Assessment of the Hyperbolic Paraboloids of the Church of the Holy Trinity, Caracas Through Architectural Visualization

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1 Introduction

The architectural heritage of modernism, characterized by straight lines in composition and articulated surfaces, also included structures with curvatures such as the hyperbolic ones. Of the five hyperbolic paraboloid types developed by Félix Candela, the one with a non-perpendicular Z axis is located on the roof of the Church of the Holy Trinity in Caracas. Four hypars (acronym in English) form a roof that rests on four pillars and has a maximum floor plan of 28 $\times$ 28 m and a height of 15 m at its highest point, with a minimum sheet thickness of 6 cm, built in 1969.

The church was given to a group of priests of the Society of St. Edmund, who have maintained it in the same architectural coherence until recently. In 2005, the Instituto de Patrimonio Cultural Venezolano declared the church an object of national interest. There is no architectural description of the building or the roof in the declaration, and the information in the other references is not correct either. This problem, which always occurs in complex geometries, is due to the lack of visualization for understanding.

Therefore, the objective is the architectural description of the temple using Infoarchitecture. For this purpose, a methodology is proposed that takes into account architectural visualization: Planimetry, 3D modeling and drawing orthogonal views as tools. The methodology is developed in three stages: first with a bibliographic and planimetric review of the church archive, then with the development of the 3D model and orthogonal views in SolidWorks, and in the last stage with the analysis of the geometric, architectural, constructive and structural characteristics of the building.

The result is the technical documentation of the building through a visualization methodology. Also, the expansion and updating of the incomplete planimetry of the archive. Figure 1.

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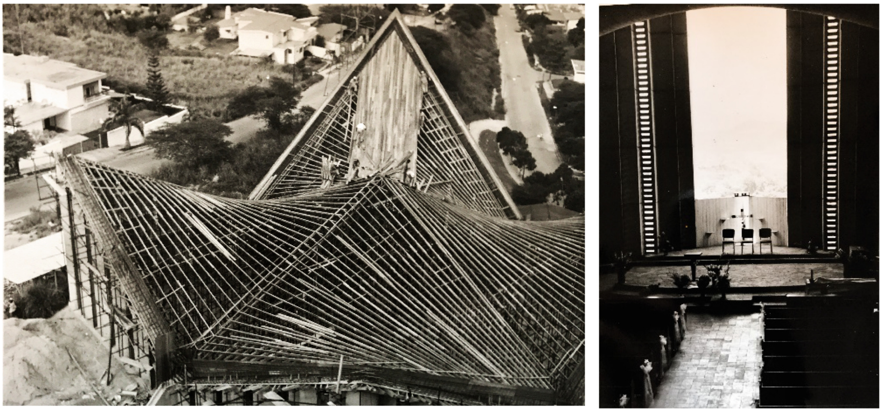

Fig. 1. Photograph of the roof and altar formwork, 1969. Church archives.

2 Justification

Holy Trinity Church is in good condition and still in use. The Reverend Edward Dubriske, who was in charge of the church for 46 years, knew the architectural concept and was careful not to change it [1]. Today, a technical analysis is essential to ensure the preservation of the building. However, with regard to the existing technical documentation, the following should be noted:

The first news about the heritage professionals comes from the Institute of Venezuelan Cultural Heritage, where it is mentioned in the I Census of Venezuelan Cultural Heritage 2004–2005, on the basis of which the Catalogs of Venezuelan Cultural Heritage 2004–2008 were prepared. The church appears in the section Lo Construido (The Constructed) and is incorrectly described as follows: “It is an isolated building with an irregular plan, whose roof consists of a reinforced concrete shell with several vaults” [2].

Subsequently, the IPC declares the church a cultural asset of national interest, without mentioning its architectural values: “*Declarations: The Church of the Holy Trinity was declared a Cultural Property of National Interest by the Institute of Cultural Heritage, published in the Official Gazette of the Bolivarian Republic of Venezuela No. 38.234 of the date of publication of this document. 38.234 of July 22, 2005, as one of the material manifestations registered in the Census of Venezuelan Cultural Heritage 2004–2005, and by the Mayor’s Office of the Municipality of Baruta as the fifth Asset of Municipal Interest, pursuant to Decree No. 181, published in the Extraordinary Municipal Gazette No. 128–04/2005 of April 14, 2005. It deserves to be protected and preserved”* [3].

