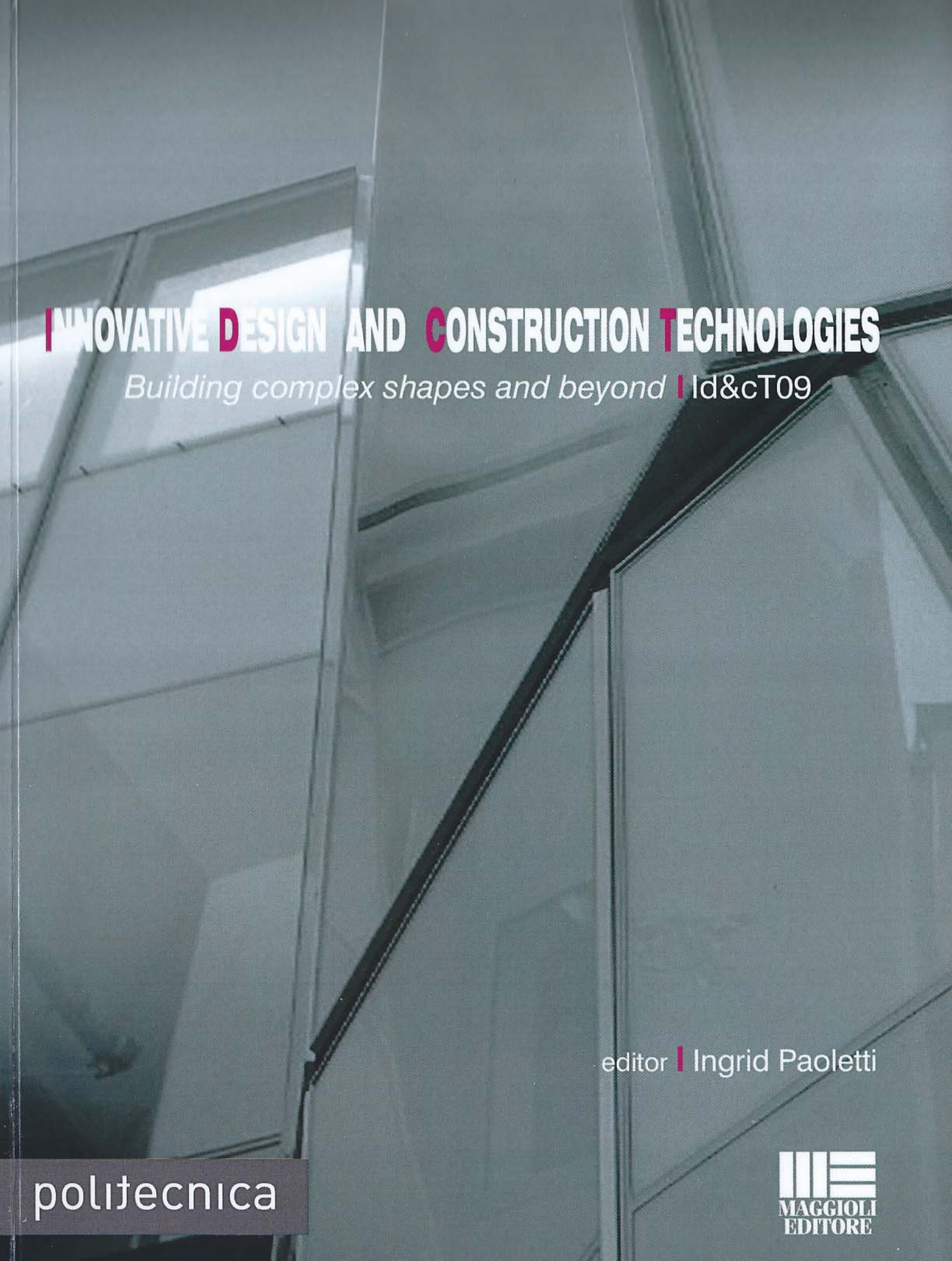

INNOVATIVE DESIGN AND CONSTRUCTION TECHNOLOGIES

Building complex shapes and beyond | Id&cT09

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Building complex shapes & beyond

