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RELATING TO THE PRODUCTS, PROCESSES AND INVESTIGATIONS OF
THE PHILIPS INDUSTRIES

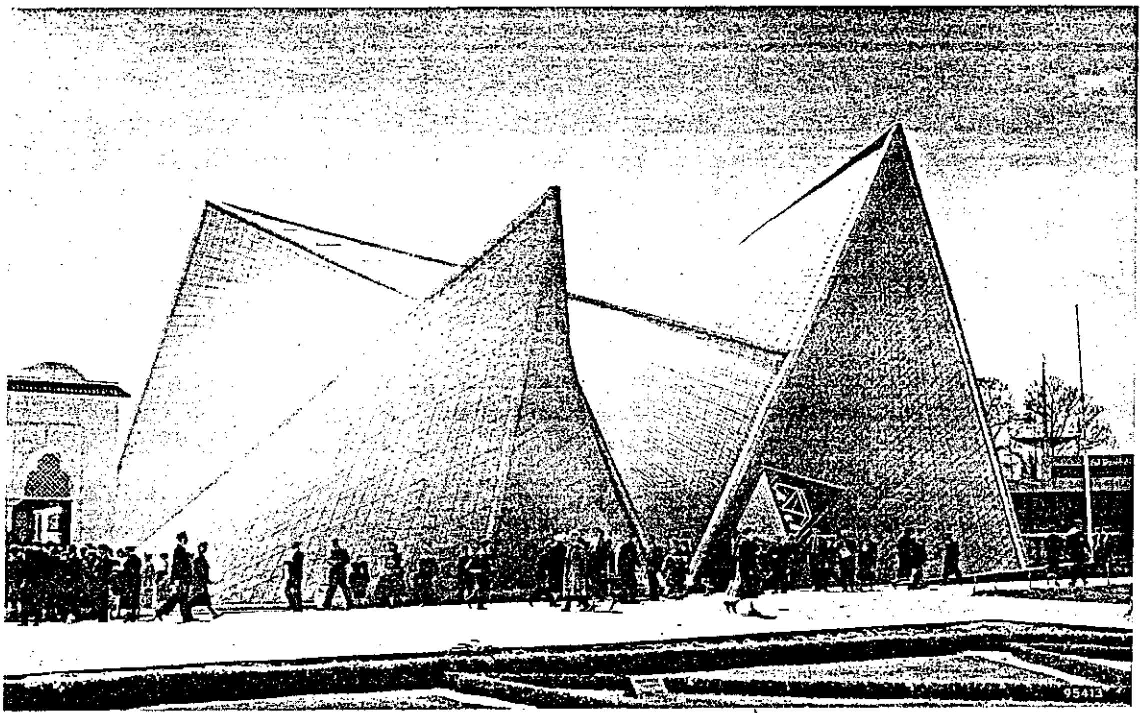

Photo Hans de Boer

→ version abrégée d'un autre article (lequel ?)

THE PHILIPS PAVILION AT THE 1958 BRUSSELS WORLD FAIR

I. THE ARCHITECTURAL DESIGN OF LE CORBUSIER AND XENAKIS
II. THE HYPERBOLIC-PARABOLOIDAL SHELL AND ITS MECHANICAL PROPERTIES
III. MODEL TESTS FOR PROVING THE CONSTRUCTION OF THE PAVILION
IV. CONSTRUCTION OF THE PAVILION IN PRESTRESSED CONCRETE

061.41(493.2):725.91

At the Brussels World Fair, near the Dutch section, Philips have had their own pavilion built. Visitors to the pavilion are entertained to a "spectacle in light and sound", the object of which is to demonstrate the capabilities of modern technology in some of Philips' major fields of endeavour — illuminating engineering, electro-acoustics, electronics and automatic control techniques — and also to give an impression of the way in which these technical facilities may in the future be turned to artistic ends. The basic conception was propounded by Mr. L. C. Kalff, Arts Director of Philips, and the architect Le Corbusier was commissioned to give effect to it. The latter wished not only to design the building but also wrote the scenario for the spectacle, which he has entitled "An Electronic Poem". The music for the spectacle was composed by Edgar Varèse. Completely automatic performances of the spectacle are now being given scores of times a day, controlled by a magnetic tape with fifteen command tracks.

