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Laminar ceilings?

Shell construction in the work of some masters of modern architecture

Keywords: masters, modern architecture, laminar, shell construction, folded plates

This contribution explores the constructive and formal potential of the laminar structures in the work of three prominent figures of Modern Architecture. Unlike the most memorable constructions of this type, the roof structures here considered are not the main and only protagonist element of the building. Conversely in these cases they have been designed as parts of the building more inconspicuous and integrated. The study excludes therefore the most important realizations and also more known, made by authors as Maillart, Candela, Isler, Torroja, Saarinen, Niemeyer, etc. which have been widely treated in the specialized literature. The paper is focused in architects as Le Corbusier, Alvar Aalto and Louis Kahn, for whom the study of their approach to the laminar seems not to have been made adequately as a whole till now. Are important too, the considerations resulting from the comparative analysis, shedding some light on the idiosyncratic way in which this type of structures was adopted by each architect.

Introduction

When we think in remarkable works of thin concrete shells after the Second World War we drive usually towards prominent engineers as Torroja, Freyssinet, Maillart, Mario Salvadori, Heinz Isler or Heinz Hossdorf. All of them developed different facets of this special continuous structures and all of them realized salient contributions in this, then so promising, field. They carried to the summit the labour already initiated by theorists as Dischinger or Finsterwalder since the second decade of the Twentieth Century. If we consider also architects devoted to or with important laminar structures in their curricula, the names of Felix Candela -also considered sometimes among the builder engineers- Eero Saarinen, Matthew Nowicki, Kenzo Tange (and the wide group of Methabolists), Marcel Breuer, Hugh Stubbins or Oscar Niemeyer would occupy also prominent positions of the ranking. Works as the Xochimilco restaurant, the TWA terminal in New York, the Dulles airport of Washington, the Raleigh arena, the Berlin Kongresshalle or the thin spherical domes of Tange, Saarinen and Niemeyer are well known among many other famous structures. Common characteristic of them is the predominance of the shell structure, being all other parts of the building secondary elements of the total composition. The world of the, then so called, free forms in architecture was largely nourished by the achievements of these authors.

Keeping in mind all the above and due to the wide diffusion reached by the laminar forms in general, and the fascination exercised by the more salient examples, looks like pertinent to make some questions. Were there also laminar solutions in other prominent architects, even though not in a so significant and visible way? And if it was so, which level of prominence reached in their architecture and in which way these shells were adopted in it? This is an exploration that does not look like to have been done in a significant way till now, and it will be, therefore, the central point of discussion of this article.[1] In this context and as study cases will be considered the works of Le Corbusier, Alvar Aalto and Louis Kahn, authors singularly appropriate for their relevance to initiate this inquiry. The study of the inclusion of these laminar elements in their work seems to represent still a certain novelty, may be not very spectacular, but perhaps still interesting by complex and subtle. As not many declarations were made by them about the significate of this new building elements, the study will be made mainly based on their realized examples.

An ever-present influence

A panoramic view of the work of Le Corbusier shows that virtually in all his career he had in mind the possibilities offered by these new curved forms of construction. For example, the idea of light vaulting was very soon incorporated, and it is founded in their first architectonic proposals. His unbuilt project of Monol houses (1919), already included a series of segmented cylindrical vaults supported on inner square columns and exterior round ones. With some structural collaboration in the stiffness by the front walls the solution

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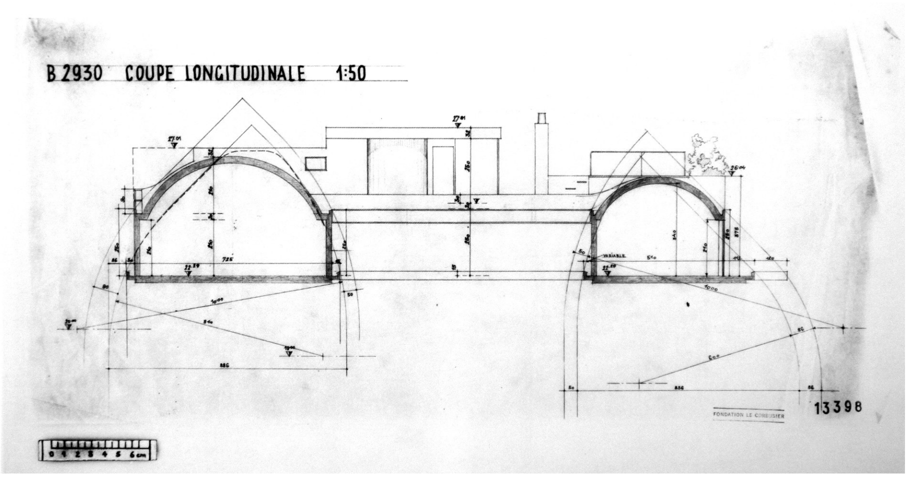


Figure 1. Porte Molitor, attic with final sections of vaults. Drawing 13398 (Le Corbusier 1983 a: 45).

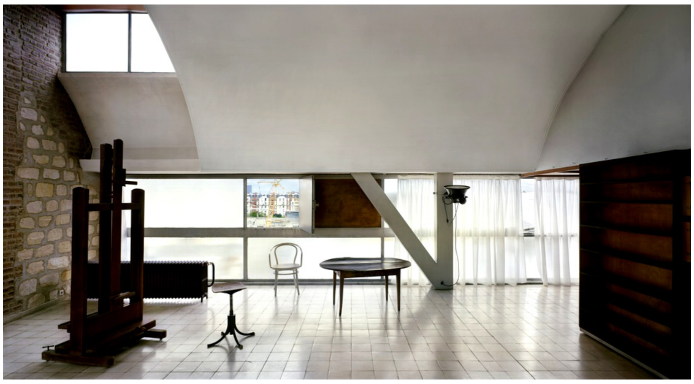


Figure 2. Porte Molitor. Interior studio (Richard Pare images 2012).

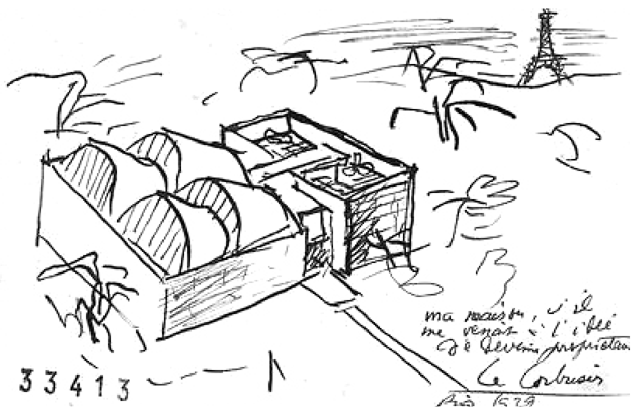


Figure 3. “Ma maison, síl me venez l’ideé de devenir propietaire”. Roof with conoids. Drawing 33413 FLC.

