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### Resistencia a través de geometría. El espíritu gótico y las estructuras de Félix Candela, una perspectiva a través del tiempo / *Strength through geometry. The Gothic spirit and the structures of Félix Candela, a perspective through time*

La relación entre estructura y geometría siempre es relevante. El presente artículo examina las estructuras de Félix Candela, arquitecto considerado artista estructural, en relación con el 'espíritu gótico' y el expresionismo estructural. Apoyado en los escritos de Bruno Zevi, Wilhelm Worringer, Frank Lloyd Wright, Erich Mendelsohn, Van de Velde, Eero Saarinen y el propio Félix Candela, este trabajo pretende mostrar la relación que presentan los proyectos diseñados por Félix Candela con el concepto que Frank Lloyd Wright denominó como 'espíritu gótico'. Un espíritu que se transmitió desde la construcción de las catedrales góticas y continuó durante el Expresionismo Estructural del siglo XX. Los avances recientes en el diseño computacional han permitido el desarrollo de nuevos métodos de optimización y búsqueda de formas que han mejorado la geometría arquitectónica y renovado el interés en este tipo de diseños.

El trabajo incluye reconstrucciones originales de proyectos no construidos de Félix Candela, defendiendo la integridad de la estructura como medio de diseño arquitectónico. Un enfoque similar al que siguieron otros arquitectos como Eero Saarinen o Frei Otto.

*Structural geometry is always relevant. This article examines the structures of Félix Candela, an architect considered as a structural artist, in relation with the 'Gothic spirit' and the Structural Expressionism.*

*Supported by the writings of Bruno Zevi, Wilhelm Worringer, Frank Lloyd Wright, Erich Mendelsohn, Van de Velde, Eero Saarinen and Félix Candela himself, this paper aims to show the relationship that the projects designed by Félix Candela present with the concept that Frank Lloyd Wright named as "Gothic spirit". A spirit that was transmitted from the construction of Gothic cathedrals and continued during the Structural Expressionism of the 20th century. The recent advances in computational design have enabled the development of new form-finding and optimization methods that have improved the structural geometry and renewed the interest in this approach to design.*

*The paper includes original reconstructions of non-built projects of Félix Candela, defending the integrity of the structure as a means of designing architecture. A similar approach that other architects like Eero Saarinen or Frei Otto followed.*

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Félix Candela, geometría arquitectónica, expresionismo estructural, estructuras laminares, reconstrucciones virtuales /// Félix Candela, Architectural geometry, Structural expressionism, Thin concrete shells, Virtual reconstructions

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### **Introduction**

«Worringer posited a direct relationship between Gothic, Baroque and Expressionism, which were seen as diachronic manifestations of a common aesthetic tendency, basically opposed to classicism»<sup>1</sup>.

Félix Candela started his career in the middle of the twentieth century, while the debates of architecture revolved around Modernism. He was considered as an independent builder without relations with the architectural theory and isolated to the trends of his century.

The work of Félix Candela ran parallel to the heyday of the architecture of Le Corbusier, Mies van der Rohe and other icons of Modernism, but also with what has subsequently been called the laminar adventure of thin concrete shells<sup>2</sup> or Neo-expressionism (fig. 01).

In 1959, Eero Saarinen coined the term 'Structural Expressionism', defending the structure as a means of generating architecture. A term which can group both engineers and architects, and whose principles are governed by the constructive system, the structural design, and the effective use of the materials.

Radically opposed to functionalists' concerns, Eduardo Torroja, Eero Saarinen, Nervi, Frei Otto, Heinz Isler... as well as Candela, developed an architecture based on principles leading to form as a consequence of structure. Candela, for his intellectual coherence, is undoubtedly one of the greatest representatives of this movement (Garlock y Billington 2008).

Candela defended that the design of a structure should be adapted according to the material used. In the case of concrete, the form would be a continuous thin shell that eliminates bending stresses. The determining factors would be constructive and hence the simplification in the

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1. Solaz, L., 2004. 'Expressionist Sensitivity, Expressionism as an Art Movement', *Espéculo. Journal of Estudios Literarios*, UCM, 27.
  2. Cassinello, Pepa. *Félix Candela Centenario 2010*, Fundación Juanelo Turriano, 2010.