A later article in this Review will be devoted to the performance, *which is produced by film projectors, lamps and hundreds of* *loudspeakers, and to the technical devices and methods used. The articles in the present issue are devoted to the pavilion itself. From the outset this pavilion, designed by Le Corbusier and his collaborator Y. Xenakis, has aroused considerable interest in the world of architecture because of its extraordinary conception and advanced design as a shell structure. The building is entirely composed of shells having the form of hyperbolic paraboloids. The method of construction in prestressed concrete, proposed and translated into reality by Dr. H. C. Duyster, director of the contracting firm N.V. "Strabed" and a specialist in this field, is remarkable for its originality and elegance. Before plunging into this adventure — as Mr. Duyster himself put it — N.V. "Strabed" approached Professor C. G. J. Vreedenburgh of the Delft Technische Hogeschool for advice concerning the stresses that might occur in the shells when loaded by their own weight, and by wind and snow loads. To satisfy N.V. Strabed as to the feasibility of the proposed scheme of construction and supply data for the actual structure, tests on scale models were made by Mr. A. L. Bouma and Mr. F. K. Ligtenberg in the "T.N.O." Institute at Rijswijk (Netherlands) and the Stevin Laboratory at Delft.*

These aspects are treated in the four articles printed in this issue: the architect's conception, the mechanical principles, the model tests and the actual construction of the building.

*As regards the first article it should be mentioned that Y. Xenakis, the architect largely responsible for designing the shape of the pavilion, has placed at our disposal a description of the way in which the architectural design of the building was evolved. In our opinion, however, there was little point in attempting to render the author's French text faithfully into English or other languages, for translation would do less than justice to the eloquence of the artist's highly individual style and risk distorting the sentiments of the original. It was therefore decided to confine the English rendering of his article to a reproduction of the factual contents *).*

The second article in this series also calls for some comment. Although Professor Vreedenburgh has kindly taken great pains to make the train of thought in his text as comprehensible as possible to the readers of this Review, we cannot disguise the fact that many readers will perhaps have difficulty in following the details of his article, lying as it does far outside the range of subjects normally dealt with in these pages. On the other hand, the article should be of particular interest to the specialist, since it provides for the first time in published form certain formulae and results concerning hyperbolic-paraboloidal shells which can be turned to practical architectural use.

*) For those readers who would like to have a copy of the original French text, reprints will be available of the article published in the French edition of this Review.

I. THE ARCHITECTURAL DESIGN OF LE CORBUSIER AND XENAKIS

after Y. XENAKIS †). 061.41(493.2):725.91

A report is given below of the ideas embodied in the architectural conception of the Philips pavilion and of the various stages through which the design passed before the pavilion acquired its final shape. This report is an authorized shortened version of an article by Y. Xenakis, who also provided the drawings illustrating the evolution of the design. These drawings are the main feature of the article.

When Le Corbusier, in the beginning of 1956, agreed to undertake the design of the Philips pavilion, he had in mind a structure to enclose a space of unconventional form and to be materialized by casting cement on a metal-gauze framework suspended from scaffolding. The structure would have a roof and surfaces on which pictures, colours and film scenes could be projected for performing a spectacle in light and sound — a so-titled "Electronic Poem". In October 1956, Y. Xenakis, under the direction of Le Corbusier, entered upon a detailed study of the project [1]). The result was a design based entirely on the use of *ruled surfaces*.

This result, to which artistic intuition as well as practical considerations contributed, will be elucidated in the following pages.

The first design

The *ground-plan* of the pavilion was fairly simply established, being dictated by the requirements for the performance of the "Electronic Poem". Each performance was to last 8 to 10 minutes and to be attended by some 600 or 700 persons, uniformly distributed over the whole floor surface of the pavilion. A space of more or less circular plan was therefore needed, with an area of 400 or 500 m² and with two large "spouts" as entrance and exit channels.

†) Paris, 35 rue de Sèvres.

[1]) A brief account of this study has already been published: Y. Xenakis, Le Corbusier's "Elektronisches Gedicht" und der Philips Pavillon, Gravesaner Blätter 3, 47-54, 1957 (No. 9).

In order to be able to produce various fantastic effects, locally changing colours, shifts of light and shade, etc. in the projection of pictures or colour slides, the enclosing walls (or at least part of them) had to be *curved* surfaces, so that they would receive the light from divergent angles. All uniformity was to be avoided, even the uniformity of curvature found in spherical and cylindrical vaults. This led to the idea of having surfaces with differing radii of curvature. Such surfaces also seemed suitable for meeting the *acoustic* requirements. To allow complete freedom for creating a wide variety of spatial impressions with the aid of loudspeakers, the aim was to avoid as far as possible the uncontrolled acoustic contributions due to reflections from the walls and which are audible either as isolated echos or as reverberation. It is known that parallel flat walls are dangerous in this respect, because of repeated reflections; parts of spherical surfaces are equally inappropriate, since they can give rise to localized echos.

