Geometry and Symbols in Sant'Ivo alla Sapienza in Rome

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The survey of the complex of Sant'Ivo alla Sapienza in Rome was a golden opportunity to analyse the relationship between form and meaning in architecture. It was even more unique because it was part of a course in a doctoral school where survey is considered a process of critical analysis taught in parallel to technical and operational learning. The church is located within the complex of the University of Rome founded in 1303; it is one of Borromini's most important works and therefore well suited to be used to provide a critical interpretation of its geometric and syntactic structure. While the spatial solution of the dome subverts its primary design, the relationship between the structure of space and its decorations betray its strong communicative force. Use and comparison of multiple measurement and visualisation techniques provided the in-depth information required to identify the possible geometries behind the design plan.

Keywords: *Sant'Ivo alla Sapienza, dome, morphogenesis, symbology.*

The survey of the complex of Sant'Ivo alla Sapienza in Rome was a golden opportunity to analyse the relationship between form and meaning in architecture. It was even more unique because it was part of a course in a doctoral school where survey is considered a process of critical analysis taught in parallel to technical and operational learning. Contemporary survey tools, including data acquisition techniques and graphic and infographic restitution methods (representation in the broadest sense of the word), make it possible to carry out a series of in-depth historical, critical and interpretative studies ranging from identification of the geometries behind the design to detection of its symbolic aspects (fig.1.,2.).

The latter make the complex particularly well-suited to be used as a case model to study the complex relationships between form and meaning and, finally, to communicate the results of the analysis in an increasingly appropriate manner.

A study of this nature carried out in a doctoral school[1] might appear over ambitious; its scope is enough to deter any scholar given the extensive literature on the subject, a topic tackled by some of today's most eminent scholars including Argan 1952, Battisti 1967, Benevolo 1972, Fagiolo 1967, Portoghesi, Scott 1982, Wittkower 1982, Zevi, 1998 – to name but a few. However, studying important architectural works is always a fertile and major learning experience. In particular the methodological approach used in a survey, the habit of physically and virtually "touching" the monument, the chance to experience its material consistency and geometric design gives the scholar a full understanding of how an architecture comes to life, of how the allegorical, symbolic, functional and constructive requirements are first turned into geometries and then into tangible architecture. In addition, the church is now the symbol of our university: it is located in the old seat

1 The study, coordinated by Professors Piero Albisinni, Laura De Carlo and Emanuela Chiavoni, was participated in by students of the doctorate courses 23 and 24 in Representation and Survey held by the University of Rome, La Sapienza. Specifically for course 23: Sara De Felici, Annika Moscati, Annarita Pincione, Raffaele Martinelli, Antonio Mollicone, Suzanne-Marie Psaila and Wissam Wahbeh; for course 24: Daria Battista, Francesco Borgogni, Michele Calvano, Marco Cellucci, Marco Filippucci, Annika Moscati, Fabio Luce and Jessica Romor.

of the "Sapienza" founded by Pope Boniface VIII who created the *Studium Urbis* in Rome in his papal bull dated 1303. The seventeen years it took to build (1643-1660) saw the reign of three popes: these were the years when science and rational knowledge were rejected, the years when Galileo stood trial. Sant'Ivo embodies the spiritual atmosphere of the Baroque universe with its tensions, crises and contradictions, a universe tinted by amazement, speculation and curiosity; this was the atmosphere that inspired Borromini to search for unusual, strange, sometimes extravagant yet always rational and analytical interpretations – as he did here in the Sapienza. Borromini's works are an almost inextricable-merger between structure, form and design. Very few architectures inspire the same exploratory curiosity in those who have the privilege to see them and experience their plastic, spatial and light effects.

Borromini was in fact one of the most outstanding, original and dynamic seventeenth-century architects.

This was the highly significant, intriguing and complex architectural work the doctoral candidates were called to study. Borromini's dome at La Sapienza is ideal for this purpose; it provides multiple interpretative possibilities because it is a unique building that subverts the traditional Christian symbolism of the dome.Domes are by far one of the best architectural features we can use to study the spatial and geometric aspects of symbolism where the reasons behind built forms pit those created

Fig. 1. Exterior of the church (photo by Marco Cellucci).

Fig. 2. Interior of the church (photo by Marco Cellucci).

by "solidity, utility and beauty" against those of symbolism which dictates the rules needed to design architecture and determine its location, orientation, proportion and ornamentation. A built dome is an *imago mundi* that represents a vision of the world and contains a theology; spatiality represents the process.

Although the way in which astral symbolism is represented architecturally differs from one civilization to another, there are two mains forms in which it is expressed in churches: the square and the circle. We can consider the church as a cube (the Earth) crowned by the heavens (the dome). The church itself is a representation of the cosmos. Therefore the church is a universe and the universe is mirrored on a smaller scale in the church: the heavens above the earth as a representation of the universe.

