

## **The Ruled Geometries of Marcel Breuer**

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In the 1950's, architectural structures began to be built that seemed to have more in common with the incipient space race than traditional buildings. Thin shells with double curvatures mostly with saddle shaped forms began to roof large and small buildings. These forms were characterized by their purely mathematical, abstract qualities. While the forms looked exotic, the ability to make these complex curved surfaces came from a simple generator, the ruled surface. Using these ruled surfaces, a complex curve can be made from straight lines, making the construction of these surfaces possible for the technology of that era.

A ruled surface is a surface defined by sweeping a line in space along two paths. The swept lines are known as rulings. The two paths at the endpoints of the lines are known as the base curve and the director curve. The simplest ruled surface is a plane; a straight line swept along two parallel, straight line base and director paths. Two other simple ruled surfaces include: cylinders, a line swept between circular base and director curves; cones, a line swept along a circular base curve and held at a point at the other end of the ruled line.<sup>1</sup>

While simple surfaces such as planes, cylinders or cones have been used in architectural geometry for thousands of years, the surfaces being explored in the 1950's were of a more complex nature: doubly ruled surfaces. In a doubly ruled surface, two lines sweep along paths that can be co-planar, defining a plane; non-coplanar, defining a hyperbolic paraboloid; or along curves, defining hyperbolic paraboloids or hyperboloids. These surfaces have the great advantage of being able to be constructed from straight lines or identical curves, simplifying the construction process. The other advantage of these surfaces is structural. The curved surface acts as a membrane and ideally forces are purely compressive or tensile, leading to a highly efficient use of material. These shell structures have the capacity to be very thin, in many cases simply several centimeters thick spanning tens of meters.

For engineers of the time, the structural logic of these surfaces was paramount. Engineers such as Felix Candela argued against the use of these forms as simply new shapes. “Space frames, hanging roofs and concrete shells are all legitimate prey in what is pronounced a move to humanize the arid, primitive idiom left to us by the pioneers (of modernism). ‘Structuralism’ is originality’s new escape valve.”<sup>2</sup> Yet, these new forms in their geometrical purity were problematic as architecture. The surfaces which were typically quite large and had no real human scale to them as purely mathematical forms. The engineer Mario Salvadori understood this problem of scale and wrote “Architects and engineers who want to use the new shell forms effectively must understand the disturbing reactions they can evoke – and how to deal with them.”<sup>3</sup> The thinness of these shells gave them an insubstantial feeling that ran counter to the primeval sheltering of a roof or the traditional weight of building.

The architect Marcel Breuer, like many of his contemporaries, worked with shells and the geometry of ruled surfaces in his work of the 1950’s and 1960’s. Unlike his contemporaries, Breuer’s initial fascination with ruled surfaces to create thin, weightless shells gave way to using ruled surfaces to express the weight and mass. In his best work, a ruled surface geometry is used to both create thin shell structures and visually ground the structure.

### **The Challenges of Ruled Surfaces**

The use of ruled surfaces after World War II started with the work of structural engineers, but spread quickly to the attention of architects as these new forms began to be published. “The hyperbolic paraboloid is now a project type in design offices and school workshops across the world” commented Felix Candela in an article for Architectural Record in 1958.<sup>4</sup> Structural engineers such as Candela, Pier Luigi Nervi and Enrique Torroja had made this form of ruled surface popular, using it for factories, warehouses, churches and other building types throughout the 50’s. For structural engineers, these forms were to be used for their structural efficiency. The

ability to span large spaces with very thin shells was the reason to use a form like a hyperbolic paraboloid. Candela reminds architects of this point in this article:

It is forgotten that the paraboloid stemmed from purely functional and economic reasoning. I doubt very much that it can be the answer to any stylistic problems. But after the novelty of its shape has subsided perhaps it will be realized that the thin shell paraboloid has qualities as a building form that are far more persuasive than just esthetic considerations.<sup>5</sup>

In a 1958 article, the engineer Mario Salvadori and architect Eugene Raskin defined some of the architectural problems inherent in the use of these mathematical surfaces.<sup>6</sup> Salvadori and Raskin saw the mathematical and in their minds 'abstract' forms of shells as having little sense of protection and no indication of scale, two traditionally important architectural qualities. Salvadori defined the first problem thus:

One such basic assumption is that a roof is for safety and protection; it is an emotional as well as physical symbol of security. How can the shell provide reassurance on this point? It looks as though it had recently and temporarily alighted from a voyage on the wings of a breeze. To the eye, which seeks protection in the conventional terms of bulk and strength, the shell will seem unsatisfactory, forcing the designer to solve the human need for shelter by another approach.<sup>7</sup>

A related but separate problem Salvadori and Raskin identified with shells is defining the scale of a shell: "Shells are mathematical abstractions, just as well represented by paper models as in concrete over 300 foot spans."<sup>8</sup> Salvadori and Raskin argued that the effect of these two problems was to create "tension, anxiety and stimulation"<sup>9</sup> in people encountering these shell structures. Combined with the unfamiliarity of these shapes as buildings, Salvadori and Raskin argue that these structures have very different qualities to them than most traditional architecture which telegraphs messages of stability and permanence. For Salvadori and Raskin, the key to the architectural use of these shell structures, besides their very weak suggestion of using terraces, plantings, steps and paving to introduce scale, is to take use the tension and anxiety these structures produce in a positive way:

The tension and anxiety that these unfamiliar shapes generate are not always undesirable, however. Games of skill, for example, produce tension and anxiety in a pleasurable sense; so does the reading of an adventure novel, or the watching of a suspense drama. There is no reason why these emotional states should not be favorably exploited architecturally as well, for example, in public

buildings for sports, shopping, meeting, or in domestic spaces for entertaining. Actually, the argument could be made that serenity, calm, and restfulness are obsolete as expressions of our age, and that the shell is not only the outcome of a technological advance, but also the inevitable signal of a twentieth century aesthetic.<sup>10</sup>

While ruled surface shells were used in the 1950's and 1960's for many building types, the issues that Salvadori and Raskin identified plagued most of these designs. In many cases, the shell structure is very symmetrical and balanced, trying to fight the inherent tension and anxiety of the shell's shape and thinness. In a few cases, such as the work of Eladio Dieste, was the ability of the shell to cause a sublime sense of balanced tension exploited. In most of the work of the period there is an awkward sense of an alien object dropped in place.

### **Marcel Breuer and the Ruled Surface**

Complex ruled surfaces began to appear in Marcel Breuer's work in the mid 1950's. While for most architects of the period, ruled surfaces were only used to create shells and space defining structures. Breuer's work shows both ruled surfaces as sculptural elements and shells. While there is acknowledgement that the ruled surface can be used for its structural efficiency, Breuer's sculptural sensibility is clearly seen to be driving the form of these elements.

The first use by Breuer of simple ruled surfaces for sculptural elements is evident in the columns of the UNESCO Secretariat Building of 1955-58 by Breuer and Bernard Zehrhaus with structural engineering by Pier Luigi Nervi. The columns on the ground floor act as legs to create an open space underneath the Secretariat building. While the columns are sculpted to impart a sense of muscularity much as the legs of Le Corbusier's Unite d'Habitation completed three years earlier, the shaping of the columns also has a structural purpose. The legs of the UNESCO headquarters are created by ruled surfaces where the base curve and the director curve are lines skew to one another. These skew lines allow the columns to be thinner at the bottom and fatter at the top in the traverse direction but fatter at the bottom and thinner at the top in the longitudinal direction. Besides the mass this imparts to the columns, the thickening at the bottom allows for greater rigidity of the column to resist forces in the longitudinal direction while the width at the top in the

traverse direction allows for the column to act as part of a rigid frame bracing the building. The credit for the shaping of columns is assumed to be Nervi's from press accounts of the time, but there is no evidence one way or another in the project correspondence that the idea came initially from Nervi, Breuer or Zehrhaus. Breuer himself saw the project as being a collaboration. In a letter to the New York Herald Tribune on October 8, 1952, Breuer corrects an article that mentions himself and Zehrhaus, but not Nervi in connection with the UNESCO building calling Nervi, "co-designer of our team in equal standing."<sup>11</sup>

