Eminent Structural Engineer: Félix Candela—Structural Artist of Thin Shell Concrete Forms (1910–1997)

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Brief CV

1910	Born on 27, January in Madrid, Spain
1929	Admitted to the School of Architecture in Madrid
1932	Spanish ski jumping champion
1935	Completes the course of study at the School of Architecture in Madrid
1936	Civil war breaks out in Spain; Candela fights for the Republic cause
1939	Exiled to Mexico after being placed in a concentration camp
1949	Builds his first shell—an experiment of a funicular vault
1950	Founds Cubiertas Ala S.A., a construction company specializing in shells
1951	Completes his first major work and first hyperbolic paraboloid, Cosmic Rays Laboratory
1954	Attends conference on Thin Concrete Shells at MIT; subsequently becomes internationally famous.
1961	Receives Gold Medal from the Institute of Structural Engineers, London
1971	Emigrates to the United States and works as a professor in the architecture department at the University of Illinois, Chicago until 1978
1971–1997	Works as a freelance consultant
1972	Delivers lecture at Princeton University where he identifies his design ideas in a brilliant lecture[1]
1979	Honorary Doctorate in Fine Arts, University of Illinois
1990	Honorary Doctorate, University of Seville, Spain
1994	Honorary Doctorate, Polytechnic University of Madrid
1997	Dies on 7, December

Introduction

Structural artists exhibit three fundamental characteristics: the ethos of efficiency, the ethic of economy, and the esthetic of elegance. Efficiency in this sense means the search for forms that use a minimum of materials consistent with sound performance and assured safety; economy signifies a minimum of construction costs consistent with low expense for maintenance; elegance implies an aesthetic motivation. One of the greatest myths in our structural engineering profession is that elegance is the province of architects and that while engineers ensure that it will stand, only architects can make it a work of art. This argument is contradicted by the most talented structural engineers over the last 200 years whose motivation included appearance along with efficiency and economy. One such engineer was Félix Candela (1910–1997) (*Fig. 1*).

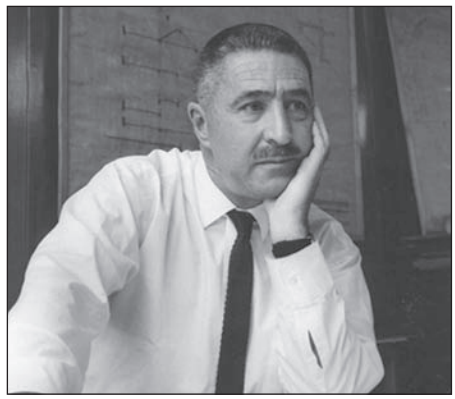

Fig. 1: Félix Candela

As Candela's formal education was in architecture, and as his shell designs are elegant, most people identify Candela as an architect. However, based on his career as a builder and designer, and his own words, we can demonstrate that Candela practiced as one of the greatest structural engineers of the 20th century, and hardly at all as an architect. He remarked at the time that "every day I feel less and less an 'architect'; I am losing interest in making plans and window details and things like that".[2] He identified himself more as an engineer and builder: "I must say … that although an architect by training, in practice I am a constructor and building contractor",[3] and one who makes his own engineering designs. This disassociation from thinking of himself as an architect was reflected even more pointedly in an essay he wrote for a symposium honoring Robert Maillart at Princeton University in 1972. One of the organizers was the second author of this paper who invited him to speak and suggested "New Architecture" as a title for his paper. Candela began his paper and lecture saying, "The title of my lecture is 'New Architecture'; but I cannot avoid the feeling that I have not too much to do with this subject. I don't think I can speak of my work as of any new architecture or even as architecture at all".[1] Later, when Candela republished this paper in Spanish, he renamed it "La Herencia de Maillart" (Maillart's legacy).

This paper provides a brief background of Candela's life and experiences, examines some of his major works, and describes the influence that others had on Candela (and vice versa). The interested reader is referred to a book recently published by the authors *Felix Candela: Engineer, Builder, Structural Artist*,[4] which coincided with a major art museum exhibition at Princeton University and later traveled to the MIT museum and the Carnegie Museum of Art.