Having turned his thoughts to surfaces with widely varying radii of curvature, Xenakis was led naturally to consider saddle surfaces, and in particular the *ruled surfaces* that come into this category. Through the work of Laffaille and other pioneers in this field, the architect was familiar with simple ruled surfaces, such as the hyperbolic paraboloid and the conoid. The conoid is obtained by letting a straight line (a generator) slide along two non-intersecting lines (directrixes), one a straight line and the other an arbitrary curve, such that it remains parallel to a given plane. The hyperbolic paraboloid (hypar) is also produced by moving a straight line such that it always remains parallel to a given plane, but in this case it slides along two skew straight lines (rectilinear directrixes). The static stress distribution in a shell having the form of a hyperbolic paraboloid can, to a certain extent, be calculated: such a shell is found to possess remarkable properties of strength and stability (see article II in this series). Moreover, these surfaces produced by straight lines readily lend themselves to construction in straight wooden beams or in concrete (see article IV). These attractive properties have led to an increasing use of such shell structures in various countries, particularly for roof constructions (*fig. 1*).

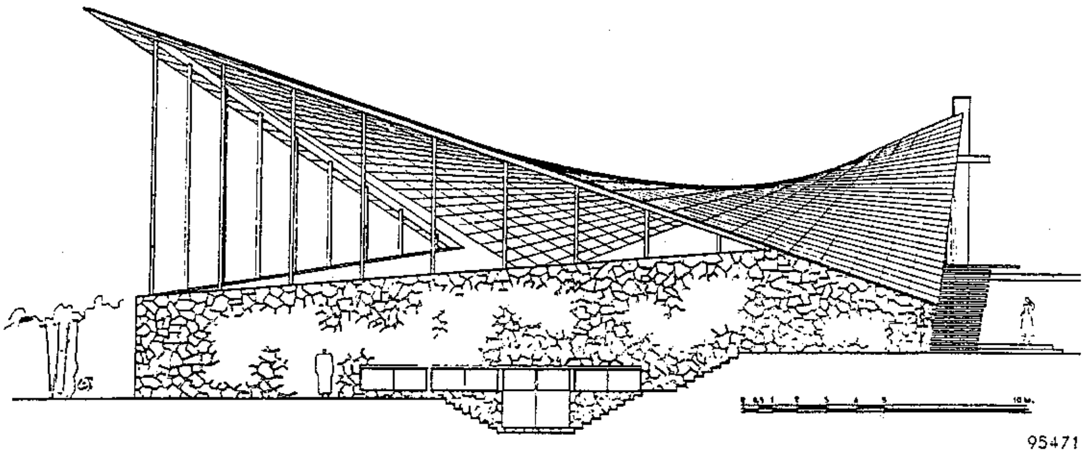

Fig. 1. The church Notre Dame de la Solitude at Coyoacan, Mexico, having a concrete shell roof in the form of a hyperbolic paraboloid, designed by the architect Felix Candela. (Illustration from: F. Candela, Les voûtes minces et l'espace architectural, L'architecture d'aujourd'hui 27, 22-27, March 1956.)

The Philips pavilion offered the architect a unique opportunity to build a structure entirely from these ruled surfaces, and in this way to create a homogeneous three-dimensional envelope in the sense that the three dimensions would each really play an independent role, as opposed to conventional architecture in which, usually, the form of the ground-plan is still manifest in every section of the building high above the ground.

The working-out of this novel architectural idea, however, was necessarily a process involving artistic intuition and a feeling for form rather than a question of reasoning. The series of sketches, *figs. 2-10*, allow the architect to show how he arrived at his first design.

This design (fig. 10) contains a conoid E, a surface consisting mainly of two conoids A and D, two hyperbolic paraboloids K and G, a connecting cone

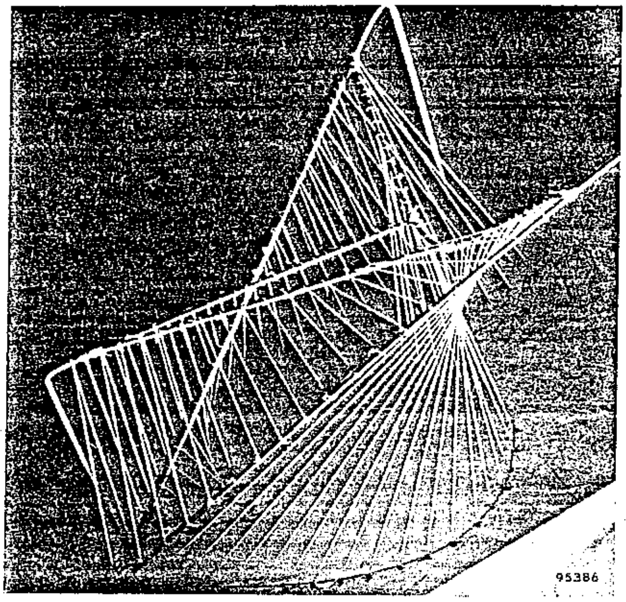

Photo Lucien Hervé

Fig. 11. The first model. The "stomach" is set out on the base of the model; the strings indicate the ruled surfaces. The intersections of the ruled surfaces are represented by spokes of piano wire. Their bent-over ends have no structural significance.

