The Geometry of Organic Architecture: The Works of Eduardo Torroja, Felix Candela and Miguel Fisac

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Abstract

Eduardo Torroja, Felix Candela and Miguel Fisac were part of a generation of structural architect-engineers who pushed the use of reinforced concrete to the limit. Creators of structures of extraordinary efficiency and lightness, they used continuous ruled surfaces with a unique talent and imagination. Their works are not only functional, but from them emanate magic and poetry: sublime curves… waves of concrete. Buildings that seem to be living creatures form one of the most passionate moments of twentieth century architecture.

Antonio Gaudí, the precursor

Antonio Gaudi (Reus 1852 - Barcelona 1926) was the author of a very personal style based on observing the shapes of nature. He possessed a special ability to model and analyze volumes as well as a huge imagination to develop geometric models, especially ruled surfaces like hyperbolic paraboloids, hyperboloids, helicoids and conoids.

He studied in depth the geometry of nature's organic forms and managed to find an architectural language to express similar forms in his works. Gaudi found in nature the geometry that characterized his architecture; he used to say that there is no better structure than a tree trunk or a human skeleton.

Gaudi's tremendous ability to visualize space allowed him to mentally project his works. In fact, he rarely carried out detailed plans of his buildings since the complexity of its architecture required its re-creation with three-dimensional models. Instead, he defined the details of the project mentally as it was in progress. No architect of his time can be compared to Antonio Gaudi. His rich personality and intense work make him one of the most important figures of world architecture. It will take nearly 100 years to see buildings with a similar geometric richness to that embodied by this great architect.

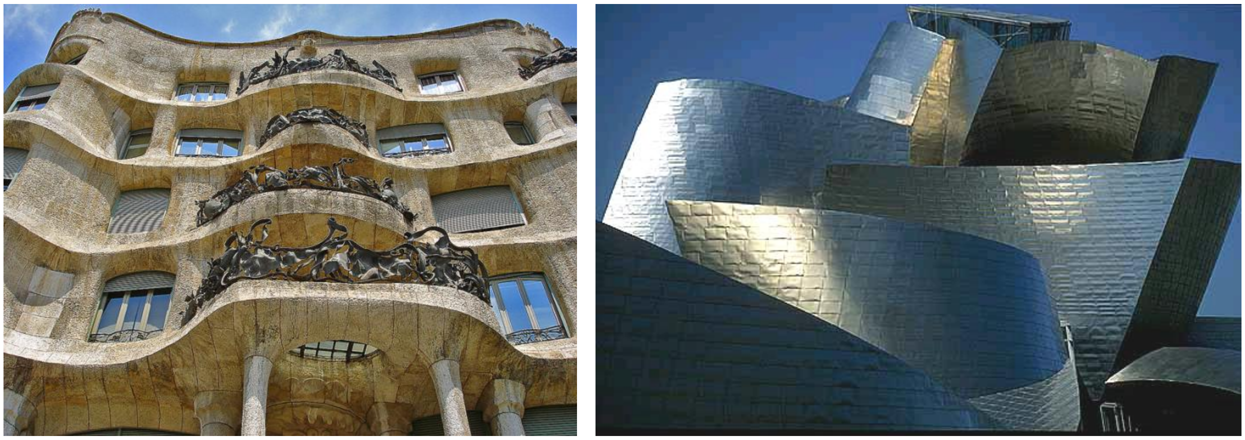

Figure 1: *On the left, Casa Milá, Barcelona 1910, by Antoni Gaudí. On the right Guggenheim Bilbao Museum (1997) by Frank Gehry. Stone and titanium curves separated by nearly one century.*