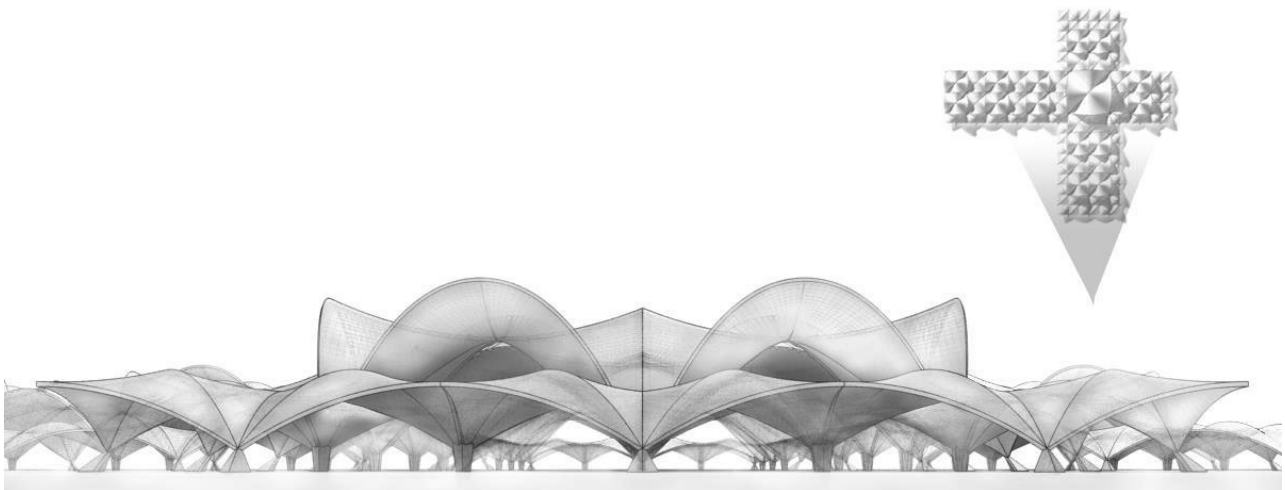


Fig. 01. Succession of hyperbolic-parabolic groin vaults with a maximum span of 52 meters. Images of the author. Reconstruction of the non-built project for the market La Merced, Félix Candela, Mexico, 1956.

geometry of hyperbolic paraboloids. Hypars are ruled surfaces with double curvature that increase stiffness, improving the effectiveness of the material<sup>3</sup>.

This approach to architectural design implementing the effectiveness of the materials and the construction systems, has its clear antecedents in the medieval builders of the Gothic Cathedrals. It had a resurgence in the 20th century with the use of thin concrete shells, especially during the 50s and 60s. The advances in computational design have placed the shells and vaults in the spotlight of architecture once again<sup>4</sup> (fig. 02).

Patrick Schumacher, principal at Zaha Hadid, raised the term «parametricism» to an architectural style, the most important since Modernism<sup>5</sup>. Form finding and optimization have become one of the main research topics for parametricism and computational design. According to Schumacher «In my design work I am now trying more and more to move away from the free form play with complex curvature towards the disciplined use of structural form finding algorithms.»<sup>6</sup> (fig. 03).

The Block Research Group at ETH Zurich<sup>7</sup> is one of the leading teams in the research of form finding for unreinforced shells using computational design methods. They have expressed the importance to change the

3. del Blanco, F.L. & García I., 2017. Fernando Higuera y Félix Candela en un retorno a la geometría de paraguas invertidos. Análisis y reconstitución gráfica del aeropuerto de Murcia, 1983. *EGA Expresión Gráfica Arquitectónica*, vol. 23, no. 32, pp. 232-243.

4. Veenendaal & Block, 2012. Computational form finding for fabric formworks: an overview and discussion. *Proceedings of the 2nd international conference on flexible formwork*, pp. 368-378.

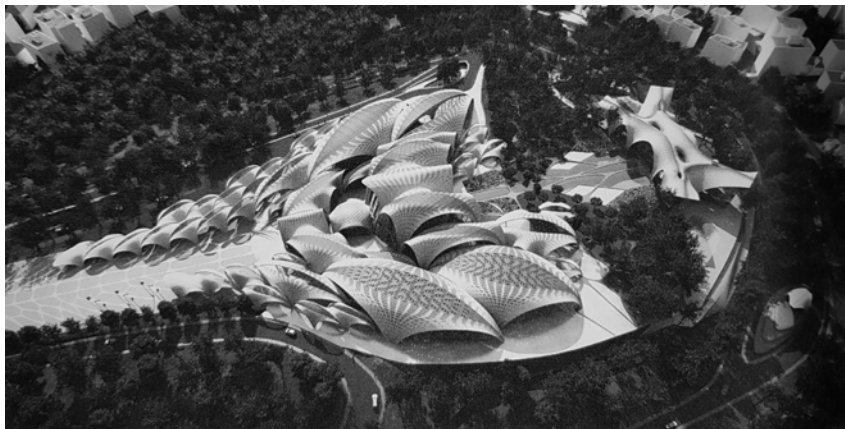
5. Schumacher, P., 2009. Parametricism: A New Global Style for Architecture and Urban Design. *AD Architectural Design* [en línea], vol. 79, no. 4, pp. 14-23.

6. Schumacher, P., 2014. The congeniality of architecture and engineering - the future potential and relevance of shell structures in architecture. *Shells Structures for Architecture*. S.l.: Routledge,

7. The Block Research Group (BRG) at the Institute of Technology in Architecture at ETH Zürich focuses on analysis of masonry structures, graphical analysis and design methods, computational form finding and structural design, discrete element assemblies, fabrication and construction technologies. <https://www.block.arch.ethz.ch/>

Fig. 02. Variations of the inverted umbrella hypars with 9-meter cantilevers. Images of the author. Reconstruction of the non-built project for the Villahermosa Cathedral, Félix Candela, México, 1960.

Fig. 03. Juxtaposition of free-form vaults. Field of domes, Zaha Hadid, 2012.



construction systems in favor of the environment, to avoid material depletion and the reduction of CO2 emissions.

«It seems logical to think that by having a new material –reinforced concrete- its rational use should give rise to new structural forms, and these forms in turn would influence the architectural composition»<sup>8</sup>.

«Thin concrete shells are the most suitable forms to be built by this material»<sup>9</sup>.

