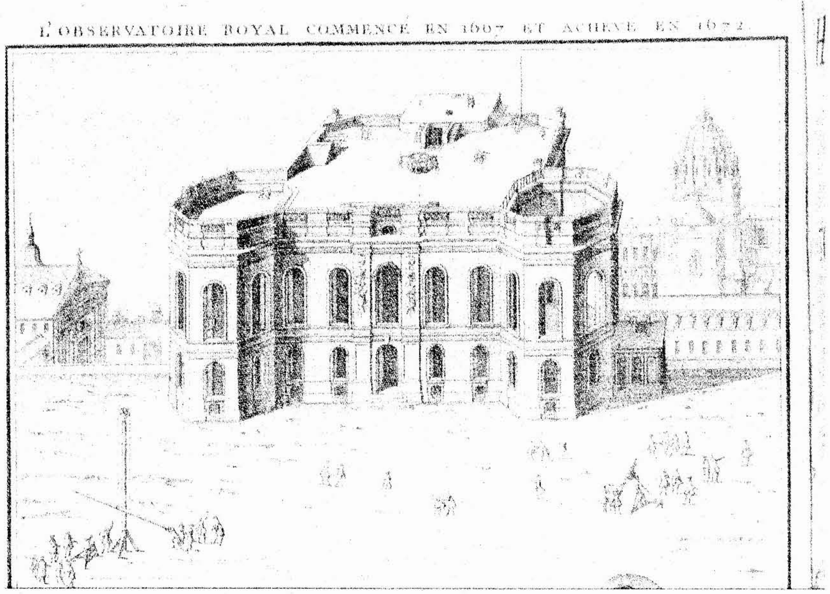


Figure 8. Bird's eye view of the Paris Observatory, dated 1740, by Dheulland after a drawing by Martin Dumont. Part of the frontispiece to Le Monnier's, *L'Histoire céleste*. (Paris, 1743). (Bibliothéque nationale de France)

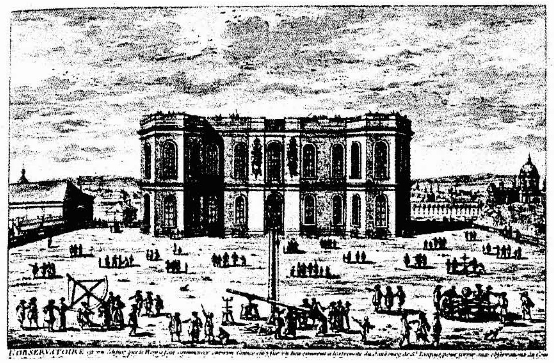


Figure 9. Nicholas Pérelle. The Royal Observatory of Paris from the south, c.1682. (Bibliothéque nationale de France. Cat. BN. Va 304 t. 2 /H79588)

century. With such a good visual record at one's disposal[25] it is surprising that questions should arise regarding the appearance of the Observatory's windows during its early history. This is largely due to the contradictory nature of the material. Even allowing for the inevitable subjective element in topographical illustration from this period, there seems to be an unusual degree of variance in this aspect of the illustrations of the building.

One theme, to show the building as an empty shell, without any glazing whatsoever (not as a ruin) - a trend started by Perrault himself with the depictions of the Observatory in his translation of Vitruvius, *Les Dix livres d'architecture* (1673/84) - persisted until the middle of the 18th century [Figure 8]. The more 'realistic' early portrayals of the building, dating mainly from c.1680 – c.1705, do, as a rule, show the frames and glazing in a fashion, but there are wide discrepancies in their depiction of detail and in some the understanding of architectural proportions is poor[26]. By far the most accurate of these, architecturally speaking, is the engraving by Nicolas Pèrelle, the well-known architectural engraver [Figure 9]. It was probably done in the early1680s, prior to the installation of the Marly Tower (erected 1685-8, demolished 1705), but after the installation of the pole telescope on the main terrace (1679)[27] In this view all the windows of the south front are shown with what looks like leaded glazing. Those on the top floor, which are wider and taller than the ones below, approximate the configuration of iron window frames of the period, each subdivided into 24 lights or 'panes' (panneaux), four wide and six high up to the springing of the arch (marked by the top of the pilaster capital). The arch-light has radial bars superimposed on the concentric segmental sections. In the central window over the front door, which is wider than the rest, the glazing runs through to the floor. No opening lights are indicated on this story. The windows on the bottom floor are subdivided into eight lights (2 x 4) below the arch, with a central mullion. In two of these windows the two bottom lights are shown with what seem to be, inward opening casements. In Perelle's view of the north front of the building (not illustrated[28]) all the windows on the top two floors are depicted with the glazing arrangement similar to those in the top floor of the south front.

The only engraving of relevance showing an interior is the famous view of Louis XIV visiting the *Académie des Sciences*, by Sébastien Leclerc, that served as the frontispiece to a series of scientific books produced under Claude Perrault's direction, 1671-6. [Figure 10] The original engraving dates from 1671 and depicts an imaginary setting which probably was a projection of the future interior of the Observatory. The skeletal framework in the two windows likewise could represent the iron windows that were intended for the Observatory, shown deliberately in an unfinished state to indicate work in progress. From the building accounts we know that the actual contract for the ironwork of the windows only began in May 1672[29], but the strategic decisions

Figure 10. Sébastien Leclerc. Louis XIV visiting the Académie des Sciences. Frontispiece to *Mémoires pour servir a l'Histoire des Animaux* (1671) showing an imaginary interior, probably a projection of that of the Observatory, still under construction in the background. (Bibliothéque nationale de France)

regarding fenestration may well have been taken by mid-1671 when the engraving was probably made[30]. Leclerc, who trained as an engineer before becoming an engraver, would have been familiar with such mechanical matters and, moreover, was working closely with Perrault on this as well as other projects at the time[31].

In contrast with the wealth of engravings, the Paris Observatory was rarely depicted in colour. The best contemporary painted view is by Henri Testelin, apparently done after a sketch by Charles Le Brun[32]. It depicts the investiture ceremony with the academicians being presented to Louis XIV, with a view of the Observatory in the background. The painting (datable to c.1672/3) shows the building from the southwest with the visible shell complete, but only the windows on the lower floor of the south front with window frames fitted. Judging from the one example that is clearly shown in this painting, that in the octagonal southwest tower, the frames were made of wood with a central mullion and two transoms that divided the window in three equal parts vertically.

B. Circumstantial Evidence:

The external factors that might conceivably have conditioned the development of a fenestration scheme for the Observatory project are of a three-fold nature: those criteria embodied in the client's brief that reflect the cultural and utilitarian aspirations of the sponsor/ intended user of the building, in this case Louis XIV, as represented by Colbert, and the scientists of the Académie; those arising from the aesthetic and technical demands of the design concept and, finally, those technological parameters determined by the capacity of the contemporary building industry to deliver the desired results in practice. Financial resources do not appear initially to have been a contextual factor in this instance, but became more critical towards the end of the project – the period when the windows were actually installed and glazed.

Client-induced Factors: As the first major public building project sponsored by Louis XIV, the Paris Observatory occupied an important place in the creation of an architectural language that would glorify his reign. Everything about the building speaks of this search for an imposing contemporary architecture whose monumental grandeur, technical ingenuity and refinement of detail execution could emulate that of the Ancient Roman builders. To that end all the resources at the disposal of the royal office of works would be employed. From the principal client's perspective it was an architectural statement, aimed more at public display than functional efficiency and symbolic references supporting this thesis are not hard to find. The connection with fortress architecture was made from the beginning – the Observatory was, as Colbert observed in 1669, aimed at the conquest of the heavens[33]. The evidence presented here of 'church-like' windows with star symbols, having been introduced to the Observatory's major observational spaces, would seem to suggest the influence of another generic model, that of a temple - in this case, presumably dedicated to the new science, astronomy.