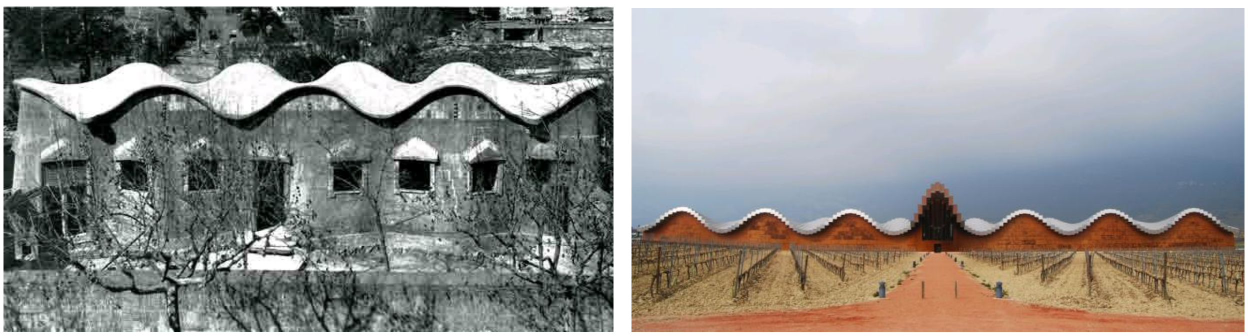

Figure 2: *On the left, Escuelas de la Sagrada Familia (1909). On the right, Bodegas Ysios, Laguardia, (2001). Calatrava uses in the impressive winery Bodegas Ysios the same geometry based on conoids that Gaudí used on his small School at the Sagrada Familia in Barcelona.*

Waves of Concrete

After the death of Antonio Gaudi, three Spanish architect-engineers revolutionized the world of reinforced concrete and its structural analysis. Hyperbolic paraboloids and hyperboloids were converted into geometric shapes of extraordinary effectiveness reaching the highest level of innovation, transcending the merely functional aspect. Their idea of organic architecture refers not only to the relationship between the building and its surroundings, but how the building is designed as a unified organism in harmony with its site.

The main feature of its architecture was the use of continuous surfaces made as lightly as possible. For all of them there is the conviction that the architect must be a poet and that the structure is due to the form rather than the material used. They succeed on anticipating the extreme possibilities of concrete contributing to one of the most exciting moments of expressive architecture of the twentieth century.

Unfortunately the deep crater that the Spanish Civil War and subsequent dictatorship provoked in that generation of architects prevented them from receiving international recognition for decades. But subsequent generations will adapt their creative fundamentals, featuring the name of Santiago Calatrava as a privileged disciple to construct new amazing structures.

Eduardo Torroja (Madrid, 1899 – Madrid, 1961)

Eduardo Torroja was the civil engineer son of the famous Spanish architect and mathematician with the same name. Eduardo Torroja was strongly influenced by his father in the mathematical rigor of architecture, as with the relationship of structures with ruled surfaces. Simultaneously Gaudi performed the first practical work of this type of architecture in the crypt of the Church of the Colonia Güell. After the death of his father, Eduardo Torroja was recognized globally and compared with the great men of the Renaissance in American technical publications. Frank Lloyd Wright said about him "Torroja has expressed the principles of organic construction better than any other engineer."

Since then, Eduardo Torroja began to stand out with his innovative spirit. It was said the most important quality of his works was that they were alive. His research and investment on the behavior of materials, especially prestressed reinforced concrete, and the methods of structural analysis he developed are internationally recognized, and are still the subject of publications, conferences and studies in many parts of the world. Torroja's exploration of reinforced concrete was characterized by the use of continuous surfaces, made as lightly as possible and with a proper sense of elasticity. According to his words: "The best structure is the one that is held by its shape and not by the hidden resistance of its material."

Eduardo Torroja left samples of his work in America, Europe and North Africa, estimated at more than 800 projects produced, including viaducts, channels, civil buildings, religious buildings, hangars, industrial structures, etc.