8. Candela, F., 1985. Divagaciones estructurales entorno al estilo. En: XARAIT EDICIONES (ed.), *En defensa del formalismo y otros escritos*. S.l.: s.n., pp. 37.

9. Cassinello, Pepa. *Félix Candela Centenario 2010*, Fundación Juanelo Turriano, 2010.

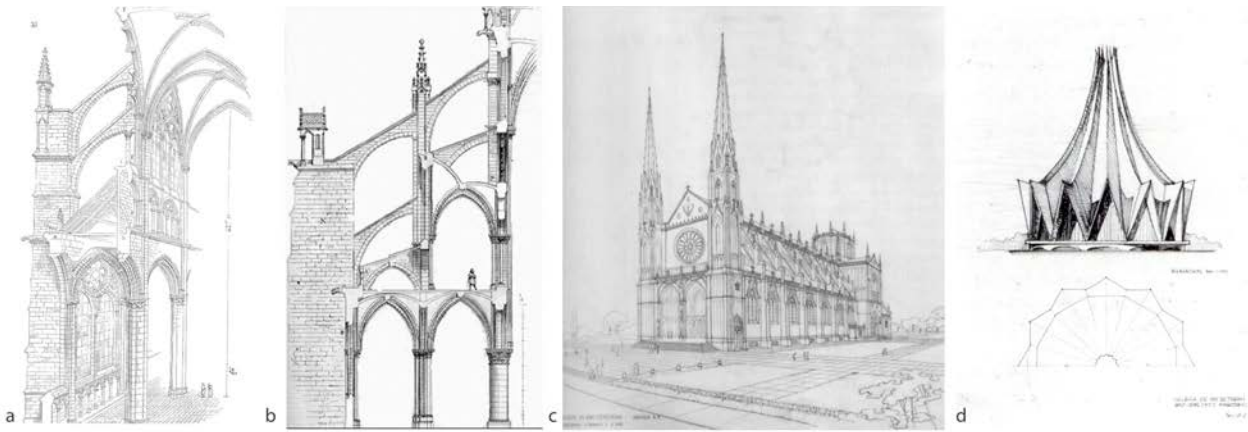


Fig. 04. Initially Félix Candela copied the forms directly from the gothic cathedrals, until he designed new structural geometries. 4a and 4b: Amiens Cathedral, dictionary of french architecture, Viollet le Duc, 1868. 4c: project for the cathedral of San Cayetano (non-built), Félix Candela, México, 1950. 4d: project for the church of San Esteban (non-built), Félix Candela and Jaime Ortiz Monasterio, México.

### Structure as a form generator

In the words of Bruno Zevi, it is during the Romanesque that «architecture begins to express itself in terms of structure and constructive elements»<sup>10</sup>. Romanesque architecture is shaped as an organism in which the spatial internal distribution appears as a unit and is shown as such in accordance with the outer envelope (fig. 04).

Gothic architecture was a great advance with regard to Romanesque in structural terms. It becomes «a bundle of bones, fibers and muscles, a constructive skeleton covered with immaterial cartilage»<sup>11</sup>. Gothic is not only a refinement of Romanesque. Gothic domes are folded and nerved, and these nerves -begining in the domes- extend through their supports transmitting their loads to the ground. This continuity is overtaken by Antoni Gaudí in the Guell Colony, by Ero Saarinen at the TWA airport and sistematically by Félix Candela (fig. 05).

The fan vaults of King's College Chapel at Cambridge in 1515 are one of the most significant examples of constructive coherence and material efficiency during Gothic. Medieval builders used the limited materials that they had at their disposal and designed a structure according to its properties. Despite its heavy appearance, the vault saves a span of 12,65 meters with a thickness of only 13 cm using unreinforced masonry. It has a slenderness greater than the shell of an egg. This is achieved by suppressing the bending stresses of the material, which has a great resistance to compression<sup>12</sup>. Medieval builders used a knowledge that was forgotten at some point in history<sup>13</sup>.

Structure is released of canons and composition, defining the space and shaping the architectural body. The freedom achieved by Candela with structures that do not hesitate to show how loads are distributed within the project, is completely different to the one Le Corbusier achieved by

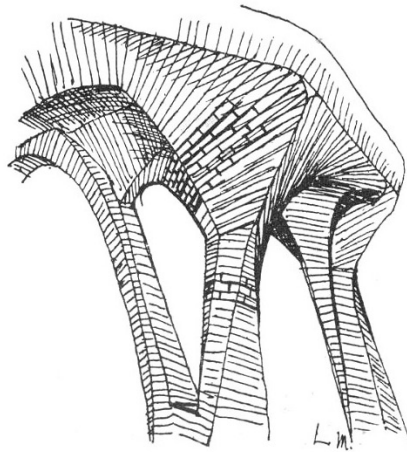
10. Zevi, Bruno. How to see Architecture (*Saber Ver La Arquitectura*), Editorial Poseidon, 1976, p. 74.

11. *Ibíd.*, p. 76.

12. Matthias Rippmann, 2017. How putting the arch back in architecture could save the environment. *TEDx* [en línea]. S.l.: s.n.,Matthias Rippmann 2017)

13. Block, P. 2018 <<https://www.youtube.com/watch?v=vAavRx7uoeA>>

Fig. 05. 5a: Colonia Güell, Antonio Gaudí, Cataluña. 5b: Terminal TWA, Eero Saarinen, New York, 1956.



freeing the plan and facades from the structural grid. These structures are capable of generating spaces in tension from a simple and functional plan but also capable of expressing themselves and communicating with their observers. The fundamental concepts of the architecture of Félix Candela are those of Gothic architecture.

