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Timber in the buildings of Jean Prouvé: an industrial material

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Abstract

Jean Prouvé (1901-84), famous for his innovations in the use of metal in construction, was also interested in timber. He used the material in its industrial-transformed form, such as prefabricated cross-laminated timber panels or plywood panels. His work with timber began during the Second World War because of the shortage of steel, and then continued throughout his later work, in two main forms: the modular prefabricated panels of façades and the roof slabs in panels of cross-laminated timber. This work with timber is different from the usual practice of French architects because it implements methods and objectives used in industrialised construction. His experiments on industrialised building construction have to be compared with those of his contemporary Konrad Wachsmann (1901-80) who was conducting similar experiments during the same period. They both explored modern forms of the material, albeit from different starting points. The diachronic analysis of several buildings highlights the constancy with which he pursued the experimental development of these construction devices, by successive improvements through industrial innovations in projects which were proposed to him. This observation reveals that his technical inventiveness allowed him to introduce industrially-produced timber elements as innovations in modern construction. Thus, timber is never used by itself but compositely with other materials using its physical and mechanical properties to achieve an enhanced combined performance. The use of timber in manufactured construction products, such as large flexible cross-laminated timber panels, allowed Prouvé to develop new relationships between form and structure, giving a new aspect to the material and producing an original aesthetic. One can see the work of Jean Prouvé as a form of 'experimental development' in architecture, in response to the programmatic requirements of his time, vital for innovation and renewal of construction knowledge.

Key words

Jean Prouvé, Konrad Wachsmann, wood, timber, industrialization, off-site construction, plywood panels, cross-laminated timber.

Introduction

Among the architectural work of Jean Prouvé (1901-84), despite being largely dominated by metal, there was a large number of buildings in which timber played a significant role. If the use of timber by Jean Prouvé as a 'designer-object' is today well known, his use of timber as a construction element is less well known and deserves further consideration.

This paper looks at a selection of buildings that illustrate his original way of using the material, from the Second World War until the mid-1960s.[1] His work represented non-conformist and unclassified design, based on curiosity and inventiveness outwith preconceived architectural styles. It was historically very much ahead of those so-called 'pioneers' of wooden architecture in France: Christian Gimonet, Pierre Lajus, Roland Schweitzer and Jean-Pierre Watel, who began their work with this material after 1965.

Unlike the pioneer group, developing an 'all timber' architecture that promoted solid timber and the art of carpentry with frameworks and associated technologies imported from the USA and Japan,[2] we will demonstrate that Jean Prouvé imagined timber as an industrial material, that is to say, as a processed product with high added value, used more for its physical and mechanical properties than for its symbolic or iconic significance. Its application was intended for industrial 'dry-construction' conditions, where the building process consisted of an assembly of prefabricated components and mass-produced elements. Moreover we will demonstrate, from a diachronic analysis of his work, that his design approach was developed in the long term through successive improvements of materials and construction methods, project after project. His method was that of experimentation in the construction field, of using innovations previously implemented in manufacturing fields such as the automotive or aeronautical industries. We will show that we can consider his approach as a form of 'research and development' applied to construction, as suggested by the large number of patents he posted in his career.

The paper begins by outlining the main features of his approach through the analysis of his use of timber in the design of prefabricated façade panels and laminated roof panels (Rousseau panels). The paper continues by seeking to identify the benefits of his experimental work for modern timber construction.

Load bearing / Enclosed: constructions with prefabricated panels

Wartime projects

Jean Prouvé began working with wood in 1939 with temporary barrack buildings commissioned by the French army. (Fig. 1) The program was to create within a period of one month, 275 movable modules approximately 3 m x 3 m. The scarcity of steel during this period led to the idea of using metal only for the structure and creating the envelope using modular, solid timber panels that incorporated doors and windows, which were prefabricated and then assembled on site.