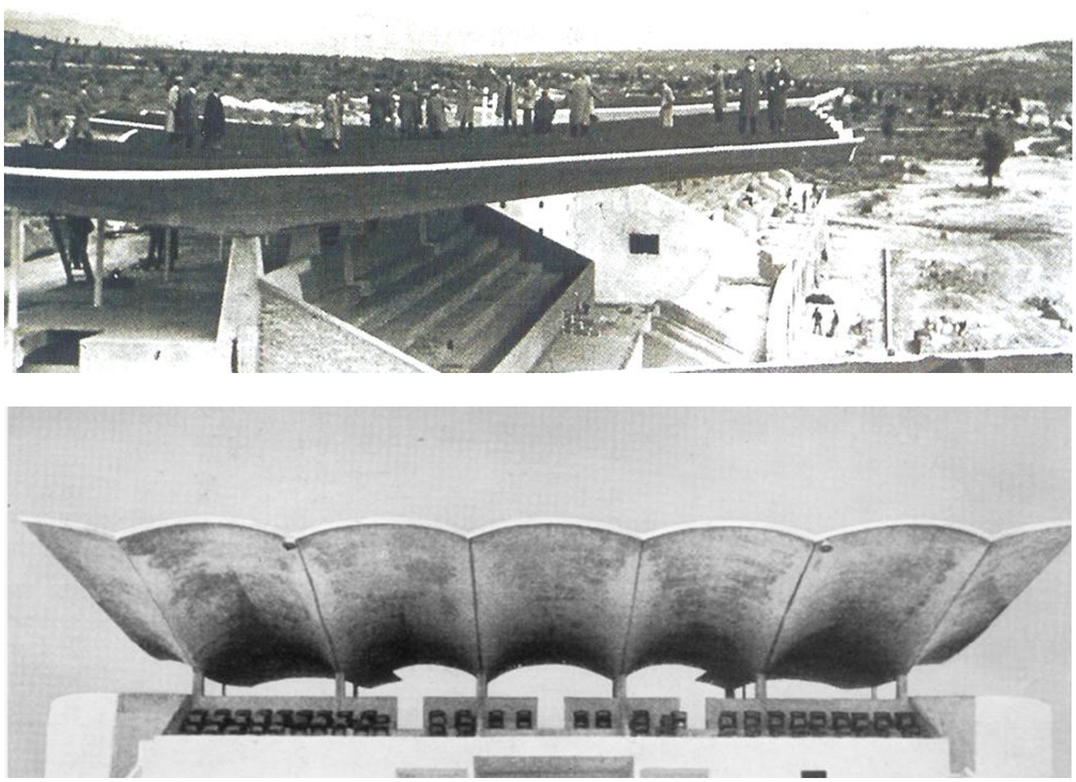

Figure 3: *Zarzuela Hippodrome (Eduardo Torroja, 1935). The amazing tribunes made with hyperboloids have a span of 12,40 metres. This structure is object of continuous study and a paradigm of the delicate equilibrium between form and function.*

Among his more visionary works are the Zarzuela hippodrome, the Pelota court Recoletos, the Fedaya water deposit and especially the market of Algeciras, inaugurated in 1935. It consists of a spherical cap-shaped dome inscribed in an octagonal frame supported on eight pillars. The diameter of the dome is 47.8 meters and the radius of curvature is 44.10 meters with only 9 centimeters thick. In its time it was a work of avant-garde, which used materials like concrete and iron to raise the dome without beams and interior support. It was a feat for the architecture of the epoch. As a curiosity we note that Saint Peter's dome in Rome needs a thickness of 3.70 meters to cover a space of 42.52 meters.