From specialized organizations such as Fundación de la Memoria Urbana, DOCOMOMO Venezuela [4], and Fundación Arquitectura y Ciudad [5] it is only stated that it has been declared a BIC, and it is also pointed out that the floor plan is irregular and the roof has different curvatures [6].

Of experts in the area, Hannia Gómez gives a very brief description of the temple in an article for La Revista de la Cámara: Fundamemoria invites to a tour of the religious architecture of the capital, where she speaks of a typology of sloping roofs that reach the ground [7]. An international organization, the German Museum of Architecture in Dam

Ostend, refers to this heritage on its page SOSBrutalism, describing it as a roof with two paraboloids [8]. Also F. Rodríguez Capriles, collaborating with @ArquitecturaVzl on Twitter, publishes a photo without any architectural description [9]. And finally, on the Internet, an article by Benjamín Sánchez Mujica, who indicates that the floor plan is irregular, that the roof has different curvatures and that it has two paraboloids [10].

In short, there is only one explanation of IPC as a cultural asset, without knowing according to what criteria. In summary, from an architectural point of view, the little technical information that exists about the geometry and the roof is flawed.

3 The State of Art

3.1 Hyperbolic Paraboloids Buildings

The first example is the church of Nuestra Señora de la Soledad by Félix Candela in 1955 in Mexico, with an asymmetrical plan and a hypar roof [11].

In Madrid there are two examples: the chapel for the Colegio de Santa María del Pilar, built in 1959 by architects Luis Moya and José Antonio Domínguez. With an irregular octagonal plan, an axis of symmetry and a hypar roof [12]. And the Church of Nuestra Señora de Guadalupe by Félix Candela, built in 1963, whose eight-hypar roof has a maximum dimension of 55 m in plan with a sheet thickness of 4 cm [13].

Other prototypes, the Bet El Synagogue by architect Roberto Acosta Madiedo, 1964 in Barranquilla, Colombia. It has a hexagonal plan with a roof of four hypars. And the Concha Hypar Magdeburg of 1969 in Germany, by the engineer Ulrich Muether, with a roof of four hypars [14].

In Venezuela there are three constructions: the first from 1955, the Club Táchira in Caracas, by Eduardo Torroja, a metal truss construction that creates a parabolic membrane. The second is the roofs of the Club Playa Azul, from 1956, made of reinforced concrete by Guillermo Shelley and José Chávez [15]. And the last, the headquarters of the Colegio de Médicos de Zulia in 1964, a symmetrical roof of eight hypars by architects Álvaro Coto and José Loperena in the 1950s [16].

3.2 3D Models and Orthogonal Projection for Visualization

Two of the best known tools for improving the visualization and understanding of 3D objects are the physical or virtual model, which makes some aspects of the geometry explicit, and the drawing of three-dimensional views with orthogonal projections [13].

The representation of a 3D object can be described as a process of prescriptive mathematical three-dimensional modeling. In this way, prescriptive modeling is useful as a tool for capturing and understanding aspects such as geometry that we cannot control [17]. Another contribution of modeling is the concepts of scale and representation, which allow us to circumvent the problem of viewpoint [14]. Leon Battista Alberti, in his treatise On the Art of Building, described physical scale models as a tool for thinking about architectural design [15]. A good tool to develop an understanding of form/design/ideas in architecture [16].

The use of drawing as a tool for analysis and synthesis to express relationships between geometric objects in space and their 2D graphical representation consists of a series of correlated orthogonal views [17]. These orthogonal projections allow us to reconstruct the geometry of complex shapes such as parabolas, curves, etc. through the use of multiple planes of projection, facilitating the construction of the model in the mind and visual/tactile exploration [18]. Definition of geometry "for the actual design process: estimation of position, volume, dimensions and adjustment of proportions" [19]. Indeed, the architect must be able to translate his idea/perception of a 3D object into orthographic views (which form the basis of his technical language) [17].

After the computer revolution, prescriptive 3D modeling and orthogonal projection rely on the systems of CAD, which provide practical tools for their creation, but are often insufficient to create three-dimensional surfaces with double curvature [20]. To integrate these two ideas, the SolidWorks program has limited research in architecture. Nevertheless, there are four contributions. The first deals with the structuring of architectural models using the concept of standard components in the design of mechanical components as a reference [21]. The second deals with a simulation of the construction process of a building [26]. And the third and last, two papers on virtual reality, one on the ancient construction methods of the Jinshanling region, the Great Wall of China [27] and the other to reproduce dynamic animations of rigid bodies [22].