Early Years

As a child, Candela showed intellectual potential and shortly after graduating from high school he enrolled in the School of Architecture in Madrid. It was during this time that he developed an interest in thin shell concrete structures. But this subject was not part of his formal education; therefore on his own, he went to the library and read the engineering journal papers on the topic that were being written by mostly the Germans. Not knowing German, nor having photocopy machines, Candela copied entire papers by hand.

At home, with the aid of a German–Spanish dictionary, he translated the text and educated himself in the higher order mathematics needed to understand the complex analysis of German shells. After completing his course of study, Candela won a scholarship to study in Germany with Dischinger and Finsterwalder (of Dyckerhoff and Widmann), who had already designed many cylindrical vaults. But on the day that he was supposed to board a train to Germany, the civil war broke out in Spain. Candela fought for the Republic cause, ended up in a concentration camp, and in 1939 he was exiled to Mexico where he created his major works.

It took him several years to get established in Mexico and when he did he began to study shells again. In 1949 he built his first shell as an experiment: a funicular vault. In 1950 he formed his company Cubiertas Ala, which was decidedly neither an architectural nor a consulting-engineering firm but rather a business devoted to building—he became a construction contractor specializing in shells.

Cubiertas Ala's first major project was in 1951 to build the Cosmic Rays Laboratory (*Fig. 2*) on the Mexico City University campus (UNAM). This structure was his "first international success and it gave [him] much encouragement".[5] For this project, the architect already had a form—barrel shells—and when Candela took on the construction, he decided to change the barrels to hyperbolic paraboloids, his first such structure.

Fig. 2: The Cosmic Rays Laboratory, 1951 (photo by Powell Draper)

The Hyperbolic Paraboloid and his Umbrellas

All of Candela's significant structures were of one geometric form, the hyperbolic paraboloid (hypar), and with that discipline he could build them only 40 mm (1,5 inches) thick. The doubly curved surface of the hypar form (e.g. a saddle) is developed with two straight line generators; thus, Candela achieved economy of construction by avoiding curved boards for his falsework in construction.

Candela's bread-and-butter structure (one that kept the company in business) was the "umbrella" (*Fig. 3*), a hypar with straight edges. The idea came from a 1936 French paper showing such an umbrella, which Candela transformed from a heavy ill-proportioned design into a light and elegant one. By placing many of these side by side, he created large roof coverings for markets, warehouses, and factories. After a few years he began to play with this umbrella form. Examples are the 1958 Candelaria subway station and the 1953 Church of Our Lady of the Miraculous Medal (*Fig. 4*), the latter being one of Candela's self-proclaimed favorites, a set that we examine next.