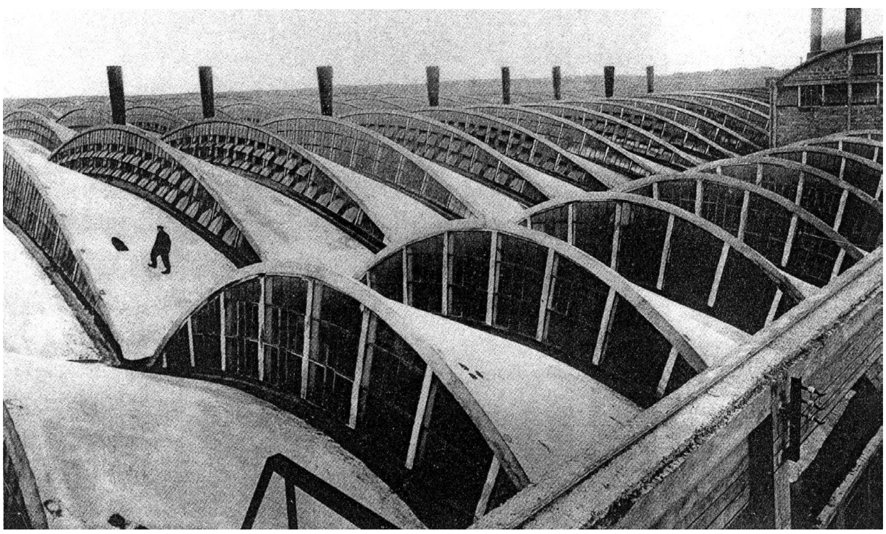


Figure 4. Radiators factory A. Dammarie-les-Lys (Freyssinet and Le Corbusier 1931: planche 21).

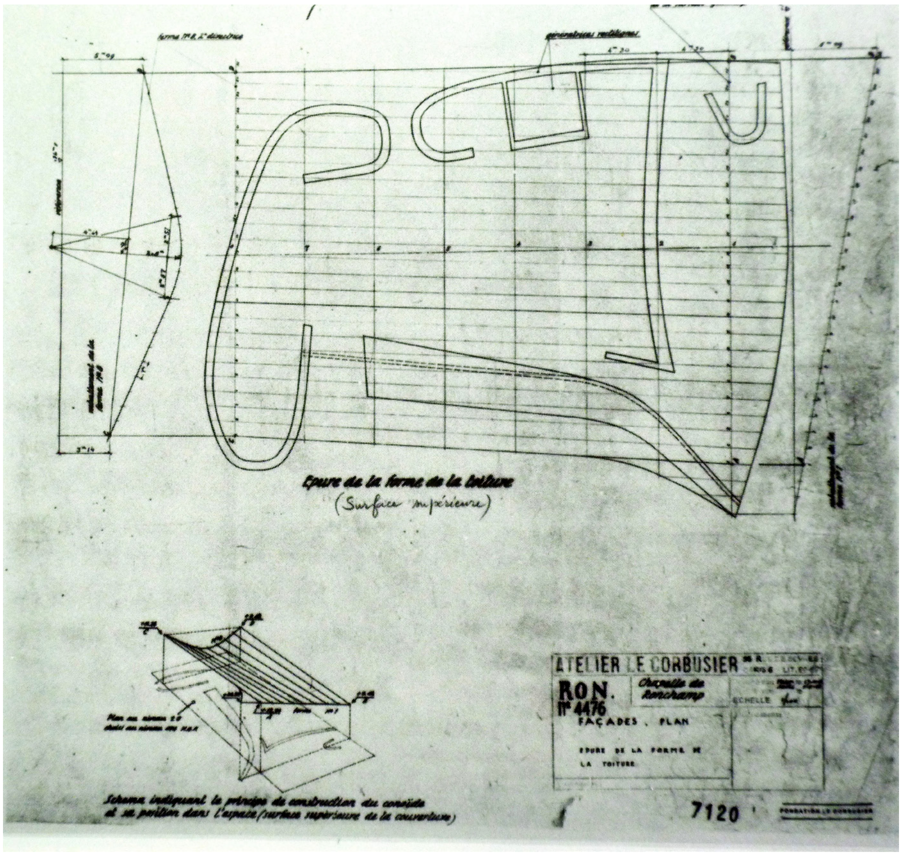
without ties looks like viable. Noteworthy as well some other vaulted spaces are represented in different designs of this initial period. Another example is the inner perspective for an artist study of about 1922. But the remarkable question is that this kind of simple vaults were finally built in his own house. This can be viewed in the attic reserved for his own atelier and house in the Porte Molitor building in Paris of 1933. As residence in the top of the building was a complete exception, in total contrast with the rest of storeys, all of them with the same height and horizontal ceilings. It is interesting that the vaults are the result of the evolution of other previous profiles, more cambered and asymmetric, and drawn following directly the profile of the building ordonnances for the construction of roofs in Paris. Finally, they adopted the more classic directrix of segmented arches (figure 1).

The larger of the two vaults constructed, that corresponding to the atelier, had a somehow oblique plan with the arched side covering a span of 6,90 m and with a rise of approximately 2,10 m. It is no easy to deduce the real supporting conditions, but it seems that it rests on two longitudinal beams parallel to the façades, being noticeable the absence of ties. The beams rest in three halfway supports, one of them V-shaped with one of his bars vertical. In that years this roof was a unique solution within the field of apartment buildings (figure 2).

The interest of Le Corbusier in vaulted roofs has been associated with his appreciation for the mediterranean tradition, which, according to Deborah Gans, was explicit in the Porte Molitor penthouse: “a massive V-shaped column supports Monol type vaults close related with mediterranean popular architecture” (Gans 1988: 50). However, it should not be forgotten that August Perret -with whom Le Corbusier worked between 1908 and 1909- had built interesting and pioneering concrete vaults of very small rise in examples like the dressmaking workshop Esders of 1919 or the church of Notre Dame of Raincy, built in 1924. It was also very suggestive, although somewhat more raised within the Perret’s cylindrical shells, the vault for the atelier Olver-Métra in París (1919-21). With a high probability, they must have had a real influence in the adoption of concrete vaults by Le Corbusier. In any case, the use of simple cylindrical vaults by the Swiss architect was present also in successive works, as the weekend house in the outskirts of Paris of 1935, the house for Mrs. Sarabhai in Ahmedabad (1955) and the houses Jaoul in Neuilly-sur-Seine (1954-56). However, the last two were built as thin brick vaults using the concrete on them mainly as a filling. Consequently, the last pure concrete cylindrical vault seems to be the weekend house of 1935.[2]