«Gothic masters managed to develop an original constructive system, overcoming the limitations of the single material available. The process of its design obeys the same structural principles of nature»<sup>14</sup>.

The engineer Jaques Heyman<sup>15</sup> deserves a special mention in this context. Known for his work applying modern theories to the study of cathedral structures, he is one of the academics who have contributed the most to the development of structure theory in the 20th century.

### **The Gothic spirit**

In 1910, Frank Lloyd Wright wrote:

«A revival of the Gothic spirit is needed in the art and architecture of modern life (...). Reviving the Gothic spirit does not mean using the forms of Gothic architecture handed down from the Middle Ages. It necessarily means something quite different (...). The spirit that fixed those forms is the spirit that will fix the new forms. Classicists and schools will deny the new forms, and find no "Gothic" in them (...). I appeal to the organic character of its form because it was better than any other (...). This is why I believe that most of my buildings were conceived and carried out in the light of the Gothic spirit...»<sup>16</sup>.

The importance of the Gothic spirit is evident not only in the 'structure' statements of Félix Candela, but in its different manifestations, either the collective commitment of 'Arts and Crafts' or Wright's moral arguments. Gothic appears as an alternative to classicism.

14. Candela, F. 'Structural Ramblings Around Style (Divagaciones Estructurales Entorno Al Estilo)', in *In Defense of Formalism and Other Writings (En Defensa Del Formalismo y Otros Escritos)*, ed. by Xarait Ediciones, 1985, p. 34.

15. Heyman, J., 1977. «Equilibrium of shell structures», Oxford University Press.

16. Wright, F.L., 1910. Preface to studies and executed buildings by Frank Lloyd Wright.

Facing the human scale of Greek architecture, Gothic architecture displays an overwhelming monumental scale. «For the first time in the history of architecture, artists conceive spaces that are in polemical antithesis with the human scale. It generates not a calm contemplation but a state of mind of disequilibrium, due to the contradictory forces and solicitations fighting against each other»<sup>17</sup>. It is an architecture that manages to express and generate feelings, as well as the expressionist architecture or the projects of Candela. The relation that Worringer stated between the gothic and the expressionism was encompassed under the term of neoexpressionism by Bruno Zevi. This term applies to the architecture of Félix Candela.

This Gothic spirit has been repeated throughout history on many occasions. William Morris (1834-1896) and John Ruskin (1819-1900) advocated the return to medieval craftsmanship, where stone-masons worked rocks and cathedrals were erected as a reward for collective labour. The phenomenon 'Arts and crafts' that Bruno Zevi relates to the Neogothic passion of the nineteenth century. An artisan singularity that also appears in the projects of Candela, in which the wooden formwork allowed to contemplate the form of the project before it was finished to the satisfaction of the carpenters.

Viollet Le Duc (1814-1879) found in Gothic cathedrals the essence that could change the architecture of his time, an architecture that he considered to be in decline after the gothic period. The advances in the technique would allow a return to the direction that Gothic had pointed to, and that Renaissance had truncated. The structure regained its lost importance.

The lines of force of Victor Horta (1861-1947) were configured as an expressive principle that allowed the transmissions of loads to be understood.

But it was most probably Gaudí (1852-1926) the architect who more closely approached the Gothic spirit. Influenced by Violet Le Duc's writings, Gaudí shared with this architect the interest for the Gothic and the understanding of the Renaissance as an interruption for its evolution. Gaudí gathered both, the importance of the structure and the mysticism of the great Gothic cathedrals. Keeping their essence without replicating its forms, he managed to arouse strong feelings in those who experienced his architecture. For this reason, Bruno Zevi considered Gaudí as an exceptional genius whose poetry emanated «a virulent expressionist component»<sup>18</sup>. This expressionist nature and his anti-classicism, as well as the importance of the structures in his projects are present in the work of Félix Candela.

The spaces of the project for «Hotel Attraction» that Gaudí designed for New York are delimited and enveloped by its structure and somehow, they evoke Gothic architecture. (fig. 06).

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17. Zevi, B. How to see Architecture (*Saber Ver La Arquitectura*), Editorial Poseidon, 1976, p. 77.

18. Zevi, B. The modern language of architecture (*Historia de la arquitectura moderna*), Editorial Poseidon, 1980, p. 22.



Fig. 06. 06a: Hotel Attraction (non-built), New York, Antonio Gaudí, 1908. 06b: project for the Chicago Tribune Competition, Bruno Taut, 1922. 06c: section of the Hotel Attraction, reconstruction by Manuel Hidalgo, 2008.