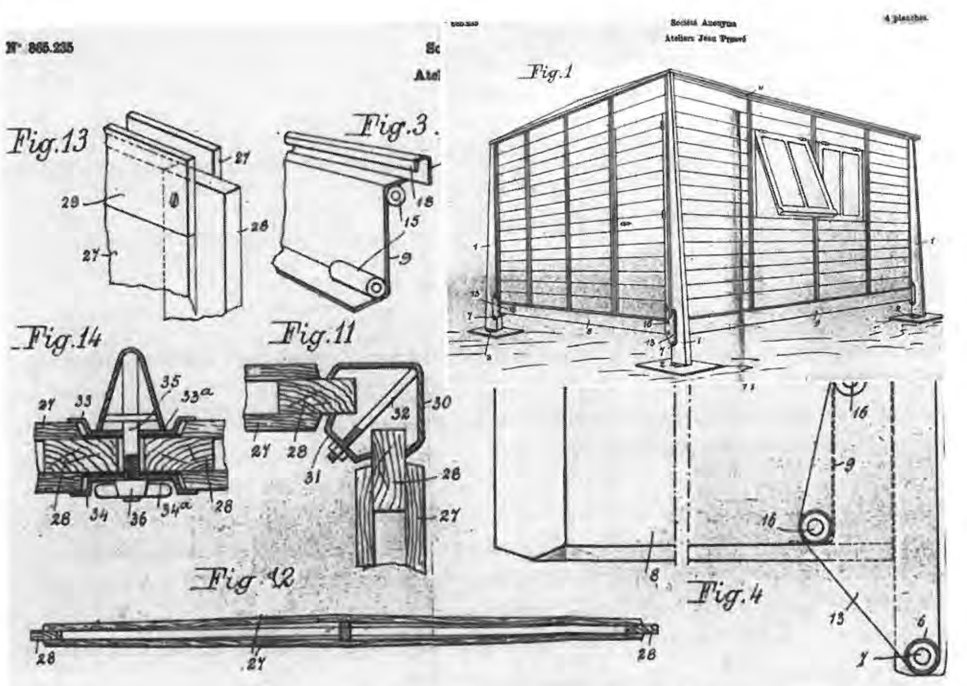

Figure 1. Movable military barrack, 1939. Drawing from the patent. (© ADMM)

Thus, World War II allowed Prouvé to experiment on the industrialization of the construction process. In the First World War army architects had designed military barracks which laid the basis for the industrialization of the timber construction by rationalizing and simplifying traditional timber frame construction.[3] By contrast, Jean Prouvé designed his movable barracks by transferring methods and techniques from steel construction to timber construction.

One can see in this apparently unsophisticated construction, the use of timber panels designed with a curved profile that evoked the metal panels that Jean Prouvé used for the house of Clichy (1936). The panels used in Clichy were profiled by the use of internal springs that expanded to stabilize the panels in the desired shape in order to avoid deformations of the thin aluminium sheets. The use of curved timber panels for the barracks permitted having thinner assemblies (and thus saving material) while providing satisfactory stiffness in the flat part of the panels. The stiffness at the joints between the panels was provided by metallic connection elements used as stiffeners. (Fig. 1) This innovative construction system was patented in January 1940.[4] This original, indeed surprising solution using curved wood panels confirms that there was in the work of Jean Prouvé, a consistency between the desire of a form for the material and the construction principles, so that one cannot identify which one regulates the other.

After this experience, Jean Prouvé worked with Pierre Jeanneret in 1941-42 to achieve the pavilions F8x8 and F8x12 for the *Bureau Central de la Construction* (Central Office for Construction - BCC). These family homes were made entirely of timber due to the shortage of steel during the war. They consisted of prefabricated timber panels, assembled *in situ* on a masonry base that was adapted according to the particular soil conditions. The structural system was an A-frame, developed in steel two years before for the clubhouse SCAL in Issoire, and implemented here in a new timber version. (Fig. 2) As noted by Christian Sumi[5]: "Prouvé is thus opposed to proponents of a reciprocity between the choice of material and the form of the construction, and experiments on the concept of transferring construction principles from one material to another." We might add that the design of the axial beam, cut at its connection to the A frame, is typical of metal construction. It is intended to lighten the beam nicely according to the principle of 'equal resistance' that Prouvé developed. The same connection on a timber beam is technically difficult to justify. Everything happens as if, as the period required, timber was used here as a substitute for steel, retaining its aesthetic aspect and consequently acknowledging a 'Jean Prouvé style'.