Adrian Snodgrass believes that the circle and the sphere are symbols of the active principles: the Essence, because they are the most dynamic geometric forms; instead the square and the cube symbolize a passive principle: Substance, because these are more static, stable and immobile. The sphere is the most kinetic of bodies while the cube, resting on its faces, is more stable and inert than any other shape or solid. So in places of worship the interaction between Essence and Substance is simulated through the dome associated with the heavens and circular movements of the stars; the static shape of the cubic base is linked to the inert receptivity of the earth. The movement of the stars measures time, while the size of the earth measures space: therefore the union between the dome and its geometric base represents the union of time and space. In this sense the dome glorifies geometry and the art of construction midway between sacred science and building science. Complex geometric and building devices are defined to adapt the circle of the heavens to the square of the earth. Bruno Zevi used to say that domes fall like a mantle to envelop our earthly space: the heavens that fall on earth.

Generally speaking all this is present in the symbology of Christian churches, yet in Sant'Ivo Borromini subverts traditional symbolism and geometries. There are no mediating elements between the earth and sacred space, between the church and the dome: the mixtilinear plan rises for 16 metres up to the cornice and then turns into the perfection of the circle: Wittkower calls this an anamorphic transformation.

The spatial plan inside the church is linked to the exterior starting with the stepped roof at the impost of the dome; it continues in the lantern and ends in a spiral topped by a huge flame (fig. 3,4,5).

As a result, Borromini's models do not mirror Christian tradition: one of the church's most visible features is the verticality of the plan, the homogeneous ascent of a unitary space. The concept of ascent is expressed in the vertical continuity of the complex mixtilinear form of the plan which rises unbroken to the impost line of the dome ending in the spiral of the lantern. As a result the dome looses its traditional feature as a familiar form or static closure; the building is an ever-changing *continuum* and the church is designed "from the bottom up", unlike traditional domes that fall like a mantle from above.

In 1952 Argan had written "the trust downwards in a contrasting thrust upwards".

However this ascensional feature is not the only unique characteristic of the church: the decorations are a structural part of the creative unit in its complex symbolic exegesis. Borromini invents new decorative models in the church; he merges inspiration and memory, different kinds of archetypes and symbols. The iconographic elements (starting with the sphere at the top of the building, the dove, the spiral of the lantern, the presence of heraldic elements or the repetition of many well-known motifs) are all elements that have to be considered as part of his design decisions.

All the iconography is not just an ensemble of decorations juxtaposed against the spatial structure of the architecture; it is a coherent system that reinforces its meaning and indissolubly coalesces in a syntactic structure that expresses the unique nature of all Borromini's work and in particular in Sant'Ivo – his crowning achievement (fig. 6,7).

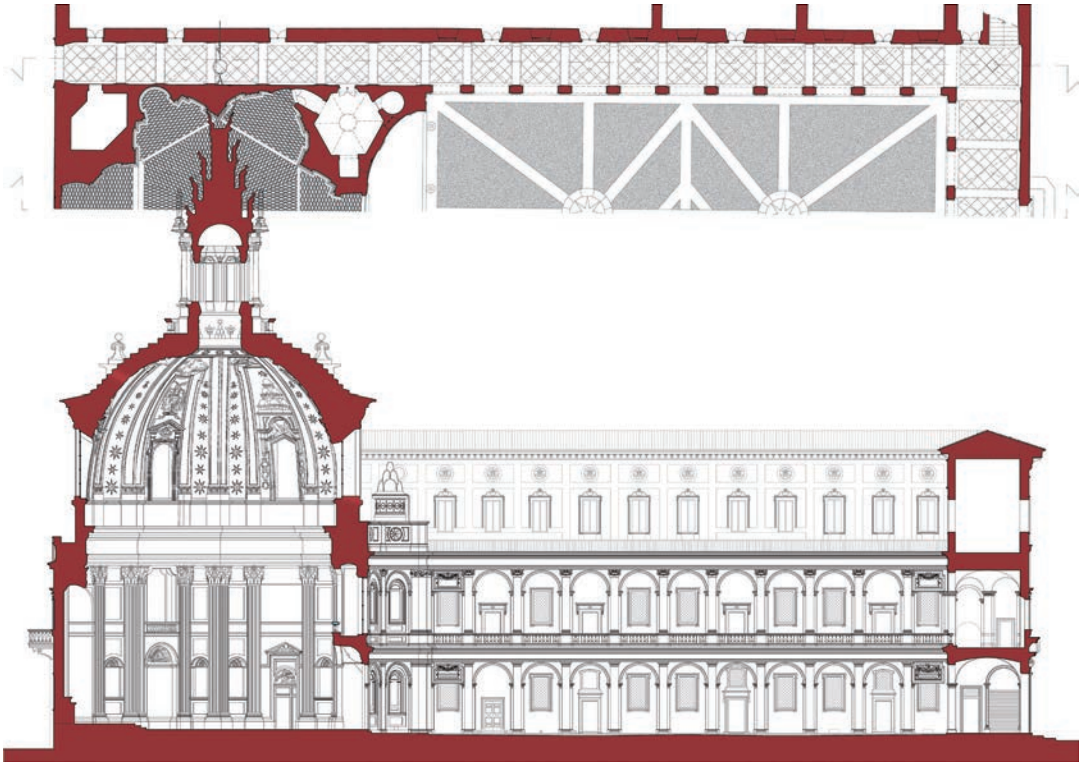


Fig. 3. 2D Survey of Sant'Ivo alla Sapienza in Rome.