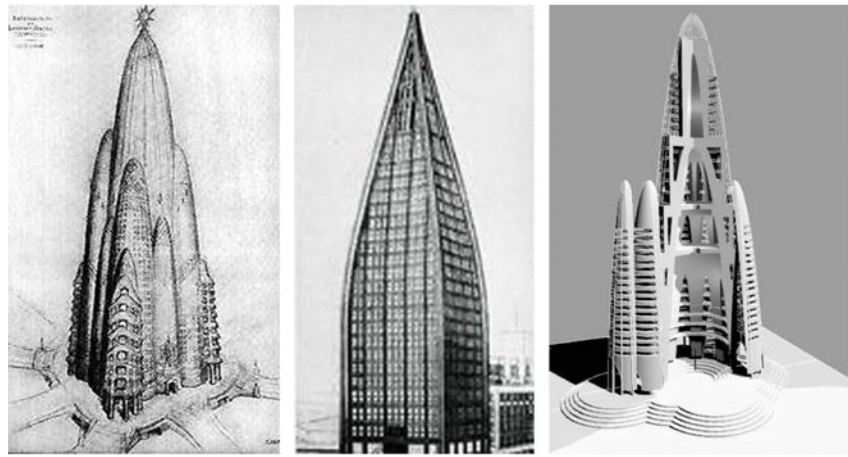


Fig. 07. Interior vaulted space with openings generated by the variations of the vault modules. Image of the author. Virtual reconstruction of the non-built project for the market La Merced. Félix Candela, México, 1956.



Zevi writes: «Shout and geometry (...) the antinomy of expressionism. The shout protests and cries out against the false absolute and eternal truths of Classicism. But the geometry of this drift is not rational, it does not look at objectivity, it does not freeze matter, indeed, it infuses energy and dynamism»<sup>19</sup>.

Expressionist architecture returned to the Gothic spirit. Unlike Candela, it was not the structural strength of the cathedrals that interested the expressionists, but their capacity to generate feelings in the observers, to express themselves, to produce emotions through a «shuddering cry» (fig. 07). An architecture that received «an essential psychological message that manifested against any principle and functional or formal method, the desire to externalize unconscious contents, the feelings...»<sup>20</sup>. An architecture that was opposed to functionalism.

According to Worringer, «Baroque is a stylistic form that displays an organic life under a strong pressure. Its transcendental pathos differentiates it from the harmonious peace and balance proper to the classical style»<sup>21</sup>. The Baroque opposition to the classicism raised by Worringer is arguable since it displays many common aspects. Nevertheless, a fissure appears in the passion for the curve and the counter curve and in the generation of new spaces untold in classic architecture. Worringer writes: «Baroque is a degeneration of Gothic»<sup>22</sup>.

19. Zevi, B., 1995. *Erich Mendelsohn: complete works. La profundación expresionista hacia lo orgánico*

20. *Ibid.*, p. 20

21. Worringer, W., 1911. *Form in the Gothic*. S.I.: Tiranti

22. *Ibid.*

Fig. 11. Traducción al italiano del permiso a Lord Elgin, Atenas, 1801. En WILLIAMS, Difry, 2009. Lord Elgin's firman Dyfri Williams. Journal of the History of Collections. p. 2.

Fig. 12. Charco detrás de la escultura de Iris, Sala Duveen del Museo Británico, 2018. En Who will rescue the Parthenon sculptures from its British 'saviours'? George Vardas, 2021. Extraída de: <https://greekcitytimes.com>

The engineer Javier Manterola<sup>23</sup> presented how Borromini used again the characteristic folding of Gothic vaults in the dome of San Ivo, allowing the structural continuity between surfaces and supports that had disappeared during the Renaissance.

Reaffirming the connection between expressionist architecture and the projects of Félix Candela, Erich Mendelsohn wrote in 1953 an article entitled «Background to design», appointing the Cosmic Rays pavilion of Candela. It was shown as an example of the «continuous elasticity» concept that Mendelsohn had already foreshadowed in his earlier drawings. Mendelsohn wrote «I believe that the architecture of elastic continuity –unlike skeletal constructions- opens up a new world in which the intellect and imagination can coexist again»<sup>24</sup>.

The comparison between Mendelsohn and functionalism architecture shows the need to «break the static envelope that encloses and paralyzes human functions, to free itself from the T rule, from the right angle and parallel lines, from the geometry and the elementary stereotomy, to sensitize matter to the spasm of its fibres: here is the declaration of Independence of classicism signed by Mendelsohn»<sup>25</sup>.

On the other hand, Zevi writes: «In his eloquent single-outlines, Mendelsohn evidences the same desire that guided Borromini and Gaudi: the building is a unitary block, swollen with solidified matter, embodied in a single blow. It is not born of irrational instincts, rather it announces shell structures and ruled surfaces»<sup>26</sup>.

The position Candela adopts against the Modernism is similar to the one that Gothic architecture displayed against Greek architecture. The forms designed by Candela could never be confused with those of a Gothic cathedral. It is the structural and constructive logic that establishes that connection. The 896 thin concrete shells that he built with his company, «Cubiertas ALA»<sup>27</sup>, show the feasibility of his principles.

### **Structural Expressionism**

«Throughout the present century, the principle of 'structural honesty' has become curiously 'expression of structure' and finally 'structural expressionism'. Structural integrity is a powerful and enduring principle I don't want to give up»<sup>28</sup>.

23. Manterola, J. 'The Resistant Structure In Today's Architecture (La Estructura Resistente En La Arquitectura Actual)', *Informes de La Construcción*, 50 (1998), 456-457.