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INGRID PAOLETTI

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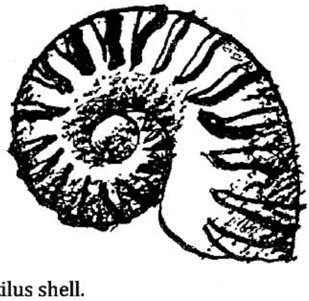
INDEX

The Geometric Construction of Morphology. Analyzing forms of some architectural designs by Le Corbusier.

Author:
A. Sdegno *(sdegno@units.it)*

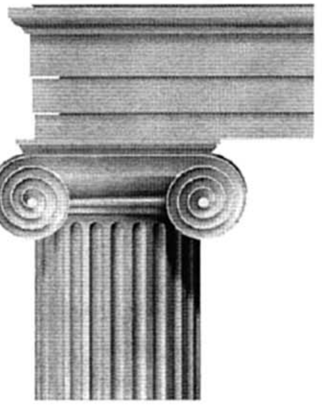
Affiliation:
University of Trieste - Faculty of Architecture

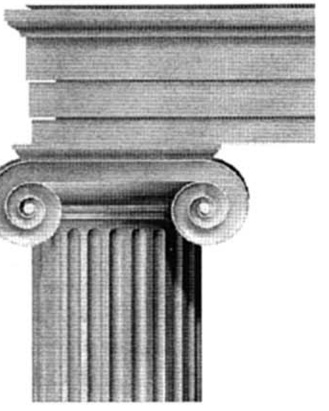
The large diffusion of free-form software, in the recent years, gives designers the possibility to create complex morphology in a very interactive way, although frequently without having an idea about the geometrical genesis of the form they are generating. In the past it was very difficult to work in a similar way, due to the strict procedure that allowed to transform every sketch and every drawing into a building. As new technology as resolved a lot of problems about the fabrication, there are many questions about the correctness to use a form without the consciousness of it. The analysis of some well-known designs by Le Corbusier, during a research on some realized and not realized projects[1], gives us the opportunity to study the genesis of the form of these architectures, understanding the relations between the morphology and the architectural space. One of the most interesting early project designed by the architect is the Museum of Unlimited Growth. The genesis of this work is very important, because allows us to understand the role of geometry in the definition of the main configuration of the form and the procedural steps that help the designer to identify the modularity for his development.



Drawing by Le Corbusier of a Nautilus shell.

As the spiral was used in architecture in the form of the Ionic capital we decided to compare both of them reconstructing the two possible volutes applied to hypothetical capitals.





The Archimedes' and the logarithmic spirals applied to the Ionic Order (elab. S. Princisgh).

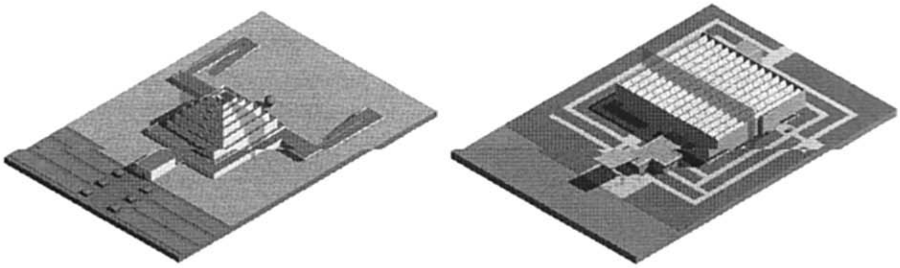
We have to remember also that the first spiral, as Archimedes explains, is a curve generated by a point moving constantly along an half straight line, while this is rotating around its end point O. In fact the formula of it, is:

$$\rho = a\theta$$

where ρ is the distance of the point from O, θ is the angle described by the half straight line and *a* is a characteristic coefficient of the curve. On the contrary, the second curve has a different value for figuring the distance between lines, giving to the spiral a more dynamic representation. The formula, which describes it, is:

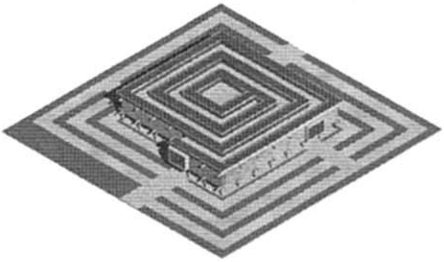
$$ax + x^2 = a$$

The next step was, for Le Corbusier, to transform the curved geometry in order to obtain a more useful configuration. So he decided to work on a squared geometry – a so called "squared spiral" – that has the vantage to create a regular space for a museum, but also allows to organize the evolution in time of the form. As the Archimedes spiral has nothing to do with the Golden Section, the main distribution of the space was defined, and so it was possible to have the articulation of the interior space. Before analyzing the evolution of the idea of the design, we have to speak briefly about some preceding projects by Le Corbusier that consider the progression of this particular "squared spiral" path.



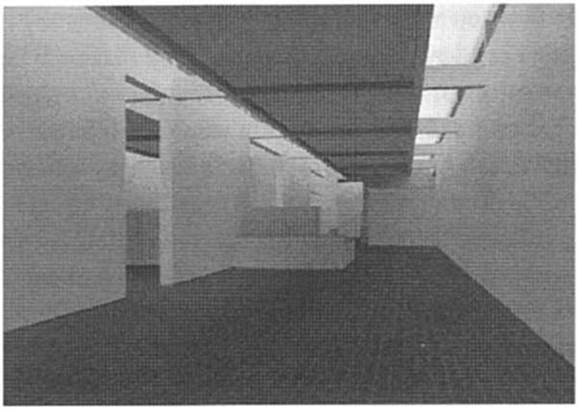
Digital reconstruction of the Mundaneum and of the "C" Project (elab. S. Princisgh).

In 1929 Le Corbusier designed a Science Museum for Geneve, that he called Mundaneum. The plan of this project is configured as a "squared spiral", but if we analyze the section or the elevation we can see that the form develops in three dimensions. So, instead of a spiral, we have an helix, a sort of "squared helix". This is due to the idea to take visitors to the centre of the form – that is at the top of it – and then let them going down inside the exhibition space. In 1936 for the so called "C Project" for International Exhibition Pavilion in Paris Le Corbusier used a similar conception developed only in plan. In fact the visitor arrives in the centre of the space and then enters the museum thanks to a ramp that allows him to go upstairs, where there is the exhibition space. The limit of both solutions is that people have to go back to the centre of the building in order to enter and exit the museum. So they need to repeat the path they have already done.



Digital reconstruction of the Museum of Unlimited Growth (elab. S. Princisgh).

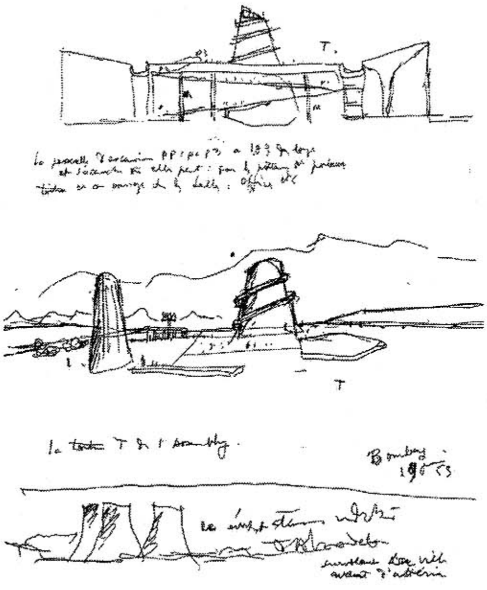
The 1939 solution resolved this problem because we have two ways to use the space: the entrance is in the middle – as 1936 design – but it is possible to exit directly from upstairs thanks to another external staircase at the opposite side of the building.