While the UNESCO building used ruled surfaces in a building component, Breuer's first large work dominated by a ruled surface was for the Hunter College Library in the Bronx, NY completed between 1957-60. The basic structure consisted of six hyperbolic paraboloid shells placed on singular columns like inverted umbrellas and fused together. Such a configuration of shells was certainly not unprecedented. Candela's "High Life" Garment Factory in Mexico City of 1955 uses a similar pattern of square inverted hyperbolic paraboloid shells to form a roof. A more direct influence is found in Eduardo Catalano, an Argentinean architect, who is listed as a consultant on the Hunter College job. Catalano first became famous in the United States as the architect of his own house in Raleigh, North Carolina built in 1954. The Catalano House, a 1700 sq. ft. house roofed over by a 4000 sq. ft hyperbolic paraboloid was published extensively in the trade journals of the day. In an Architectural Forum article of 1955, the Catalano house is featured, but also Catalano's own diagrams and models showing how hyperbolic paraboloids can be combined together to create larger roofed structures.<sup>12</sup> While the multiple paraboloid combinations in the article do not match the Hunter College paraboloid configuration, the concept of how to combine the paraboloids is common to both.

In the design of the Hunter College Library, Breuer treats the hyperbolic paraboloid shell much as his contemporaries do, as a thin, weightless, abstract surface. The shell roof is hidden from exterior view by glass walls on all sides screened with chimney flue tiles. The glass walls are actually supported by the shell structure, but their placement on the edge gives the sense that the

shell structure is lightweight and is supported by the glass. The shell is only revealed when inside the main reading room of the library. The construction details give the ceiling a sail-like quality that belies the weight of the shell. The ceiling, while revealing the board forming of the shell with raised fillets where concrete was allowed to seep out between the wooden boards, is painted white which negates the materiality of the concrete and further reduces the ceiling's sense of weight and mass. The raised fillets from the board forming are unbroken along the rulings of the hyperbolic paraboloid surface emphasizing the mathematical geometry of the shell. Even the roof of the shell is striped with alternate colors which again emphasizes the nature of the shell as a geometrical figure and not a mass.

Breuer continues with his work with ruled surface columns in a number of office buildings, but usually not with the structural sophistication of the UNESCO building columns. Sculpted columns become a feature of Breuer office buildings such as the IBM Building in La Gaude, France or the HUD Headquarters in Washington D.C. These columns are created using ruled surfaces in the most basic sense, rectangular solids are cut at angles with planes to create the column shapes. The use of non-parallel base and director curves as in The UNESCO building is not used again by Breuer except for two projects: the Priory of the Annunciation in Bismarck, North Dakota and St. Francis de Sales Church in Muskegon, Michigan.

At the Priory of the Annunciation, Breuer was commissioned to create a new priory and college in the plains of North Dakota. The Priory, the first piece of the campus to be completed, is composed of living and communal areas, a chapel, bell tower, and cloister. While the living and communal areas are rectilinear buildings, the chapel and bell tower have used ruled surfaces in new ways that close the gap between the abstract shell of the Hunter College Library and the muscularity of the UNESCO columns. The Chapel has a shell roof in some ways like the shell of the Hunter College library. The difference between the Hunter College Library and the Chapel is that the Library has a complete "umbrella" shell supported by a column, the Chapel is covered by four halves of an umbrella shell (Figure 1). The shells are split in half at the column, allowing the

columns to be at the edge of the space rather than in the center as with the Hunter College Library. While placing the columns at the edges allows the space in the center to be column free, it does create a problem structurally. The lateral forces from the shell which are balanced in the complete shell are not balanced by the asymmetry of the half umbrella. The columns need to become buttresses, much in the same way in a Gothic cathedral the flying buttresses need to brace the vaults. The columns achieve this through ruled surfaces which flare out at the bottom of the column to act as buttresses and twist to run parallel to the wall at the top, much in the way the columns at the UNESCO building work.

The idea of the ruled surface as a way to brace a column is carried into the design of the bell banner at the Priory of the Annunciation as well. The bell banner is a 100 foot high tower that holds a banner surface with a cross cut into it and underneath the surface, bells. To resist wind pressures due to the large, flat banner surface, the base of the banner is oriented perpendicular to the banner. The ruled surface runs the entire 100 foot height of the tower and twists from the base orientation to the orientation of the banner. The discontinuity of the ruled surface makes it clear that the ruled surface is not a necessary structural element, but instead an expression of the forces that are being transferred by the steel reinforcing hidden within the concrete (Figure 2).