24. Mendelsohn pointed out the project of a still unknown Félix Candela together with the Racecourse of Eduardo Torroja and the Theatre in Rio by Niemeyer. (Mendelsohn 1953)

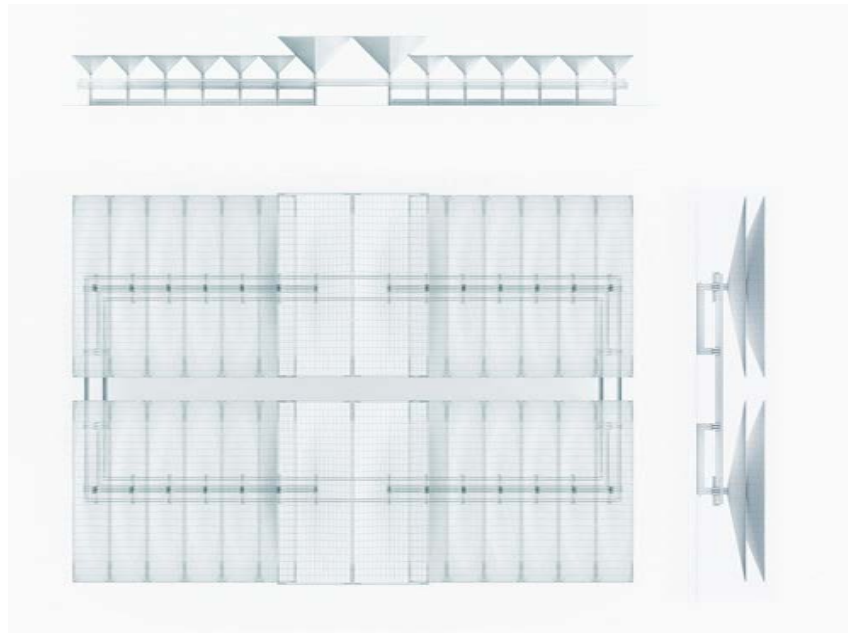
25. Zevi, B., 1995. *Erich Mendelsohn: complete works. La profundación expresionista hacia lo orgánico*. S.l.: s.n.

26. Ibid.

27. The Avery Architectural and Fine Arts Library» at Columbia University (1984) preserve the documents of the Cubiertas ALA company.

28. Eero Saarinen, conference Remarks at Dickinson College, 1959. <http://arquitectura-mashistoria.blogspot.com/2007/04/eero-saarinen.html>

Fig. 08. The stiffness provided by the double curvature of the hyperbolic paraboloids enabled 12-meter cantilevers with a thickness of only five centimeters. Image of the author. Virtual reconstruction of the non-built project for the airport in Murcia, Félix Candela and Fernando Higueras, 1982, Spain.



«We only have the structure as a rational principle to give sense to the architectural forms, to produce, in sum, expressive forms determining a style»<sup>29</sup>.

Thin concrete shells had their peak in the 50s and 60s. As Rafael García García wrote, «(...) these are mostly distributed between the beginning of the 50s and the end of the 60s of the 20th century, ending with the Congress of the International Association for the Shell Structures (IASS) held in Vienna in 1970. In this Congress, the latest and greatest achievements with this structural system were presented (...). Notwithstanding the hopes placed in folding geometries, to a large extent encouraged in this congress, no more outstanding works were done ever since»<sup>30</sup>.

As with Expressionism, during the twentieth century the presence of Structural Expressionism was relegated to the background of the architectural scene, while modernist architecture was the main protagonist. The circumstances of Candela after being exiled led him to design a constructive system in which economy of means was the main goal. Subsequently, far from carrying out conventional projects, he optimized and lowered the costs of existing solutions using thin concrete shells with double curvature (due to their better structural behaviour) and ruled surfaces (such as the hyperbolic paraboloid) with the subsequent savings of time and material<sup>31</sup> (fig. 08).

29. Candela, F. 'Structural Ramblings Around Style (Divagaciones Estructurales Entorno Al Estilo)', in *In Defense of Formalism and Other Writings (En Defensa Del Formalismo y Otros Escritos)*, ed. by Xarait Ediciones, 1985, p. 40.

30. García, R. 2007. 'Folded Reinforced Concrete Sheets. Realizations in Spain (Láminas Plegadas de Hormigón Armado. Realizaciones En España)', in *Proceedings of the 5th National Congress of History of Construction*.

31. Del Blanco, F.L. & García, I. 2016. De las estructuras laminares a las estructuras metálicas en la arquitectura de Félix Candela. Análisis y reconstitución de la sala de exposiciones para el concurso del Palacio Olímpico de los Deportes, México 1968. *Rita Revista Indexada de Textos Academicos*, vol. 5, pp. 98-105.

The structure and constructive system will be the main aspects defining the final form of his projects, rejecting the connection between form and function<sup>32</sup>.

«The architectural revolution of our century has been unable to rid itself of the classic vices of origin. It won an easy battle against the decorative media (...), but the classic skeleton remained intact. It was a classic revolution against classical art»<sup>33</sup>.

The figure of Eero Saarinen is of special interest in this context, because in the evolution of his projects we can see both trends. In his early works, while still working with his father (Eliel Saarinen), he worked on symmetrical projects, free compositions that do not make any reference to the interior space... an architecture linked to the nineteenth century. The projects he developed afterwards, without Eliel Saarinen, turned towards the modernist tendencies. In the first architectural competition he won –a theatre-, symmetry disappears, since the outer volumes are the result of the internal functions, there is no reason for them to be symmetrical<sup>34</sup>. A great change appears again in his last projects. The TWA terminal's form and space are defined by its structural design (fig. 09).