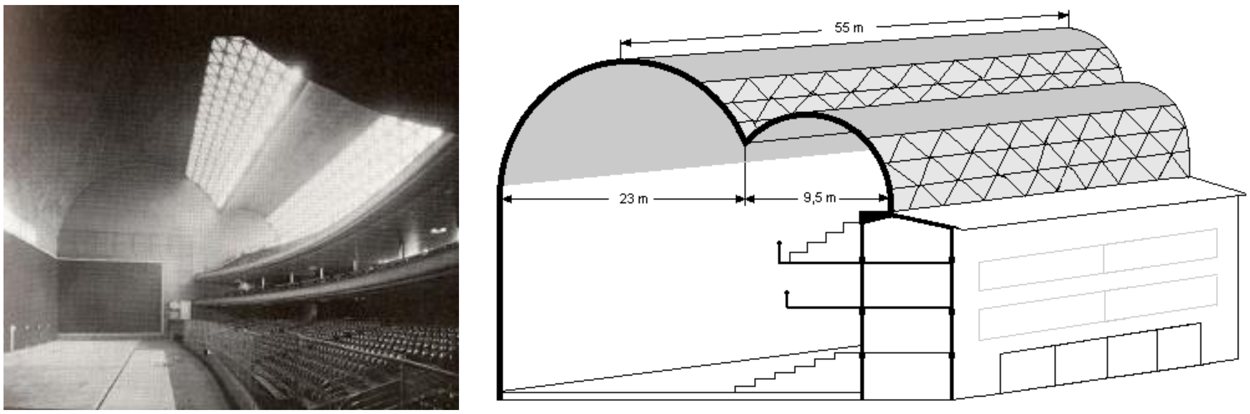

Figure 4: *Pelota Court Recoletos (Eduardo Torroja, 1935). The original solution found for the roof consisted of two barrel vaults traced by two asymmetrical circular arcs perpendicularly cut.*

Figure 5: *Water Deposit in Fedala (Eduardo Torroja, 1956). Project, scale model and real structure calculated with the geometry of a hyperboloid of equation* $(x^2 + y^2)/ 85.0084 - z^2 / 34.5128 = 1$.

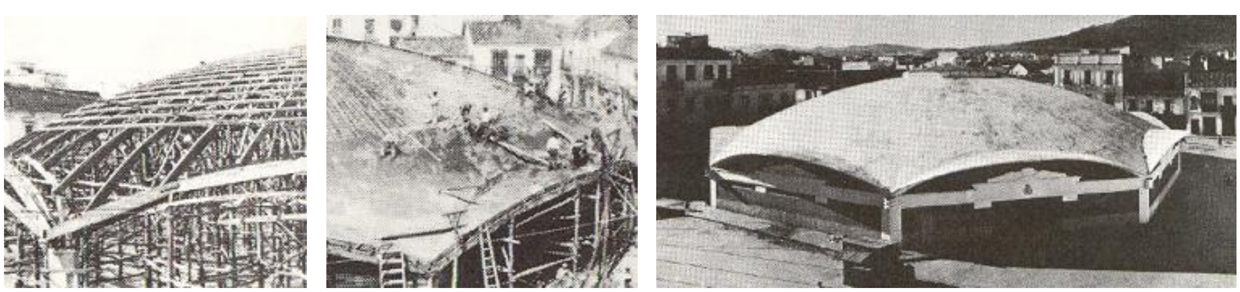

Figure 6: *Formwork and concrete application during the construction works of the market of Algeciras (Eduardo Torroja, 1935).*

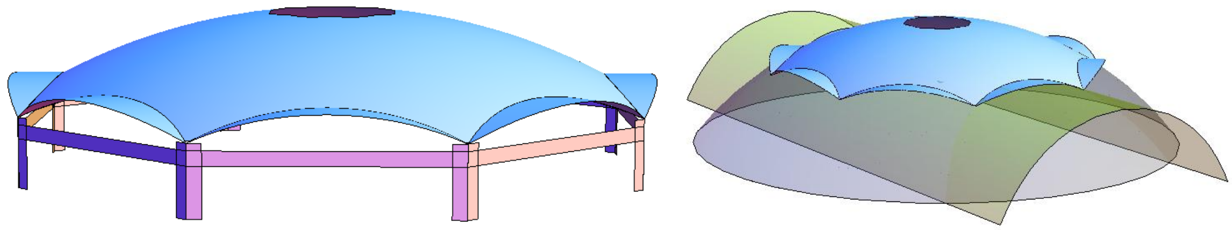

Figure 7: *Computer model of the market of Algeciras. The spherical cap is crossed by four cylinders that reinforce the edges of the structure and create an octagonal plan.*

Félix Candela (1910, Madrid – 1997, Durham)

He inherited from his teacher Eduardo Torroja, some of the basics of his work: the idea that the engineer must be a poet, the conviction that the structure depends on the form rather than the material used. His greatest contribution to the structural field are the shell structures generated from hyperbolic paraboloids, a geometric shape of extraordinary effectiveness that has become the hallmark of his architecture.

Félix Candela was a great expert on structures, but never completed an architectural work. He did not put doors or windows, or culminated other constructive details. His structures were carried out by intuition, not by strict mathematical calculations, and this is the reason why it was sometimes repudiated by both architects and engineers.