L and two open triangles as entrance and exit. The two peaks, produced from the oblique straight lines arising out of one of the channels (fig. 6) are counterbalanced by a third peak projecting above this channel.

Fig. 11 shows a model of the first design. The ribs in which the surfaces intersect are formed in this model by spokes of piano wire, the bent ends being anchored in a wooden base. The surfaces are produced by spanning strings between the ribs.

The second design

At this stage, engineers of a Parisian firm of contractors were consulted by the architects regarding the system of construction.

With a view to soundproofing, Philips had specified a wall weight of 120 kg/m^2 (concrete or cement about 5 cm thick). There was therefore no question of building the pavilion in the form of a tent, whether or not with metal-reinforced "canvas". The engineers consulted believed that in these circumstances the pavilion would have to be constructed on a fairly heavy metal skeleton, after the manner of the wire spokes in the model and with supporting stanchions corresponding to the vertical bent wires in the model. At all events they thought it desirable to change from conoids to hyperbolic paraboloids so as to make it possible to specify more easily the exact curvature of all surfaces and simplify the calculation of static stresses as well as the work of erection.

This advice was accepted by Le Corbusier and Xenakis, especially since they themselves felt that the first design had certain aesthetic weaknesses which in any case called for modification.

Xenakis set about converting the surfaces by experiment. His method was simple: he used two straight metal spokes joined by a system of elastic strings fixed at equidistant points along each spoke. The strings formed the ruling lines of a hypar, whose geometry was determined by the distance between the spokes, the angle between them and the positioning of two arbitrary strings. Other variables determine the position of the hypar with respect to ground level. To select each of the pavilion surfaces the architect had to proceed by trial and error, simultaneously varying all the above variables; as soon as he found a satisfactory form for a particular surface, he immediately put it down on paper in the form of an orthogonal projection [2]). For this purpose it is sufficient to give horizontal and vertical projections showing the positions of the two spokes and of two pairs of corresponding points thereon (e.g. the end points of the two outermost strings on the spokes: see *figs. 12* and *13*). This done, *all* pairs of corresponding points are fixed, each pair defining a ruling line. The points at which the ruling lines meet the horizontal plane give the intersection of this plane with the part of the hypar surface involved (*fig. 14*). This intersection can be part of a hyperbola or of a parabola (this is the case when one of the spokes is *below* the horizontal plane), or it can be a straight line (one of the spokes lies *in* the horizontal plane), or, in special cases, it can be a single point. There are also some hypar shells in the design, of which the part of the surface used does not touch the ground at all.

The first step in revising the original design was to change the position in space of the three peaks so as to obtain more harmonious proportions. The difference between the second and third peak had to be accentuated, and the middle cone *L* widened. The architect now fixed the height of the peaks at 21 m, 13 m, and 18 m respectively. He then proceeded, by alternately experimenting with the spoke and string model and drawing the surfaces found, to establish the hyperbolic paraboloidal surfaces that both gave an aesthetically satisfying form and yielded intersections with the ground level which were as much as possible in keeping with the original ground-plan.

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[2]) It is clear that it would hardly be convenient to define the hypar surfaces in terms of the numerical values of the coefficients in the appropriate equation of the surface (see II).