The conoid solutions preconized by Freyssinet also attracted powerfully the attention of Le Corbusier. The French engineer begun to use them somewhat before 1930 in industrial halls. It is not casual that just from those years are dated a series of skechtes of Le Corbusier -number 22423 Fundation Le Corbusier (FLC) and successives- in which four vaults of this type cover a space that it is supposed to be used as workshop. All dated in 1929, one of them is however accompanied by the following text: “ma maison, s’il me venait l’idee de devenir propietaire” (figure 3). The transposition of this laminar surfaces from utilitarian to domestic use was therefore viewed by Le Corbusier as a plausible option. Even more striking is that in one of the previous sketches for the roof in Porte Molitor are also drawn two conoid-shaped surfaces in succession (drawing 13836). The issue of spring 1931 of *L’Architecture Vivante* shared its content between the work of Freyssinet and that of Le Corbusier. By Freyssinet were presented among others his more important halls built with conoids, ending with the radiators factory A. Dammarie-les-Lys and the railway repair workshops in Bagneux. One of the illustrations of the radiators factory is a famous image of the roof of conoids taken from outside (figure 4), in which is shown the striking configuration resultant that so much interest aroused in Le Corbusier. The first building showed of the Swiss architect and therefore in pages close following to the Perret’s halls was the Ville Savoye. Its proximity seems to certify the connection indicated here and, in any case, a clear desire for confrontation as pioneering works of its time on the part of the editor.

The period after the Second World War, had in Le Corbusier even more importance in the realm of curved and biomorphic forms. That invite us to an even more close inspection. Ronchamp attracts our attention in first place for its peculiar concrete roof, although a detailed exam lets us see that it was not a real laminar solution. The idea of a soft-looking shape almost like a cushion but transformed in something stiff, dropped on the church is already present from the first sketches. However, the final solution had a decided geometric rigor, especially in its external upper surface where was used, again, the shape of a conoid.



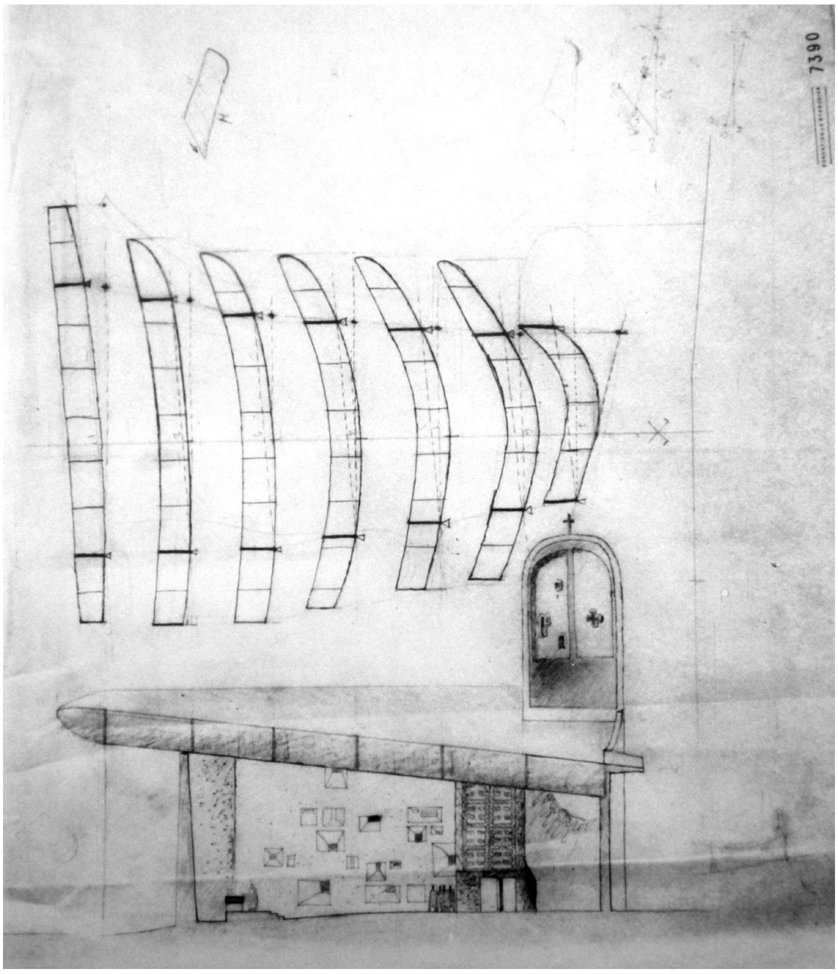


Figure 5. Ronchamp. Roof. Upper conoidal surface. Drawing 7120 (Le Corbusier 1983b: 12).

Figure 6. Ronchamp. Curved beams system of the roof. Drawing 7390 (Le Corbusier 1983b: 115).

In this case in an asymmetric and inverted position. With the proper choice of supports and directrix was allowed that the roof drains at a single point, although another drainage was also planned in one of its vertices (figure 5). The solution is not laminar because the two outer shells, upper and lower that constitute the roof, are supported in a series of seven transverse ribs that act as beams and are supported on pillars included in the perimeter walls. These ribs also cross with other thin longitudinal ribs or spars forming a rigid grid. The upper part benefited from its ruled surface condition, being resolved with straight joists supported on the ribs, while for the lower one it was necessary to formwork a thin surface that works hanged from the grid of longitudinal and transversal beams (figure 6).

The system just described for the lower surface deserves to be highlighted since it found wide application in many other solutions in which a soffit or concrete ceiling must adopt free vaulted forms. We find a first example, also in Le Corbusier, in the porch of the Assembly of Chandigarh building of 1961. The inverted surface of the vault, vaguely evocative of an awning, it is separated into sections of approximately 13 m corresponding to the separation of the supports. These moreover trespassing the shell and are extended upwards. Since they protrude above and become ribs with the curved shape of the vault, their function is also the bonding and stiffening of the laminar surface. The continuous vault is, therefore, divided into seven sections in which, in turn, and similarly to Ronchamp, large bays are subdivided by two long beams that run longitudinally from above leaning on the supports. All this is complemented by the reinforcement, also on the upper side, of some minor nerves, both longitudinally (straight) and transversal (curvilinear) (figure 7). The apparent shell visible as such from below is actually a continuous lower cladding of the structural grid of ribs.