In 1936, he obtained a scholarship to study in Germany, but at the time the Spanish Civil War began and Candela was named captain of engineers on the Republican side. He was held four months in a French concentration camp while awaiting asylum as a war refugee. Mexico hosted him in 1939. There, in 1950, he founded the company Cubiertas Ala, which lasted until 1976, even though Candela left it in 1969. The construction company enjoyed remarkable growth for twenty years, culminating in the building of the Palacio de los Deportes in connection with the 1968 Olympic Games in Mexico.

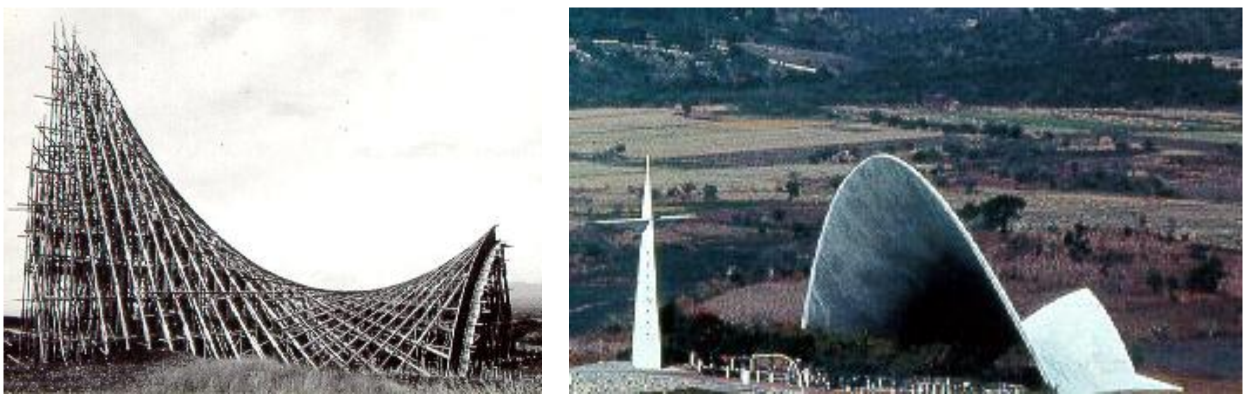

Figure 8: *Open Chapel in Lomas de Cuernavaca (Felix Candela, 1958). The formwork clearly shows the hyperbolic paraboloid as a ruled surface.*

Cubiertas Ala developed 1439 projects and 896 of them were built. A lot of these works were raised on the basis of crossed vaulting composed of hyperbolic paraboloids, or a single concrete sheet with hyperbolic paraboloid shape with edges constrained by arches such as the Church of Lomas de Cuernavaca.

Felix Candela moved to Chicago and worked as a full-time professor at the Illinois University, a task he continued until 1978. He did not neglect his business; he was associated with a U.S. firm based in Toronto. He signed a large number of projects, almost all very ambitious. One of the last one in which he participated before his death was the City of Arts and Science in Valencia, which included a large oceanographic park in whose construction also collaborated the famous architect Santiago Calatrava. During his stay in Valencia, Félix Candela suffered from a heart disease that forced him to return to Durham, North Carolina, where he died in December 1997.