Symmetry, repudiated by modernist architecture, reappears with Structural Expressionism. It helps to achieve a better structural behaviour, since the inner horizontal forces are negated. The evolution in Saarinen architecture happens gradually. We can find Saarinen's projects with a classical language where the structure becomes the protagonist, such as the folding houses designed with the Eams.

Bruno Zevi wrote in «The Modern Language of Architecture» that symmetry belongs to the classical language of architecture as asymmetry to modern language, rejecting apriorisms. But... hasn't asymmetry become the apriorism in Modernism?

Great masters such Alvar Aalto or Mies van der Rohe showed that under the functional premises, symmetry can be accommodated, and under structural constraints it is advantageous.

Saarinen states: «The principle of respecting function is deeply rooted in my projects, just as it is in others belonging to this age. But, like others, I do not use it to solve my architectural problems»<sup>35</sup>.

The evolution of the work of Kenzo Tange maintains some similarities with the one of Eero Saarinen. In his early works, one can see the

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32. del Blanco, F.L. & García, I., 2017. *Las cúpulas de Félix Candela. Análisis y reconstitución de las instalaciones deportivas de la Universidad Brown, 1965-1972*. 2017. EGA Expresión Gráfica Arquitectónica, [S.l.], v. 22, n. 29, p. 228-239, mar. 2017. del Blanco García y García Ríos 2017)

33. Candela, F., 1954. The shell as space encloser. MIT, United States.

34. Merkel, J., 2005. *Eero Saarinen*. S.l.: Phaidon

35. Eero Saarinen, conference Remarks at Dickinson College, 1959. <http://arquitectura-mashistoria.blogspot.com/2007/04/eero-saarinen.html>



Fig. 09. 09a: First prize for the Theater of the University William and Mary, Eero Saarinen. 09b: Terminal TWA, Eero Saarinen, New York, 1956. 09c: Kenzo Tange, Centre for Peace in Hiroshima, 1949-1956. 09d: Olympic Pavilion, Kenzo Tange, Tokyo, 1962-1964.

influence of Le Corbusier's language. He could have been influenced by his master, Mayekawa, who in turn was a collaborator of Le Corbusier. The influence of the cubic volumes, concrete planar surfaces and pilotis can be appreciated in the Centre for Peace in Hiroshima (1949-1956) and the project for the City Council in Kurashiky (1958-1960) (fig. 09).

In the 60s the projects of Kenzo Tange evolved, leaving the functionalist premises behind and looking for new forms from «technique» and construction systems. Kenzo Tange wrote: «machinism has begun to significantly influence man's entire life and henceforth it is useless to attempt to escape the effects of technique»<sup>36</sup>. Can the current technique excite humanity? Will the machinism improve human conditions? The Tokio Olympic warehouses, the hyperbolic paraboloids for Santa Maria Cathedral or the Sports Palace in Takamatsu try to answer those questions. The structure and the construction system, the technique and the materials generate their forms independently from their function.

As stated by Udo Kultermann<sup>37</sup>, the Assembly Hall in Shizuoka (1955-1957) marks the turning point in Tange's work. According to Kultermann, the warehouse Matthieu Nowicki performs in Raleigh influences Kenzo Tange decisively. Even so, a more direct antecedent can be found to his work: The Church of the Solitude that Candela build during the same year.

«My attitude towards architecture and urbanism was inspired by its functional concept; but soon there were problems that went beyond the limits of functionalism»<sup>38</sup>.

### **The rise of thin concrete shells**

Like Candela, Saarinen and Tange built their projects mainly in the decade of the 50s and part of the 60s, a peak period for the thin concrete shells. Born in the same decade (1910, Félix Candela; 1910, Eero Saarinen; 1913, Kenzo Tange), they stood aside from Modernism. Considering form as a result of the constructive systems, efficiency of materials and structural design, they kept closer to the path that engineers had begun, with special reference to the concrete bridges of Robert Maillart.

36. Boyd, R., 2011. *Kenzo Tange: Makers of Contemporary Architecture*. S.l.: Literary Licensing, LLC Boyd 2011)

37. Kultermann, U., 1989. *Kenzo Tange*. S.l.: Gustavo Gili

38. Kenzo Tange, 'Function, structure and symbol', 1966, Reprinted in Kultermann 1970, pp. 242-243

“There are people we cannot deny the title of artists. These artists, the creators of a new architecture, are the engineers”<sup>39</sup>.

Heinz Isler (1926) deserves special mention regarding thin concrete shells. The engineer «was born professionally» (Moreyra Garlock y Billington 2014) in 1959 at the first congress of the International Association for Shell Structures (IASS), where he presented the paper «New shapes for shells», in which he explained the method of the hanging reversed membrane to design thin concrete shells.

In this context, in 1958 during the Brussels exhibition, Le Corbusier built the Philips pavilion. The same year, Eero Saarinen designed the TWA terminal in New York, and a year earlier, in 1957 the Opera of Sydney by Jörn Utzon was announced as the winning project. Thin concrete shells were in full swing, and even Le Corbusier, one of the greatest exponents of functionalism, showed an interest in them. Philips Pavilion’s volumetric complexity had nothing to do with the «magnificent play of volumes brought together *in light*».