There was, however, another side to the client body, namely, the people for whose actual use the building was intended, the scientists, more particularly the astronomers. And their perception of how the building was to serve their operations seem to have been decidedly more pragmatic than that of the Surintendant des Bâtiments, Colbert, and, in all probability his architect, Claude Perrault as well. Following the departure of the first specialist adviser, the French astronomer, Adrien Auzout, after a row with Perrault, and the arrival of the famous Italian astronomer, Giovanni Cassini, in 1669, when the structure of the Observatory had already reached first story level, things began to change. The energetic Cassini brought a different, more proactive approach to the formulation of the client's brief that led to significant alterations to the original design. While one should be careful not to read the actions of Cassini I too readily through the utilitarian prism held up by his great grandson, Cassini IV - the source for much of the information on the early history of the building[34] - there is no doubt that the great astronomer from the onset had a very clear perception as to how the new Observatory was to function, and left no stone unturned to get his views implemented. Upon his insistence, extensive living quarters were fitted out for himself and other scientists on the first and second floors of the building, where previously none were intended and he, moreover, insisted on moving into his quarters long before the building was completed. This introduction of a domestic component into the design of a public building changed the criteria for environmental design at a late stage, which may have had a negative impact on the development of a coherent system of fenestration for the building. Cassini also found the geometrical configuration of the segmented floor plan, based on a strict, 'celestial' axial scheme, culminating in three attached octagonal towers [Figure 6], over-complicated and too restrictive for astronomical observations. He complained especially about the difficulty of having to move heavy and bulky equipment from tower to tower during observations, and about the loss of heat in the rooms due to the large windows constantly having to be opened. Cassini's stated preference was for the whole of the top floor to be one big, open space with an observational gallery around its perimeter. This solution proved too difficult to achieve within the constraints of the adopted masonry-vaulted structural system, and a compromise was reached with a square hall formed in the centre of the building, on the south side, the so-called *Grande Salle*.

Apart from causing the complete reorganization of the original grand staircase – much to the chagrin of the Perrault brothers – this move required changes to the vaulting scheme as well, and compromised the observational gallery planned along the south front to link the two towers (the arrangement survived on the first floor). Above the central window to the south, within the cornice, Cassini also had a small, semi-circular opening inserted [see Figures 8 & 9], which turned the floor of the *Grande Salle* into one huge sundial. Unfortunately, this meant that Perrault's decorative scheme for a large Zodiac belt of inlaid marble on the floor of the room had to be abandoned. Another example of Cassini's determined pursuit of his pragmatic objectives is the southeast tower on the second floor, where the roof was left off and large vertical slits cut in the top of the walls to the south and north, above the windows, in order to facilitate better telescopic observation [see Figure 8]. This must have created a rather strange architectural space, with large and expensively glazed windows but no roof! It is something that would have been very difficult for an architect to accept (not to mention design), and serves as a good illustration of how much Cassini, as client contributed to the realization of this early example of an *édifice-machine*. No evidence could, however, be found to support the view (apparently still held within the scientific community in France[35]) that the reason why iron was not used in the building was because Cassini I believed it would interfere with the magnetic compass, commonly used in conjunction with observations at the time. The practical implications of this phenomenon were not properly understood until the early 19th century[36].

Design - related Factors: Commenting on the design of the Observatory, when the ambassador of Siam visited there in 1686, the Paris journal, *Le Mercure Galant*, found much to admire in the building. It concluded that the special qualities it observed in the design were attributable to the fact that Perrault was a medical doctor and a scientist, and therefore had insights into mathematics and structures that other, traditionally trained architects did not have[37]. The windows were not one of the features singled out for praise in this respect but, in fact, they do lend credence to the view that Perrault's approach to design differs significantly from what was customary at the time. It is perhaps best summed up as a tendency towards designing from first principles following a rational analysis of the problems to be solved, rather than direct reference to architectural precedent – a characteristic that Perrault shared with the other major scientist/ architects of the era, Robert Hooke and Christopher Wren[38]. This methodology was more likely to produce solutions that were unique to the particular circumstance than traditional practices could, and there is ample illustration of this in the way that the fenestration of the Observatory project developed, with respect to typology as well as technical invention.

In the first instance one could point to the decision to adopt a type of window, composed of iron frames glazed with leaded lights (*vitraux*), associated in France at the time with church architecture, not civil architecture. It was a bold move which, as we shall see later, had some practical advantages, but one that challenged the boundaries of decorum (*bienséance or convenance*), an increasingly important criterion for architectural criticism under Louis XIV[39]. With the 'church' windows came another motif that was soon to become a standard feature of the grand manner of the new architectural idiom created to glorify the sun king's reign, namely, the circular or compass head (*plein cintre/ fenêtre cintrée*), arranged in series to form arcades. Already established in classical church architecture in Paris by then (eg. S. Roch, 1653-; St.Sulpice, 1645- see below, page p35), but not yet employed in other building types, the tall circular-headed window was well suited to light high vaulted spaces and its subsequent popularity in grander secular architecture was ensured by its large-scale adoption at Versailles.

Linked with this, at the Paris Observatory, was the novelty of the pattern proposed for glazing [Figure 4]. It was the practice at the time for glaziers to provide the designs for this kind of work and André Félibien in his *Des Principes de l'Architecture, de la Sculpture, de la Peinture* etc. (1676) illustrates 24 standard patterns with their contemporary terminology [40]. The contract document mentioned earlier (see above, page p22) does not identify the pattern used in this case and none of the patterns illustrated by Félibien comes close to the one employed in the original design drawing halted by Colbert in 1679; nor do any rival its geometrical sophistication. There is only one with star-like figures, called, *Croix de Malte*, but it is not an overlapping pattern and comparatively crude as a design. In effect, the Observatory glazing pattern appears to be unique for its time, and nothing like it could be found in other pattern books from earlier in the seventeenth century, nor from the eighteenth century. If anything the Observatory design has some of the qualities of medieval Arabic designs, which would fit in well with the orientalism in decorative style associated with Louis XIV's reign[41]. Could Perrault have been the author of this? It is certainly a possibility. The surviving drawing has something of the quality of a sketch design about it, and in parts the pattern shifts as if variations in the theme are being explored – not the kind of thing one associates with final contract drawings prepared by craftsmen. What is more, the design is of such a specific nature, symbolizing the astronomical purpose of the building, that Perrault must, surely, have been involved in its conception[42]. Perhaps it was one of those 'things' that, according to the Mercure, he knew about, but which other architects were not expected to have knowledge of?

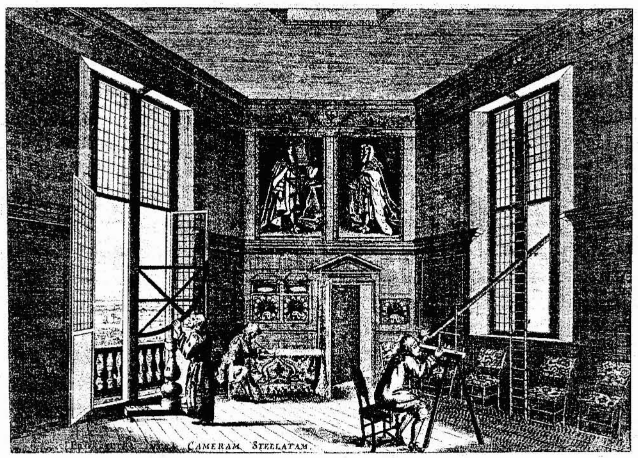
The windows proposed for the abovementioned unexecuted *petit observatoire* pavilion project of c1670/1 [Figure 5] were no less of an original conception, one that, moreover, reveals another facet of Perrault's complex architectural personality, namely, a tendency to invest his designs with

classical authority by reference to the work of Vitruvius. These windows were of a type that originated in France and in its mature form comprised *chassis brisés* – tall casemented windows that looked and operated like doors, with two leaves, sometimes extending up to the full height of the opening, closing on themselves without fixed mullions and transoms. (Outside France they are still known as 'French windows'). The genealogy of the glazed window-door can be traced back to the early 17th century in Paris[43], and they were used intermittently ever since, but they only became popular following their transformation in accordance with the grand manner of Louis XIV's palace architecture.

It would appear as if Claude Perrault had a hand in bringing this to pass. André Félibien, the first lexicologist to adopt the term, '*portes- fenêtres*', in his *Dictionnaire des termes propres à l'architecture* (1676), defines them as, 'windows that open all the way to the floor', and likened them to the 'Valvatae fenestrae' mentioned by Vitruvius[44]. Félibien's source for this reference was Perrault's translation of the *Ten Books of Architecture*, published three years earlier. In Book VI, Chapter III of this treatise Vitruvius describes a type of Greek dining room called 'Cyzicene'. He explains that these dining rooms were usually built with a northern exposure, facing gardens, with windows to either side of a door, through which the landscape could be viewed from the dining couches. In his commentary on this chapter Perrault argues that previous translators, who interpreted Vitruvius's, 'fenestrarum valvate' to mean 'double window', were mistaken and that instead what is referred to is a window that had no sills, opening, like a door, all the way to the floor, such as were installed, upon Louis XIV's command, to all the apartments of Versailles facing towards the gardens[45].