Fig. 4. Section of the dome and isometric cross-section of the church represented through the model.

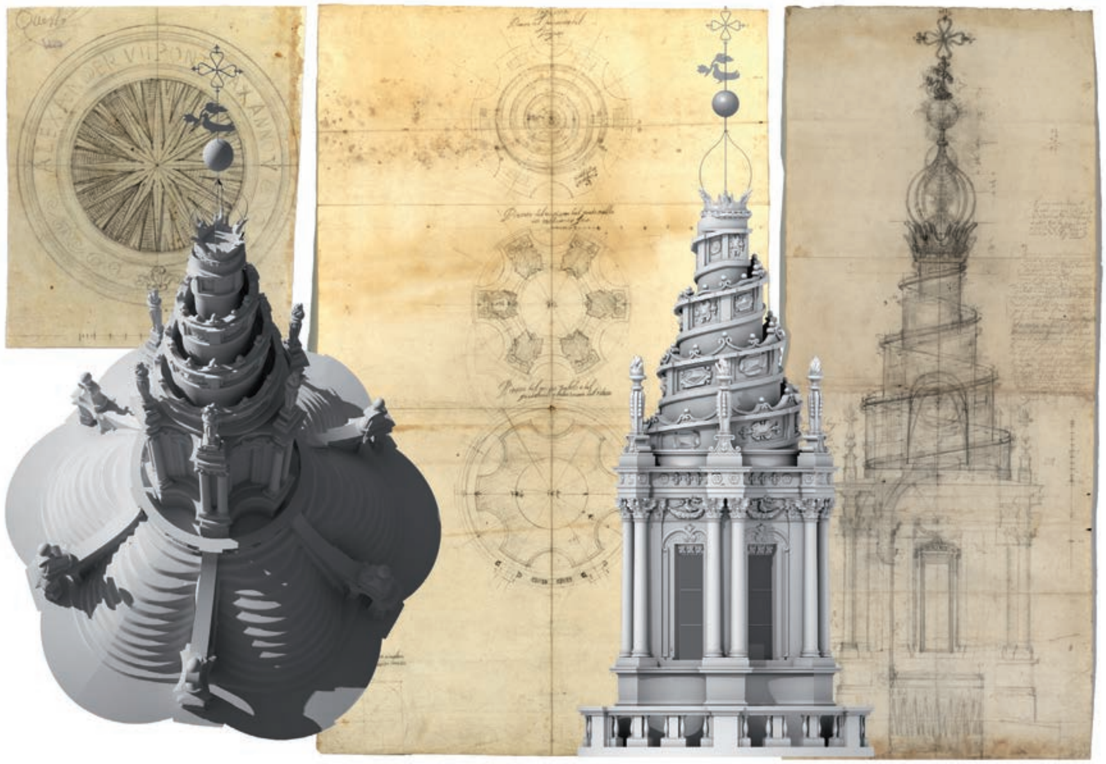


Fig. 5. Albertina library's dome and lantern drawings and 3D model of the dome.

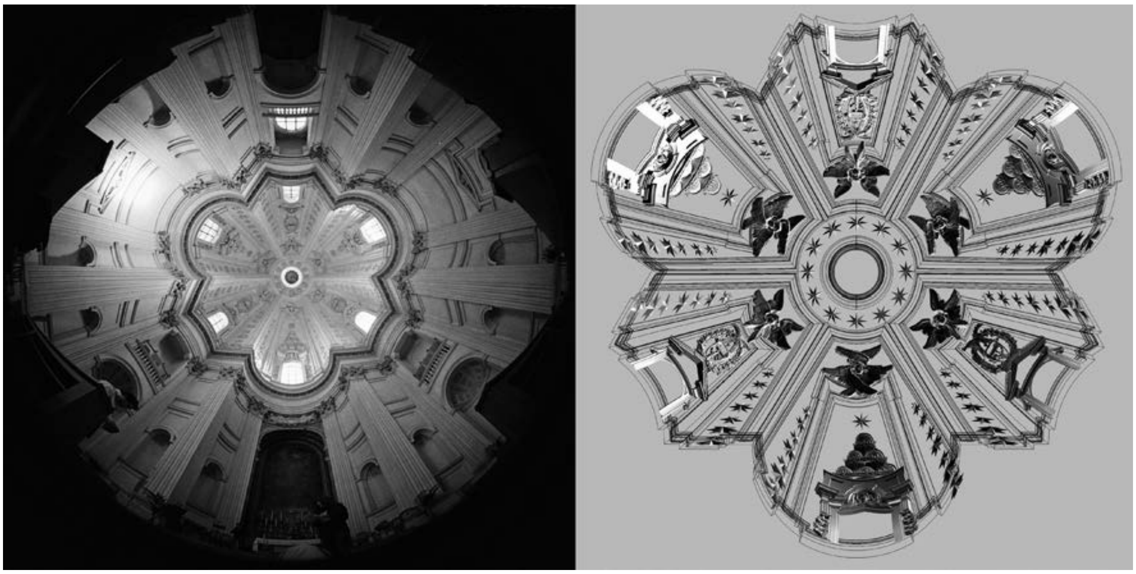


Fig. 6. Interior of the church (photo by Marco Cellucci) and the decorative elements of the intrados of the vault (elaboration by Annika Moscati based on the 3D model).

