Art and Structural Engineering-Art of Structural Engineering

René Motro

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Motro René [1]

Summary

Beyond the classical dispute between architects and engineers, it is a matter of fact that art and engineering are not only compatible, but also for some cases indissociable. This communication aims to contribute to the debate. In the first part the experience of artists is exemplified in terms of influence on structural engineering : Pevsner and Snelson opened the way to complex surfaces and innovative structural composition. Following David P. Billington proposal for a so called Structural Art, some few examples are described enhancing the symbolic dimension of realizations, whose morphology reflects artistic processes. Some explanations provided by cognitive sciences help to understand the mental process of designers and the required conditions for a creative process. Historic examples of artistic movements like Constructivism, Bauhaus and the experiment of Black Mountain College illustrate the benefice of crossing experiences of designers, whatever can be their field.

Keywords

Art, structural engineering, structural composition

Theme

Structural and architectural design

1. Introduction

Beyond the classical dispute between the architect and the designer, there is another one debate which is of interest for structural engineers: can we speak of Art when Structural Engineering ends with some solutions which are recognized as pieces of art, like it is for the Eiffel Tower, and more recently the Millau Viaduct ? This communication intends to provide some arguments following previous publications reflecting our interrogations (Motro [1]), and willingness to associate in the same project at the training level architects, artists and engineering (Aanhaanen [2]). We firstly present some cases enhancing a close relationship between art and structural engineering, and secondly we describe some of the features and conditions of situations where structural engineering becomes an art.

2. Art and structural engineering

2.1. Pevsner and Xenakis : from constructivism to Pavillon Philips in Brussels

Constructivism is an artistic movement born in Russia at the beginning of the XX° century. Brothers Pevsner and Gabo wrote its manifesto. This movement proclaims a geometrical construction of the space, using especially elements such as the circle, the rectangle and the straight line. This way of thinking adapts itself also well to the sculpture as to the design even in the architecture. A somewhat recent exhibition held at the Guggenheim Museum, The Russian and Soviet Avant-Garde, 1915-1932, gives more details on the work of constructivists who organised their first exhibition manifestation, the Obmokhu (the Society of Young Artists) in May 1921. Rodchenko, one of the constructivists, claimed in January 1921 (Lodder [3]):

[1] Professor Emeritus, University Montpellier 2 Rene.Motro@univ-montp2.fr

“All new approaches to art arise from technology and engineering and move towards organization and construction”.

Artists and engineers are indistinctly members of this group. Vladimir Grigorievitch Choukhov, a famous Russian engineer was member of the Constructivism. He developed and achieved several hyperbolic towers. In the field of metallic structures design (Figure 1 A). Choukhov is one of first to develop practical methods of calculation of the efforts and the elastic deformations of the beams, the shells and the membranes. His design is based on ruled surfaces.

Following the same geometrical principle Antoine Pevsner realized many sculptures based on ruled surfaces and sometimes developable (Figure 1-B). Such artistic achievments opened the way to double curved surfaces generated by straight lines.

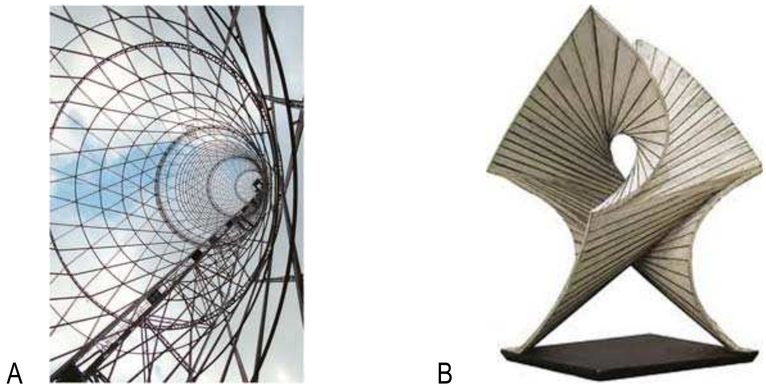

Figure 1: Constructivism : A-Hyperbolic Tower Moscou 1922 (Choukhov) B-Developable surface (Pevsner)