Since the new translation of Vitruvius was commissioned by Colbert, personally, in 1667, and dedicated to Louis XIV upon publication in 1673, there can be no doubt that they would have been kept up to date with Perrault's findings as he progressed with the work. It was a critical time in the development of the Palace of Versailles with the creation of the so-called '*Enveloppe*' (1668-1671) and Perrault was intimately involved with this project[46]. He would therefore not have missed a chance to promote this solution, especially as his inventive preoccupations extended to the design of building components – it is known, for example, that he provided designs for bronze doors for the *grands appartements* at Versailles in January 1674[47]. It is also easy to see why the concept of windows that blurred the distinction between interior and exterior would have appealed to Louis XIV, who was known for his love of the outdoors, all the more so when that element carried with it the authority of ancient precedent. According to the building accounts, the process of replacing older windows with *portes-fenêtres* in the royal apartments in the original chateau continued until 1674[48], but these, like the ones in the new-built sections, would all have been of the square-headed variety (*fenêtre en plattebande*) that still followed the format of the traditional French double-cross window. Perrault's own windows for the roof pavilion project at the Observatory were altogether more progressive and foreshadowed the grand compass-headed *portes-croisées* introduced by Jules Hardouin-Mansart on the principal floor of Versailles ten years later[49].

Finally, there is another lost invention of Perrault's that might have found application in the Observatory project. In 1693, five years after the death of the architect, his brother, Charles, Colbert's chief clerk, showed Daniel Cronström, the Swedish ambassador at the French court, a collection of Claude Perrault's architectural drawings which he had compiled in two volumes. Amongst these there was a design for a sliding window operated by a counter-balance that Charles Perrault claimed to be an invention of his brother's. Cronström was evidently much impressed by this invention for he immediately informed his friend and compatriot, Nicodemus Tessin the younger, the Swedish court architect of it by letter. Tessin wrote back saying that he had already seen such a device in operation at Het Loo Place, Netherlands, when he visited there in 1687. It appears that a copy of the '*invention contrepoids nouveau pour les chassis de fenestre*' was subsequently sent to Tessin, who collected French architectural drawings, but nothing of the kind



PROSPECTUS INTRA CAMERAM STELLATAM FROM 'TOM TOWER' BY W. D. CARÖE
THE STATE ROOM, ROYAL OBSERVATORY

Figure 11. Francis Place. Engraving showing the interior of the Great Room at Greenwich Observatory, built 1675-6. (Wren Society XIX, plate LXVIII)

could be traced in the voluminous Tessin Harleman Collection in the Swedish National Museum, Stockholm [50]. There can be little doubt that the original perished with the rest of the material in the collated volumes in the fire that destroyed the Bibliothéque du Louvre in 1871. It remains to be seen whether this contrivance of Perrault's could have been developed in order to serve some purpose at the Paris Observatory.

Technological Factors: The practical concerns that would have influenced the decision making process regarding the fenestration of the Paris Observatory most directly, are those that relate to its functional typology and structure. What kind of window products were available on the market at that time that could have fulfilled all the criteria set by the brief, be manufactured in sufficient quantities and to an acceptable quality, and be delivered on time? The fact that the windows were the last component of the building contract to be completed suggests that the builders found this to be one of the most intractable of all the problems to resolve. And it is not difficult to see why. There was no architectural precedent for the fenestration of a building dedicated to astronomical observation.

Common sense suggests that 'star-gazing' is essentially a fair weather activity, conducted outside buildings, and there is specific contemporary evidence to confirm that this indeed remained the case for the majority of observations even after purpose-built structures were being erected. Christopher Wren admitted as much with respect to the Greenwich Observatory, begun shortly after the Parisian one, 1675-6, when some years later he noted that the building was essentially meant for housing the astronomer and storing the instruments – the observations were mainly carried out in the court outside[51]. At the Paris Observatory too the major observations were undertaken from the various terraces created on the site, including the one on the roof. But with astronomy becoming a professional activity there was a demand both for more, and a more varied range of opportunities for this kind of work all year round, in relative comfort.

The challenge was to get as many as possible viewing angles with ample space for manoeuvring awkward, bulky equipment into position (the focal length of telescopes used at the time commonly ranged from 25 to 40 feet, with some measuring well over a hundred feet) – it is not for nothing that the early observatories resembled castles! Even the rather cramped situation at Greenwich - as the famous engraving by Francis Place of the interior of the Great Room shows [Figure 11] –

permitted limited in-door observations, and the Paris Observatory, which was considerably more spacious and flexible, had much greater scope for this activity. Unfortunately there are no pictorial representations of how this was achieved at Paris and very few contemporary descriptions. One such recounts the demonstration of the use of a 100-foot 'open' telescope (i.e. without cylindrical tube), set up along the north/south axis on the upper floor of the Observatory, to entertain James II of England in August 1690[52]. Cassini IV's, complaints a hundred years later, that the inoperability of the windows in Observatory greatly impaired his ability to conduct proper observations (see above page 25), confirm that this kind of work remained an established part of astronomical practice. The question remains: exactly how did the windows function, and was the type of window adopted the most appropriate one for the purpose?

The basic requirements were fairly straightforward: the windows had to serve to ventilate the building, provide good light for the scientific business conducted inside the Observatory and facilitate astronomical and cartographical observations. Due to the large volumes of the interior spaces the ventilation aspect would not have been problematic; as was noted before, heating was more of an issue. Views to the outside were also not an objective in this instance, but getting sufficient light of good quality to those areas where scientific work was carried out, was, hence the many large windows which are such a distinctive feature of the design. As can be seen from the numerous contemporary engravings of scientists of the period at work, they tend to congregate close to the windows[53]. Prior to the advent of electricity this was the norm for all indoor activities requiring close visual attention, and the plan arrangements of the Observatory show how carefully work areas were concentrated along the perimeter of this deep-plan building. Cassini I also demonstrated insight into the problem by exploiting the darker central area of the large hall on the upper floor for his sun clock (see above, page 29).

Apart from the daylight factor, and the obvious need for correct orientation and structural stability, the other two important criteria for choosing a particular system of fenestration for the Observatory would seem to have been, ease of manipulation of the opening mechanisms and sufficient open-able surface area. And the most logical place to have looked for this kind of technology was in the field of residential and public building. By early1670s, when the Paris Observatory project had reached the stage where decisions regarding the type of window were unavoidable, a revolution in window design was already underway in secular buildings. It concerns the way in which the window glass was fixed within the frame, and coincided with significant improvements in glass and woodworking technology. France led the way in this transition from the traditional use of small glass panes or quarries set in a lead lattice to form larger panes (*panneaux*), to larger square panes of glass (*carreaux*) set individually in a grid of thin wooden bars (*petits-bois*). The latter system produced a sturdy, economical framework with the potential of combining greater transparency with a flexible opening system and lower maintenance costs - advantages that provided for the contemporary quest for lightsome, well-tempered interior environments, especially for residences.

As Leproux and Belhoste have shown in their study of Parisian windows of the period[54], the technique was first employed regularly in sliding windows from the second quarter of the 17th century onwards, only transferring to *portes-fenêtres* in grander buildings in the 1660s. By the 1670s, despite the new technology having been given the seal of approval by leading architects like François Mansart, wooden windows with leaded panes were still the norm in Parisian buildings. The simple cross variant of the latter type, with four inward-opening casements, was typically from eight to ten feet high by four to five foot wide[55]. In the three-tiered, double cross (*croix de Lorraine*) variety with two transoms and six opening casements, larger sizes were achievable.

At that stage the main rival of the traditional leaded wooden window, the casement window with *petits-bois* and square panes of glass, was probably not much better regarding overall transparency

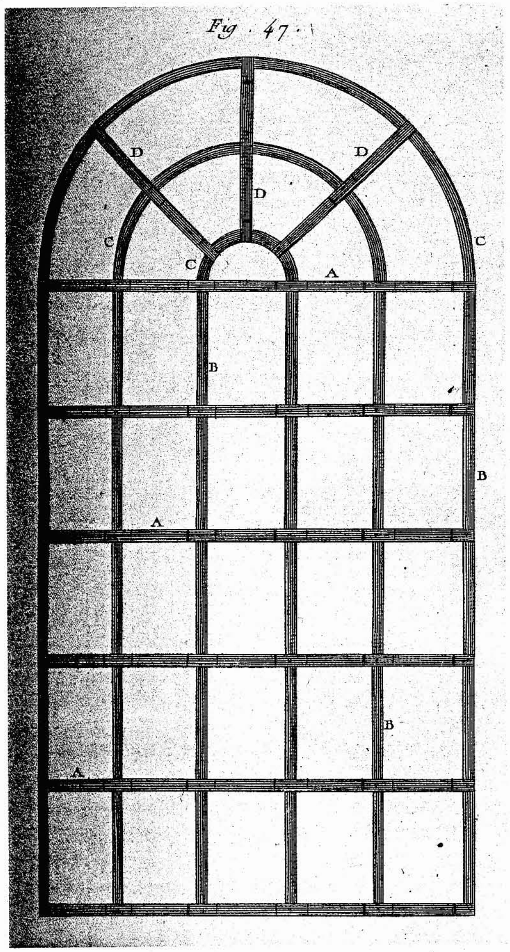


Figure 12. Constructional frame of an iron church window from Diderot & d'Alembert, *Encyclopédie, Volume IX: Planches* (1771), Plate VII, fig. 47. (Newcastle University)

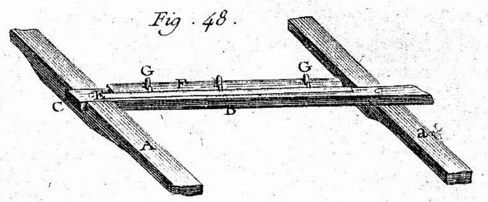


Figure 13. Detail of frame in Figure 12 (Plate VII: fig.48) showing the method of construction.