Light simulation of the interior of the Museum (elab. S. Princisgh).

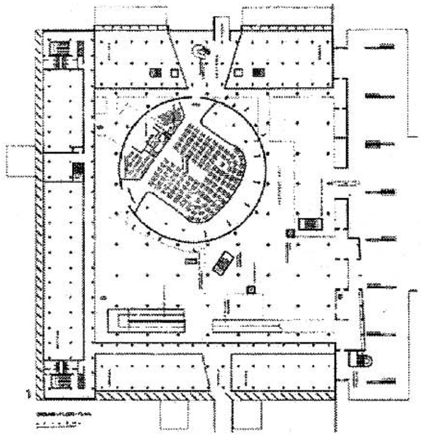
After the geometrical analysis of the complex structure, we decided to study another important aspect of this design, well considered by the author: the illumination of the space. Le Corbusier adopted in this case his typical ***fenêtre en longueur*** but putting it on the top of the building. It is a very innovative solution, previously used in a different manner both in Mundaneum and in C Project. In this case the light comes inside the space indirectly, creating a very comfortable illumination, the best one for a museum. In fact the natural light doesn't enter the rooms directly, but arrives to the wall – where there should be pictures and art works – after a reflection, obtaining a diffuse condition of lighting. It is also interesting to note that a similar effect is done by the artificial light, due to the presence of a linear neon lights that run in a parallel way as the long windows. Comparing sun and electric lights with radiosity algorithms we have found similar lighting parameters (lux) and the same condition of illumination, that confirm the great ability of the architect in controlling this important aspect of a project.

But the use of geometry characterized some other projects by Le Corbusier. One of the most difficult to build is the hyperbolic shapes that was used in different declinations. In this case we are in the period of maturity of the architect, in which the tri-dimensional form isn't a simple vertical extrusion of a bi-dimensional one – such as in the first designs – but it is studied directly in 3D. In particular the hyperboloid are used mainly in two projects, although in a different way. In fact we can find one inside the Parliament building in the town of Chandigarh in India, that was designed totally by Le Corbusier, starting from 1950. As a new town, the author could work without any reference to the context, using the best way to render a space. In this case the idea was derived from some factories' towers that the architect saw from the airplane, flying near the Indian town, and redrawn by himself in some small but very clear sketches with some textual notes. As we told before their geometry is defined by a straight line moving in 3D, leaning itself to other three lines and generating a ruled surface, not so difficult to generate in 3D, above all using a three dimensional modelling software. Although could be very easy to think about the construction of a form, in terms of geometrical genesis, the final result was not only the exhibition of the shape itself, but the organization of an articulated architectural space. In this case, in fact, some other aspects were studied: the combination of the form with the rest of the building – an empty compact squared volume; the relation between the *pilotis* structure of the whole building and the internal structure of the hyperboloid; the natural lighting system, due to some particular windows cut on the top of the roof; the acoustic effect that had to allow a good listening of every speeches of the Parliament delegates. In fact this building is more complex than the other of the town. So it required more time to be finished, because of the articulated space. There are offices, rooms for commissions and the main hall for the Deputies' meeting.