In the same building of the Assembly is the larger laminar surface made by Le Corbusier. It is the hyperboloid of revolution that involves the House of Representatives Parliamentarians. It is inspired directly from the concrete cooling towers of the same form used in large industrial facilities and whose origin seems to date around 1917-18 in facilities of mining companies in the Netherlands (Emmen 1962, 98). Although Le Corbusier designed it closed on the bottom, is preserved a previous drawing with the typical inferior lattice of those of industrial origin. The hyperboloid tower solution it had turned out to be a resistant shape of great economy, which allowed thickness extremely thin and easy formwork thanks to be a ruled surface, besides not presenting excessive calculation difficulties. The built in Chandigarh has a wall thickness of 15 cm, something thicker in the supports, radious of 19,10 m in the basis,

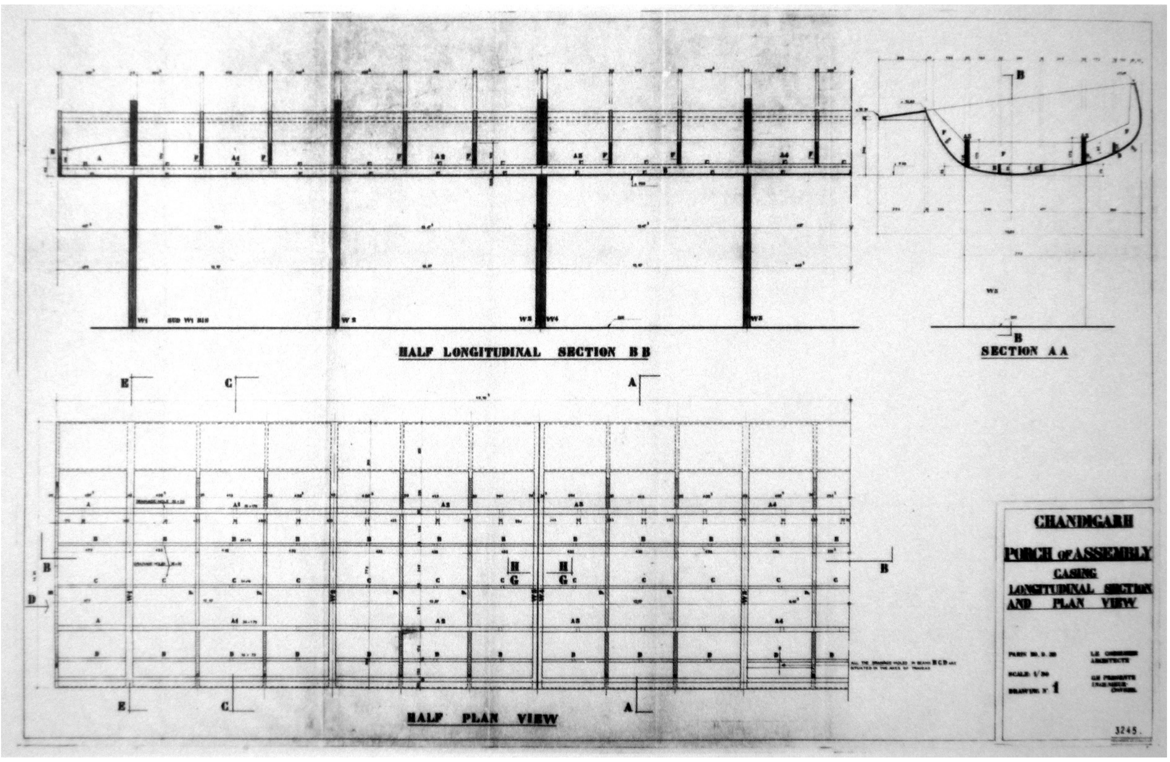


Figure 7. Chandigarh. Porch of the Assembly. Structure. Drawing 3245 (Le Corbusier 1983c: 282).

smaller radious of 9,10 m and asymptotic cones of inclination 31º, according to the measured drawing number 3117 of the Le Corbusier Fundation (figure 8).

Similar basic idea, that of a vertical shell supported on a closed perimeter was followed in the Firminy church of Saint-Pierre, started to be built posthumously in 1971. Here instead, the basis was a square with rounded corners and not a circumference as in the Assembly, and the lateral surfaces were inclined planes and not a ruled surface. The absence of favourable curvatures and the thickness of 22 cm of the walls brings the solution closer to one formed by slabs than to one of a truly laminar type.

The trajectory of Le Corbusier included in his final period other two works of great prominence within the laminar and/or warped surfaces world: the Phillips Pavilion of Brussels 1958 and the pavilion of Man in Zurich of 1956. They have been the subject of specific studies and we will not treat them here. Moreover, the very original constructive solution of the Phillips pavilion was not a real laminar structure since was realized with prefab concrete panels. All its technical details have been the subject of monographic studies (Capanna 2000, Treib 1996). On its part, the roof of the Zurich pavilion was not made of concrete but with large steel plates.

Cast ceilings

In the architecture of Alvar Aalto we find many curved or inclined ceilings which are constituent of much of his idiosyncrasy in the conception of spaces and capture of light. Notwithstanding, it is not always easy to deduce whether they are structural elements, or they are simply false ceilings. We can have the certainty of the second, when they are not continuous and are simple plaster false ceilings (often acoustic), and obviously when are formed by wooden slats as was the case, for example, in the library of Vipurii (1927-35) or in the house Louis Carré (1956-59). From the analysis of constructive sections and when the ceiling is unequivocally of concrete, seems to be extracted in many cases an idea relatively like that of Le Corbusier previously commented: that the slabs or shells hang from the bottom of great depth girders which in turn rest on supports or other master giWrders. Sometimes, even more conventionally, the ceilings are leaned on the top of the girders. In some other cases, and for the sake of continuity the ceilings were casted together with walls and vertical screens, also in concrete.

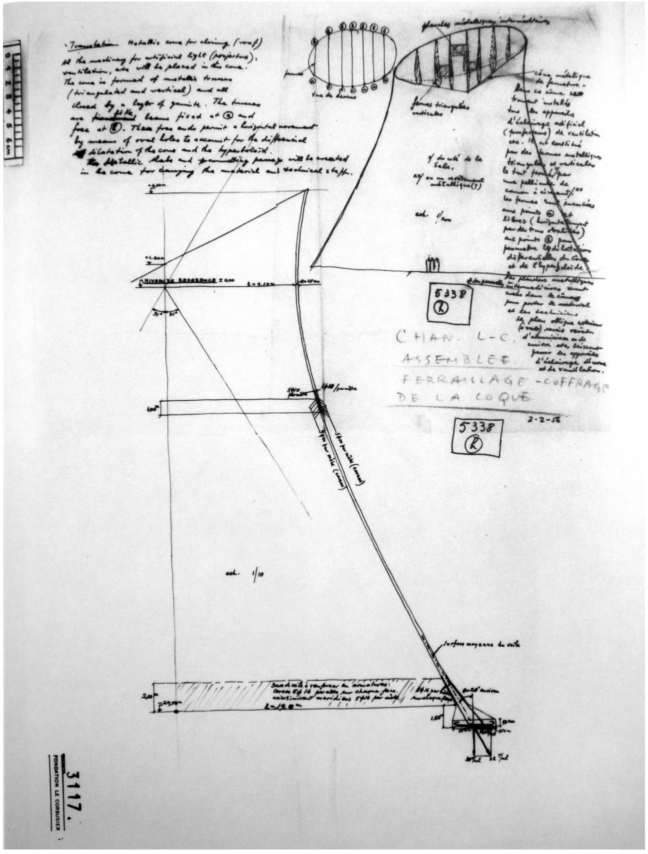


Figure 8. Chandigarh. Hyperboloid shell of the Assembly chamber. Drawing 3117 (Le Corbusier 1983c: 225).