(which may explain why Perrault adopted both varieties for the abovementioned pavilion), but the latter type was only at the beginning of its development. The so-called, *porte-fenêtre*, was to be the flagship of the movement that, within a few decades would lead to the large-scale adoption of the all-wood window in Parisian secular architecture. The rate of this progress depended on advances in three types of technology: joinery, window glass making and ironmongery, and Louis XIV's building projects were the laboratory where these technologies were perfected. The windows that Perrault proposed for the pavilion project at the Paris Observatory c1670/1 were part of this programme of development that began with the first *Enveloppe* project at Versailles (1668-71). The *portes-fenêtres* installed on the principal floor of the garden front of the latter building at roughly the same time were 5'6" wide by 15'0"[56], a considerable advance in scale on contemporary leaded wooden windows, but they still seem to have retained the fixed central mullion with two transoms of the traditional French cross window which Perrault's scheme for the pavilion windows omitted. This, and the size of the latter, 6'0" x 16' 0", confirm the precocity of the Perrault design.

Iron was the material typically employed for metal windows at the time and in France, unlike England, the technology was restricted to church windows (a fact recognised in the glazier's contract of 1679, referred to above, page 22). The use of iron as a structural material would have appealed to the classically minded designer of churches, because its superior

strength allowed the creation of an internal framework that was neutral, structurally as well as visually, by omitting the obtrusive tracery of earlier church windows, thus placing the emphasis on the overall geometrical form of the window. The iron windows that were progressively adopted for classical church windows in Paris during the seventeenth century were generally very large. The compass-headed windows installed in the nave of the parish church of St Roch, Paris, probably during the 1660s, were approximately 9 feet x 19 feet (2.92 x 6.17 metres); those installed and glazed at St Sulpice, Paris, 1672-4, were approximately 13 feet x 27 feet (4.22 x 8.77 metres)[57]

Locksmithry, i.e. the art of fine work in iron (*serrurerie*), was one of the crafts that saw rapid progress during the reign of Louis XIV. The quality of locksmiths' work, which ranged from decorative railings to window and door furniture was much admired at the time, also by foreign visitors like the Swedish architect, Nicodemus Tessin the younger, who, through his friend the Swedish envoy, Daniel Cronström, obtained several designs and models of such fixings (*fermeture*). Amongst the novelty objects that Cronstöm sent Tessin in September 1693, via La Rochelle, were two spring-loaded catches for high shutters to iron windows[58]. Since church windows at the time were not fitted with shutters this device must have been developed for secular buildings, and the Observatory project was a likely venue for experimentation of this kind. In Etienne Doyart, who installed the original iron windows in 1672/3, and Thomas Furet, who did the alterations in 1680, Perrault had at his disposal the skills of two of the best locksmiths in France. Furet was responsible also for the iron balustrade of the four-story high principal staircase of the Observatory (installed 1679[59]), and Doyart, who also worked on the Louvre project, was a descendent of a famous locksmith dynasty originally from Nevers[60].

While intrinsically less bulky as a structural material for windows than either wood or stone, iron windows of the period were elaborate and costly affairs, comprising flat bands of iron forming a glazing grid being bolted together using cross pieces of reinforcement on all junctions. The technology for the handcrafted '*vitrail d'église*' survived virtually unchanged into the 18th century and is explained in technical manuals like those by Duhamel du Monceau, *Art du serrurier* (1767), who used plates from the 1720s to demonstrate how the manufacturing process worked[61] and Diderot's, *Encyclopédie* (1765-), where a typical arrangement for such a window is shown together with the components from which it was assembled [Figures 12, 13].

A drawback of the contemporary iron window, as employed in ecclesiastical buildings in France was that, since ventilation and views were not an issue, little or no provision was made for opening the window – in fact the structure, comprising loose pieces bolted together, would not readily have accommodated large opening sections. In England, where opening iron casements were regularly used in civic and domestic and buildings, these were invariably set in either a wooden or stone framework in order to provide stability with the tightest possible closure, with one exception: the so-called 'folding casement window' which appeared during the 1660s in aristocratic houses, and which was considered the very best that window technology could offer at the time. In civic buildings with larger windows framed entirely in iron, of similar size to the French church windows, for example, the Dining Hall, of Christopher Wren's Royal Hospital, Chelsea (1682-90), the opening lights were restricted to, two small inward opening hopper windows each the size of a single pane (panneau), about two foot square per window. This arrangement was used for ventilation in English churches as well, usually with only one small opening light or ventilator, and something similar must have obtained in France. The iron casement only became a factor in French civic and ecclesiastical architecture with the advent of industrialization in the mid-18th century, and much later in the domestic field[62]. In choosing iron over wood as the structural material for the windows of the Paris Observatory, Perrault would, therefore, immediately have been faced with the problem of having to devise a special way of opening the windows sufficiently for the needs of the astronomers. It remains for us to try and figure out, on the basis of the available evidence, how this matter was resolved.

Part Two: Conclusion:

A. *The Selection of Material & Type*: In order to build up a plausible scenario for the fenestration of the Paris Observatory the obvious place to start is with the most secure pieces of evidence, the building records: From the accounts it is known that Etienne Doyart, master locksmith in the royal office of works, was paid about 19,254 livres for iron windows and related work on the building between 20 May 1672 and 19 April 1673[63]. It is the only specific entry related to windows for the main period of construction. The exact number of windows involved is not stipulated, but it seems likely that the payment was for the seventeen iron windows of 7 x 21 foot that figure in the glazier's contract of 1679. At first sight the cost appears excessively high for so few windows (i.e. about 1133 livres per window), but a comparison with the locksmithry contract for the iron windows of the new chapel at Versailles (1707-10) puts this figure in perspective. There, the total cost for about 44 windows of varying sizes came to 62, 069 livres, of which 22,848 livres went on 11 large tribune windows, each about 9 x 27 foot, and 13721 livres on 10 attic windows of 7 x 16 foot[64]. The chapel windows were more ornamental than those of the Observatory, hence their higher cost per unit, but the overall format and method of construction were similar, so the above assumption seems reasonable.

There is no indication as to the intended location of these iron windows within the building in any of the original documentation, nor is there any surviving evidence in the fabric of the building itself. What we do know for certain is that they were installed at the time of building the Observatory in the late-17th century and survived until the 1770s. Cassini IV's report of 1775, which is quite specific as to the number and location of these seventeen windows, places them on the second floor of the south front giving to, what became known as, the '*Cabinet des Secrets*', in the west tower, the *Grande Salle* and its flanking vestibules in the middle, and the, initially roofless, observation room in the east tower [see Figure 6, top plan]. The window openings on this floor are 22 foot high by 7'6" wide, which allows for the fitting of the iron frames within a timber sub-frame (an arrangement that was adopted for the late-18th century replacement windows as well). As for the date of their installation, there are two possibilities. Either the windows were stored off-site until 1680, when the accounts next refer to them specifically (see below), or, they were installed directly upon completion early in 1673, in sequence with the rest. The latter seems the more likely course of action even though work on the upper vaults and the roof was still in progress at the time[65], because the floor had to be made habitable so that the scientists Picard and Roemer could move into their living quarters on the east side of the building. It is recorded that when they did so later that year the windows on that floor were in place, but still unglazed[66].