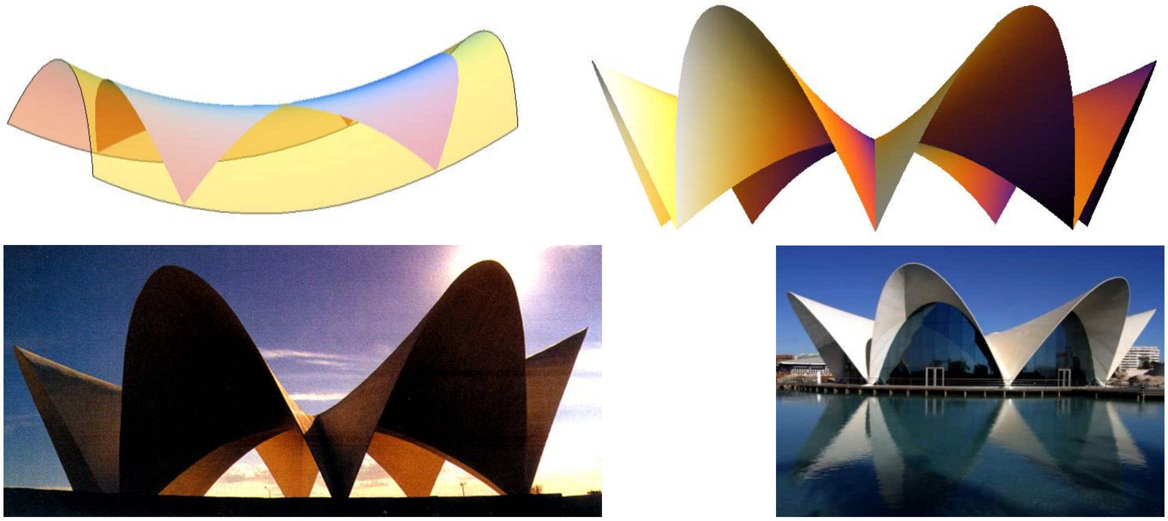

Figure 9: *Construction of L'Oceanografic in Valencia. The vaults are formed by rotated hyperbolic paraboloids of equation* $y^2/100 - x^2/4.6792 = z - 6$. *The building is inspired on Restaurant Los Manantiales (Xoximilco, 1953); a former project of Felix Candela from his Mexican period.*

Miguel Fisac (Daimiel, 1913 - Madrid, 2006)

In Miguel Fisac's buildings, beauty was a consequence of a daring inventiveness at finding appropriate and ingenious solutions. He was a great defender of prefabrication and mass production and an introducer of prestressed and post-tensioned concrete in Spain. His job was that of an artist of architecture, who invented and experienced new sections for the concrete beams applied into his works. He explored the expressive possibilities of using flexible plastic concrete forms and shaped concrete to give his structures the lightness of cloth.

Figure 10: *Miguel Fisac's "beam-bones". Inspired on real bones (top left) they integrate lightweight structures with beautiful designs.*

During the sixties, Miguel Fisac had his most fertile years with the invention of his "bones" of concrete, very light beams with sculptural sections and organic appearance with which he executed most of his works. The material used is prestressed concrete with the form of hollow pieces resembling bones that fulfill the requirements of both great lightness and strength. He then started a productive experimental relationship with his "beam-bones," prefabricated pieces that managed to solve the problem of saving big spans, control the zenith lighting and evacuate rainwater.

Figure 11: *Mathematical model (left), inauguration (centre) and destruction (right) of Laboratorios Jorba in Madrid (Miguel Fisac, 1965). The architect was asked by the owners to build a singular and eye-catching building that people later surnamed as "Pagoda". Although it was a symbol of the new Spanish architecture it was demolished in 1999 due to a speculative real-estate operation.*

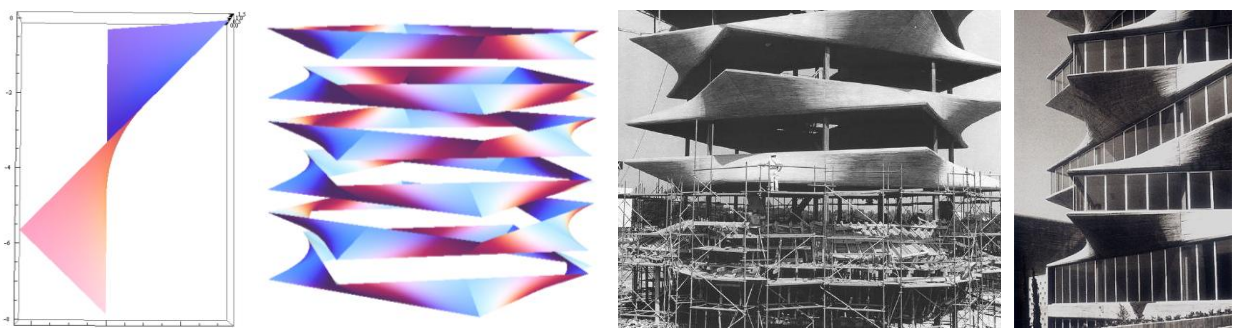

Figure 12: *The amazing design of Laboratorios Jorba is based on a hyperbolic paraboloid of equation* $x\,(0.1249 - 0.0244\,z) - (0.0808 + 0.0589\,y - 0.0539\,z)\,z = 1$. *This shape is rotated ±45º along the Z axis four times on each direction, generating eight hyperbolic paraboloids between each two floors to sum a total of forty eight in the building.*