Fig. 7. Decorative elements of the soffit of the dome.

Geometric Analysis of the Plan

The analysis of geometrical genesis of Sant'Ivo Church's plan, which is expression of Francesco Borromini's genius, was very hard and so full of contradictions that it's still open to many interpretations.

After detailed cataloging of the main hypothesis, formulated in the last two centuries on this argument, that allowed to outline the history of Borromini's project's interpretations – we can think, for example, to the remarkable contributions of Fagiolo, Portoghesi, Hempel, Blunt, Stalla and Bellini – we chose to analyze a specific drawing by Borromini, called Cimeli 77 and stored at the State Archives of Rome, because it best describes real shape and dimensions of the Church and coincides almost completely with the plan we obtained by the survey, except for a few details (fig. 8).

The analysis of the drawing (including the signs of its creation and revision variously present on the paper) allowed to deny some hypothesis and formulate new assumptions, based on the comparison with other drawings by Borromini on the same subject. First of all, the relation between the single elements and the whole plan has been precisely clarified, such as, for example, the presence of the equilateral triangle, on which sides the apses are built, using a radius measuring 1/6 of the triangle side. After resizing the drawing in roman palms, that's the unit adopted by the Architect, some dimensions related to the main architectural elements have been identified: starting from the width of the pilaster, that amounts to 5 palms, and using number 3 and 7 as multipliers, many other dimensions related to other remarkable elements are resulting (e.g. the diameter of the apses measures 35 palms, the side of the equilateral triangle measures 105 palms).

The overlapping between the survey of the existing plan of the Chapel and the plan designed by Borromini in the drawing Cimeli 77 is practically perfect, except for the solutions chosen for the realization of the altar and of lateral Church access.

The plan's project is probably related to an equilateral triangle whose sides measures 105 palms, as we can see in the metric scale designed by the Architect in the upper side of the sheet. Borromini aligns the main access of the Chapel and the high altar on the first triangle's axis, that coincides with the longitudinal axis of the entire building; along the other two axes he places the other altars and the accesses to the vestries (fig. 9).

After tracing transverse axis of the Church and the circle that intersects the triangle, dividing every sides in three equal parts (105 palms / 3 = 35 palms), the Architect draws an hexagon whose sides measure 35 palms. On these sides he sets up an alternating rhythm of concave and convex shapes that characterize the spaces taken by the altars, the big niches and the access. The circle traced around the equilateral triangle is tangent to the exterior side of the back wall of the Chapel (fig. 10).

We can suppose that Borromini traced a second circle, between the ones circumscribed to the triangle ad the hexagon, whose diameter coincides with the width of the building. This circumference trims the triangle's axes in important points, highlighted by the Architect with three crosses corresponding to the altars. This circumference is also tangent to both big niches and the hexagons of the vestries.

The big niches, in which you can find the accesses to the vestries, are geometrically built on a circle, whose diameter corresponds to the side of the hexagon. The center of this circumference coincides with the intersection of the triangle's axis and its side. On these circles are built the anterior sides of the columns, that measure 5 palms width. A niche, that measures 6 palms width, is placed between the two columns, on both sides (fig. 11). Borromini uses the same geometric construction for the apse, but with a difference: the circle is translated upward of 1 palm in the longitudinal axis (fig. 12).

Regarding geometric analysis of the niches of the minor altars, we have detected – by a careful observation of the signs traced on the drawing Cimeli 77 – a complex succession of constructions that was probably used by the Architect for drawing the arc of circumference that generates the niche of the minor altar (fig. 13). As in the case of the big niches, the columns are 5 palms width, the semicolumns are 2,5 palms width and the space between them measures 8 palms. There is a little niche of 6 palms width between the columns.

The columns and the big arc that connects the straight wall to the big niche are built on a series of concentric circles, whose centers are placed on the vertexes of the equilateral triangle (fig. 14).

The placement of the main triangle along the longitudinal axis of the church is still difficult to define and we can't give certain answers to the several questions that concern to the geometrical plant of the Chapel. However, as demonstrated by our more recent analysis conducted on some

Borromini's drawing of the Church's project, the answer to this intricate question can be very easy, if we think that the it can be mostly related to structural conditions: in fact, we must not forget that Borromini was working in a complex architectural context and he faced a series of significant constraints given by pre-existing structures, toward whom he operated with an attitude of integration and continuity. Therefore, those constraints may have suggested to the Architect how to place the new Chapel, for structural and logical reasons.

Anyway, as everyone can see looking at the inner space's articulation of the Church, the geometrical concept applied to the complex and articulated plan of the building also characterizes, with a growing emphasis, the entire architectural structure and guides the dome's spatial development.