The glazing contract for the building that had begun on the lower floors in May 1672 continued until November 1673[67]. Presumably this concerned every window in the building except the set of seventeen iron windows on the top floor which, since Charles Janson's contracts of 1679-81[68] make no mention of existing glazing, seem to have remain unglazed for five-and-a-half years! There could have been several reasons for this delay: Up to 1676 when the roof terrace were finally completed resources in the Observatory project would have been channeled towards this structural work and the windows might have been considered a luxury item. Moreover, the glass specified for this contract was a rare commodity, much in demand elsewhere on the royal projects, and so were the master craftsmen. Colbert's abrupt halting of the glazing contract shortly after it had finally resumed, on 23 June 1679 (see above, page 22), is an example of this pressure. By the time that attention turned to the windows again, the original glazier appointed to the building, the Widow Vierry, was no longer around, nor was the locksmith who made the windows in 1672/3, Etienne Doyart (apparently he died in 1676). The latter's replacement, Thomas Furet, was occupied until June 1680 with making the balustrade to the main staircase of the Observatory[69].

It is also possible that there were technical problems with the windows that had to be sorted, seeing that Furet had to carry out extensive alterations in 1680[70]. Good practical causes for the delay therefore existed. For the scientists, who ever since 1671 had effectively been living on a building site, it must have been just one more inconvenience they have had to endure, but considering that the windows gave onto general work spaces, one of which (in the east tower) had no roof anyway, the situation was probably not unduly aggravated. Moreover, although not specifically provided for in the accounts, it is likely that the iron windows were fitted with oiled paper or linen as a temporary glazing measure (A common practice on building sites during the period) and they almost certainly would have been provided with shutters (hence the earlier suggestion about the latch, see above page 35).

The contract for glazing the iron windows in 1679 allowed for 165 livres per window, i.e. 2805 livres in total. However, the amount actually paid out to Janson between 1679 and 1681, specifically earmarked for the Observatory windows, came to only 1100 livres, a shortfall of 1705 livres and enough for only seven out of seventeen windows. There are further payments to Janson after 1686, one of which (25 December 1689[71]) is large enough to have included the remainder of the contract sum, but these covered work on other buildings as well, which means that it cannot be regarded as conclusive evidence. The very fact that this contract was referred to the notaries in 1686 (which is probably the reason why it alone survived) suggests that it was under dispute, so it is possible that the terms of reference may have changed in execution – the glazing in the open east tower might have been omitted, for example, or, a cheaper type of glass substituted for the windows in the two towers. It is impossible to be sure. Cassini IV's report appears to confirm the use of the original contract design in at least some of the windows.

As for the rest of the windows in the Observatory: On the basis of the evidence of the building documentation it would appear as if they were all made substantially from wood. In view of Claude Perrault's special interest in the use of iron as a building material (as was demonstrated by his contemporary work at the Louvre [72]), it is possible that iron might have been the initial choice for most of the windows in the building, or at least all the larger ones. But, the changes in the brief brought about by Cassini I's insistence on turning significant sections of the Observatory into living quarters for scientists, brought different criteria into play. Wood, well established in residential architecture as the best performing material for achieving weather-tight fenestration, thus became the more appropriate choice with the use of iron being reserved for a few spaces of special social/symbolic significance.

No doubt cost would also have been a factor in this decision. From the late-1660s onwards all royal projects in Paris were negatively affected by the progressive switch of resources towards the building of Versailles and funding the later construction phases of the Observatory appears to have been problematic. In such circumstances the relatively high cost of iron windows would definitely have counted against their selection. Cost, likewise probably dictated the adoption of leaded glazing (panneaux) for the majority of Observatory windows instead of the increasingly fashionable wooden-barred frames (à petits-bois) - the estimate for the windows of the unexecuted octagonal observation pavilion of c.1670, discussed above, shows that the latter type of construction was 20% dearer per unit area[73]. From this it is clear that although the windows are not specifically identified within the accounts, the contract for wooden windows must have constituted the main part of the total sum of c. 19200 livres spent on joinery at the Observatory between 1671 and 1683, just as the 17 iron windows accounted for most of the outlay on locksmithry.

B. *Method of Operation, Structure & Appearance*: The most reliable reference points for a reconstruction of what the original wooden windows in the Observatory might have been like are the surviving drawing of the two *portes-fenêtres* for the roof pavilion project of c.1670 [Figure 5] and the report by Cassini IV of the state of disrepair of the Observatory windows in 1775. Cassini

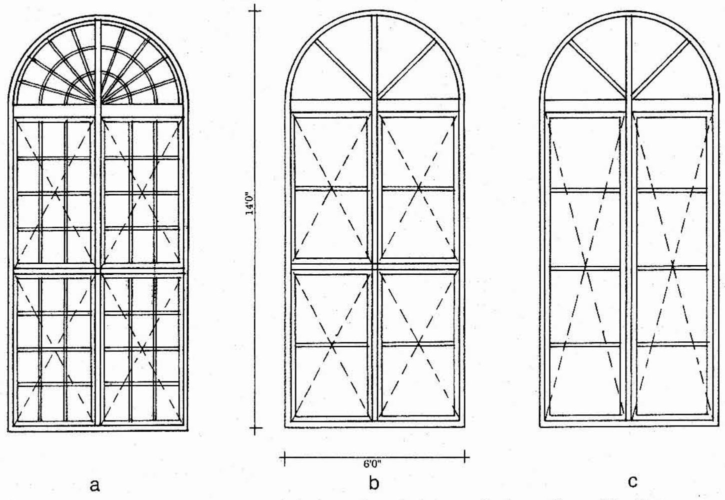


Figure 14. Suggested configurations for the original wooden windows on the lower floor of the Paris Observatory, on the south side. a) The new arrangement proposed by Cassini IV, b-c) Possible variations for the original leaded wooden windows, with either four or two casements per window.

mentioned eight 'ancient windows' on the first floor, south side, that were in a very poor condition. From his description it is clear that these windows had a timber structural frame that divided the window in tiers and were fitted with the traditional leaded panes. The frames themselves were still in a good enough state so he proposed to re-use these in order to save money, but to replace the leaded panes with four wooden casements, each comprising 12 windowpanes (*carreaux*) of 12 x 8 inches. [Figure 14a] Not only does this information allow a reconstruction of what the composition of the original window frames on this floor might have been [Figures 14b-c], it also raises the possibility that there were yet another variety of wooden window in the building, where the glazing was set in sash-bars (*petits-bois*) – the system which Cassini IV preferred.

In his account of the problems that he had with the ancient iron windows on the second floor of the south façade, Cassini specifically excluded the windows on the staircase to the West, stating that they were in good repair, and since he did not mention any of the other windows in the building on the north and east sides, we can assume that these were of a similar condition. It is, of course, possible that all these windows have been replaced at some stage during the 18th century with more durable wooden-barred casements, but no evidence to that effect has emerged. The example of the un-built observation pavilion of 1670 shows that the two glazing systems were sometimes mixed in new-built structures, for what reason is not entirely clear. Also, the pane size specified by Cassini was a common one for the late-17th century, but would have been rather old fashioned for the late-18th century when large glass panes were plentiful. Cassini himself used large panes in the window design he proposed for the top floor [Figure 7] and the panes of the wooden windows that were eventually installed in the building during the restoration of 1780-5, were 16.1/2 x 13.1/2 inches (530 x 420mm.). It is, therefore, conceivable that he might have been trying to harmonise the replacements with an existing fenestration system, and that the confused messages about the appearance of the Observatory windows that we get from the various engravings are a consequence of there having been several different types of window in one building.

The principal clues as to the structure and functional format of the iron windows on the top floor

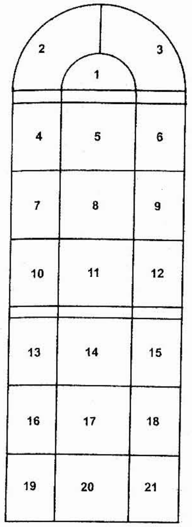


Figure 15. Diagram showing the probable arrangement of the leaded lights in the iron windows as stipulated by the 1679 contact.

of the south façade of the Paris Observatory come from the glazier's contract and the report by Cassini IV. If we take as a starting point the one accurate piece of contemporary visual information available, namely the contract drawing of 1679, it shows what is evidently only a section of one of the windows in question, which, logically, would be the bottom half. The contract stipulated a seven feet wide iron frame, 21 feet high with 21 leaded glass panels or lights. Scaling from the drawing [Figure 4] the size of the lower frame can be established, as well as that of each individual light: 7'- 0" x 8'- 3" for the frame with nine lights, each 2'- 9" high, those in the middle being 3'- 0" wide, flanked by a row of 2'– 0" wide lights on either side. This allows for a nine-paneled top frame of exactly the same size and arrangement as the bottom one, plus a three-paneled arched light, with two, six inches deep transverse bands allowing for cross bracing in-between the frames [Figure 15].

