Structural Architecture: from form finding to free form design

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1. Abstract

The empirical method in structural form finding has achieved world-wide efficiency and recognition as massive building tradition has continued to expand in history. Through direct involvement of lithoid materials, working under unilateral state of stress, designers driven by "static intuitions" have largely succeeded in giving shape to complex constructions, stabilized by gravity acting on the structural dead load mass (Fig. 1a). Ever since the second industrial revolution, with the help of materials able to carry tensile stresses, still the form of the structures have nevertheless been conceived and found observing the laws of statics, as a guarantee of an aesthetic result achieved. For membrane and cable structures, where the morphology must satisfy equilibrium conditions under an initial state of stress, finding the form of the structure is a "must" and, hence, a form finding procedure is required to identify the initial geometry.

Nowadays, architects and engineers alike are immerged in a new challenge: the Free Form Design (FFD); a new fashion with the prevalence of aesthetics over static rationality where the role played by the structures is merely to support the architectural design Fig.1-b). Many novel projects attempt to extend the "state of the art" but, according to personal experiences, new structural morphologies adopted in actual conceptual design methodology generate uncertainties in reliability assessment [i].

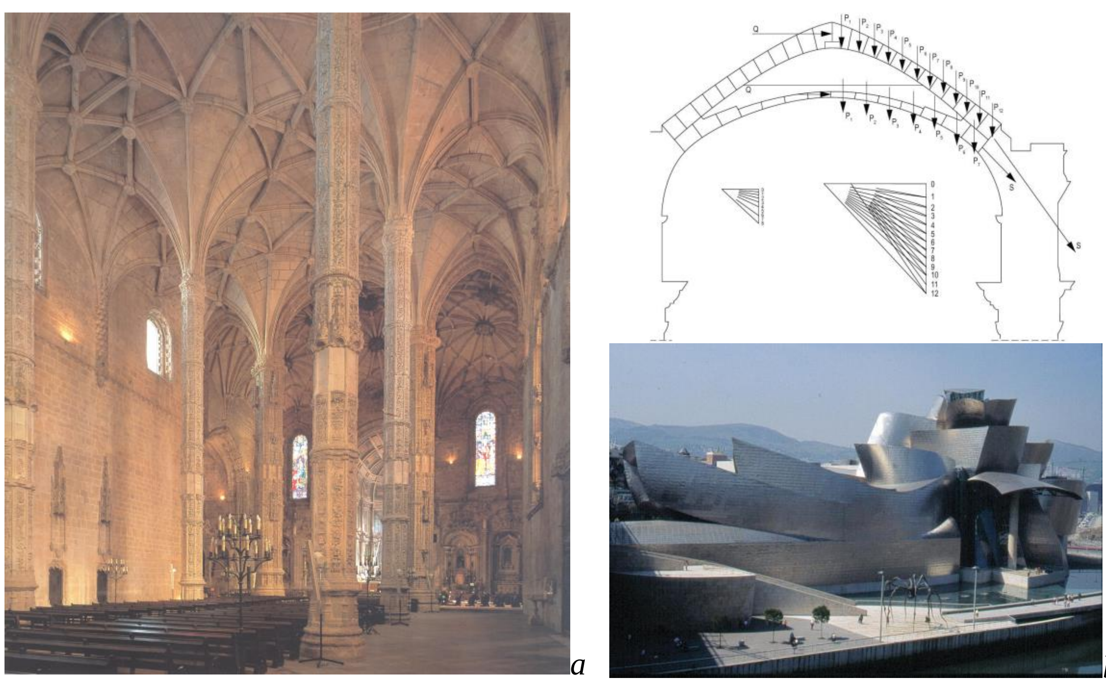

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Fig. 1: a)A Gothic Architecture (1517); b) The Bilbao effect

2 Morphology and structural analysis

Of course, the information technology revolution has influenced structural engineering as well. During the 50s and the 60s the design methodology of the structural engineer has been remarkably influenced by two major developments: the harmonization of the various theories of structural mechanics and the introduction of electronic processors accompanied by symbolic and matrix languages and finite element methods.