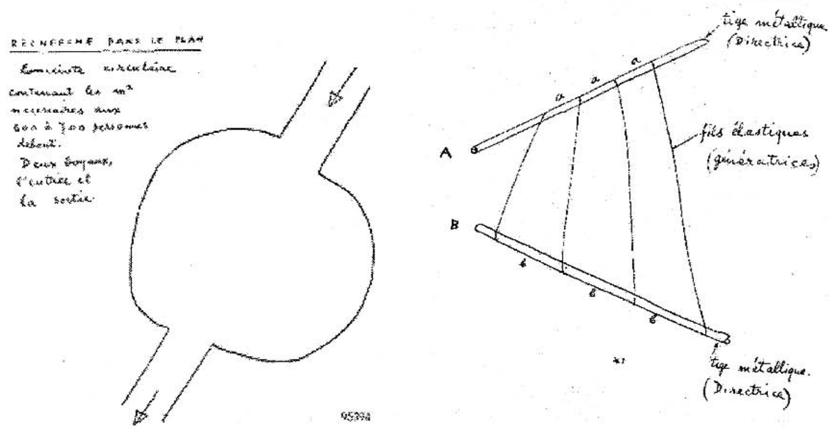
Sketches by Le Corbusier for the Parliament building of Chandigarh.

As in the Palace of Soviets all spaces were disconnected one to the other, and then reconnected only thanks to some paths, in this case we have a close aggregation, similar to the Convent de la Tourette in France. There are three rectangular forms for offices, each one with a length of 60 meters, and the curved volume inside that never touched them. The fourth side of the great box is only a wall, with the typical Le Corbusier's brise-soleil. This side defines the main entrance to the building in which the architect drew, on the principal door, the typical symbols of his work in enamelled steel: the poem of the right angle, the path of the sun, the Modulor, etc. The great empty space on three levels of the main room receives light from some big skylights on the roof. The critic W.J.R. Curtis gave a very significant description of this characterized building, a place "where the portico, the structural grid, and the circular form were been called with great force and clarity. The decision to choose these forms exceeded pure functional interests [...]; they were generated from the architect's desire to create an equivalent modern element of an ancient doom"[1].



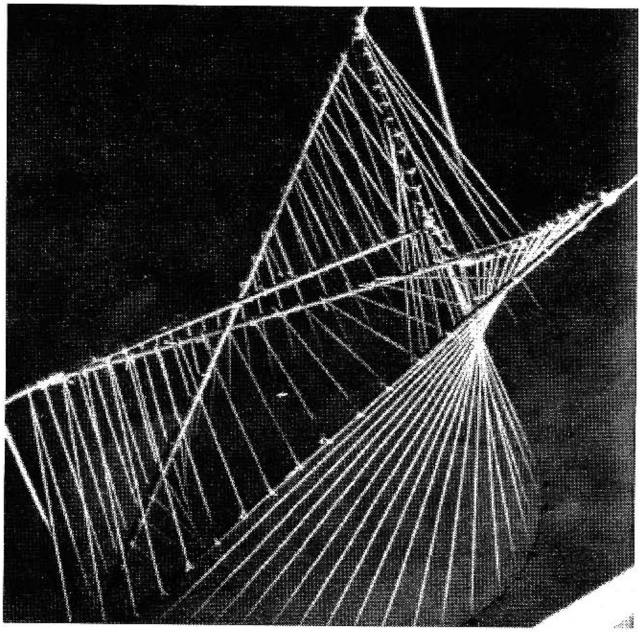
Plan of Le Corbusier project for the Parliament building.

Then in 1953 the architect started to consider the idea to allow the sunlight enter the space from the top. In this case some "towers of light" were projected and oriented to some significant elements inside, to obtain some particular light effect. One of the first ideas was to construct a spiral staircase inside the hyperboloid, but in the end he decided to maintain visible the pure double curved shape. The holes on the roof were inspired to the astronomical observatories of Jantar Mantar in Dehli and in Jaipur (XVIII Century). But we can find the best description of it in the words used by its author in his *Oeuvre complète*: "One of to help him for this work: the first one was Edgar Varèse, that was the music composer that have already worked with the architect creating some electronic sounds for the bell-tower of Ronchamp chapel. Although in this case the music wasn't used, Le Corbusier appreciated his work and decided to base the whole musical support of Bruxelles Pavilion on the Varèse's composition. The second collaborator was the Greek engineer Iannis Xenakis who, in that period, worked inside the studio. Not only was Xenakis involved in structural, acoustic and lighting problems but also he was a musical composer as Varèse, so in this case questions of tectonics were studied better in relation to acoustic behaviour of sounds.