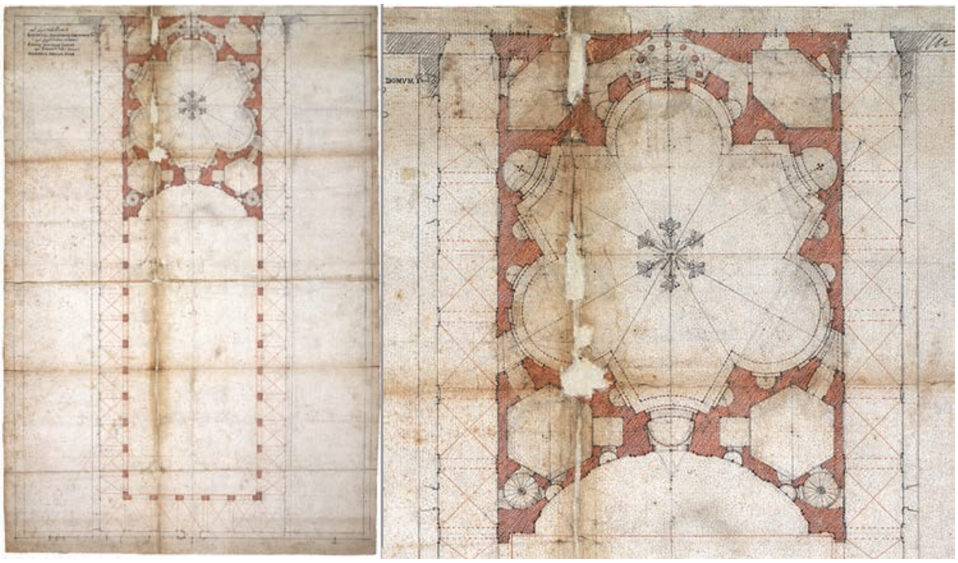


Fig. 8. Autographic drawing by Francesco Borromini called Cimeli 77, stored at the State Archives of Rome.

Fig. 9. The equilateral triangle, 105 palms sided, that is probably related to the plan's project. The metric scale is represented by the Architect in the upper side of the sheet.

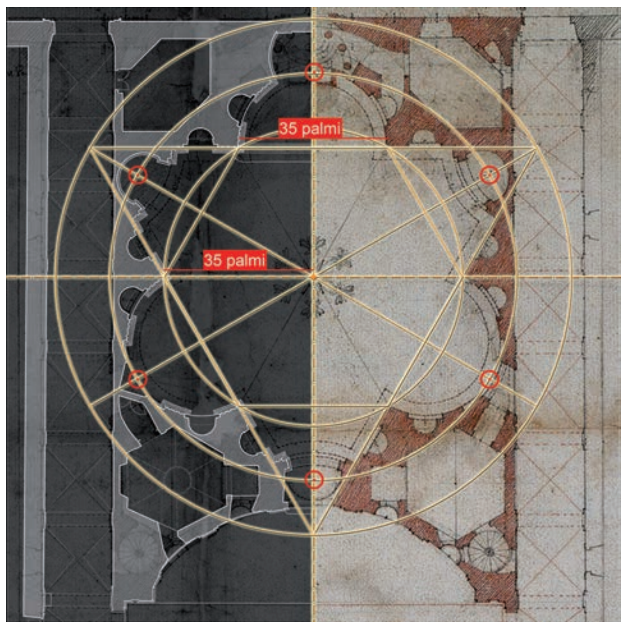
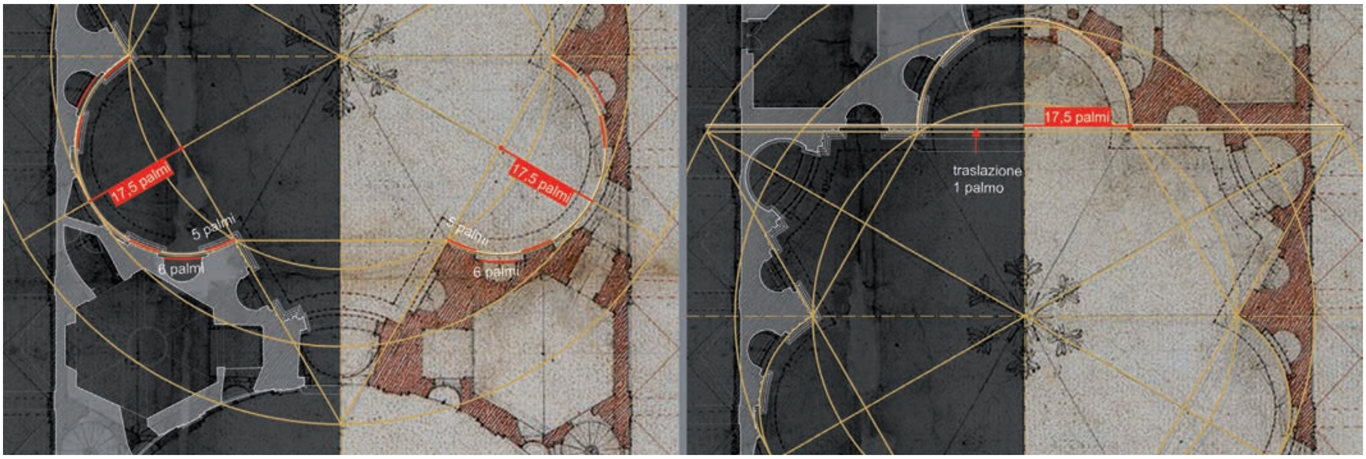


Fig. 10. The alternate rhythm of concave and convex shapes that characterizes the spaces taken up by altars, big niches and access.