My generation bridged the era between approximated methods of analysis and the advent of FEM automatic analysis but, from the point of view of the conceptual design we get an inheritance from Eiffel, Gaudì, Torroja, Nervi, Morandi, Maillart and others (Fig. 2); all using a common “structural language” as stated by Musmeci :“Through its form, the structure immediately reveals the flow of internal forces that cross it, which is not enclosed and hidden within the volume of an abstractly conceived morphology, prone to esthetic and static prejudice, in which most part of matter and space is superfluous”.

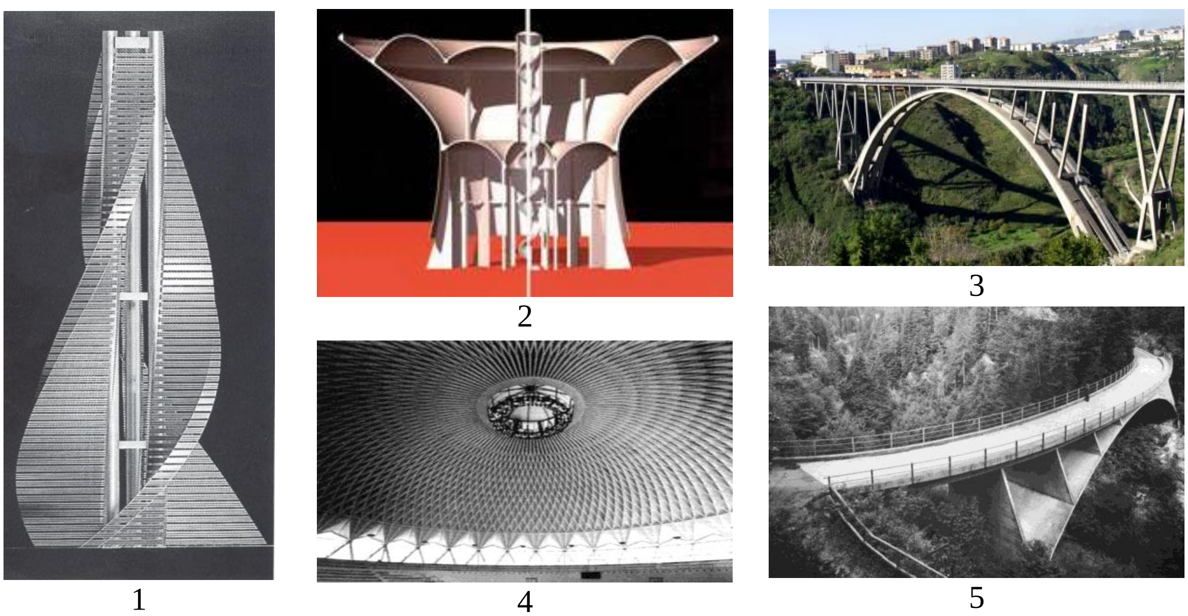


Fig. 2 (1-S.Musmeci, 2-E. Torroja, 3-R. Morandi, 4-P.L. Nervi, 5-R. Maillart)

Now we live in the era of «language metamorphosis», as it was called by E. Benvenuto in his recent “history of building science”, in which symbolic language and mathematical formalism have gone beyond the mechanics of structures putting it at the service of automatic calculus. Therefore the “mentality” on which scientific empiricism was based has changed radically.

J.T. Oden and K.J. Bathe see in this change the beginning of a new era of «computational empiricism». One of their interesting articles reads as follows:

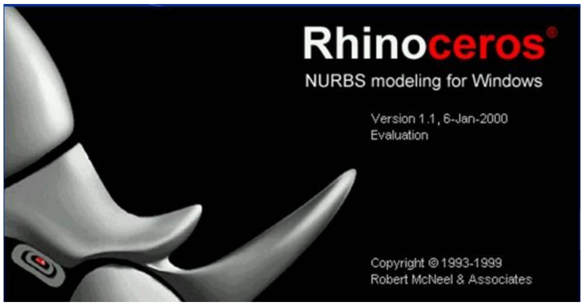
«The engineers’ community of 40 years ago was aware that the use of classical analytic methods offered limited tools for the study of mechanical behaviour and, as a consequence, the engineer had to enrich his analysis with a great deal of judgement and intuition achieved after many years of expertise. Empiricism played a crucial role in design: despite some general theories that were available, the methods to apply them