Figure 2. Pavilions BCC, St Auban (Alpes Maritimes), 1941-42. Jean Prouvé with Pierre Jeanneret, architect. Building under construction. (© Centre Pompidou, Bibliothèque Kandinsky)

Development of prefabricated panels

Once the war had ended, Jean Prouvé reused the metallic A frame construction system many times, combining envelopes of composite load-bearing panels with a timber frame (e.g. houses for victims of war in 1945), (Fig. 3) or a metallic frame with wood cladding (e.g. the Ferembal factory, Nancy 1947, and experimental houses at Meudon 1950-52). The panels were at first simply made by bonding the inner and outer sheets to a central timber frame; gradually they became more complex sandwich panels using cross-laminated timber sheets, insulated and clad with an outer skin of aluminium such as at the Air France Holiday Camp in Arbonne, built in 1954-55. Although Prouvé had often used panels with two metal faces, for housing he frequently used panels with an internal face of timber, which was warm to the touch, and an external face of either timber or aluminium. Furthermore the timber had the advantage of resolving the problem of internal condensation caused by the high thermal conductivity of the metal. Thus, timber naturally found a place in Prouvé's work, and he developed many composite construction systems which, in addition to their high strength and stability, also met the requirements of acoustic, thermal, ventilation and lighting comfort. In other words, his approach was not only structurally innovative, but it also mastered the physical phenomena associated with the 'architecture of the well-tempered environment'.[6]

Figure 3. Houses for victims of war, Nancy, 1945. Buildings under construction. (© ADMM)

These successive experiments with façade panels, developed since 1939, led Prouvé to file an ambitious patent in 1955 for 'construction elements of buildings and the buildings implementing them',[7] that revealed the principles of composite panels composed of a core of cross-laminated panels or plywood, with a thin layer of insulation , and a stainless steel face. This patent described in detail the panels themselves and the methods of assembly; the building thus appeared to be the result of an industrialised *Meccano*.[8] Successive additions to this patent up to 1957 improved the technical details in order to increase the thickness of the insulation by inserting expanded polystyrene foam between the plywood and the outer metal coating.

Prouvé's ideas had progressed from the handcrafted connected timber elements developed for the movable barracks in 1939, to laminated timber core panels covered with aluminium sandwich panels (insulation - plywood – aluminium) fixed on lightweight metal frames (in the Metropolis House in 1953), to technical improvements leading to lighter panels, together with the successive layers of composite panels that continuously improved their strength, watertightness, thermal insulation and acoustic properties. These wall panels were designed not only as technical objects in themselves, but also as an efficient architectural module that allowed manifold combinations, and already foreshadowed the later concept of *open industrialization*.[9]

Jean Prouvé and Konrad Wachsmann: pioneers of the industrialization of construction

At this point, one has to compare Prouvé's work on panel-based construction systems with the work of Konrad Wachsmann, a contemporary of Jean Prouvé, with a similar career. Both of them were born in 1901; Wachsmann died in 1980 and Prouvé in 1984. They both went through the 20th century taking an active part in the adventure of modernity. They shared the conviction that the construction sector, still largely based on manual craft skills, was inappropriate to the demands of modernity, in so far as it was incapable of achieving the levels of cost, quantity, productivity and quality that was required in this era.