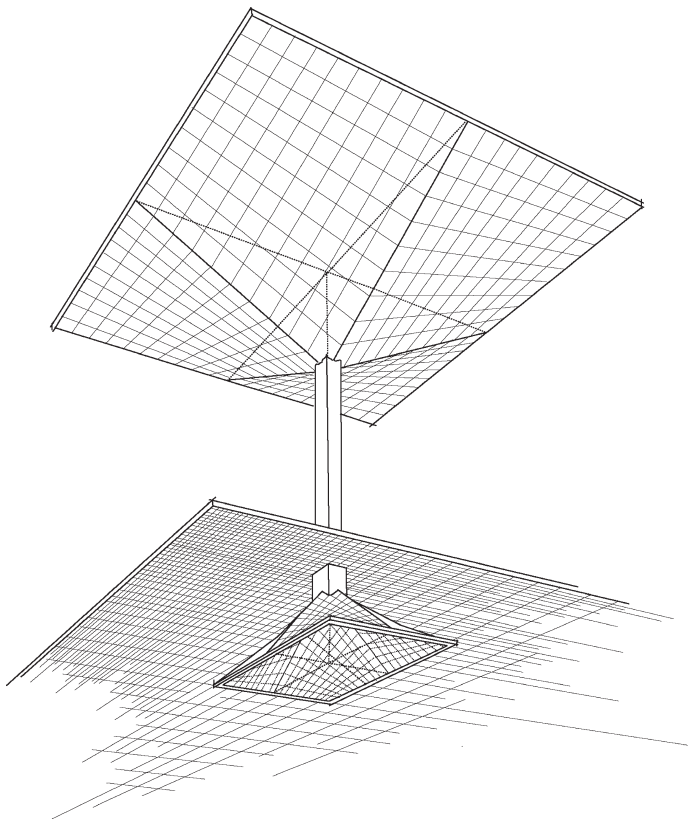

Fig. 3: Sketch of an umbrella shape

Candela's Favorite Structures

In an interview, when asked to name his favorite structures Candela replied: Church of Our Lady of the Miraculous Medal (Milagrosa), the Chapel at Cuernavaca, Restaurant Los Manantiales at Xochimilco, and the Bacardi Rum factory.[6] The umbrella he transformed into a church in 1953

for Milagrosa (*Fig. 4*). The church leaders wanted a gothic style church to be designed by an architect and built by Candela. The architect had proposed a single curvature hangar-like structure, but Candela proposed a radically different design to the clergy who accepted his design over that of the architect.

For the restaurant Los Manantiales at Xochimilco (*Fig. 5*), Candela was asked by the architects to take up the project as both designer and builder. The restaurant is pure structure (void of architecture) and reflects the hand of a structural artist. The same pattern emerged for the Cuernavaca chapel (*Fig. 6*); the architect approached Candela to be the builder and brought him a sketch of a triangular raised roof. Candela reshaped the form into the thin curved structure that made the chapel unique and dramatic.

Finally, for a new project he was stimulated by the cylindrical groin vaults of the St. Louis Airport terminal building designed by the architect Minoru Yamasaki and modified strongly by the engineer Anton Tedesko.[7] For his next project, Candela decided that whatever its function he was determined to create three groined vaults as in St. Louis; it so happened to be a Bacardí Rum bottling plant (*Fig. 7*). Once again, the client employed Candela as builder first, but that assignment also included, as did most of his other projects, functioning as structural designer.

Influences

Structural artist Robert Maillart[8] (1872–1940), a Swiss engineer, stands out as Candela's greatest influence: "[Robert Maillart] may have been one of the strongest influences at the critical moment in my career in which I was trying to become a builder of shells."[1] Robert Maillart influenced Candela, but in turn, Candela influenced other developing structural artists. For example, in the early 1960s, Swiss shell designer Heinz Isler[9] came across a book cover with a photograph of the Restaurant Los Manantiales designed and built by Candela; its forms were completely new to Isler and appeared almost paper thin, and stimulated Isler to think about how he might express the same kind of thinness.

Conclusion

From all these works, the same pattern emerges. Candela the builder makes a simplified analysis to jus-

Fig. 4: Our Lady of the Miraculous Medal Church (Milagrosa) (1955) (photo by Bruce White)

Fig. 5: Restaurant Los Manantiales, Xochimilco, 1958

Fig. 6: Chapel Lomas de Cuernavaca (1958)

Fig. 7: Bacardi Rum Factory, 1960

tify the engineering design and then takes the overall form, which sometimes comes from somewhere else, and plays with it to make it structural art. This art can only arise when that play is disciplined by efficiency and economy. As Candela explained: "But an efficient and economical structure has not necessarily to be ugly. Beauty has no price tag and there is never one single solution to an engineering problem. Therefore, it is always possible to modify the whole or the parts until the ugliness disappears".[1] The principles of structural art (efficiency, economy, and elegance) are realized in the thinness of Candela's concrete shells, with their grace and refinement of form, and their endurance. They remain in excellent condition today after a half century of continual service—including surviving earthquakes, fully intact, such as the 8,1 magnitude 1985 Mexico City earthquake. The thin shell concrete roof structures designed and built by Félix Candela represent a major gift to the modern profession of structural engineering and serve as a model for the future of what is possible in structural design.

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