This use of concrete sometimes as a sort of continuous envelopment is interesting and idiosyncratic of Aalto although it is not easy to determinate if, by the thickness of the concrete ceilings, their behaviour must be deemed as shell or as slab. From drawings available the thickness seem to be comprehended between 10 and 20 cm, which can be considered far from the true thin shells but also, in the lower range, as very thin slabs. Maybe those of certain dimensions and curvatures could approach to membrane behaviour. Anyway, if laminar they would be certainly modest, being only secondary structural elements between the always existent system of girders.

The idea of suspended concrete ceilings is already clearly observable in the early exam-

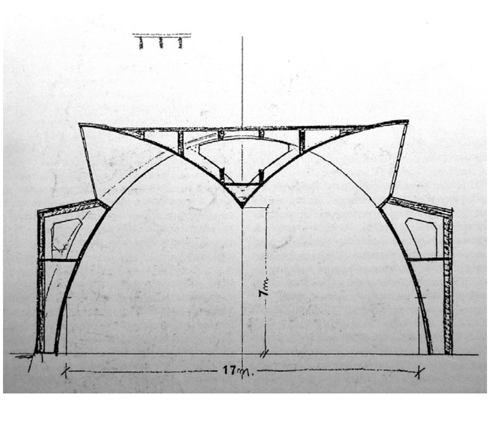


Figure 9. Alvar Aalto. Institute of Physical Education of Vierumäki, project, 1930 (Schildt 1994: 72).

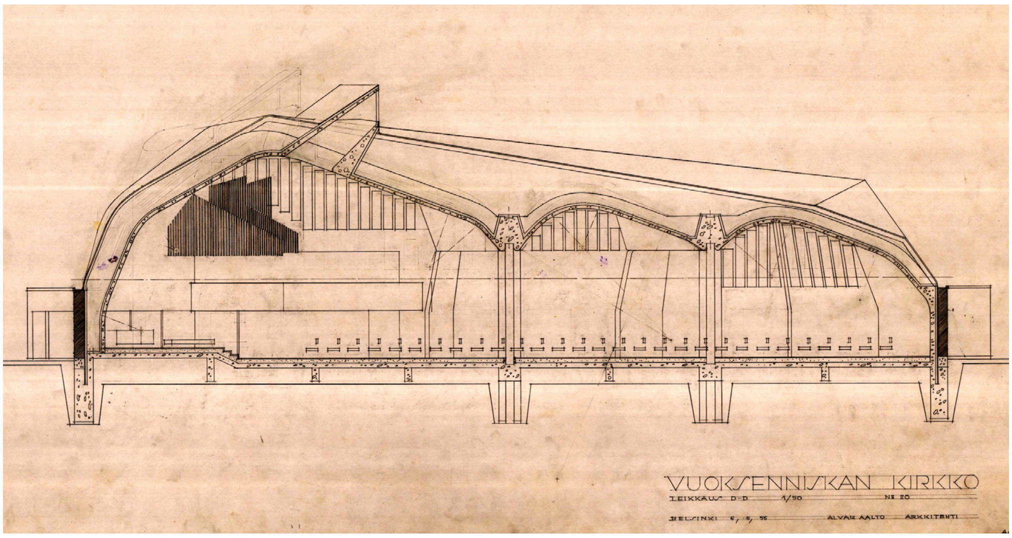
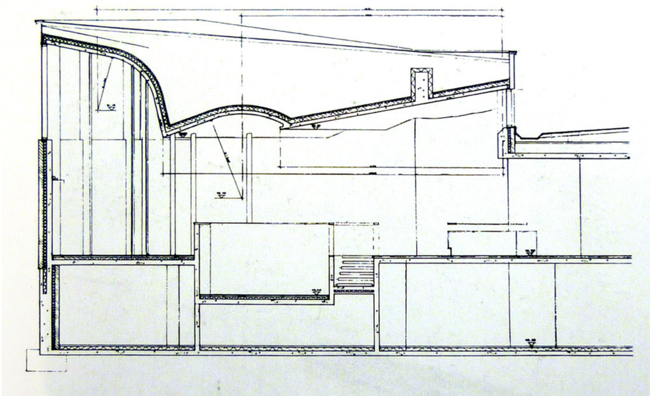


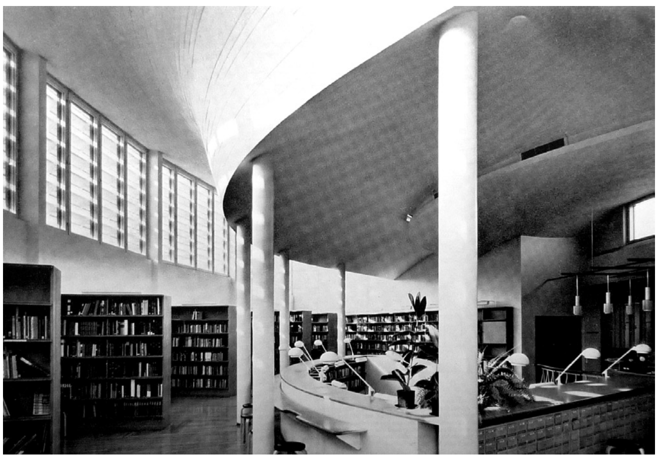
Figure 10. Vuoksenniska church. Longitudinal section showing the concrete ceiling. AAA 20-1080 (Alvar Aalto Fundation).

Figure 11. Seinäjoki library. Section (Fleig 1999: 118).

Figure 12. Seinäjoki library. Interior with formwork marks at sight (Weston 2004: 183).

ple of the unbuilt project for the Institute of Physical Education of Vierumäki of 1930. It can be seen in the section of its hall and for the year of the design it is suggested that maybe it is in Aalto where this idea is found with greater anticipation (figure 9). That section is also indicative of the dissociation between the lower concrete ceiling and the true roof, which will happen very often later, for example in most of their libraries. Between the inclined planes of the roof and the ceiling





will result consequently large intermediate chambers. The list of buildings in that a continuous ceiling seems to be a suspended thin shell is great, although only a more detailed study would allow to confirm it and to see the details of every case.

In the churches of Imatra (1956-59) or Seinäjoki (1952-60), for example, the system of girders can be deduced easily. In Imatra by the longitudinal and convergent straight lines indicated in the plan and in Seinäjoki by the transversal and cambered groin lines of the ceiling. Both cases show however the typically never very large areas between girders, spanned by the presumable concrete shells/slabs. The girders of Imatra are visible in the plans and sections and they adopt variated curved directrices to conform the singular vaulted ceilings (figure 10). More clear and explicit yet seem the curved ceilings and skylights of the classic fan-shaped plan libraries of Seinäjoki (1963-66) (figure 11) and Rovaniemi (1963-68), being visible in the first of them from bellow the marks of the wooden formwork (figure 12).[3] In this case we find a new way of supporting for the ceiling, leaned on slender round columns and not suspended from beams as usual. The House of Culture of Helsinki (1955-58) is a mixed case of slabs hanged and leaned on the girders. On the contrary and as a clear counter-example, there are no laminar surfaces in the University Polytechnic of Otaniemi (1955-64), whose curved skylights are actually big hollow beams of approximately triangular section.