Critical to the development of the bell banner and the priory is the use of isometric drawings (plan, section, elevation) to completely describe the geometry. The geometry of the ruled surface for the bell banner is described only through elevation, section and plan with no three-dimensional representation. In the construction documents for the bell banner, the curving surface is not apparent, except as rulings between the straight line base and director curves. The priory roof is drawn in plan and section, but also in two axonometrics for the construction documents. Studies for the priory roof show a grid of 10 by 20 squares. This grid is organized into 8 larger squares of 5 by 5 grid squares, each large square is then bisected by two diagonals. The diagonals plot the curvature of the roof as shown in an elevation below with a one diagonal showing the maximum curvature and the other showing the minimum curvature of the shell. As

shown in the drawing, the curvature of the shell is the result of setting the elevation of the ends of the grid line, the grid is the rulings of the surface.

The ability to show the constructional geometry in isometric views is critical to the ability to construct these forms as well. For the bell banner, the construction drawings show plans at the level of each concrete lift. The formwork would be built so that the plan outline would be built at the top and bottom of the form. Planks would then be nailed between the two outlines creating the rulings of the surface and the sides of the form. Concrete would be poured and the process repeated for the next lift. The entire curved surface can thus be created by following a series of outlines.

The Priory roof shell was constructed in much the same way that the vaults for a medieval cathedral were constructed. From the construction photographs, it appears that the formwork for the ribs, the lines of the 5 by 5 grid squares was constructed first. The ribs set up the system for planking, again the rulings of the surface, to be laid in straight lines infilling between the ribs. Again, the advantage of the ruled surface is that the entire surface can be formed by connecting points with a straight line.

The most dramatic use of a ruled surface in Breuer's work was at St. Francis de Sales Church in Muskegon, Michigan completed in 1967. The side walls of the church twist upward in a hyperbolic paraboloid for 72 feet to meet beams that are twisted as well to meet the geometry of sloped, splaying front and end walls. The church from the exterior seems to be a large solid with inward sloping east and west walls and twisting side walls which rise up to hold the roof (Figure 3). From the inside, a series of structural ribs and beams that hold the building together as a giant moment frame are exposed. These ribs run east-west and splay out to match the trapezoidal surface of the east wall and narrow to match the west wall. The result of this geometry at the roof level are beams that not only need to fan out from the west wall to the east wall to connect to their respective ribs, but the beams also twist in their cross section to connect from to the sloping,



splaying column ribs (Figure 4). The side walls, as evidenced by the construction photos which show the building of the east and west walls and roof first, are not structural but are only for enclosure.

Breuer spoke about the use of the hyperbolic paraboloid for St. Francis in an interview conducted by Shirley Rieff Howarth in 1977:

...the hyperbolic paraboloids are used in the St. Francis Church for enclosure and not for structural support. Now, this is the first time that they have been used for enclosure – they were never used in this manner before. However, hyperbolic paraboids have been used in structure before. An example of this is in the Hunter College Library in New York... But in the St. Francis church, the hyperbolic paraboloids are side walls and they are really enclosures and purely for space and form reasons – this was not done before.<sup>14</sup>

Why was Breuer so concerned to state that his use of the hyperbolic paraboloid was non-structural? I believe that this had to do with his desire to bring mass and a sculptural sense to modern architecture. In his Reed & Barton Lecture at the University of Michigan in 1963, Breuer stated:

With the rebirth of solids next to glass walls, with supports which are substantial in material but not negligent in structural logic and practical requirements, a three dimensional modulation of architecture is again in view; the brother or lover of our pure space. Although not resting on lions or acanthus leaves, space itself is again sculpture into which one enters.<sup>15</sup>

Breuer saw a possibility in the use of these ruled surfaces that Salvadori and Raskin did not: ruled surfaces used to create mass, scale and connection to the earth. The ruled surface was not an abstract mathematical form for Breuer, but rather a method to create sculptural form using the construction methodologies of the day. Breuer understood the structural implications of the ruled surface, but he was also able to look beyond Nervi's and many other structural engineer's view of the ruled surface as simply an efficient structural form. For Breuer, his own sense of the architectural and sculptural requirements came first to the design and the structural implications were understood but did not overtake those requirements. Breuer's work was always grounded in the traditional qualities of building in many ways; mass, solidity and material. It may have been difficult for him to see a new possibility of expression in lightness and immateriality that Salvadori

and Raskin pointed to. By reconciling this geometry with traditional architectural qualities however, Breuer solved many of the problems of the shell seen by Salvadori and Raskin, bringing new expression to this geometry.