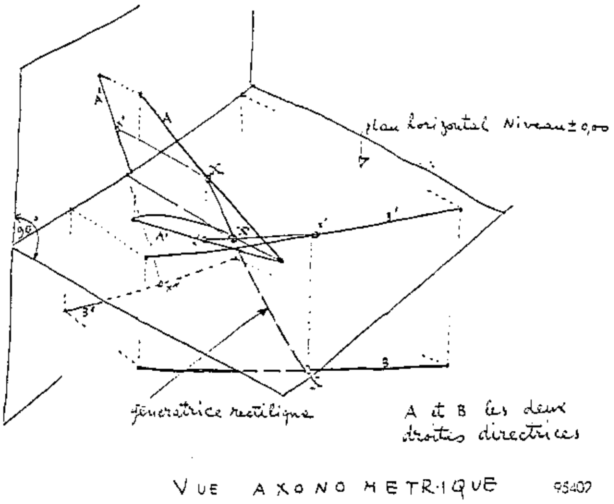

Fig. 12

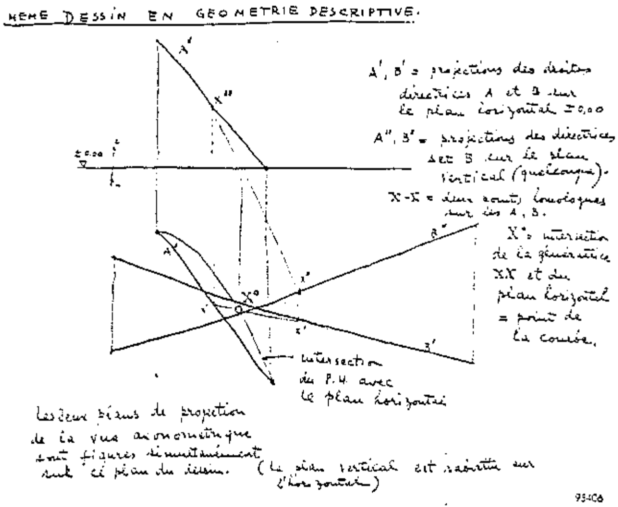

Fig. 13

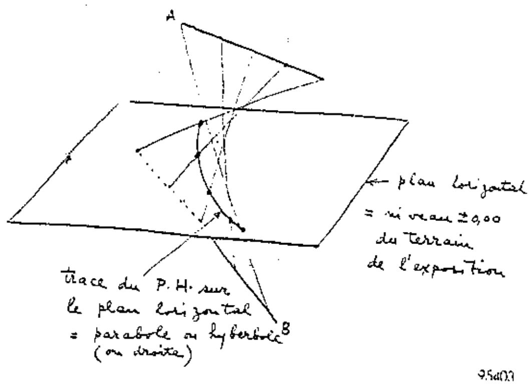

Fig. 14

Fig. 12. Isometric drawing to indicate how the orthogonal projection (fig. 13) of a hyperbolic paraboloid may be constructed. The two directrixes A, B are projected on to a horizontal plane (A', B') and on to a vertical plane (A'', B''); two pairs of points, viz. the end points of A and B, and their corresponding projections are shown.

Fig. 13. Horizontal and vertical projections of the directrixes of a hyperbolic paraboloid from fig. 12. Also shown are the projections $X'X'$ and $X''X''$ of an arbitrary generator line connecting two corresponding points X, X on the directrixes. This generator passes through the horizontal plane at point X^0.

Fig. 14. The intersection of a hyperbolic paraboloid with the horizontal plane is constructed from the points at which a series of generator lines intersect this plane.

By December 1956 the second design had been completely worked out in this way and set down on paper (*figs. 15* and *16*). From this design a new model was made (*fig. 17*).

Comparing the second with the first design, we see that the hypars G and K (which form the most important surfaces for the projection of pictures) have been retained, but the cone L has been widened and the conoids A, E and D changed into five hypars A, E and B, N, D. In addition, two new hypars C and F appear. Surface F, which abuts on E, provides the necessary space for certain installations (air-conditioning plant, toilets, control room) and for the extensive equipment needed for automatically performing, several times an hour, the spectacle of light and sound.

Final modifications

Most of the contracting firms approached by Philips at this stage of the design had only more or less conventional schemes of construction to propose, which were conspicuously out of keeping with the revolutionary style of the structure. Double-walled shells were suggested, having a total thickness of

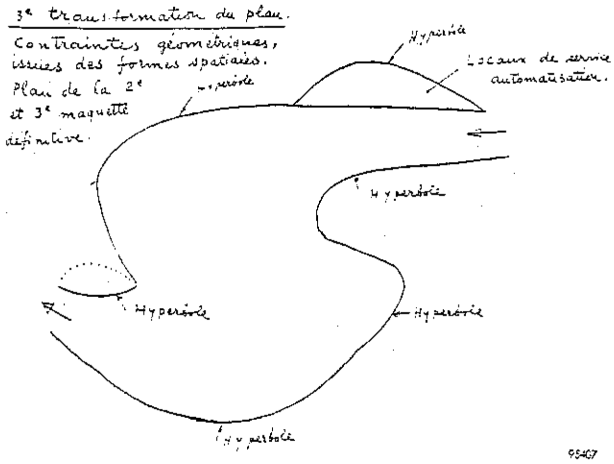

Fig. 15. Revised ground-plan for the second (and definitive) design. The bounding curves are now composed of parts of hyperbolae (for practical reasons the entrance and exit were interchanged with respect to the first design).