One different and singular solution is the roof of the church of Lahti of 1970, in which the roof structure can be assimilated to a real concrete folded plate, in this case convergent towards the altar and partially coincident

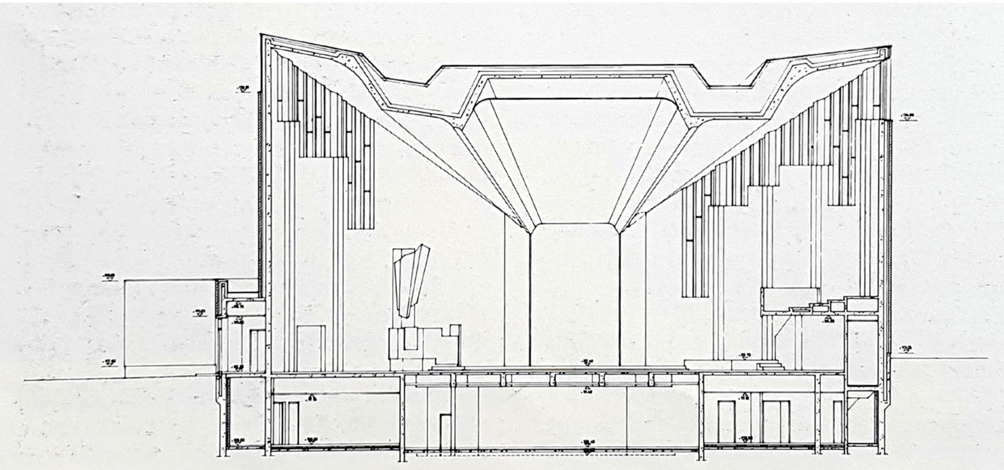


Figure 13. Lathi church. Cross section (Aalto 1988: 44).

with the ceiling (figure 13). It is interesting because the type is not found in other examples of the Aalto work. Here inclined beams and horizontal slabs compound a continuous element whose variation of thickness and rounded connections differ it from typical uniform folded plates. It is also an example of the always complex and sophisticated treatment of forms received by the concrete in the Aalto structures.

Other types of laminar structures are exceptional in Aalto's work. In Sunila (1935-39) was built a singular sulphate warehouse with a roof adopting the form of a large cylindrical shed but the inner structure was made with wooden arches. This type of curved profile appears many years after in the roof of one of his last works, the Riola church in Italy (1966-68) but built much closer to the laminar type. Aalto designed for it a series of concrete curved sheds convergent towards the altar and of decreasing sizes, echoing, with some transformations, of the laminar solution frequently employed in industrial halls and warehouses of those years (figure 14). Noteworthy is also that the vaulted sheds were prefab by sections in a workshop and then by mean of cranes left in position on the peculiarly curved and, also prefab, portal frames.[4]

Form, design and order

A look to the work of Louis Kahn reveals the existence of at least three significant cases of laminar construction. According to the general intentions of his architecture, the three reflect a sense of geometrical order and exactness very different from the till now analysed examples. In chronologic order the first example corresponds to the Unitarian Church of Rochester (1959-67) whose main assembly room was covered with a simple but ingenious solution of inverted folded plate, cruciform in plan (figure 15). The same configuration but upside down is very similar to the folded plates in pavilion (folded plate truss) that the American engineer Milos Ketcham specialized in this kind of structures in those years showed in his catalogue of types and forms of shell structures (Ketchum 1990) (figure 16).[5] The inverted solution however intensifies the sense of space, pressing it in its centre and letting it scape towards de corners, where are situated the four skylights. The way to lean is also original with three concrete supports in every arm but fixed among them by a horizontal tie. To balance as much as possible the bending efforts the plates prolong outwards beyond the line of supports up to the exterior façades. A previous variant had a unique support in the centre of every arm with two crossed beams following the horizontal groin lines. The built solution was reached after many other essays among them a crown of triangular facets thought for an intermediate design with polygonal plan. August Komendant, the consultant engineer

Figure 14. Riola church. Model (Fleig 1990: 143).

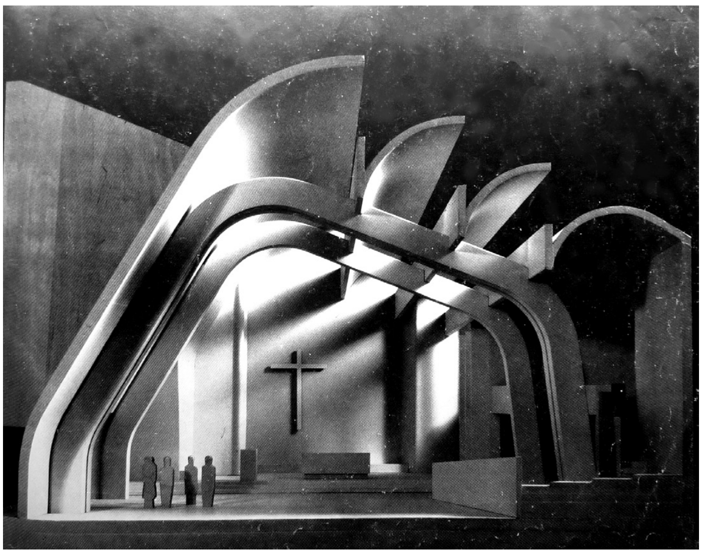


Figure 15. Unity church. Interior (MacCarter 2005: 174).

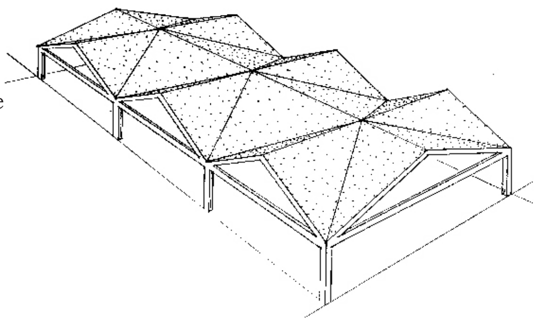


Figure 16. Folded plate truss. The inverted type was used in the Unity church (Ketchum 1999).

of Kahn from 1956 was decisive not only in the structural resolution but also in the forms adopted by the three concrete shells here considered. For the Unitarian church he suggested at least the inverted folded plate and its way of supporting.[6]

The facets concept of the preliminary roof for the Unitarian church was eventually present in the solution of the modular roof for the Olivetti-Underwood factory in Harrisburg (1966-70). The whole structure was built with the same octagonal module rested in only one support in its centrum and repeated 72 times leaving square skylights in the corners (figure 17). This faceted folded plate, whose strict geometry solved the totality of the industrial building, can be included within the semi prismatic type stablished by the German engineer Angerer (1972, 49).[7] It was constructed in prestressed concrete being the form of every unit an inverted square pyramid cut by inclined planes in the corners. Each shell is 9.1 m above de factory floor and 18 m across, covering a plan of 330 m2.