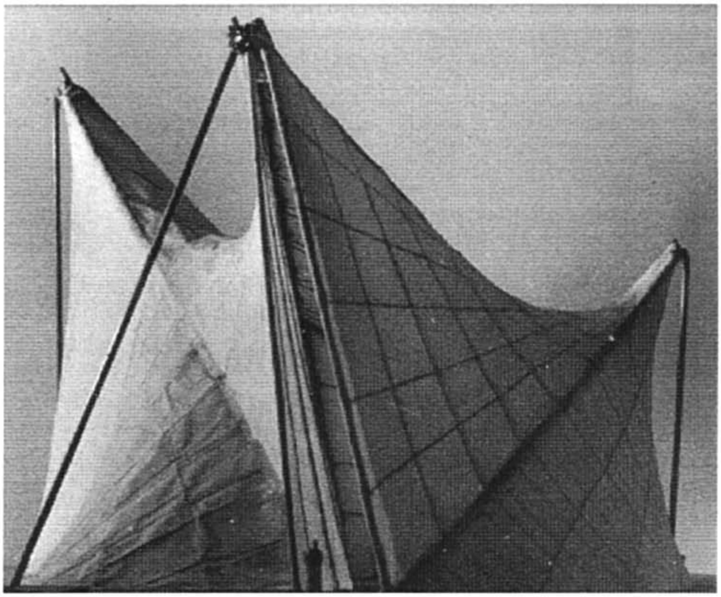
Drawings by Le Corbusier: a stomach and an instrument for the construction of complex surface.

To understand the process of composition it is very useful to read some notes by Xenakis describing the first ideas by Le Corbusier and the way in which they started to develop the complex shape: "In October 1956, Le Corbusier asked me to draw up these ideas and try to 'translate them using mathematics'. He handed me a sketch. Le Corbusier [proposed that] the building would be a 'bottle' containing the 'nectar of the visual presentation and the music' For the film spectacle, he wanted flat vertical surfaces. For the spatial effect, he wanted a tapering 'bottleneck' high up in the ceiling of the pavilion where the projected images would disappear. For the desired luminous colours, he wanted concave and convex surfaces [...] He agreed with the requests of the architects of the adjacent Dutch pavilion: 'We would recommend a simple and convex surface as the back of the Philips pavilion, so that it does not overpower the garden and the greenery which surround the Dutch buildings'. As it is night inside the 'bottle', beauty is not really a concern".[1]



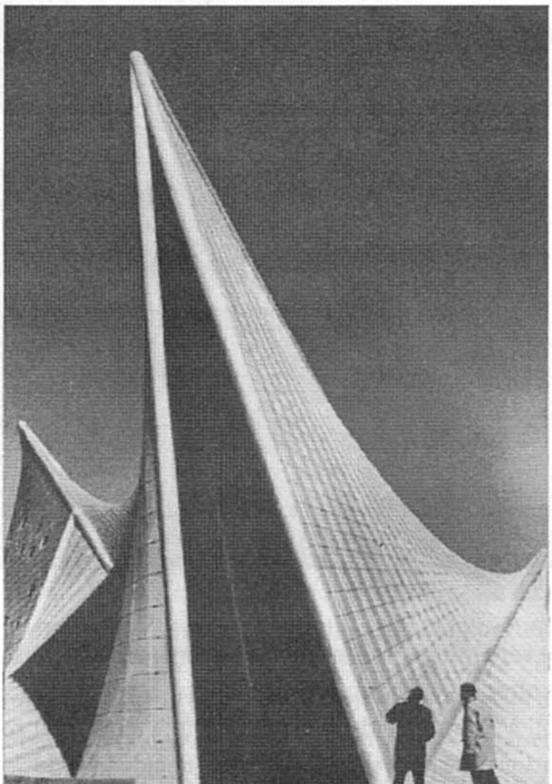
Iron-made model for the study of form.