4 Methodology

The methodology, based on the Use of orthographic projections and three-dimensional models for visualization [22], is developed in three phases, first with the bibliographic and historical verification from the church archives. Second, the construction of the 3D model and orthogonal projections in the SolidWorks program. And finally, the analysis of the detailed geometric, architectural and structural content of the church using the planimetry information.

4.1 Holy Trinity Church (Iglesia Santísima Trinidad)

In 1963, talks began about building a church in the Prados del Este housing development in Caracas on a 4.200-square-meter plot of land that was given a year later to a group of priests from the Society of Saint Edmund, led by Father Lawrence F. Lyons.

The best professionals in the country collaborated on the building: architects Andrés E. Betancourt Silva and José Antonio Ron Pedrique, and engineers Frederick Klindt Marcellini and Omar Sotillo Parilli, who were responsible for the structural calculations. Lima & Rodríguez Soto S.A. and Augusto Mendoza were also involved in the electrical installations. The architectural project was carried out between 1968 and 1969, but was not completed until 1976.

Since 1964, the church has had 4 pastors of the Society: Lawrence Lyons, Edward Dubriske, Marcel Rainville and Howard Muehlberger. The Rev. Edward Dubriske provided all the information for this study.

4.2 3D Modeling

The following is a procedure for modeling, rapid geometry extraction and generation of orthogonal views of the building using SolidWorks software, which allows to generate geometrically complex curves and orthogonal views. The phases of modeling are:

4.2.1. *Graphic documentation*: for the creation of the model, the plans of the building project are available in the church archives. The plans are divided into architecture, structure and installations. It should be noted that the basic, elevation and detail drawings in which the roof appears have been geometrically simplified and their proportions are not correct. And also some basic views for the construction of certain elements, such as the skylight, are missing.

4.2.2. *Geometric criteria*: The geometric relationships between form and construction define the architecture of modernism, so it was decided to model the church according to its own geometry. With a symmetrical floor plan formed by a regular quadrilateral of 28 $\times$ 28 m, the criterion is to locate the quadrilateral and the meeting of its four axes of symmetry in the point of origin, which is the point of X, Y and Z coordinates of the program and, in turn, the type of projection of the two-surface system. Placing the origin point in this position makes it possible to create a half element and then complete it with a 3D symmetry and the plane of its diagonal, since the working planes of the elevation and side view pass through the center of the figure.

4.2.3. *3D modeling–structure*: the following reference is used for the model: "*the design of architectural models using the concept of standard components in the design of mechanical components*" [25]. These components are modeled in five part files and then coupled in a file called Assembly. The five part files are: for the ceilings; for the roof and columns; for the cladding; for the drainage detail; and the last one for the skylight detail (Fig. 2). They are modeled as follows:

4.2.3.1. *Floor slabs*: for the floor slab with its slope and the access module consisting of two slabs and the stairs. They were drawn in sketches at different heights and then extruded with the thickness of the slab. Only the inclined slab was machined as a surface (Fig. 3).

4.2.3.2. *The roof and the structure*: this file is for the double ruled surfaces constructed with straight lines in the middle and facade planes, varying the angle of inclination of the straight line moving over another curve. The vertices of these lines have a different height, so the angle of inclination varies. With them and the Insert/Fill Area command, as Patch Boundary, the paraboloids were created. Also, the Optimize Curve Mesh option was enabled with a density of 15 to improve the accuracy of the curvature. The abutments were drawn in the plane and extruded (Figs. 3 and 8).

4.2.3.3. *The envelope*: the third file for two types of envelopes, opaque and transparent panels. The opaque panels were drawn from the floor plan and then these silhouettes were selected and extruded according to the height of the slope plane of the roof. The brise-soleil enclosure was drawn with a sketch in the plane perpendicular to the opaque enclosures, and a linear matrix was created in height and plan (Figs. 3 and 4).

4.2.3.4. *Rainwater drainage*: The fourth file for the detail of the drainage. There are four examples, in floor plan view they lie on the four axes of symmetry geometrically connected to the vertex of the four columns. It was created from the middle plane and with a *circular matrix* the other three were placed (Fig. 6).