But the more pregnant example, at least from the perceptive point of view, are the repetitive cylindrical shells that almost without variation cover the Kimbell Museum of Beaux Arts in Fort Worth (1967-72), last case of analysis in this paper. Except for its undeniable refinements, it was a roof solution mainly used for industrial premises, like the many built till that moment for industrial halls and, especially, warehouses. Marshall Meyers, one of the Kahn assistants, proposed the first sketchs of the roof, firstly with prismatic forms and finally vaulted (figure 18). August Kommendant proposed the final solution deciding that the shells act as long vaulted beams, which according his comments was not well understood between most of architects of the office in the beginning. Eventually were the subtle nuances, such as the selection of materials, the precise design of the directrix and the layout and separation of their bays, which make that, far for a repetitive

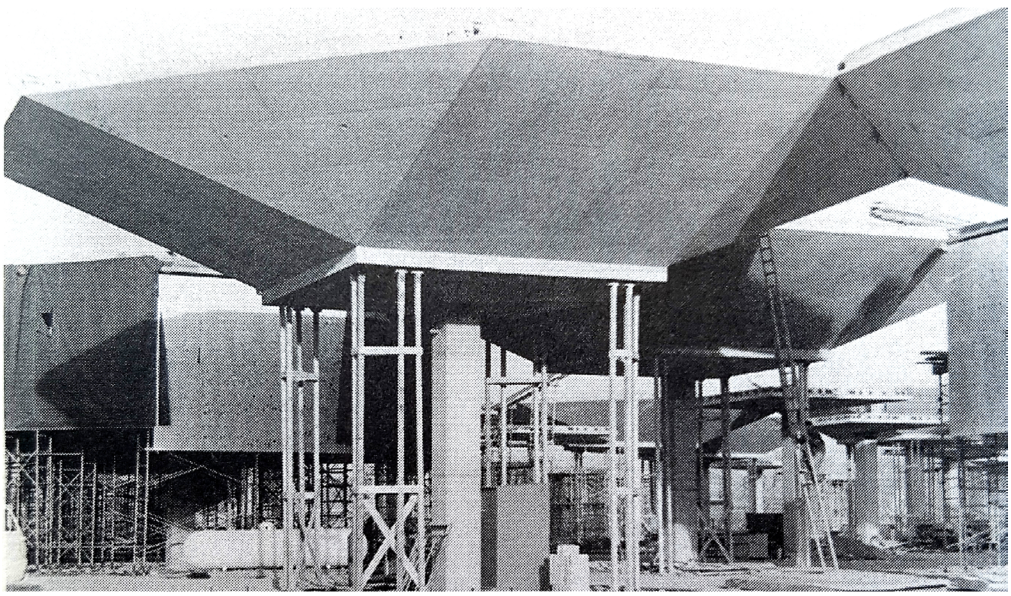


Figure 17. Olivetti-Underwood factory, Harrisburg, 1970 (Komendant 1975).

structure, the museum becomes a building with classic reminiscences and a rhythmic sense of monumental character. Especially refined is also the cycloid curve chosen as directrix of the shell, only theoretically considered until then and justified by its properties of light diffusion (figure 19).[8] As said, all the shells were of the large cylindrical type and in this case, supported by arcs of stiffening at their ends. An interesting detail between the arcs is the separation by a slit of light between arcs and the non-bearing front walls, making clear their different structural functions. Another characteristic is that its free edges are continued downwards by thin edge beams along its entire length which theoretically could increase the structural depth. It can also be seen that those beams are joined with horizontal plates to the adjacent ones, creating an impediment to the horizontal deformations in the interior spans.

A final look reveals that only two of the vaults -those corresponding to porches- are fully cylindrical since the rest are divided in two by a skylight the whole length of its coronation (figure 20). Although they could be, therefore, assimilated to the so-called solutions with section in gull wings, Kommendant explained that they work as if were complete shells due to the series of short bars that joint regularly the adjacent wings. The length of the shell between supports was 30.5 m, its thickness slightly greater than 11 cm and the transverse span 6.1 m. Although the larger cylindrical shells previously built seems to be that of a buses garage in Bournmouth of 1954 (Vlugt 1954: 51) (figure 21) using also the post-tensioned technique and reaching a length of 45.75 m, the shells of the Kimbell Museum deserve also a non-small place among the realizations of its gender.

Conclusions

This article has intended to explore the most representative examples in which laminar or shell construction was employed in the work of the three selected architects. Focusing in constructive elements that apparently could be included in this category, has been discussed to what extent they can be considered real laminar structures. As the study is based only in texts, architectural drawings and photographs and not in calculations the conclusions should be checked with more accuracy in some cases. That could be the matter for successive and more detailed studies on specific structures. But even with the level of precision here available, the arguments exposed seem to be enough for a valuation of the constructive aspects of the ceilings in relation with the form of their architectural spaces.

Of great importance is also the discussion about the types of laminar surfaces employed in the different cases. About this, can be said for example that Le Corbusier was interested mainly in somehow simple forms or derived from them. His curved ceilings were often sections of cylinders, conoids or revolution surfaces although in the late period included more complex forms as hypars (Philips pavilion) and transformated surfaces (Firmini church). On the contrary, the concrete fol-

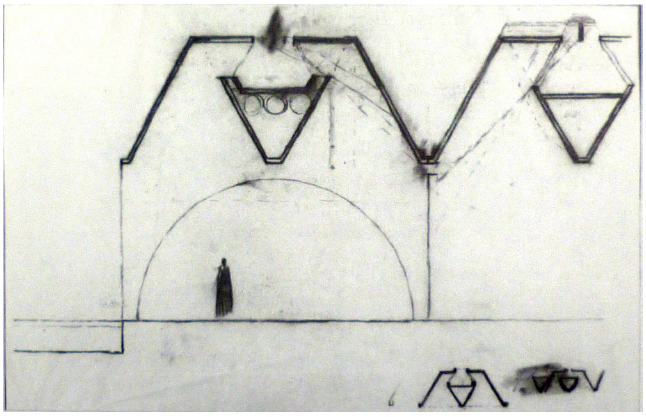


Figure 18. Kimbell Art Museum. Section of vaults as folded plates (Kahn 1987: drawing 730.142).