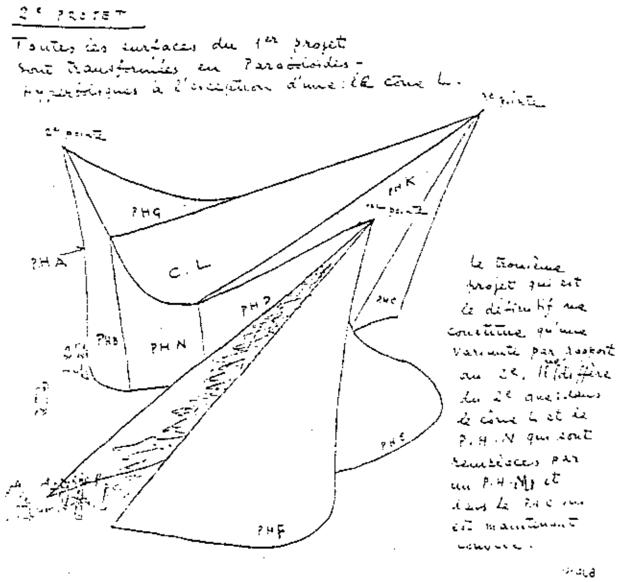

Fig. 16. The second design. All surfaces of the first design, except cone *L*, have now been converted into hyperbolic paraboloids, and two new hyperbolic paraboloids (*F* and *C*) have been introduced. Compared with fig. 10, the design is seen here from the opposite side, as can be seen from cone *L*, the apex of which appears top right in this sketch. The first peak is here in the foreground.

80 cm and made of wood, metal or plaster carried by fairly complex skeleton structures. The only proposal that was really in unison with the architect's intentions, while being at the same time reasonable in price, came from the Belgian contracting firm N.V. "Strabed", directed by Dr. H. C. Duyster. Mr. Duyster's plan was to build the pavilion as a shell structure of prestressed concrete 5 cm thick, which would be largely self-supporting, i.e. only a few stanchions would be used merely to give the walls some additional support. The intention was to follow closely the form of the second design, with only one minor modification. The latter arose from a misunderstanding of the architect's drawing, in which the hyperbolic paraboloids that did not touch the ground were indicated only summarily, leading Mr. Duyster to interpret the cone *L* and the hypar *N* (fig. 16) as parts of a single hypar (denoted *M* below). In fact, this simplification improved the geometrical purity of the structure. The elegant method by which Mr. Duyster proposed to construct the ruled surfaces of the pavilion in concrete is described in the fourth article of this series.

Finally, another modification was decided on, which, though a minor one in its effect on the strength of the structure, was of the utmost importance as regards the overall architectural effect. The design still envisaged supporting stanchions, one of which was actually inside the enclosed space, and as such was a nuisance. The architect Xenakis now proposed a slight change in the new hypar *M* and in *B* in order to make it possible to dispense with the stanchions entirely. The reasoning was that the edge members (ribs) at the relevant shell intersections ought to be able to take over, at least for the greater part, the supporting function of the stanchions.

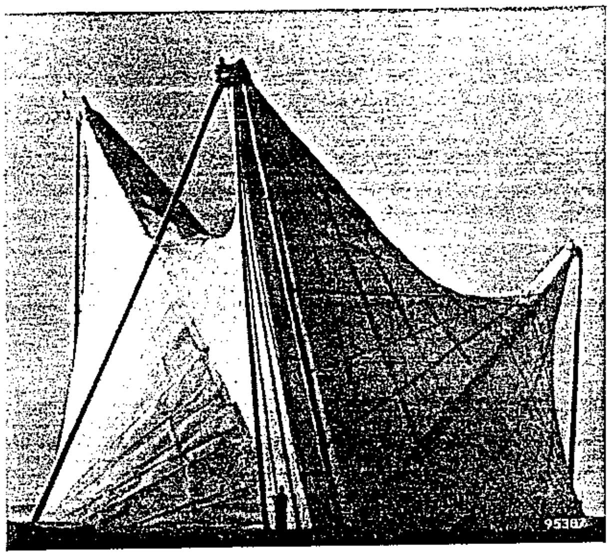

Photo Lucien Hervé

Fig. 17. Second model, seen from the side which now forms the entrance; the third peak is in the foreground.