In 1958, for the Universal Exhibition in Brussels, Yannis Xenakis designs the so-called “Pavilion Philips”. Yannis Xenakis, mathematician, musician and architect worked at that times with Le Corbusier. It is a matter of fact that the two men disagreed during this event, but this dispute is beyond our text. What we want to underline is the formal analoghat we want to underline is the formal analog between this Pavilion and the sculptures presented by Pevsner. It is obvious that the geometrical design, based on ruled surfaces (Figure 2 A) is clearly in the line of Pevsner’s sculptures. The sketch of Figure 2 B, even if difficult to read has been drawned by Xenakis (his name is mentioned on it), the third illustration (Figure 2 C) represents the completed structure.

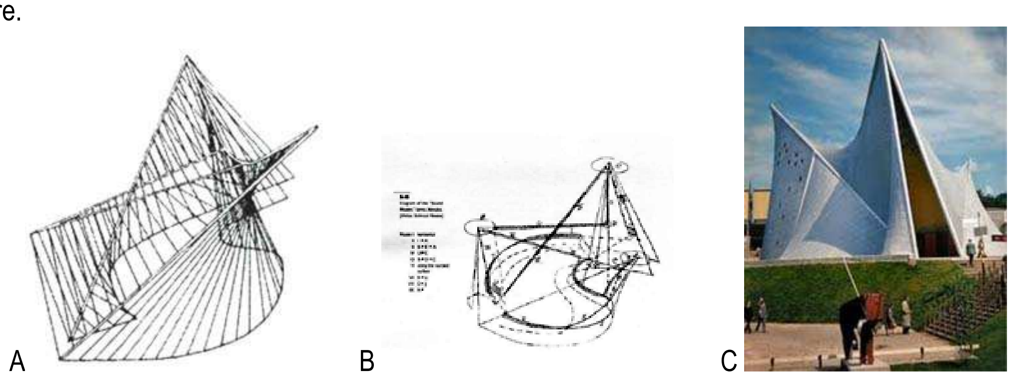

Figure 2 : Pavillon Philips : A Ruled surface - B Sketch by Xenakis - C Realization

It is interesting to note that the double negative curvature surfaces result from the assembly of double negative curved paving stones poured on sand on the ground of a rough dimension of 1 m 50 aside. These paving stones are 5 cms in thickness ; they are supported by a double network of prestressed cables 8 mm in thickness. Following this realization, and keeping the same concept of surfaces with negative double curvature, Yannis Xenakis will design steel and membrane system for his famous “Polytope” raised behind the Pompidou Center in Paris.

2.2. Kenneth Snelson, Forces made visible

Kenneth Snelson is an artist who is at the key point between art and structural engineering. Many papers have been devoted to his pionneer work in the field of tensegrity structures. His controversy with Buckminster Fuller he met in Black Mountain College in the early fifties is beyond the scope of our paper. He himself explained his view in a public letter inserted as annex of the book that I devoted to tensegrity (Motro [4]). The most important thing to note is that he had a pure artistic behaviour and he reached a first concretisation of the tensegrity concept by working successively on three sculptures ending in the well known “Double X”. Every “X” component described in his patent is strut – like element. Using an assembly of three (Figure 3) gives access to the classical simplex (Motro et al [5]).

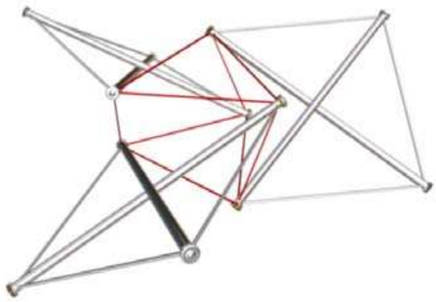

Figure 3 : Simplex generation by assembly of three “X” components

A  B 

Figure 4 : Snelson sculptures A Easy Land, Boston – B Tensegrity Tower

In 2009 Snelson had an exhibition in Marlborough Gallery, Chelsea, New York. The title was “Kenneth Snelson Forces Made Visible, and this is also the title of the book edited for this opportunity (Hartney [6]). The best title for the work of this artist who is able to make forces visible. Forces are a mechanical concept useful for engineers who want to size their structures and they are by nature invisible. On the other hand forms are visible and measurable, and they are the product of the artistic process. Why are forces made visible? Some keypoints may be put forward:

- By differenciating clearly cables and struts, Snelson's sculptures provide an information on whether tension or compression is present..This is not the same for classical reticulate systems
- If the level of tension and/or compression can be qualitatively evaluated according to the external diameter size of components, it is insufficient since this level is depending upon the material, and the thickness of tubes, or the arrangement of cables.
- The very specific structural composition surprises and fascinates everyone seeing them for the first time : struts seem to float in the air. And this is also a key point, since people, and engineers more

than the others, are surprised by this new kind of flow of forces. They are accoutumated to gravity effects, and in this case gravity seems to be absent. The artist provokes interrogations by submitting an unknown process for transmitting forces.

- Last but not least : art is a source of emotional feeling. In case of tensegrity systems people feel that at every end of each strut, cables contribute to the equilibrium. And it cannot be possible without an amount of stress of tension in cables, and compression in struts: struts are "lifted" inside the structure by a continuum of cables. But or course it is not easy to understand how all these forces are distributed, we only know that the whole is in equilibrium, stressed and stable

Finally it can be said that the artistic work by Snelson obliges the structural engineers to question their structural approach, and to enrich it.

3. .Art of structural engineering

3.1 Structural art

Some engineers brought up their practice at the level of the art. Several were celebrated during the exhibition The Art of Engineer, Builder, Contractor, Inventor, held in Paris 1997 (Picon [7]).

"The Tower and the Bridge" (Billington [8]) has as subtitle "The New Art of Structural Engineering". In this book many famous engineers are presented in their artistic way of designing: Thomas Telford and Gustave Eiffel, Robert Maillart, Felix Candela and Heinz Isler among others. Let Billington speak about this structural art:

"The conservative, plodding, hip-booted technicians might be, as the architect Le Corbusier said, "healthy and virile, active and useful, balance and happy in their work, but only the architect, by his arrangement of forms realizes an order which is a pure creation of his spirit… it is then that we experience the sense of beauty". The belief that the happy engineer, like the noble savage, gives us useful things but only the architect can make them into art is one that ignores the centrality of aesthetics to the structural artist"

Following this affirmation he describes the three "dimensions of structure" : scientific, social and symbolic. The symbolic dimension is closely related to aesthetics. These classical virtues **Firmitas**, **Utilitas**, **Venustas** enhanced by Vitruve could appear as an old history without any interest. Nevertheless if "Venustas" is recognized as one of the characteristics of artistic manifestation, some engineers practiced a real art.

Figure 5 : Garabit Viaduct – Gustave Eiffel

3.2 Morphology in question

There is always a close relationship between the resulting morphology of a design process and the personality of the designer. The following quotation is generally attributed to Victor Hugo :

"La forme c'est le fond qui remonte à la surface"

A direct translation would be without meaning. The idea is that every form is somewhat the visible result of an invisible content.

The external appearance is insufficient to conclude, and it is a matter of fact that in the case of the Millau Viaduct (Figure 6), known as Foster's project, the resulting morphology is strongly related to Michel Virlogeux's work. We can perhaps claim that Virlogeux has been the soul of this project. The soul assesses the expression of the designer through the resulting morphology among other parameters. At the beginning of the process there is at least one symbolic choice that is not related to scientific or social dimensions. Michel Virlogeux said that in this case the main idea was to design a viaduct not to span the river Tarn, but to span the entire valley.

Figure 6 : Millau Viaduct – Foster and Virlogeux

For other cases the morphologic appearance allows one to identify the designer. Isler's (Figure 7) morphologies are characteristics of their strong expression as designers, but the morphology is also the result of a strong coupling between form and forces: they are somewhat "funicular shapes" as Gaudi's Colonia Güell.