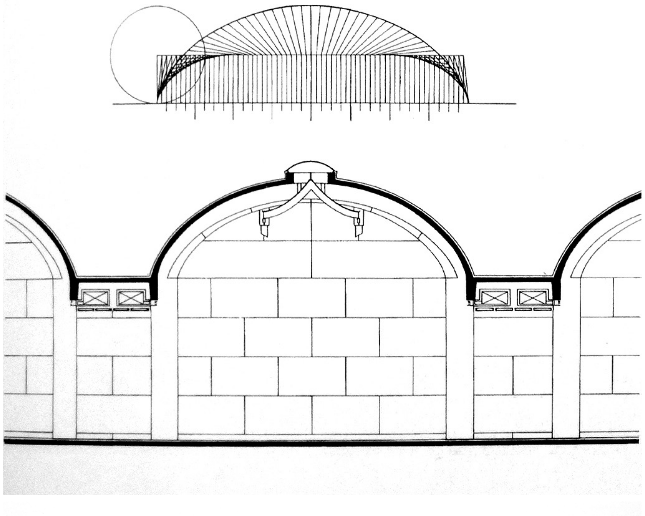


Figure 19. Kimbell Art Museum, cylindrical vault section. Drawing Michael Kleinschmidt (MacCarter 2005: 363).

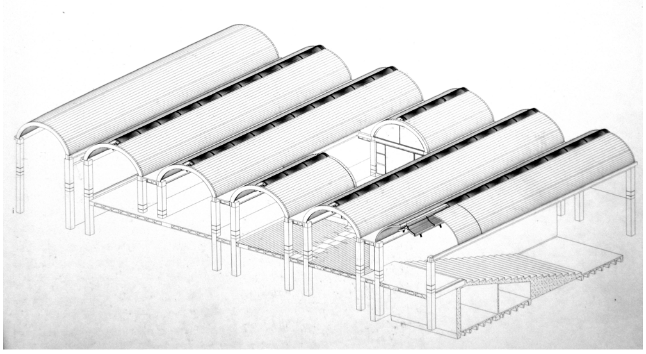


Figure 20. Kimbell Art Museum, axonometric of the Museum. Drawing Michael Kleinschmidt (MacCarter 2005: 364).

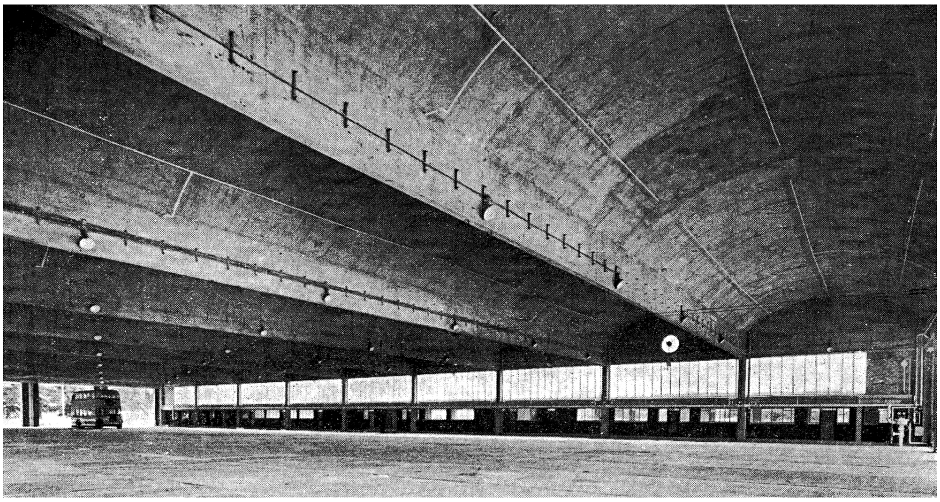


Figure 21. Garage in Bournmouth. Vaults of 45,75 m length (Vlugt 1954: 51).

ded or curved roofs in Kahn's work were not a priori solutions but as result of a studied process. Everyone was different although all of them marked with a sense of regularity not found in the other architects. This can be seen for example, in the biaxial symmetries of his two folded plates here considered and in the modular repetition, this last both in the Olivetti factory and in the Kimbell museum.

Very different was the approach of Aalto, who built plenty of curved or vaulted ceilings adopting a great variety of forms. Frequently they were constructed by concrete, but as the sections usually reveal, they cannot be considered real shells because of its excessive thick. With some points in common with Le Corbusier, his ceiling surfaces are in most of cases curved slabs hanged from upper beams, straight or curved. It is possible however that in any case the curved form of the slabs has permitted to consider an almost membrane behaviour, but nonetheless spanning very reduced bays. In the late church of Lathi the roof form suggests exceptionally a structure assimilable to a folded plate. For the three architects their non-traditional ceilings have been the starting point that has guided this study. If as Kahn said, design is the "how" and form is the "what", the structural solutions analysed are "hows" that maybe help to understand a little bit better the "whys" of some of their architectural forms.

Notas

1 There are of course analysis and detailed studies of some of the examples here considered (among them, Bellini 1999; Norderson 1998; Gresleri 2004; Ford 1990, Komendant 1972) but although in some cases they include comparative analysis these are not so extensive as the here realized, which is referred to three different masters.

2 According to the details showed by Ford (1990: 176-177) for the unbuilt Monol houses, the form-work as projected was a corrugated asbestos sheeting which would remain in place and at sight. The section drawn of the weekend house vaults is very similar and presumably was used the same formwork system. However, in this house the intrados of the vaults was cladding by bended plywood panels. Of these two houses only the Monol concrete vaults are enough thin as to be considered laminar, reflexing surely the more direct influence of Perret. The weekend house vaults were casted in a more traditional massive way.

3 In most of the ceilings formwork marks are not visible, being deduced that a plaster coating on concrete was applied.

4 The more striking structure in Aalto work was designed for the competition, won but not built, of the Sporting and Musical centre of Vienna (1955). Its roof, covering a multiuse sports hall for 25000 spectators, was nevertheless projected as a huge structure of hanging cables. Within the laminar type can be also mentioned the concrete screen wall of the Police Headquarters in Jyväskylä (1967-1970) although its rol is mainly sculptural acting only as enclosure wall.

5 In Spain these same solutions of pavilion folded plates were employed some years later by the architect Francisco Coello de Portugal as roofs of chapels and cloisters in several religious buildings.

6 According to Kommendant (1975) the solution completely satisfied to Khan although the way of supporting was not fully achieved from the point of view of the structural elegancy. The trasdos of the structure has only reinforcement beams in the perimeter.

7 The book of Angerer is cited repeatedly as consulted in the Kahn's office (Frampton 2000; Leslie 2005: 190)

8 Another favourable property of the cycloid is the vertical spring of its ends, advantageous for the edge stresses. Marshall Meyers was who found the cycloid directrix in the Angerer`s book (Leslie 2005:190). The possible use of the cycloid as directrix for cylindrical shells is al-

ready mentioned in Lundgren's book about the calculation of this type of structures (1949:25).

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