The model tests (see article III) confirmed that in the design so modified the stanchions were superfluous. The structure was thus made entirely self-supporting, that is to say it no longer contained supporting elements that were not embodied in

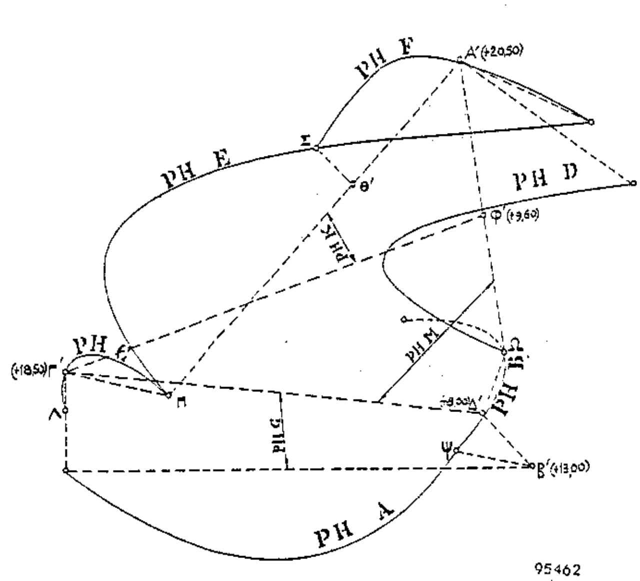

Fig. 18. General plan of the final design (enlarged from fig. 19).

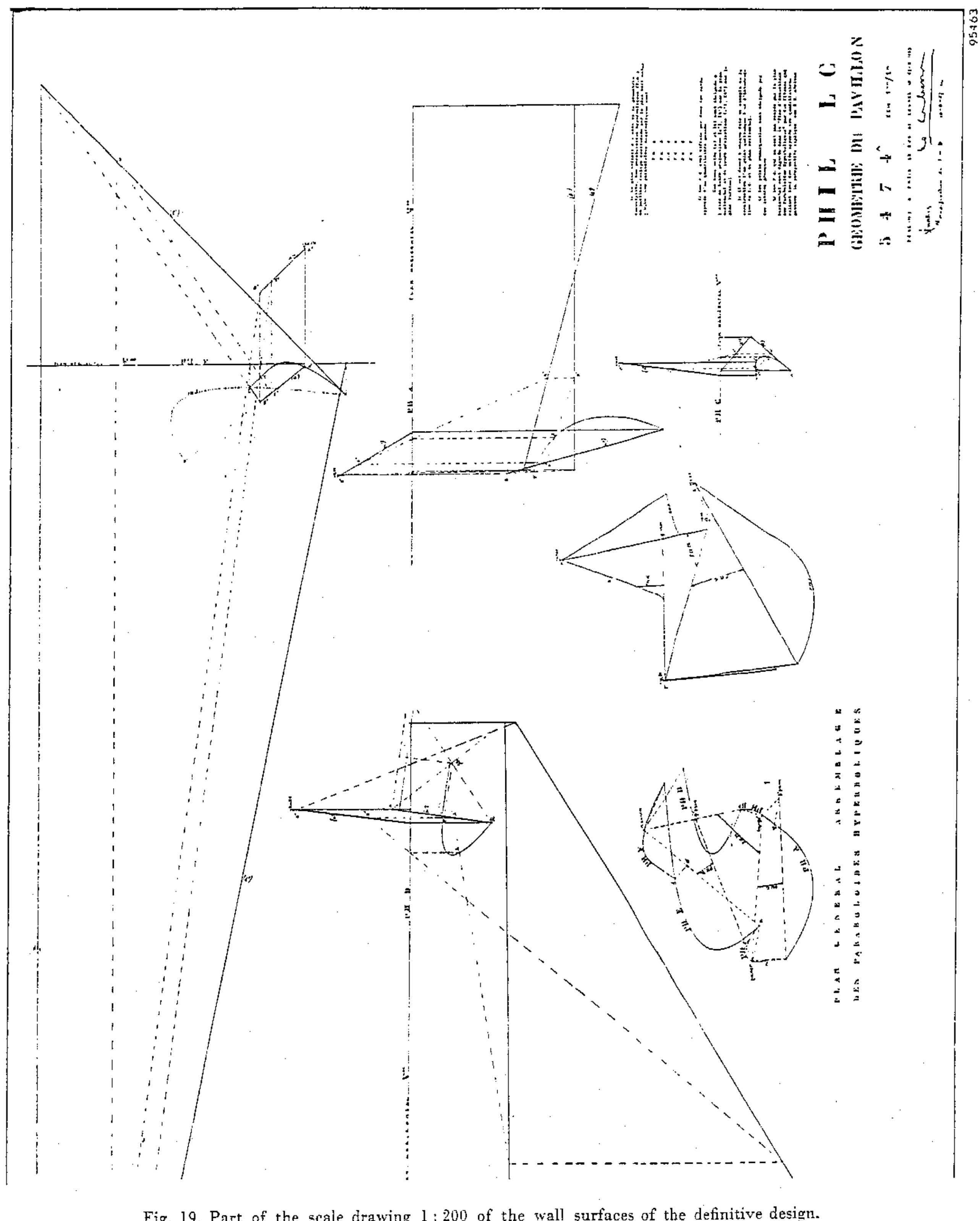

Fig. 19. Part of the scale drawing 1 : 200 of the wall surfaces of the definitive design. signed by the architects Le Corbusier and Xenakis.

the wall surfaces. To strengthen the third peak, which slopes at a very oblique angle, the hypar *C* was made convex at its foot instead of concave, and finally the two triangular openings were partly closed with extra hypars abutting on the existing ones. In this way the definitive form of the pavilion was arrived at, as illustrated in the plans of *figs. 18* and *19*.