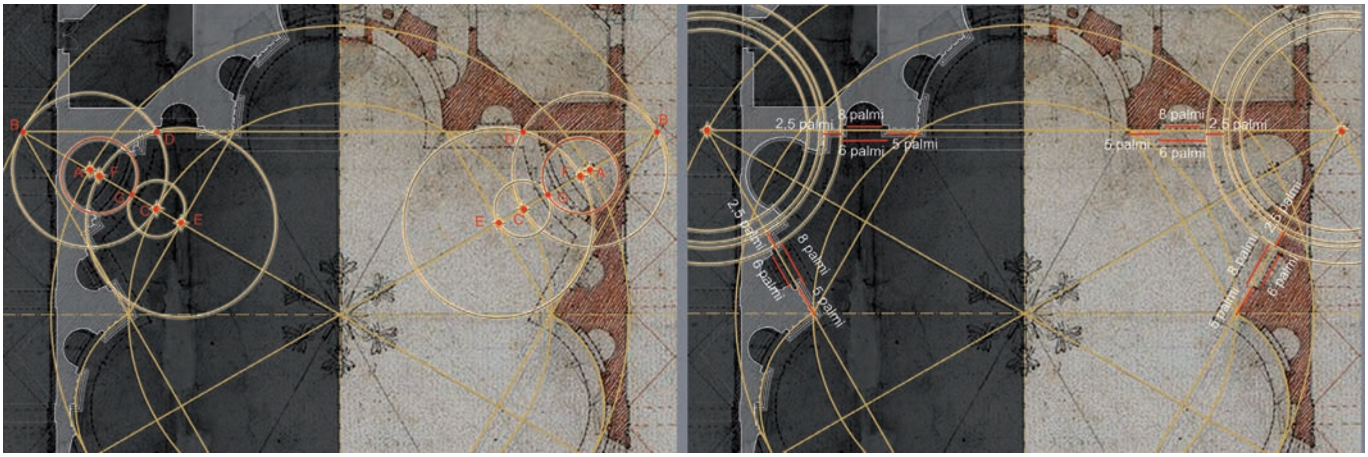


Fig. 11,12. The semicircles on which anterior sides of columns are built and the same construction used for the apse.

Fig. 13,14. The arc of circumference which generates the niche in correspondence minor altar, and the series of concentric circles centered at the vertices of the triangle that govern the performance of the pilaster and arch of connection between the straight portion of masonry and the niche.

Morphogenesis of the Dome's Surfaces

This interesting masterpiece of Francesco Borromini is one of the most complex domes in the world from the geometrical and structural point of view, despite the relatively small size of the church.

Borromini in this church kept the complex geometrical rhythms of the interior plan growing vertically to create the dome, which covers the church and terminate on the top with an oculus starting his famed spiral lantern.

The most interesting architectural quality in this dome is how Borromini could transform all his church complex plan curves growing up with the dome into a single ring in the top without noticeable interruption. And the most remarkable structural feature which is unusual in domes configuration, observing from the interior, is the presence of concave surfaces as components of the dome to continue the concave walls of the church, so how could a genius like Borromini overcome a problem like this, and challenge himself as an architect?

The dome height is about 12.5 m the first 2 meters are vertical, then it starts to bend inwards. The diameter of the circle area which is covered by is 16 m. In plan, as the church, it is divided mainly in six segments of two types, three segments composed of one arc with a centre inside the church plan (convex segments) and three segments composed of three elements a central arc with the centre outside the church plan and two lateral direct lines (mixed segment).

The analysis started with a Point cloud from one central Laser scan by Leica HDS3000 Scanner which covered almost all the dome. Then, the point cloud was sliced by series of horizontal sections every 50 cm of height with a high accuracy reading, sections were plotted again interpreting every horizontal section. It was easy to recognize that the section elements were straight lines or arcs of circles (fig. 15).

By observing the sections from the top view, it is noticeable that all sections are similar, while moving higher through the sections it is noticeable that the arcs of convex segments become more curved and those of the concave segments become less curved. However all arcs centres move toward the centre of the dome as going higher in the sections. Completing the circles of the arcs was the revelation "with minimum approximation. All circles are tangent in one point". Those circles as a movement from the bottom to the top, they starts from the bottom with the same radius for the two types of segments. Since, the point of tangency for circles of the convex segment is inside the church, consequently, going higher the circles become smaller to cover the church. On the contrary, those of the concave segment, which have the point of tangency outside, becomes bigger, that's why arcs becomes less bend.