4.2.3.5. *The skylight*: the fifth, for the detail of the skylight supported by the central beam and by the middle planes of the square. As for the water drainage, one example was modeled and the other three were created with a *circular matrix* (Fig. 6).

4.2.3.6. *Assembly or 3D modeling structure*: In this file, all the part or components files were inserted and a decomposition was performed using the *Explosion* command. This exploded view is the schema of the used method for 3D modeling. When a component is added to an assembly, a link is created between the assembly and the component. Changes made to the component are automatically reflected in the assembly (Fig. 2).

4.2.4. *The creation of drawings*: With the assembly model completed, *drawings (blueprints)* were created from this file at the first projection angle; with all orthogonal views, two sections, perspectives and isometrics of the building and construction detail drawings in SolidWorks. The general arrangement drawings were then sent to CAD to add architectural detail to the drawing (Figs. 5, 6 and 7).

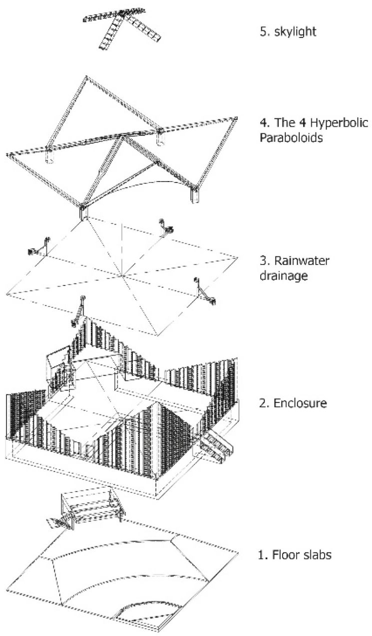

Fig. 2. Schema of the used method for 3D modeling

4.3 Analysis

According to the 3D model and planimetry, the church consists of two volumes, that of the religious space and that of the access. The access volume has a rectangular floor plan

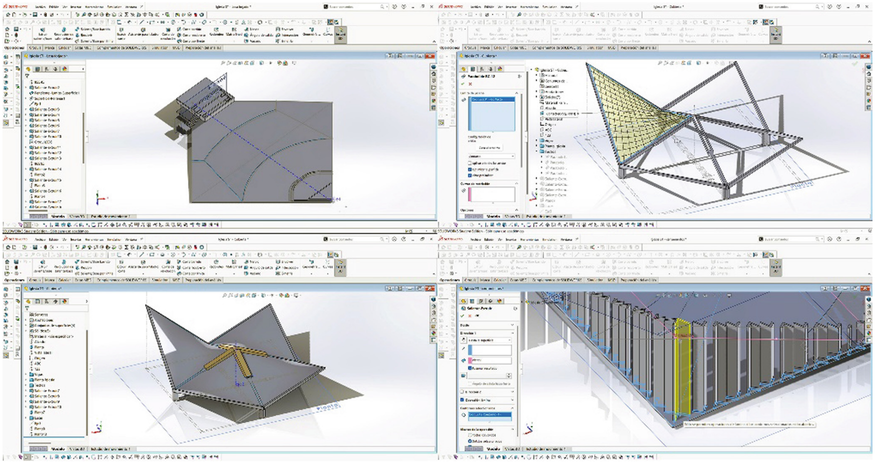

Fig. 3. 3D modeling of slabs, roof and envelope in SolidWorks. Own elaboration

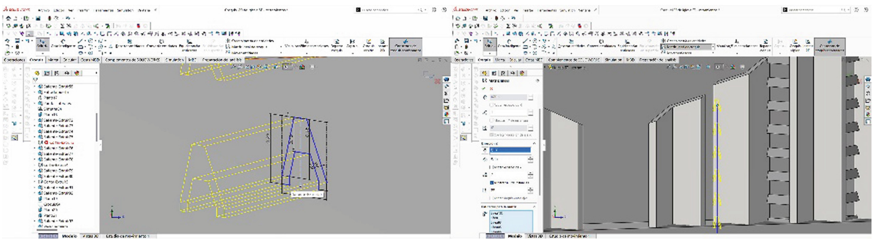

Fig. 4. 3D modeling of slabs, roof and envelope in SolidWorks. Own elaboration.

of 8.40 × 8.10 m and is integrated with the other volume with a square floor plan of 28 × 28 m, both within the same roof of regular surfaces, with a total area of 784 m^2.