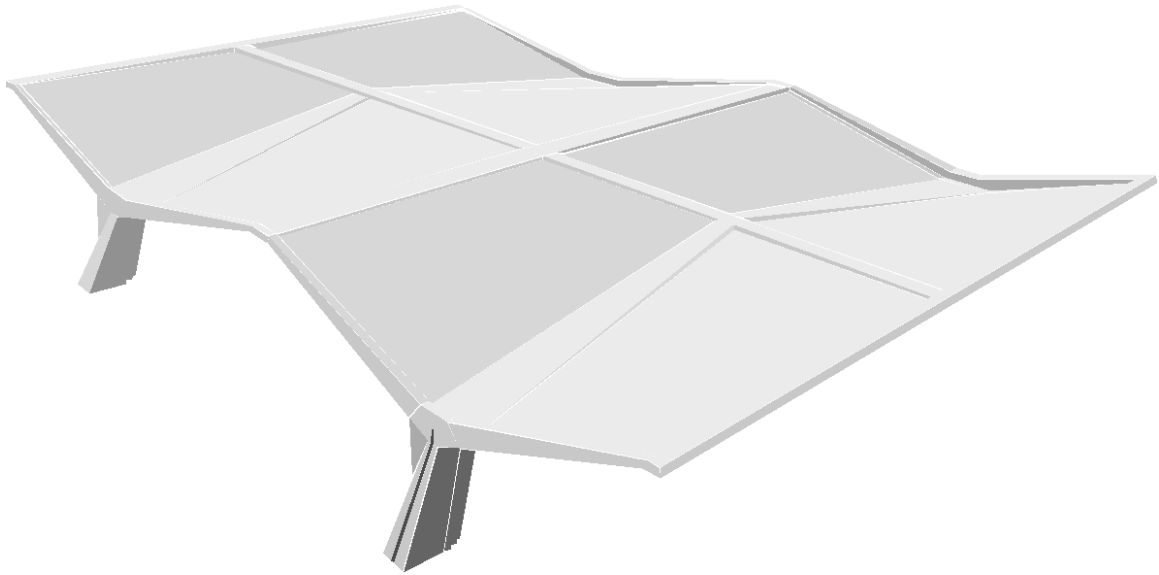


Figure 1: Shell of Annunciation Priory Chapel, drawing by author

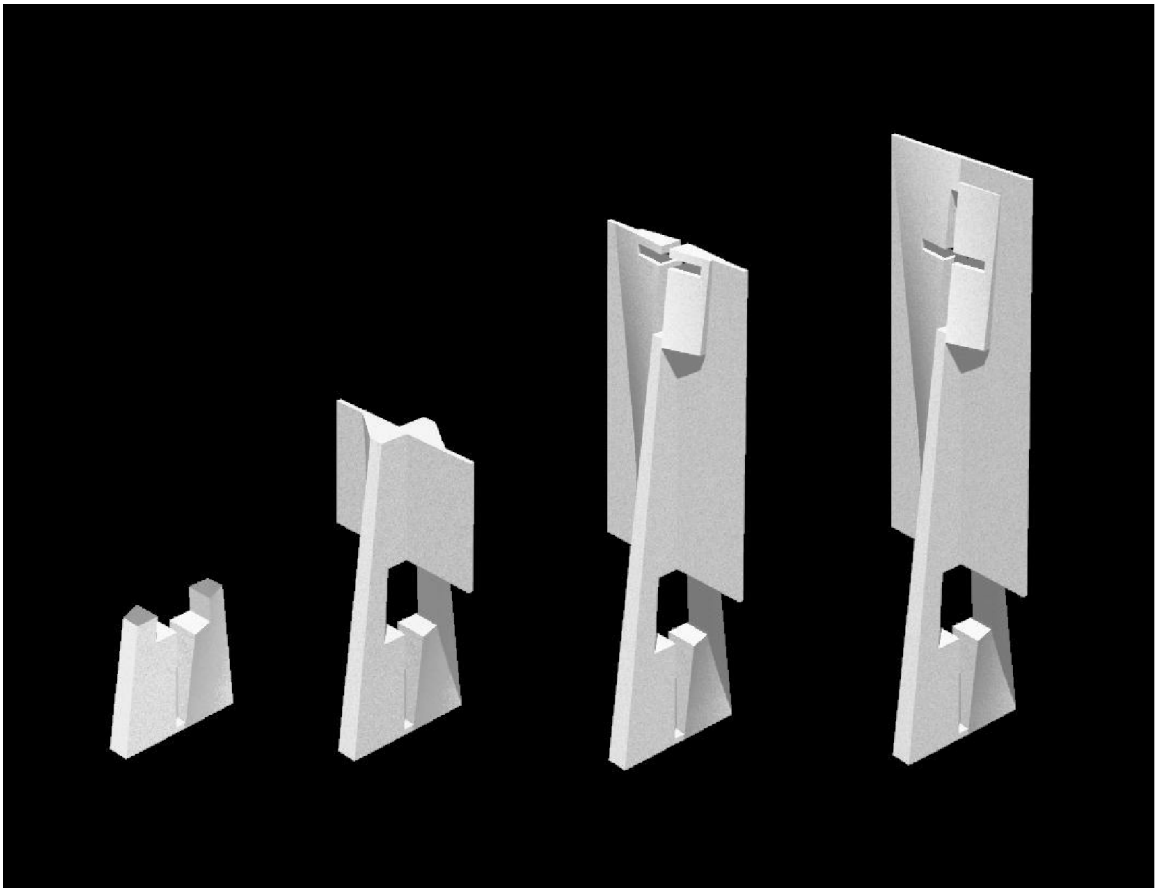


Figure 2: Bell Banner geometry, Priory of the Annunciation, digital model by author