The tri-partite vertical arrangement of the lights with a wider central section, Format A [Figure 16a], reflects that of most church windows from the period (although those usually culminate in an ornamental circular or oval light centred in the arch), but does not correspond with anything shown in engraved views of the Observatory. There are some similarities with the arrangement proposed by Cassini IV as a replacement in 1775, which, as was suggested before, could have been inspired by what he found in the building at the time. Transverse bands like those shown are often found worked into the subdivision of large window frames in 17th century French buildings, usually to coincide with the articulation of the classical orders of the façade as, for example, at the springing of the arch in line with the capital of the pilaster or column.

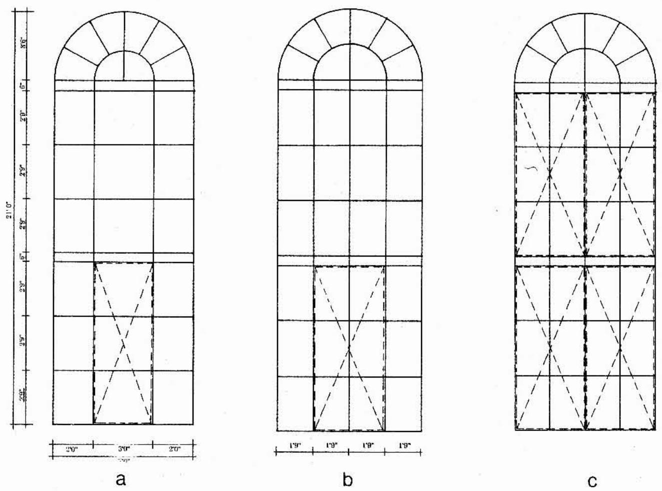


Figure 16. Suggested configurations for the iron windows on the top floor of the Paris Observatory, on the south side. a) Arrangement based on contract information, b) Arrangement based on the evidence of the engravings, c) Arrangement showing the maximum possible open-able surface area.

An alternative arrangement, Format B, one that corresponds more closely with what the engravings suggest, is shown in Figure 16b. This allows for all leaded lights to be of equal size (1'- 9" x 2'- 9") throughout, arranged in four vertical rows. However, this adds up to 27 glazed lights, which is contrary to the 1679 contract. This raises the possibility that the alterations carried out by Furet between February and April 1680 on the windows made in 1672/3, involved rearranging the structural grid of the frames. But, if so, which format changed to which, and at what point?

The doubling up of the frame for the central bay in the drawing suggests that this section was meant to be a single opening light, (3'- 0" x 8'– 3") and as the rest of the window is not shown the logical conclusion is that there were no other open-able parts intended. An opening light, of this size and about three feet above floor level, would probably have sufficed for indoor observations of the kind illustrated in the engraving of the interior of the near contemporary Greenwich Observatory [Figure 11] - where the casements are about 7'- 0" x 2'- 0" and the door consists of two leaves, each about10'- 0" x 2'- 6"(English Feet). Such a single opening light could have operated either as a side-hung casement, or, as a sliding sash, both solutions requiring significant adjustments to the traditional French iron window frame. The advantages that the sliding method (assuming counter balancing) offered over the casement were primarily ease of operation, compactness and stability. All of these were important considerations in this instance. The first two to facilitate optimum usage by the scientists who had to manoeuvre awkward equipment, the last mentioned to secure the building in inclement weather conditions. The Observatory site, on top of a hill, is exposed to strong winds, as the builders and the occupants found out to their cost during a violent storm on the nights of 21 and 22 September 1671, when the building was not quite finished, and which destroyed some of their equipment[74].

The casement, on the other hand, offered greater flexibility and a larger percentage of open-able surface area per window. This method, as is demonstrated by wooden windows of the period, permitted a variety of solutions, from having each single pane opening independently, to having only four large, three-pane casements achieving a total opening area of 115.5 square feet [Figure 16c]. Some engravings even suggest that the opening sections extended into the compass head, but it is highly unlikely that so much open-able area was required from the Observatory windows at any level because of the many different viewing options available to the scientists. Moreover, numerous very large opening sections would have required substantial structural reinforcement of the iron frame with stanchions etc. and heavy casements high above floor level would have been very difficult to operate.

All things considered, and notwithstanding the evidence of some of the contemporary engraved views, it seems most likely that the simplest solution, that of one large open-able light in the bottom half of the three-light wide frame, as suggested by the contract drawing (Format A), was the arrangement finally implemented for these iron windows, i.e. in sixteen of them because, what the glazier's contract of 1679 curiously did not provide for is that the central window on the top story of the south front, above the entrance door, was different from the other windows on that floor. This window opening is a foot wider and correspondingly higher than the rest. It has been like that from the beginning and allows for the four-light wide Format B arrangement shown on the engravings. Some engravings show the central window at some stage extended to the floor to form a balcony [Figure 9], which would have allowed for an arrangement of an iron frame in configuration very close to what Cassini IV proposed, c1780 (compare Figures 7 and 17b)

However, the painted view of c1672/3, by Testelin clearly shows the sill height of the central window to be level with the others, and this is confirmed by the survey drawings of 1692. This evidence seems to outweigh that of the engravings and one can only speculate as to why the engravers would have indicated such a feature if it never existed!

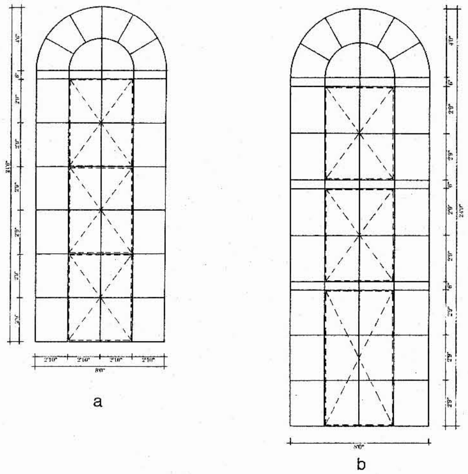


Figure 17. Suggested configuration of the central iron window on the top floor of the Observatory, on the south side. a) With its sill level to those of the other windows, b), With the window extending to the floor as suggested in some engravings.

This leaves us with a central window that is only about six inches higher than the others and about one foot wider, which allows for an iron frame, 21'- 6" high x 8'- 0" wide. As Figure 17a shows, it could still have been fitted with a three-tiered opening light arrangement operating as a combined system of a casement with sliding sashes over that may have served as the model for Cassini IV's highly unusual design proposal of 1780. This is, of course, pure conjecture, but neither impossible, nor improbable in view of the likelihood that the Observatory was the building project for which Claude Perrault had developed his counter-balancing window system shown by his brother, Charles to the Swedish envoy in 1693. And, there is one more piece of evidence that lends support to the suggestion that iron sliding windows were indeed used in the building. In Cassini IV's report on the state of the Observatory windows in 1775, where he described one of the glazier's tricks to hide scamped repair work, he noted that they would hide broken panes and operating mechanisms by leaving them stuck in a raised position[75]. This observation only makes sense if one thinks of a sliding window where the sashes slide behind each other, sometimes getting stuck in that position and thus could obscure the glass of the hindmost sash from view. With rusting iron windows, that would have been a common occurrence.

It is not difficult to see why and how Claude Perrault, the scientist and inventor, when faced with the challenge of finding a novel way to open the very heavy iron windows of the Observatory, would have hit on the idea of employing a counterbalancing mechanism to operate a sliding system. As an architect, he would have known about the mullioned type of sliding wooden window, used in Paris ever since the 1620s[76]. Those were not counter-balanced but, like other experimental scientists of his day, Perrault would have been familiar with (in fact, may even have designed) instruments operating typically with a system of counterbalances, consisting of lines, weights and pulleys[77]. There is also a possibility that he may have arrived at this solution - as was so often the case with him - through his translating of Vitruvius's *Ten Books of Architecture* where, (Bk. IX, Ch. VIII), there is an account of a system devised by Ctesibius of Alexandria for raising and lowering a mirror in a barbershop by means of lines and pulleys[78]. Although Perrault did not comment on this particular passage in either of the two editions of the work produced in his lifetime (1673/84), he was actually working on this translation at the time that the iron windows were first installed at the Observatory, 1672-3, and it would not take much for an inventive mind like his to make the connection. If it was in fact the case that this device was fitted to the Observatory windows at this time, rather than in 1680 when the work was completed, it places Perrault's invention of a counter-balancing system for windows very close in date to the first appearance of the counter-balanced window in England. There its development has also been linked two scientist/architects, Christopher Wren and Robert Hooke.