This is the creation of Borromini to overcome his problems with a simple geometrical solution, which is even simple to apply in the site workshop. Therefore, the concept is that the form of the dome is based on horizontal steps as if the carpentry of the dome consisted of arcs of wood with a centre on the same height of every arc in this way, getting higher the arcs create dome surfaces connecting the horizontal arc in the tholobate with the oculus of the dome without interruption.

In the case of the convex segments, since the point of tangency is close, going higher needs more than half circle arc to cover the segment then the convex surface tends to close before the arrive to the arrises between the surface of this segment and the two neighbour surfaces (fig. 16).

This problem was solved by Borromini by placing a wide moulding on the ribs. Therefore, at this point the moulding is not only a decorative element but even an geometrical solution and the width of the moulding was commanded by this: After positioning the centre and fixing the radius of the vertical arc of the ribs, he determined the total height of the dome to which he had to arrive with his series of tangent circles which becomes smaller to create an arc in their vertical section which cross the centre of the segment. Then, the width of the moulding projection in plan was determined to cut the last circle on the top exactly to a half and this width was a fix offset from the rib edge projection in plan then, having the point of tangency fixed in that place cannot permit to close dome with the oculus by a smooth surface if circles can't break this rule in moving their centre to coincide with the centre of the oculus at the top (fig. 17).

Therefore, Borromini in this case decided, instead of breaking the rule, to continue with this system to the entire height then to cover the last part, which is about 1m, with a horizontal element covering that unwanted interruption with his beautiful angels.

This problem does not exist in the concave type of segments where arcs can arrive to the top, so we can notice that the three angels of the convex segments are quite higher than those of the concave segments (fig. 18).

While the angels of the mixed segments are covering another unwanted aspect, the wings of the angels are covering the edges produced by the intersection between the three surfaces which consist the mixed segment. In addition, the entire angel hides the transformation caused by overturning the direction of the central concave surface of the segment to fillet it with the ring around the oculus in the dome, Borromini tried to pinch it going higher by the two neighbour surfaces. We can notice that in the lower part, where the inclination is minimal (and where he opened the windows), the convex surface is bigger than the other two in the mixed segment, but in the higher part, where the inclination is greater, it becomes the smallest surface and horizontal arcs which are almost direct at this height, therefore, he could even use direct beams to support the weight, since the great weight of the lantern is supported by ribs arcs. In addition, the presence of concave surfaces is magnified by the vertical shift of the Dome. For Borromini, those angels and mouldings were not only symbols and decoration elements of the dome whereas a very important element to refine his geometrical solution (fig. 19, 20).

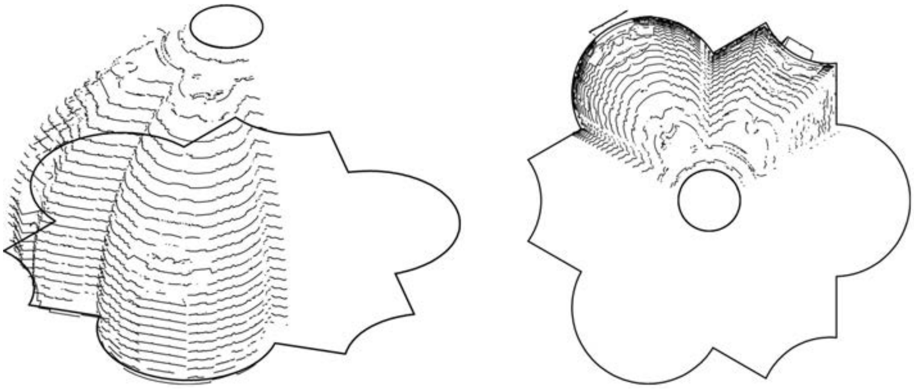


Fig. 15. Series of horizontal sections.

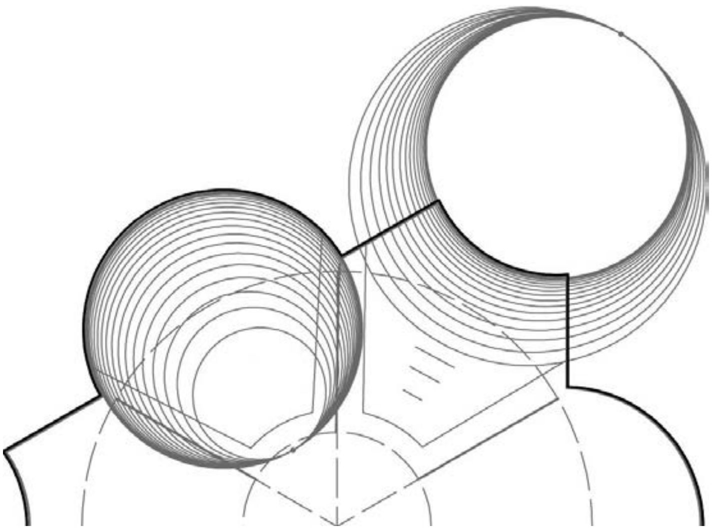


Fig. 16. Arcs of tangent circles generate internal dome surfaces.