Fisac began experiments with his concrete bones, which he employed as beams, lattices or pergolas in countless projects, featuring the spectacular nave of the Centre for Hydrographic Studies, the Parish of Santa Ana and the IBM building, all of them in Madrid. This group of masterpieces portray the technical and social optimism of the Spanish development during that period. From these years is also the Jorba Laboratories tower, built with concrete hyperbolic paraboloids and popularly known as "the pagoda." Its demolition in 1999, under the astonished look of Miguel Fisac, started a heated debate amongst the citizenry which changed the course of architecture in Spain.

In the last period of Miguel Fisac's work his flexible forms gave concrete a fluffy appearance in a technical and aesthetic adventure that connects with the techniques and tactile concerns of the latest generations of architects. Fisac juxtaposes forms and deconstructs buildings, segregating them in irregular elements with a newly-formed minimalist expression. Precursor of future trends and researcher of innovative solutions, through his legacy, the inquisitive, demanding and lucid spirit of Miguel Fisac will obstinately continue with us.

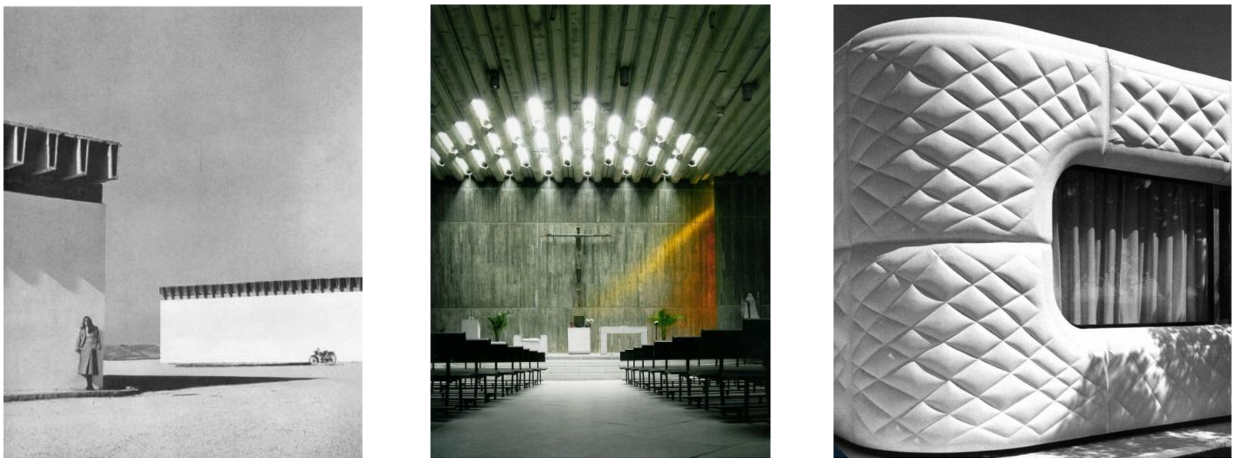

Figure 13: *The virtuosity of Miguel Fisac is manifested in the design of his "beam-bones", able to cover huge spans with a minimalist beauty, like in Garvey wineries in Jerez (left), the beautiful inner space of the Chapel from the School de la Asunción in Madrid (centre) and the expressive possibilities of concrete using his flexible plastic formwork in Casa Pascual de Juan in Madrid (right).*

The work of Miguel Fisac always had a heroic character, fighting against routine, ignorance and preconceived or borrowed ideas. He always maintained his dignity and his fighting spirit and a deep passion for architecture.

Figure 14: *Postwar vs. Modernity. Who copied whom? From left to right: Caja de Ahorros del Mediterraneo in Alicante (Miguel Fisac), Omotesando in Tokio (MVRDV Architects), Casa de la Cultura in Cuenca (Miguel Fisac) and Wozoco's Apartment in Amsterdam (MVRDV Architects).*

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