The counter-balanced vertically sliding window, or, 'sash-window' - as it became known in England - made its first appearance c.1670 in London, in Whitehall Palace. It was a further development of the un-balanced wooden sliding window with a central mullion - imported from France about a decade earlier, which was then transformed at the Royal Office of Works under the surveyor-ship of Christopher Wren. The new window type first received its characteristic two-light format in 1674, in a building designed by Robert Hooke, and from then on its development progressed rapidly, becoming within a generation the staple of fenestration practice in England[79], in contrast with France where the idea never caught on. It is conceivable that Perrault may have heard about the English invention through his contact with members of the English scientific community who had visited Paris, but seeing that the sash-window was still considered a novelty in the mid-1680s in London, when the first French reference to it is recorded[80], it is not likely that he would have known of its existence at any point relevant to the design of the Observatory. The reverse is also true, the chances that Wren, Hooke or any other Englishman involved with the development of the sash-window, would have known about Perrault's invention of a counter-balanced window by c1670, when it mattered, is very low indeed. It would therefore seem as if this may prove to be yet another case of parallel development rather than direct borrowing in a field where the boundaries between such categories are notoriously difficult to draw.

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The task we set ourselves with this paper was to establish: what materials the original windows of the Paris Observatory were made of; how they operated; what they looked like; the reasons for their selection, how they relate to the development of fenestration practice in France and, finally, what role the architect of the building, Claude Perrault played in the process. To many of these questions satisfactory answers have been found. In some cases, due to the incomplete nature of the historical evidence, the probability of an outcome could only be arrived at through deductive reasoning with reference to the socio-technological context. The picture that emerged from this 17th century case history, while not clear, does tell us something new about the work of one of most the most progressive architects of the era and, hopefully, contributes to a better understanding the complex and contradictory nature of invention and innovation in architecture.

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2. J.D, Cassini (Cassini IV), 'Mémoire sur les réparations à faire à l'Observatoire Royal', 23 January 1775. Copy in Bibliothèque, Observatoire de Paris, Cat. No. D5-39: 'Bâtiments et Documents'. Discussed in Wolf, *Histoire*, Chapter XIX.
3 Michael Petzet, 'Claude Perrault als Architekt des Pariser Observatoriums', *Zeitschrift für Kunstgeschichte*, 30 (1967), Heft 1, pp.10-14.
4 Antoine Picon, Claude Perrault, 1613-1688, ou la curiosité d'un classique (Paris, 1988), Chapter 10. For a perspective on the contemporary developments in scientific instrumentation see, A.van Helden, 'The Birth of the Modern Scientific Instrument 1550 – 1700' in J.G. Burke, *The Uses of Science in the Age of Newton* (Berkeley, 1983), pp.49–84.
5 See Wolf, *Histoire*, Chapters I – VIII; Michael Petzet, *Pariser Observatoriums*, pp.1-54.; Picon, *Perrault*, passim. As early as 1663 French scientists had called for a 'physical academy where there could be constant experimentation. A special structure [....] built to order.' (Quoted in Robert W. Berger, *A Royal passion: Louis XIV as a Patron of Architecture* (Cambridge, 1994), p.47.)
6 H .J. Louw, 'The "Mechanick Artist" in late-17th Century English and French Architecture: The Work of Robert Hooke, Christopher Wren and Claude Perrault compared as products of an interactive science/ architecture relationship', *Proceedings of the Hooke 2003 Conference, held at the Royal Society, London, 7-8 July 2003*, pp.248-63.
7 For an analysis of the figures see, Wolf, *Histoire*, pp.13-17. An early estimate for the total cost of the project, communicated to the Royal Society of London in April 1669, was for 100,000 livres. A.R.Hall and M.B.Hall, *The Correspondence of Henry Oldenburg* (Madison, Wisc., 1965-), V: 497.
8 BN. Cat. No. Va 304t.1. Michael Petzet, *Pariser Observatoriums*, gives the most comprehensive overview of this collection.
9 Apart from the abovementioned papers by Picon and Petzet (see above notes 3 and 4) see also, Michael Petzet, *Claude Perrault und die Architektur des Sonnenkönigs: Der Louvre König Ludwig XIV und das werk Claude Perraults* (Berlin, 2000), pp.355-395.
10 Centre Historique des Archives nationale, Paris, Cat. No. O/1/1691 piece 14.
11 The term, 'Verre de France', at the time indicated spun window glass made in Normandy in the Forêt de Lions (See Appendix to second edition of Louis Savot, *L'Architecture françoise*, revised by François Blondel, Paris 1685, p.413).
12 Centre Historique des Archives nationale, Paris, Cat. No. O/ 1/ 1691/ 14-15.
13 Bibliothèque Nationale , Cat. No. Va 304 t1 / H79513 –H79520.
14 B.N. Va 304 t1 / H79516 and H79520.
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16 Ibid., Figures 17,18,43.
17 Ibid., p.4. Guiffrey, *Comptes* I, Col.368 (see below, note 18).
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21 A redrawn version of the document, amongst the Oldenburg/Vernon Correspondence, is reproduced in Hall & Hall, VI: 147-9. Original in the archives of the Royal Society, Cat. No. EL. v. 8.Item 8.
22 Bibliothèque de l'Observatoire de Paris, Cat. No. D5/ 39. File marked: 'Observatoire de Paris: Bâtiments et instruments'. Wolf drew extensively on this material for his account of the restoration project
23 Wolf, *Histoire*, p.301.
24 Bibliothèque, l'Observatoire de Paris, Cat. No. D5 / 39. File marked: 'Bâtiments et instuments'.
25 The Département des Estampes of the Bibliothèque Nationale has an excellent series of engraved views of the building, dating from the 17th to the 19th century.
26 The most explicit view, datable to 1686 because of the large brass telescope on the roof (B.N. VA 304 t.2 / H79572), shows all the windows in the south front with a central mullion and two transoms, with three tiers of open-able lights and square panes of glass over their full height.
27 For information on the Marly Tower, a massive timber installation 40m. high erected on the south terrace between 1685-8, see, Wolf (*Histoire*, p.167). The tall timber mast for operating extra long focal length telescopes (50, 60, 100 feet) had been erected on the same terrace a few

years earlier, in 1679 (Wolf, p.162).

28 B.N. Va 304 t2 /H79592. Illustrated in Picon, *Perrault*, figure 183, p. 218.

29 Guiffrey, *Comptes*, I: col. 600. Etienne Doyart, 20 May 1672 – 19 April 1673: 'pour croisees et ouvrages de fer qu'il a fait' = 19254# 8s 9d.

30 E.C. Watson, 'The Early Days of the Académie des Sciences as portrayed in the Engravings of Sébastian Le Clerc', *Osiris*, volume 7 (1939) (reprinted, Amsterdam 1971), p.570, notes that the gazelles illustrated in this engraving were first dissected in 1671. A letter, dated 4 February 1672, to Henry Oldenburg, Secretary of the Royal Society of London, from a correspondent in Paris mentions a book on the history of animals which was, 'lately printed', (Hall & Hall, *Correspondence*, VIII: 523) suggesting late 1671 as the likely date of publication.

31 Claude Perrault's mother was Paquette LeClerc (*Dictionary of Scientific Biography* (N.Y., 1974), so it is possible that Perrault and Leclerc was related.

32 For a discussion of this work see, F. Bouquet, 'l'Observatoire de Paris: A Propos de deux gravures relatives a sa fondation', *Bulletin de la Societé astronomique de France* (Février, 1911), pp.53-6. Bouquet dates the work to the earlier part of the period, 1667-1680. A large colour representation of the painting can be found in A Zega and B.H.Dams, *Palaces of the Sun King* (London, 2002), Figure 4.

33 See, Petzet, *Pariser Observatoriums*, pp.14-5.

34 Jean Dominique Cassini, *Mémoires pour servir à l'histoire des sciences* (Paris, 1810)

35 Communication from Dr. Suzanne Débarbat, astronomer at the Paris Observatory, 6 May 2002.

36 It is known that by 1664 Robert Hooke was aware of the influence of iron in structures on magnetic instruments (See letter to Boyle, 6 Oct. 1664 (R.T.Gunther, *Early Science in Oxford*, 1930, VI: 203)), but general awareness of the implications of this for compass readings only came after tests at sea early in the 19th century. See Matthew Flinders, 'Concerning the Differences in the Magnetic Needle, on Board the Investigator, arising from an Alteration in the Direction of the Ship's Head'. Paper read 28 March 1805. *Philosophical Transactions of the Royal Society*, 95(1805), pp.186-197. Also, T.K. Derry and T.I. Williams, *A Short History of Technology* (Oxford, 1960), p.369.