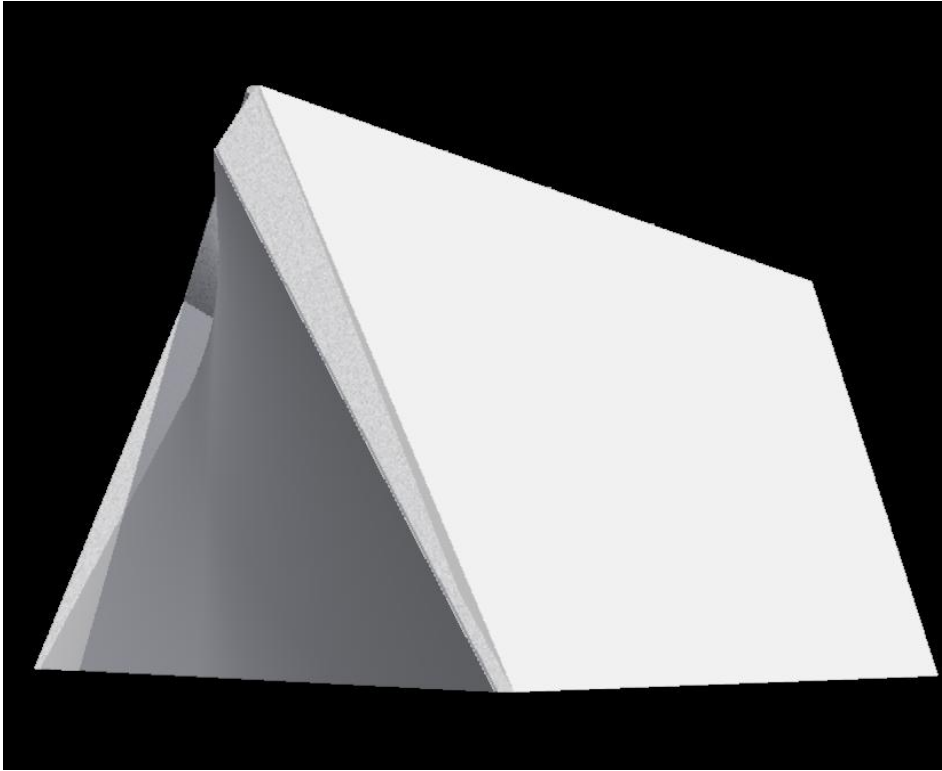


Figure 3: Exterior geometry of St. Francis de Sales, digital model by author

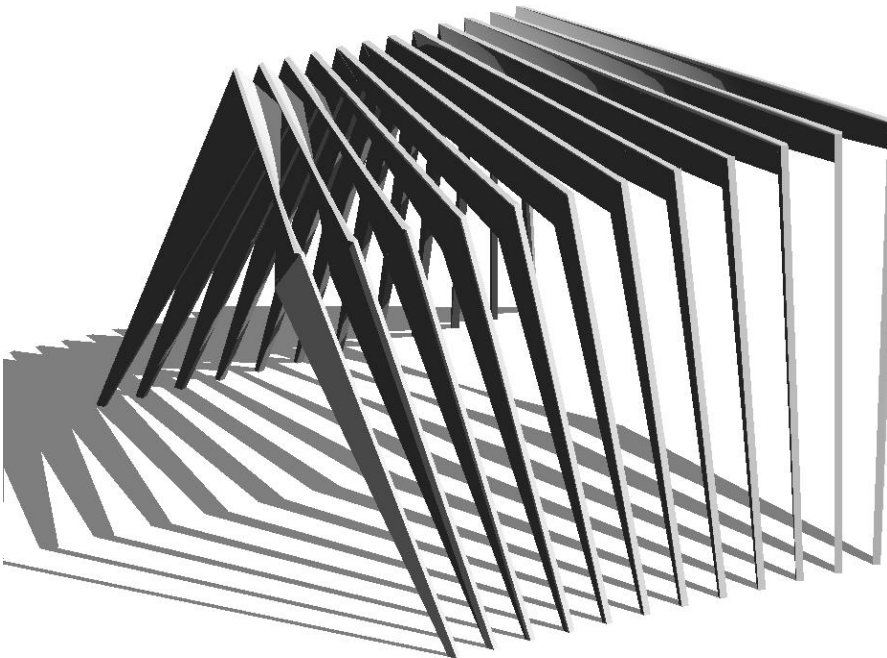


Figure 4: Concrete structural frame of St. Francis de Sales, digital model by author

## Endnotes

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- <sup>1</sup> Internet: <http://mathworld.wolfram.com/RuledSurface.html>, 9/16/2007
- <sup>2</sup> Felix Candela, "Understanding the Hyperbolic Paraboloid," *Architectural Record*, v. 123 (July 1958): 191.
- <sup>3</sup> Mario Salvadori & Eugene Raskin, "The Psychology of Shells," *Architectural Forum*, v. 109 (July 1958): 112.
- <sup>4</sup> Felix Candela, "Understanding the Hyperbolic Paraboloid," *Architectural Record*, v. 123 (July 1958): 191.
- <sup>5</sup> Ibid: 191.
- <sup>6</sup> Mario Salvadori & Eugene Raskin, "The Psychology of Shells," *Architectural Forum*, v. 109 (July 1958): 112-114.
- <sup>7</sup> Ibid: 112.
- <sup>8</sup> Ibid: 113.
- <sup>9</sup> Ibid: 113.
- <sup>10</sup> Ibid. p. 113.
- <sup>11</sup> Archives of American Art, Smithsonian Institution. Marcel Breuer Papers. Series 8.3.5: United Nations Educational, Scientific and Cultural Organization (UNESCO) Headquarters, Paris, France. Chronological correspondence, 1952. (Reel 5722, Frames 828)
- <sup>12</sup> "A New Way to Span Space", *Architectural Forum*, v. 103. November 1955, p. 170-177.
- <sup>14</sup> Shirley Rieff Howard, "Marcel Breuer: Concrete and the Cross."
- <sup>15</sup> Marcel Breuer. Reed & Barton Lecture University of Michigan, Ann Arbor, March 6, 1963