These projects maintain strong analogies and could be grouped together. The skin and structure are one and the enclosure becomes the main element. However, a more detailed analysis reveals how different is the Philips Pavilion designed by Le Corbusier.

The plan of the Philips pavilion is configured as a curvilinear perimeter that mimics the shape of a stomach that guided the visitors. A complex space defined not only by the concrete surfaces, but also by the itinerary to be followed. On the contrary, Candela’s plans are simple, it is just the enclosure that generates the tension inside.

«It is not a matter of ingeniously solving a plan that works and covering it with a conventional structure... but designing an expressive interior space, an envelope to be admired from the interior of the project»<sup>40</sup>.

As seen before, symmetry had become a strategy by structural designers. Under the physics laws, symmetry confers a better behaviour, and that is why Candela will not hesitate to return to it. The drawbacks of symmetry under functionalism are clear. And a symmetrical project designed by Le Corbusier would be inconceivable.

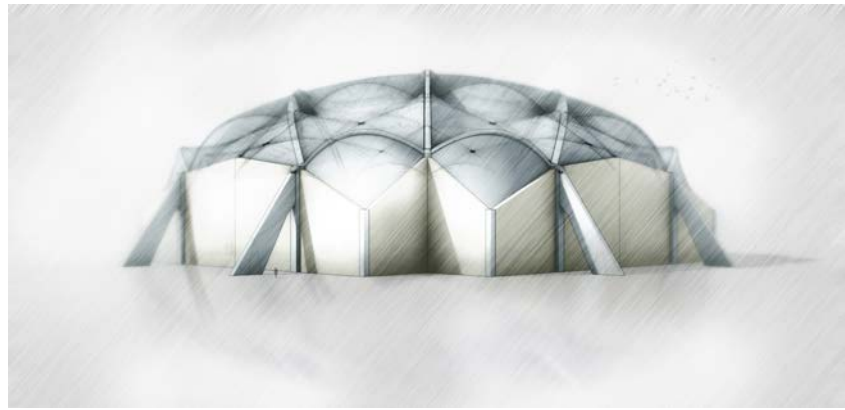
There is another common factor in structural expressionism: the envelope as a space generator. Candela, Saarinen, Niemeyer, Frei Otto, Kenzo Tange, Heinz Isler or Buckminster Fuller, attach great importance to it as space encloser.

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39. Van de Velde, H. Essays drawn from the book «Historia de la Arquitectura Moderna». (Zevi 1980)

40. CANDELA, F., 1985b. La Iglesia de la Virgen Milagrosa 1956'. En: X. EDICIONES (ed.), *En defensa del formalismo y otros escritos*. S.l.: s.n., pp. 53

Fig. 10. Spherical arches holding up thin concrete shells with 30 meters span. Shells are formed by the intersection of two hyperbolic paraboloids forming a groin vault. The buttresses transmit the loads to the ground. Images of the author. Reconstruction of the non-built project for the sports facilities at the Brown University, Félix Candela, USA, 1968.



The spatial complexity in the architecture of Félix Candela is determined by the skin of the projects (which is the structure itself), being the plan simple and even traditional (fig. 10). As Candela states in his writings, the history of architecture confirms that simple plans are functional.

### Conclusions

Félix Candela never manifested interest in functionalism. The evolution of his projects focused on thin concrete shells. Influenced by the structures that were built mainly in Germany and France, as well as those of Eduardo Torroja, Candela's formal repertoire increased with his constructive findings, making a clear separation between form and its function.

Bruno Zevi uses the term Neo-expressionism to include Candela, Saarinen and Niemeyer in the same group, leaving Frei Otto and Fuller under «utopia and futuribles» and Kenzo Tange under the Mannerism. They all have in common the search of form-finding techniques from the structure design, the construction systems and the efficiency of the materials.

The term Neo-expressionism suggests a return to Expressionism, which is partly true. However, Expressionism did not seek structural strength as a means of expression. Neo-expressionist architecture could express and communicate feelings as well as overcome the spectator. The complex structures erected could materialize what expressionists could only draw.

Expressionism should be understood in the context of the World War and the pre-war situation in Germany, when emotions were transmitted as a «shuddering cry by means of geometry». The motivations of expressionist architects were completely different from those designing thin concrete shells. This is why the term Eero Saarinen coined himself: «Structural Expressionism», seems more appropriate for this architecture. The expressiveness that these architects achieve is precisely thanks to the structure. As Félix Candela stated, the structure is configured as the only means capable of generating expressive forms without falling into figurative formalisms.

Regardless of the architectural style, the needs of our time demand new ways of building, improving the efficiency of materials and taking care of environment. The structures of Félix Candela appeared as a means

of survival, out of a need to optimize conventional structures. It was pragmatism and no architectonic styles what guided his designs.

The main reason that forced the decline in use of thin shells was economic. The increase of minimum wages, job safety issues and much stricter fire protection regulations affected the work of Candela till the point that he rarely build any more projects after the 60s. The renewed interest in the design of thin shells has led to the research of new formworks that reduce its economic impact, trying to offer new viable alternatives for the current times.

The development of computational design methods, digital fabrication and the increasingly restrictive measures established by governments in terms of reducing CO2 emissions, have promoted research in the fields of form-finding and optimization, marking the return of disciplined and complex forms for architecture guided by structural geometry.

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