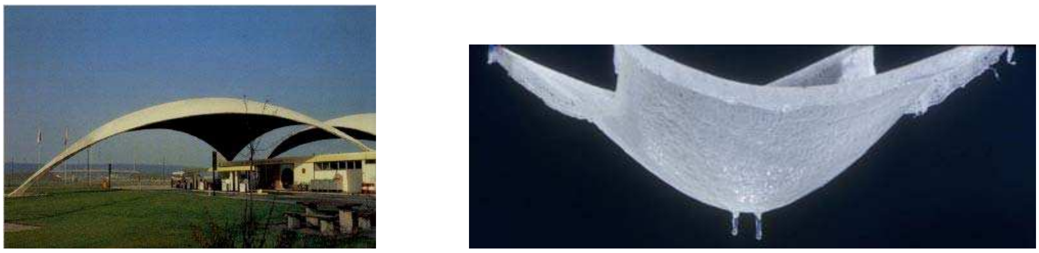

Figure 7 : Concrete Shell by Isler and experimental funicular model

3.3 Which way to Art of Structural Engineering?

3.3.1 New design situations

Nowadays, the scientific aspects of design are helped by the increasing power of available numerical tools, but if designers can use them at the different stages of the process, since the initial idea to the realization of the project, they cannot reduce their work to manipulation of tools. They are now freer for expressing their own personality by a continuous process, and as artists can experiment, they may simulate by prototypes and numerical modeling the continuous materialization of their project. Besides, let say, the classical artists they have to take into specific

dimensions as claimed by Billington: scientific (in terms of mechanics of material and structures), and social (adequacy with the ongoing progresses of technology, the cost necessities, and the apparition of new constraints like environmental ones). Nevertheless some of them are sufficiently imaginative and also creative to submit new solutions evolving from their experience and meeting the actual constraints.
If the design process in structural engineering is governed by the scientific dimension, true designers do not provide the same solution to a given problem. Their own experience and way of thinking are conditioning the quality of their proposal. There are many differences with classical manifestations of art like size of construction and the necessity of permanence in terms of security, but the mental process is of the same kind. Similarly training conditions are also very important, and common training with artists and architects may contribute to increase the level of their art of engineering.

3.3.2 Contribution of the cognitive sciences

According to the preceding remarks, it appeared interesting to try to identify some characteristics of the mental behavior of a designer regardless of his training as architect, engineer or artist. Taking advantage of cognitive sciences results we could investigate more precisely some aspects of the design process.
One major issue is related to the mental representation for the designer of an existing or a projected object. Perception, and conception are two faces of this issue. The perception of real 3D objects is firstly the source of a mental representation in the so called “working memory” of the designer. These mental representations are progressively stored in the long term memory of the designer. The link between mental and physical worlds, during design process and morphogenesis, takes advantage of “a knowledge tank” (so called “Long term memory”). This tank is filled step by step during designer’s life according to his perception of the physical world and his own skills.

During the conceptual design phase mental representations of previously perceived objects arise in the working memory of the designer, coming from his long term memory. This long term memory is like “a memory tank” which is filled by perception operations and training, and which is also dependent of heredity, culture, training, travels, discussions… An iterative work is then operated and requires a progressive materialization of the projected solutions, generally by means of 2D representations (computer’s screen or sheet of paper) and/or by means of physical models. This iterative process is a sequence of problem solvings in working memory. They give access to solutions (hypotheses) which are analyzed and compared with known solutions stored in the long term memory . This long term memory is continuously enriched by perceptions and training. A major point is that the designer is not always filling his long term memory with elements, he is also building links between the information of increasing complexity, he is building procedures and he memorizes these procedures.
On the basis of this cognitive approach undertook by Silvestri [9], and associated with an experimental study (concerning more than thirty people), we have some information useful for a better understanding of the mental process of designers.