were still under development and using approximate schemes and resorting to indications derived from numerous tests and confirmations was inevitable.
Today the common belief is that automatic calculus has put an end to this semi-empirical age of engineering: by now sophisticated mathematical models can be built on some of the most complicated physical phenomena and if the processor is sufficiently powerful, reliable numerical results can be obtained based on the response of the examined system».
The advantages brought by electronic processors may, on the other hand, create an uncontrollable exaltation of the automatic calculus and give the false impression that man can be outshined by machines and the logic by the automation [ii][iii].
The advantage offered by informatics and automation has been very important in the field of structural design in general and particularly significant in the case of special structural systems. It was possible to examine more rigorous theoretical models avoiding, on the one hand, excessive simplifications that deprive the theoretical model, like a schematic reduction of the reality, of all significance and, on the other hand, that exhausting calculations lead to the loss of facts with a true influence, thus discouraging designers from trying out different structural solutions.
Under such apparently favorable circumstances, many documented structural failures have been detected in which mistakes regarding the inadequate evaluation of structural behavior were caused by unreliable man/machine interaction and the illusion that computers, those powerful instruments of analysis, could replace conceptual design and the expert synthetic criticism of results.
Documented FEM modeling errors are illustrated in the First International Conference on computational Structures Technology .

3 Actual trends in Structural Architecture: the Free Form Design

Auxiliary IT (Informatics Technology) resources activated “modern tendencies” in Structural Architecture [iv] with:

1. the prevalence of aesthetics over static rationality;
2. stringent search for structural efficiency to solve a more complex issue than reality, in order to achieve an original solution;
3. the categorical rhetoric of structural actions that translate into design languages;
4. the structure as a sculpture;
5. mechanistic impressionism;
6. the metaphorical transposition, into architecture, of Nature and other foreign elements;
7. the rhythmic and monotonous repetition of an architectural motif;
8. the emphatic representation of a typical element’s detail, to identify the overall scale;



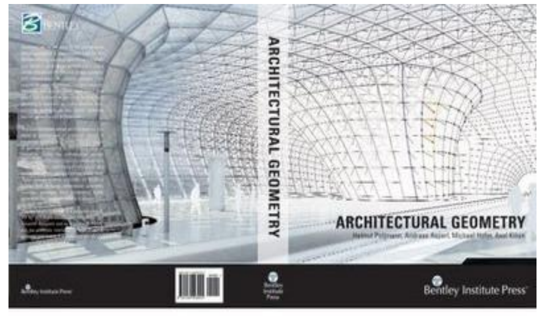
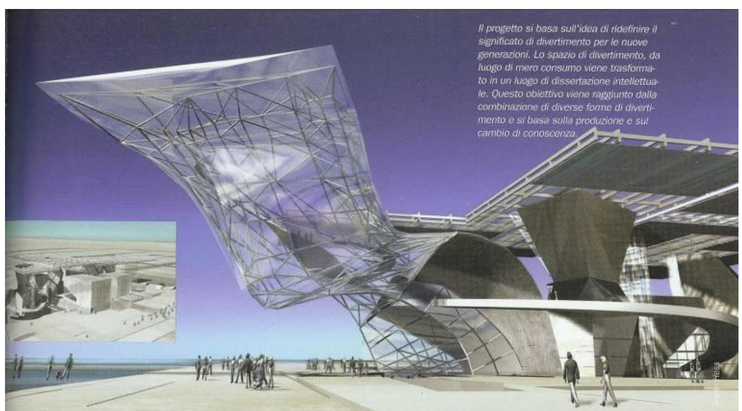
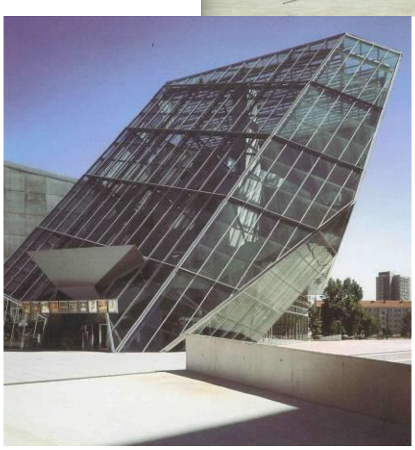


Fig. 2: IT(Informatics Technology) resources for FFD

Phenomenological uncertainty may be considered to arise whenever the form of construction or the design technique generates uncertainty about any aspect of the possible behaviour of the structure under construction, service and extreme conditions.
Those uncertainties are introduced in designs which attempt to extend the "state of the art", including new concepts and technologies. In actual realizations, phenomenological design uncertainties play a very important role; today we see free formal expressiveness originating architectural objects such as leaning towers, sculptured bridges, free-form enclosures and the like, whose shape sometimes has no connection whatsoever with structural principles.