Explaining the work in the book that was published in occasion of the inauguration of the building, Le Corbusier and Xenakis used these words: "They would to transform the conoids in hyperbolic paraboloids for simplifying the calculation and the executive process. The construction couldn't be a self-supporting structure. The logic solution was to use a double curved cables and a double wall, similar, definitively to a tent."[1] The main formal idea was a plan drawing of a section of a stomach. What happens inside it – a great change that conditions the physical human subject and his state of wellness – expresses very well the different condition of perception by the people visiting the Pavilion, from the entrance o the exit. As the curved sketch of the main plan was very simple, the configuration of elevations was more complex. In this case, in fact, a lot of ruled surfaces in space were created, started from the form of hyperbolic paraboloids. But it is very interesting to note that to obtain the result Le Corbusier used a very simple instrument, made by two linear elements connected one to the other with some rubber bands. In this way every single forms was generated by hands, "playing" and having a different position of the two sticks. In order to understand clearly the procedure, a double operation was done: in the beginning the construction of a similar physical instrument, to replicate the movement of Le Corbusier's hands. Then, we decided to redo this one in a digital manner in order to add a new value using a video animation. So the genesis of every single surface allows to understand the first and final step of generative process, to explain in detail the evolution of the form. We have also to ad some information about the method used by Le Corbusier to verify and physically build the idea. Another important tool for controlling the status of the shape is the *maquette*. A lot of abstract and realistic models were done by Le Corbusier using different materials. In the beginning these were iron-made, to study the structured figure in the real condition of tension. During the phase of construction there were a lot of models in scale to verify the behaviour of concrete, and it was necessary to contact a great French firm in the field of structure that would undertake the calculations and eventually the realization of the pavilion: the Ancient Etablissements Eiffel.



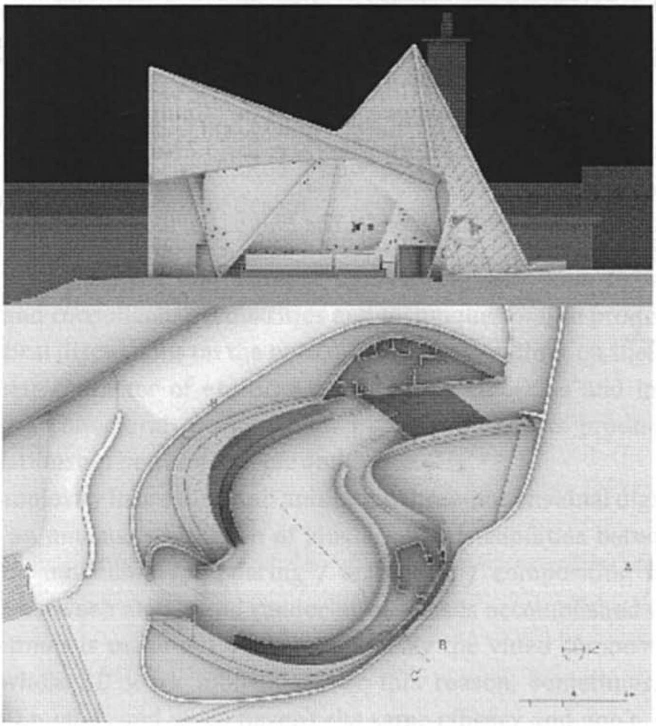
Complete model for the study of surfaces.