3.3.3 Creative movements

We evoked at the beginning of this paper the role of Constructivism. There was also a similar attempt with “De Stijl” with Pietr Mondrian and Theo Van Doesburg (Figure 8). A true and free dialog between architects, engineers and artists was clearly fruitful in other places where they worked together like the Bauhaus or Black Mountain College inviting designers to exchange their thoughts for a better mutual understanding.
In Black Mountain College (Figure 9), where Snelson was sculptor student in 1948, the experimentation was the main adopted principle as it can be understood by reading the essay by Diaz [10] who writes :

These three models of experiment- the methodological testing of the appearance and construction of form in the interest of designing new visual experiences (Albers), the organization of aleatory processes and the anarchical acceptance of accident (Cage), and “comprehensive, anticipatory design science” that propels, teleologically current limited understanding towards a finite totality of universal experience (Fuller)- represent important incipient yet disparate directions of post-war art practice, elements of which would be sampled, if not wholly adopted, by Black Mountain students and subsequent practitioners.

Again, like for the famous Bauhaus, cross pollination between creative people creates the best condition for improving the experience of every one, and enriching his knowledge gained by very separate practices that have in common creativity and artistic attitude in common. Generally engineers who shared this kind of training have more chance to reach the Art of Structural Engineering.

A B

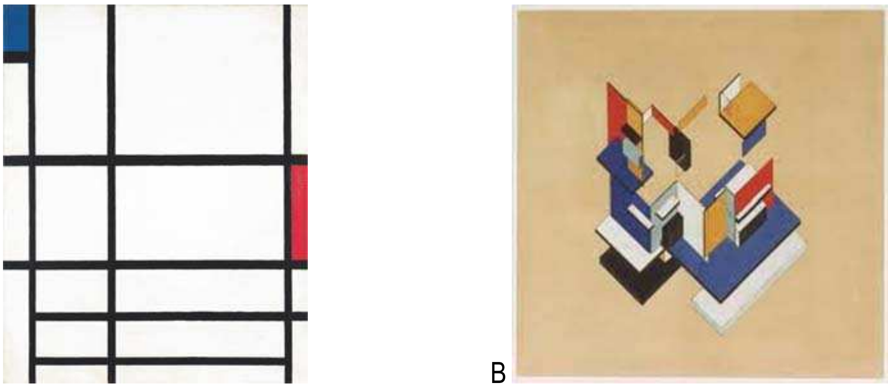

Figure 8 : A Piet Mondrian painting B Project by Theo Van Doesburg.

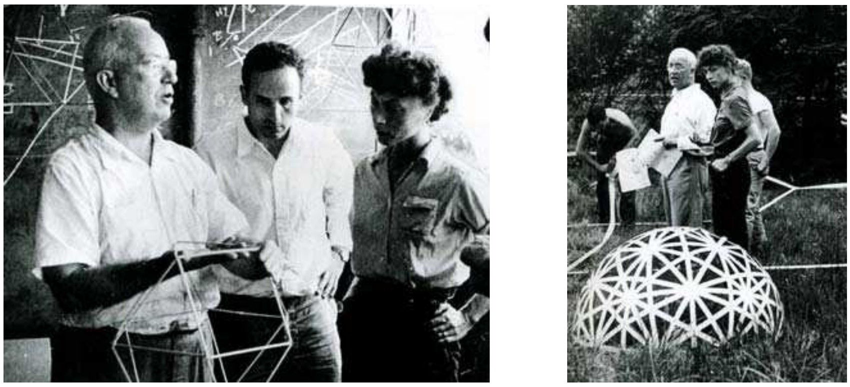

Figure 9 : Buckminster Fuller teaching at Black Moutain College.

Conclusions

At the era of computers and numeric models, the engineers have an impressive set of tools that they can use during their design process. But they remain, as human, the key element able to make their practice an art. Some of them reached this level for the benefit of mankind. Memory, experimentation, own culture, imagination, creativity are the prerequisite for this art of structural engineering that needs to provide appropriate answers to the three dimensions quoted by D. P. Billington : scientific, social and symbolic.

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