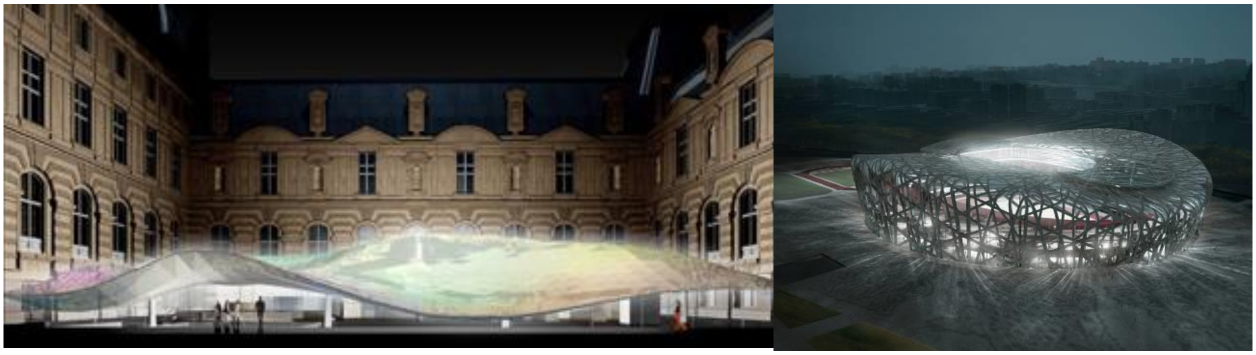


Fig. 3: Some actual examples of Free-Form-Design

According to the technical and scientific philosophy taken from Eiffel. Torroja, Nervi and others, who designed by looking first and foremost at the construction, quite sure that observing the laws of static engineering would be seen, per se, as a guarantee of aesthetic results achieved, they are no more than structural forgeries.
On the contrary, many of these new architectural objects marvelled us and are appreciated in the name of the very definition of the word architecture, as an intellectual and technical exercise directed at adapting our physical environment to the needs of social life. It cannot be denied that some works achieve the level of architectural and sculptural art and the role played by structures is merely to support architectural design.
Under those circumstances Torroja anticipated, with an Ethic sentence, how to behave under the FFD which constitutes a new challenge for Architects and Engineers alike:

"If being creative simply stands for emerging driven by no sensible arguments, if creativity fails to happen as a direct result of reliable and accurate principles applied to new issues, then original ideas, torn between misrepresentation and inconsistent mannerism, move from genius to vanity, converting art into expediency. Innovation alone shall never take an instrumental role in promoting the artist; the skills of the artist should deserve respect and praise first and, eventually, focus the public interest on their innovatory potential" (Torroja, razon y ser de los tipos estructurales, cap.XVII).

At this point we have to say that from a statistical viewpoint, human errors in the fields of design and construction tend to increase remarkably when innovation is discontinuous and sudden and when it does not take place gradually with the aid of scientific knowledge [v][vi]. The free structural morphology that stems from the current FFD trends represent, at the same time, challenge and anxiety in building science and technique, which are traditionally anchored to conventional typologies and geometries (frames, arches, shells, etc.). This entails a radical change in the civil structural engineer's forma mentis and methodology, especially with regard to the interpretative control of the structural response in terms of state of stress and deformation under the action of permanent and live loads, obtained through sophisticated analysis carried out according to the finite elements method.
Therefore, the FFD needs from structural engineering some new contributions , for instance, as shown in Fig. 4, the use of conventional steel profiles, conceived to be connected mainly at 90°, are no more appropriate when the structural geometry is also involved into the FFD. A first International Colloquium of FFD, addressed to a new

technologic contribute to facilitate production and construction process, was held at TU Delft in 2006 , where,