37 *Le Mercure Gallant*, 11 Novembre 1686: 'M.Perrault, qui a donné le dessin de la façade de Louvre, est aussi l'architecte de ce bâtiment et ce qu'il sait de médicine et de mathématiques lui a donné lieu d'observer des choses dans la construction de cet édifice que tous les autres architectes ne sont pas obligés de savoir'. Quoted in Petzet, *Pariser Observatoriums*, p.42.

38 See above note 6.

39 On this see Berger, *Royal Passion*, p.8.

40 André Félibien, *Des principes de l'architecture, de la sculpture, de la peinture et des autres arts...etc.* (Paris, 1699), Plates XXXIX –XLII, pp.192-200.

41 On this see especially Louis Hautecoeur, *Histoire de l'architecture classique en France*, Volume II (Paris, 1948), pp.77-9.

42 There is no specific evidence to support this suggestion. On 23 January 1678, Perrault was paid 4000 livres for designs in connection with the Louvre, the Triumphal Arch and 'other places' (Guiffrey, *Comptes*, I: col.1012.). This may have included further work on the Observatory a well, and the iron windows were probably the only design issue unresolved at that stage.

43 According to the 17th century historian, Henri Sauval (died c.1670) this type of window was made popular by the famous Marquise de Rambouillet – when she had them installed at her home, c1620. However, such window/doors were recorded in use in England by 1618, when they were described as 'French windows'. Shown in a drawing for the interior of a room at Bolsover House, Nottinghamshire in *Architectural History*, 5 (1965), p.127, Plate III/ 1(2).

44 André Félibien, *Dictionnaire*, 1699, p.494 (1676 Edition, p.706).

45 Claude Perrault, *Les Dix livres d'architecture*, 2nd Edition (Paris, 1684), p.220 (1673 Edition, p.207).

46 On this see especially, Zega and Dams, *Palaces*, Chapter III, pp.49-95.

47 Wolfgang Herrmann, *The Theory of Claude Perrault* (London, 1973), pp.25-6.

48 Guiffrey, *Comptes*, I: cols. 738,756,757.

49 Ibid., col. 1270: The joiner, Jacques Prou was paid 8000 livres for making the 17 windows of the *Grande Gallerie*, Versailles, between 23 June and 1 December 1680.

50 R.A.Reigert and C. Hernmarck (Eds.), *Les Relations artistiques entre la France et la Suède, 1693 – 1718* (Stockholm, 1964), pp. 15-6, 20, 25. Letters dated, 18 March, 17 May and 19 June 1693.

51 Lisa Jardine, *On a Grander Scale: The Outstanding Career of Sir Christopher Wren* (London, 2002), p.315.

52 Wolf, *Histoire*, p.125.

53 For an excellent series of engravings of scientists at work see, Watson, *Engravings Sébastian Leclerc*, pp.576-587.

54 Jean-Francois Belhoste et Guy-Michel Leproux, 'La Fenêtre parisienne aux XVIIe et XVIIIe siècles: menuiserie, ferrure et vitrage', *Fenêtres de Paris XVIIe et XVIIIe siècles, Cahiers de la Rotonde no.18* (Paris, 1997), pp.15-43. Also, unpublished paper by G-M Leproux, 'L'apparition du chassis a carreaux dans l'architecture parisienne du XVIIe siecle' (n.d.), 5pp.

55 As, for example at Colbert's own residence, the Chateau Sceaux, near Paris. Designs for its windows, dated 1673, have survived in the Tessin-Harleman-Cronstrom Collection at the National Museum, Stockholm. For a discussion of the project see, Michael Petzet, 'Plänungen für Sceaux, das Schloss Colberts', *Zeitschrift für Kunstgeschichte* (1986), pp.502-35.

56 As scaled from contemporary drawings published in Zega and Dams, *Palaces*, Figures 47 and 54.

57 Sizes as scaled from sections in Jacques Francois Blondel, *Architecture françoise* (1756). For the St Sulpice date see, Marcel Aubert, *Le Vitrail en France* (Paris, 1946), p. 47. Perrault himself introduced a large iron window in his unexecuted façade design for a church in Paris, c.1675. See, M. Petzet, 'Un projet des Perraults pour l'église Sainte-Geneviève, Paris', *Bulletin Monumental*, 115(1957), p.88.

58 Weigert and Hernmarck, *Les Relations*, p.29.

59 Guiffrey, *Comptes*, I: col. 1126: 24 September – 12 November 1679.

60 Henri Sauval, *Histoire et recherches des antiquités de la ville de Paris* (Paris,1724), II:171.

61 Duhamel du Monceau, *Art du Serrurier* (Paris, 1767), Chapter IV, Plate XIV. Belhoste and Leproux note that the engravings for this came from the collection of the Académie des Sciences and date from the 1720s. Félibien, who included a section on 'serrurerie' in his *Des principes de l'architecture* (1676/1699), curiously does not discuss metal windows at all, only the various fixings and locks known as, 'fermeture'.

62 On this see especially, Cyril Stanley Smith, 'Architectural Shapes of Hot-rolled Iron 1753', *Technology & Culture* 13 (1972), pp.59-65. Such windows are illustrated in both Duhamel du Monceau (op.cit., Ch.III, Plate VI) and Diderot & d'Alembert, *Encyclopédie: Planches*, Vol.IX (1771) Plates XXXIX, XLI,XLII, where the iron window profiles are based on joinery patterns.

63 Guiffrey, *Comptes*, I: Col.600. Etienne Doyart: 'pour croisées et ouvrages de fer qu'il a fait.' = 19254# 8s 9d.

64 Idem., V: cols. 121, 211-12,313,408-9.

65 On 18 June 1674 Cassini I wrote to Oldenburg, Secretary to the Royal Society, London: 'We have a well-shaft in the Observatory prepared for this [Zenith observations], having an aperture in the vault open to the sky...but hitherto obstructed by the works of the masons constructing

the upper vault. And so it has not been possible for us to attempt anything with it so far.' (Hall and Hall, *Correspondence*, XI: 34-5, Letter no.2505).

66 Wolf, *Histoire*, p.66.

67 Guiffrey, *Comptes*, I: cols. 600, 686.

68 Ibid., cols. 1126, 1243; II: 84.

69 Guiffrey, *Comptes*, I: cols 1126, 1243.

70 Ibid., col. 1242: 5 February: 'pour les ouvrages et menus réparations de serrureries' = 39# 2s; col.1243: 'pour raccomodages de vitraux des croisées' = 1100#

71 Idem., III: col. 286.

72 See Robert Berger, *Palace of the Sun: The Louvre of Louis XIV* (University Park, PA., 1993), p.29.

73 B.N. Va 304 t.1 / 79520.

74 Wolf, *Histoire*, p.109.

75 Note marked (4) on page three of the original manuscript. It reads: 'Il l'est moins à la vérité en ce que lors qu'un panneau est brisé et enlevé on le laisse fort bien un an entire dans cet etat, mais c'est une friponnerie des vitriers que le Roy ne paie mon chers.' It has been incorrectly transcribed by Wolf (*Histoire*, p.303), who did not fully understand the technical implications of the reference

76 According to Louis Savot, *L'Architecture françoise* (Paris,1624), pp.100-1, such windows were used in the ante-rooms of steam baths. For measured examples of surviving sliding windows from the mid-17th century onwards see, Centre des Recherches sur les Monuments Historiques, *Albums relevés Vol. IV: Fenêtres (menuiserie) à chassis coulissants XVIIe et XVIIIe siècles*, (Paris, n.d.).

77 Several of Perrault's mechanical inventions were published posthumously as, C.Perrault, *Recueil de plusieurs machines de nouvelle invention ouvrage posthume de M. Perrault* (Paris,1700); M.Galon, *Machines et inventions approuvées par l'Académie royale des Sciences depuis son establissement jusqu'a à present* (Paris, 1735), Vol.I: 95-101. See also, Picon, *Perrault*, passim.

78 Vitruvius, *The Ten Books on Architecture*, translated M.H. Morgan (N.Y.,1960), pp. 273-4. The description of this device is confusingly mixed up with an account of Ctesibius's experiments with water clocks and pneumatics.

79 H.J. Louw, 'The Origin of the Sash-window', *Architectural History*, 26(1983), pp. 49-72; H.J. Louw and R. Crayford, 'A Constructional History of the sash-window c.1670-c.1725', Part One: *Architectural History* 41(1998), pp.82-130; Part Two: *Architectural History* 42(1999), pp.173-240.

80 Louw, *Origin*, p.49: A French visitor to London, C.A. de Sainte Marie, commented favourably on the new window type in a letter home, dated 8 May 1685, indicating that he had never come across this arrangement before.

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