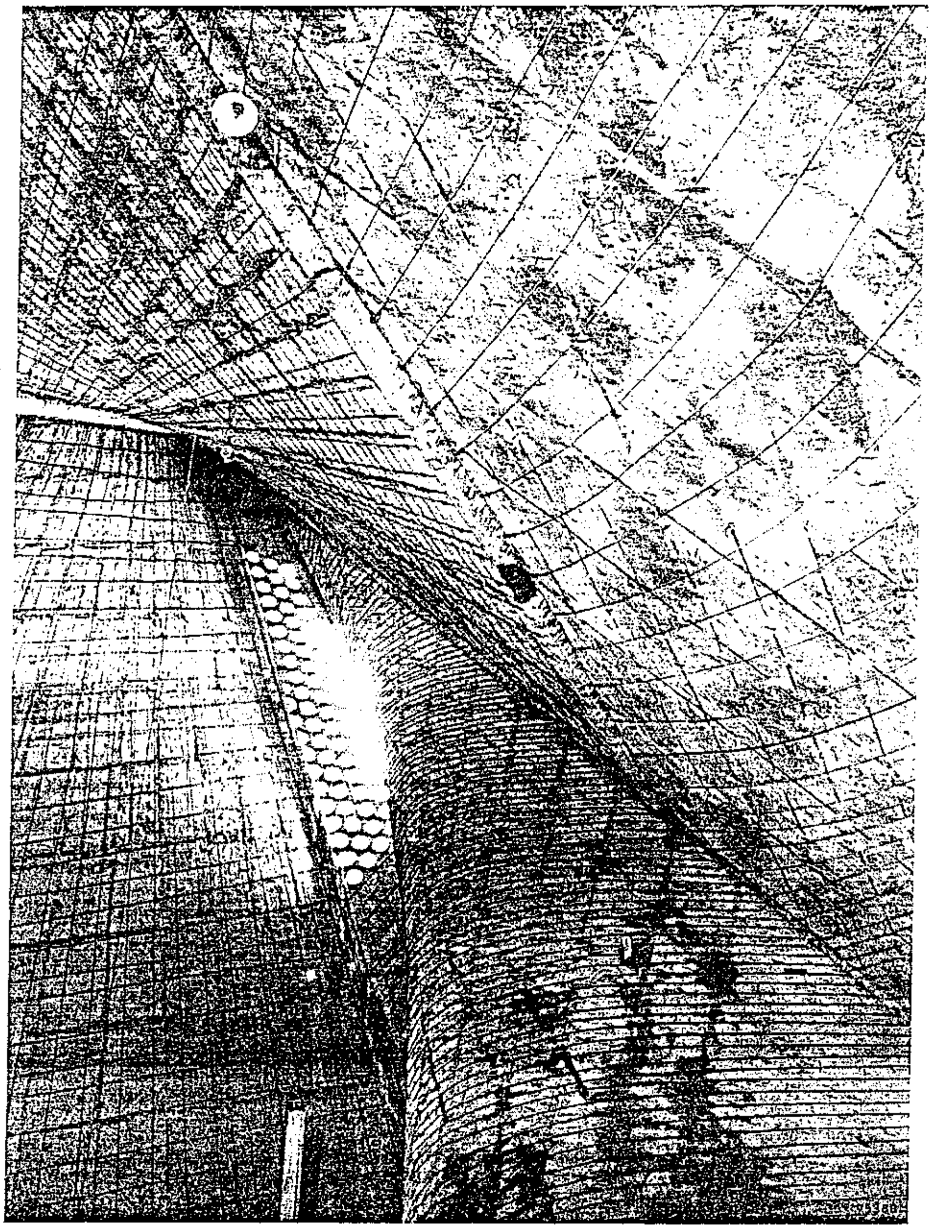

Fig. 20. Photograph of part of the interior of the pavilion. The prestressing wires on the concrete, which enhance the plastic form of the structure, are unfortunately concealed in the finished pavilion by a surfacing required for the projection of colours and pictures.

Fig. 20 shows a photograph of the interior made before the concrete's prestressing wires were concealed by the internal surfacing. This photograph and the title photograph (and also fig. 12 in IV) give an impression of the remarkable plastic figuration of the building.