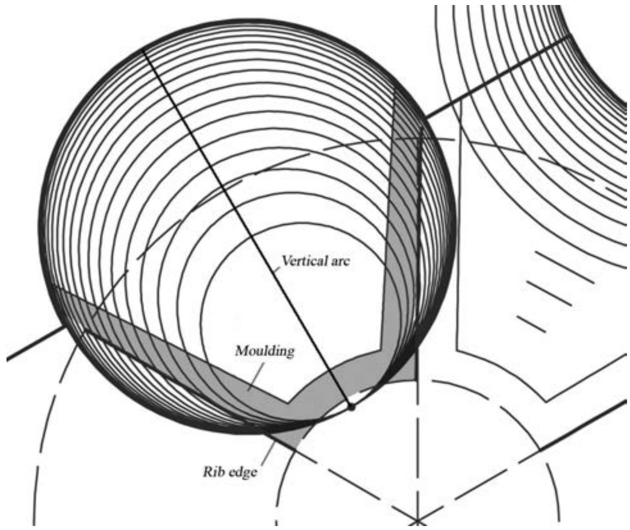
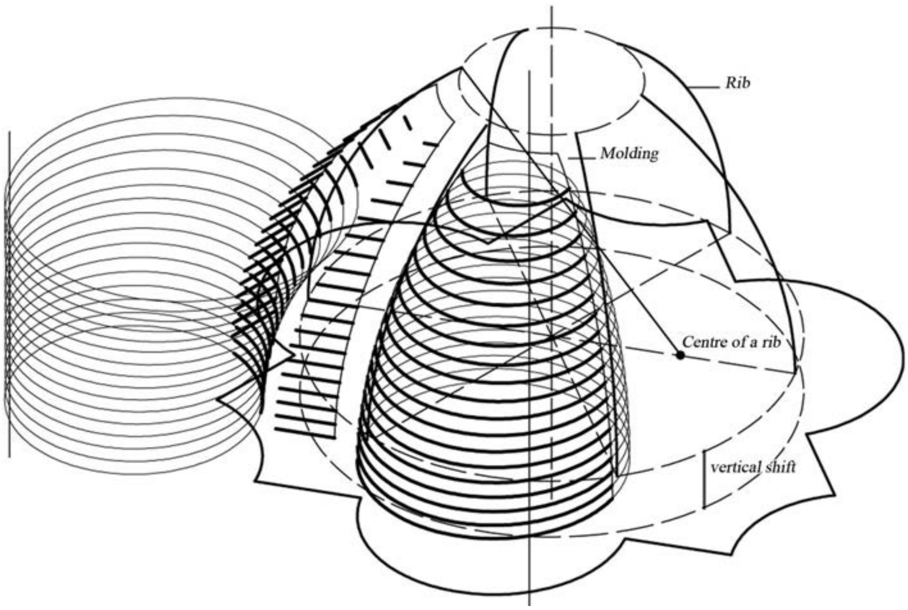


Fig. 17. Without the moulding in this position and size the curve surface tends to close going towards the point of tangency, even, the upper part of the surface cannot be terminated by Ribs edges.

Fig. 18. Section in Convex segment of the Dome's point cloud shows the horizontal part at the top covered by the decorative angel.



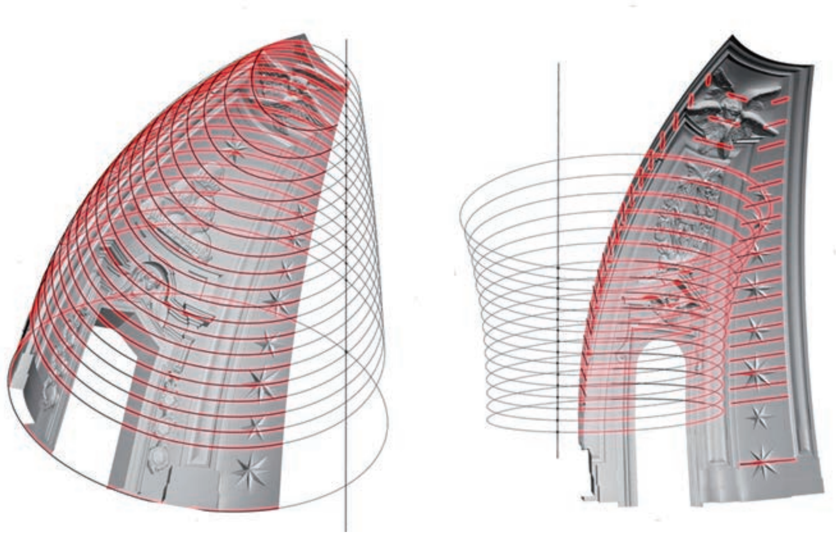


Fig.19, 20. Geometrical reconstruction of the two types of segments in the dome. Virtual reconstruction of the two types of dome's segments.

In this articles the first part is by Laura de Carlo and Emanuela Chiavoni, the second part, Geometric analysis of the plan by Jessica Romor and the third part, Morphogenesis of the dome's surfaces by Wissam Wahbeh.

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