Then, it could be very interesting to listen from the words of these representatives the conclusions after the valuation of the work, showed with drawings and scale models: "We believe that the ideas expressed in your model correspond to the construction rationale upon which we have decided: rigid structural frames of metal upon which are supported flexible surfaces in the form of hyperbolic paraboloids and whose transverse surfaces comprise metallic cables set in opposing curves"[1]. The definition of the structure is well described by Marc Treib in his book on the Pavilion, in which he reported also the discussion during the meeting between Xenakis and Eiffel engineers: "Two networks of cables of opposing curvature would compose each screen wall segment; in turn, these would be sandwiched between two skins of bituminous ruberoid. The engineers were confident of their ability to execute the calculations without delay, as they knew that time was a consideration. The use of gunitage was dismissed because it was inelastic, and given the flexibility of the frame, the sprayed cement was sure to crack. In spite of their favouring a system of cables suspended from a structural frame, the engineers also allowed that it was possible to realize the walls in reinforced concrete. While it was technically feasible, the inclination of some wall segments was far from vertical, undermining the structural efficacy of the hyperbolic paraboloid as a structural form."[2]



Photographic image of the Pavilion.

So we can consider the final realization – having an area of about 600 m^2 and a maximum elevation of 22,5 m – as the best representation in real scale of the idea. The quantities and qualities of hyperbolic paraboloids allows to confirm this project as one of the best solution of architecture of XX Century, to express the innovation in the field of building construction. The best words to understand the specific aspect of this work are by Marc Trieb, the main researcher on this architecture. He called it an "eccentric building"[1] in which a lot of aspects are put together: "Architecture, colour, voice, sound, and images were superimposed, without any full comprehension in advance of the nature of the resulting work. The completed *Poème électronique* would *emerge* as a conglomerate greater than any of its constituent parts, to some degree planned, to some degree the product of fortuitous accident".[2] A significant way to analyze the generative procedure of a complex shape whose mathematical aspects – such as in the case of the Museum of Unlimited Growth, or for the central volume of the Parliament Building in Chandigarh – are strictly determined by the architect that controlled *a priori* a geometry instead using it without consciousness.



Digital reconstruction of the Philips Pavilion (elab. M. Soraperra, M.S. Soraperra).

Notes

[1] The research on *Unbuilt Projects* was developed at IUAV University of Venice between Academic Years 2004-05 and 2007-08 and from 2007-08 at the University of Trieste, Faculty of Architecture. Some graduation thesis at IUAV University of Venice (supervisor A. Sdegno), used some results of the researches and gave their contribution to understand better these architectures, creating the 3D models and rendering of them. In details they are: *Le Corbusier e la spirale. Geometrie configurative per il Museo a Crescita illimitata*, student: S. Princisgh, IUAV, Venezia, 2004-05; *Il disegno delle architetture di Le Corbusier per Chandigarh: analisi geometrica e ricostruzioni digitali*, student: L. Donati, IUAV, Venezia. 2004-05; *Padiglione Philips (1958). Analisi della geometria configurativa e ricostruzione digitale*, students: M. Soraperra, M.S. Soraperra, IUAV, Venezia 2007-08.

[2] W.J.R. Curtis, *Le Corbusier: ideas and forms*, Phaidon, Oxford 1986, p. 431.

[3] Le Corbusier, *Oeuvre complète, 1952-57*, Les Editions d'Architecture, Zurich 1957, p. 94.

[4] I. Xenakis, *Le Papillon Philips: A l'Aube d'une Architecture*, in *Musique Architecture*, Casterman, Paris 1976, pp. 127-8.

[5] Le Corbusier, *Le poème électronique*, Éditions de Minuit, Paris 1958.

[6] Letter from Eiffel Studio to Le Corbusier/Xenakis, 17 November 1956, Fondation Le Corbusier.

[7] M. Treib, *Space calculated in seconds. The Philips Pavilion* , Princeton University Press, Princeton 1996, p. 43.

[8] Ibidem, p. IX.

[9] Ibidem, p. X.