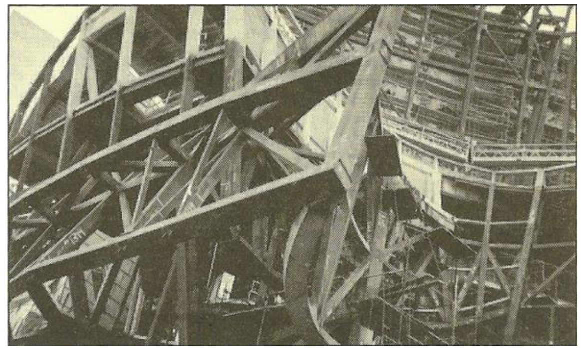


Fig. 4: External view and part of structures of the Walt Disney Concert Hall. Who is the column, who is the beam?

an interesting contribute to generate structural composite steel plated elements able to follow a free form is shown in Fig. 5.

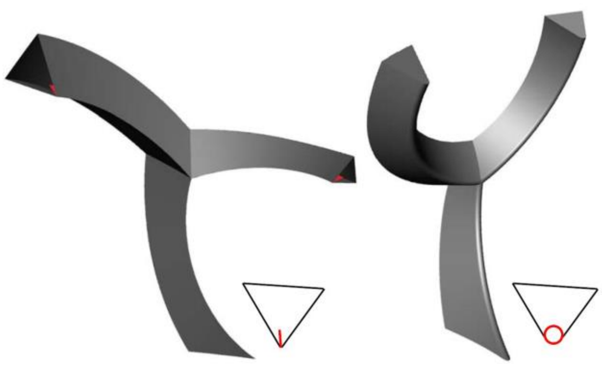
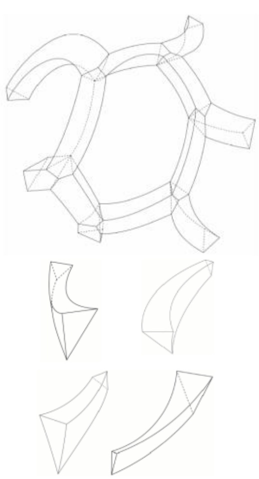


Fig. 5: Wetkamp Delta rib- system

Fig. 6: The new Pecking Olympic stadium



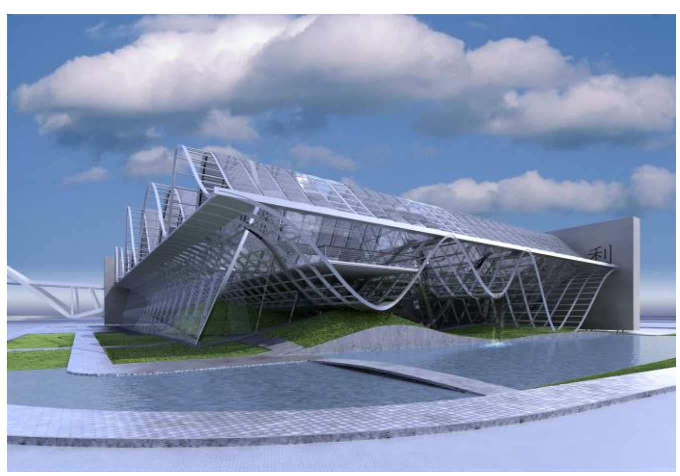


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Fig. 7: a) Variety of Delta Rib-shapes; b) Italian Pavillion for Shangai Expo 2010 (2ndPrice-Arch. T. Valle)

FFD is a challenge for architects and engineers alike but, after the first's impressive realizations, the ethic and aesthetic repercussions of FFD's appeal on the social context must be carefully considered, to avoid the inclination to view innovation, of any kind, as positive merely because it is innovative, irrespective of its real merits or its contribution to knowledge.

From the structural point of view, in order to guarantee the required reliability level, special expertise is needed in the design and construction of free structural morphologies involved in FFD. Considering that modern design & construction activities are part of a complex, holistic, trans-multi and inter-disciplinary process that must achieve a required reliability level a Value Analysis is also highly recommended, even in the preliminary design phase, in order to find the most suitable and compatible solution in accordance with the expected function worth , focusing from the "know-how" to the "know-why", in designing and constructing the "what" or – better - the "what for".

3 References

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