In the ground plan of the regular square, the axial axis of the church is arranged along the diagonal, from west to east. This axis of axial composition allows for a symmetrical solution of the form. The main entrance of the church begins on the axial axis of the diagonal, located at the highest point of the topography, at elevation 965.45 m, in the west. In this element are the sacristy and the access to the choir on the second floor, reached by a lateral staircase of 2.5 × 3.77 m. The axial axis, which descends to a height of 965 m, continues with the main religious room, where the parishioners are located, and ends with the altar at a height of 965.45 m. At the other two vertices, perpendicular to the axis, are the confessional in the north and the tabernacle in the south. In the north and south of the building there are two additional accesses. The access in the north with two staircases perpendicular to the facade that lead to the parking lot that surrounds the northern part of the church, and the access in the south that is directly connected to a garden that leads to the rectory (Fig. 5).

The structure is one of the elements with the best structural coherence and consists of two systems, the hyperbolic paraboloid system and the traditional system of beams and columns. The roof is composed of four reinforced concrete paraboloids supported by four pillars rotated around their axes. They are 1 m × 1 m and 2.7 m high and have a square plan. Each paraboloid rests on two piers, and in the overhangs the parabola retracts to make way for a cavity into which the zenith light enters through a skylight (Figs. 5, 6, 7 and 8).

The paraboloids, of which there are two typologies, measure 14 × 14 m, the first, three of them, whose four vertices are 8.50 m high in the Z coordinate. The second typology, the one that covers the altar, has three vertices at a height of 8.50 m and the easternmost at a height of 15 m. This distance allowed to place a large stained glass window in the corner. The panel is 0.06 m thick (Fig. 8).

Each paraboloid consists of four beams located on the periphery, two edge beams and two center beams. The thickness of the edge beams in the plane is 0.4 m and that of the center beams is 0.5 m. When the skylight appears, the central beam splits into two beams 0.25 m thick, so that there is a gap of 0.5 m. In the elevations, the dimensions of the edge and central beams are variable, 0.70 m for the columns and 0.30 m for the cantilevers.

The traditional column and beam system of the access module consists of two reinforced concrete slabs in two directions, nine columns and four beams. The deck slab is 0.20 m thick and the entire structure is founded on cast-in-place concrete piles.

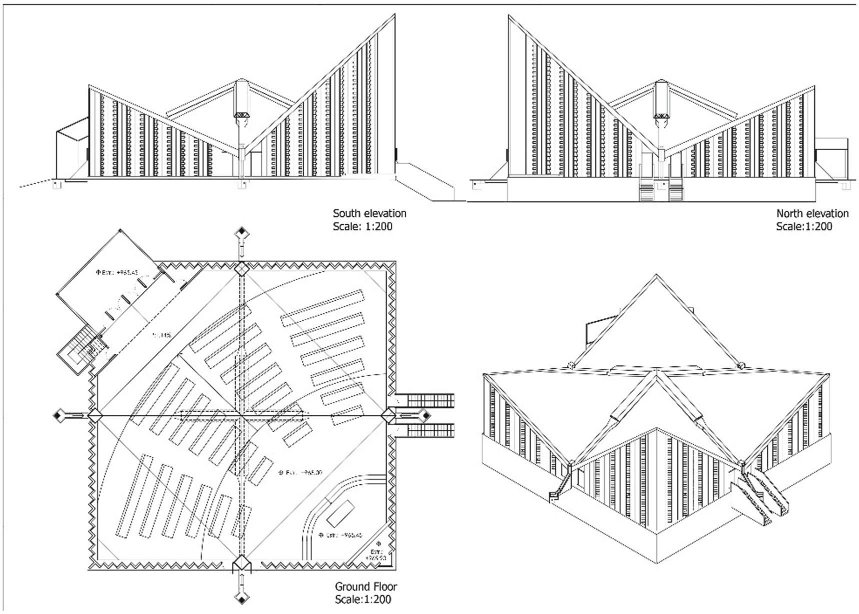

Fig. 5. Planimetry church. Own elaboration.

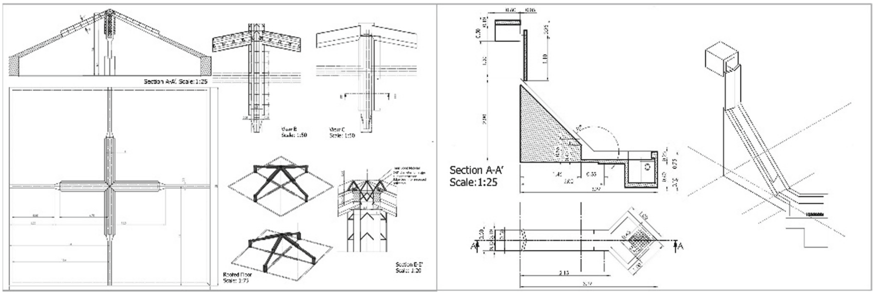

Fig. 6. Details of skylight and rainwater drains. Own elaboration.

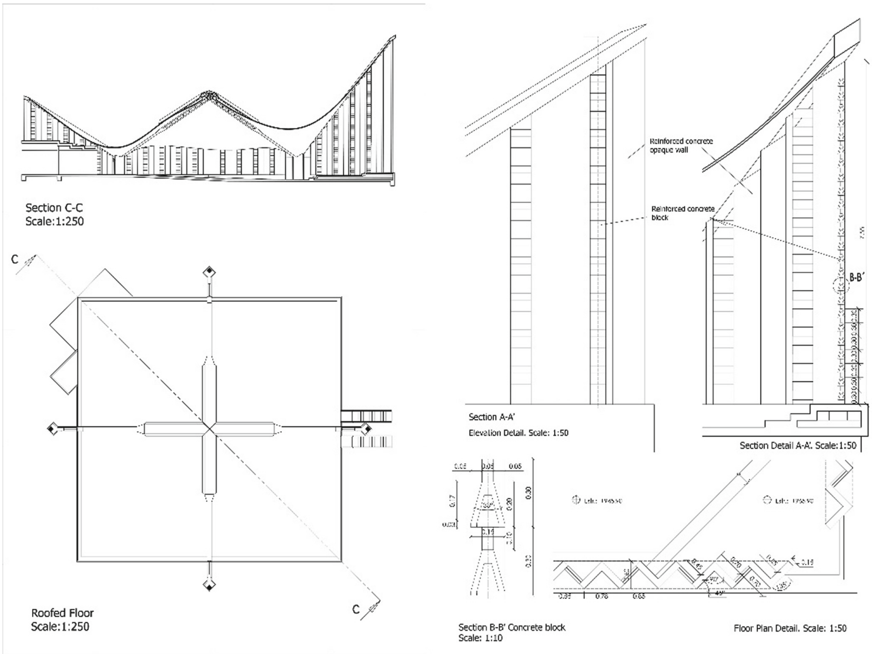

Fig. 7. Section and roof plan and Detail of the envelope. Own elaboration.

5 Conclusions

This work has confirmed that architectural visualization is a tool to understand, define and obtain an architectural analysis of complex geometries. The conclusions are divided into two parts:

3D modeling has benefited in three ways in this case: First, by providing an agile and efficient design for creating curves. Second, by defining geometry as a design and modeling criterion that allowed its control and modification. And third, by orthogonal projection and rapid construction of views, their enlargement and improvement of drawings in the plans and their construction details.

After the analysis, the church was defined as a volume consisting of two bodies in plan, a regular quadrilateral of 28 × 28 m, which contains another rectangle of 8.40 × 8.10 m that intersects it. This central body is arranged diagonally to the axial axis and the function is developed through it. Its structure and roof are composed of four hyperbolic paraboloids supported by four columns on their symmetry axes. These paraboloids are of two types depending on the Z coordinate, the first measuring 8.5 m at its four vertices and the second measuring 8.5 m at three vertices and 15 m at the other. At the meeting of these four hypars there is a gap of 0.5 m where the skylight is located. The canopy with its two types of cabinets allows natural lighting and ventilation. The geometry of the canopies, both in plan and elevation, determines their height.

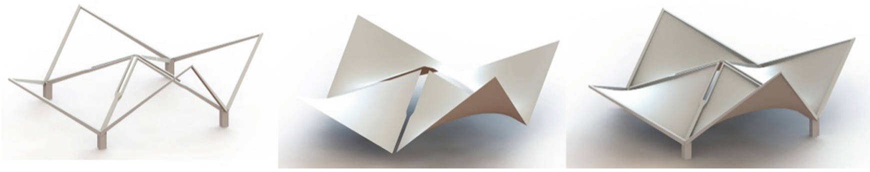

Fig. 8. The 4 Hyperbolic Paraboloids. Own elaboration.

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