Jean Prouvé had trained as a craftsman in wrought iron, and Konrad Wachsmann trained as a carpenter and joiner. Self-educated, they had no engineering or architectural qualifications but they both developed a passionate interest in the industrialization of construction, through metallic construction for Prouvé and timber construction for Wachsmann, slowly opening their fields of thought to all materials. Both men were contractors who ran into misfortune, and both later became famous university professors, engaged in the industrialization of construction, respectively at the Conservatoire National des Arts & Métiers (CNAM) in Paris and in the Chicago Institute of Design.

Wachsmann, the 'joiner' was working on the industrialization of traditional joinery know-how, as it appears in his studies published in *Holzhausbau* in 1930,[10] and later developed in *Wendepunkt im bauen* in 1959.[11] (Figs 4-5) His work was mostly on industrialization of timber construction and he put forward designs for 'all timber' houses, industrially produced with panels that could be quickly assembled. He developed a system of construction with prefabricated wood panels that he notably implemented in the *Packaged House System* designed with Walter Gropius in 1942. The panels were factory-made in the USA by the *General Panel Corporation*, a manufacturing company created for the purpose. This system made possible the construction of houses from kits, where a manufacturer carried out all the production and the processes for on-site construction. It allowed for many variations of layout within the limit of the standardized dimensions of the façade panels and roofing spans. The frames for the panels and the roof structure were made of solid timber, probably for cost reasons; industrial plywood sheets were used for bracing and to enclose the prefabricated panels. Wachsman took great care to design the joint details between panels using elegant geometrical systems of interlocking timber elements and metallic keying devices, which saved time during construction compared to screwed or bolted connections. These connecting systems were obviously adapted from woodworking know-how, and transferred to the scale of a building.

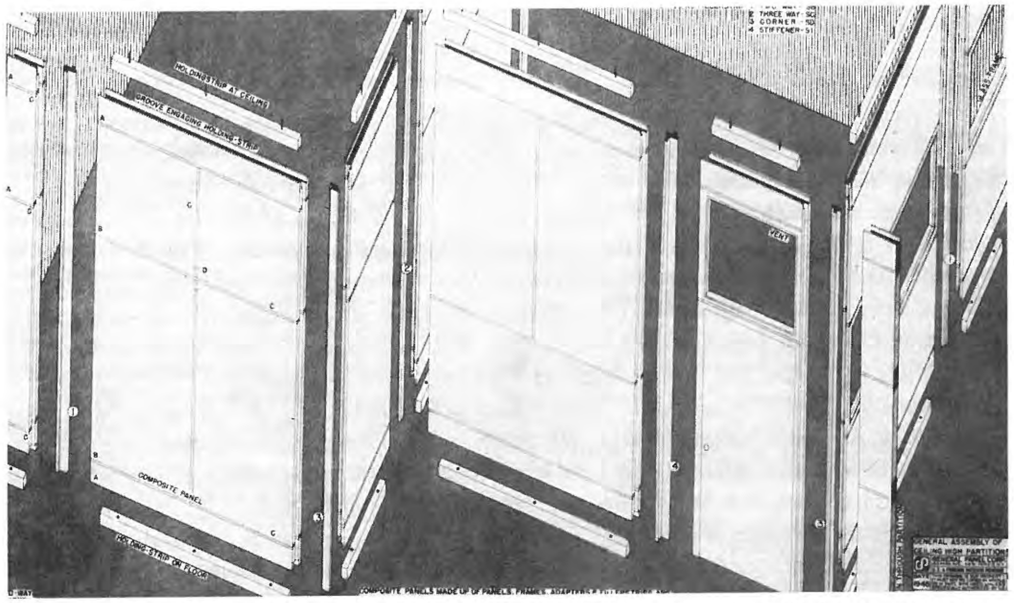

Figure 4. Packaged House System, Konrad Wachsmann and Walter Gropuis, 1942. Axonometric view. (© Sparks Co Inc NY, / Wachsmann Wendepunkt im Bauen, Krausskopf, 1959)

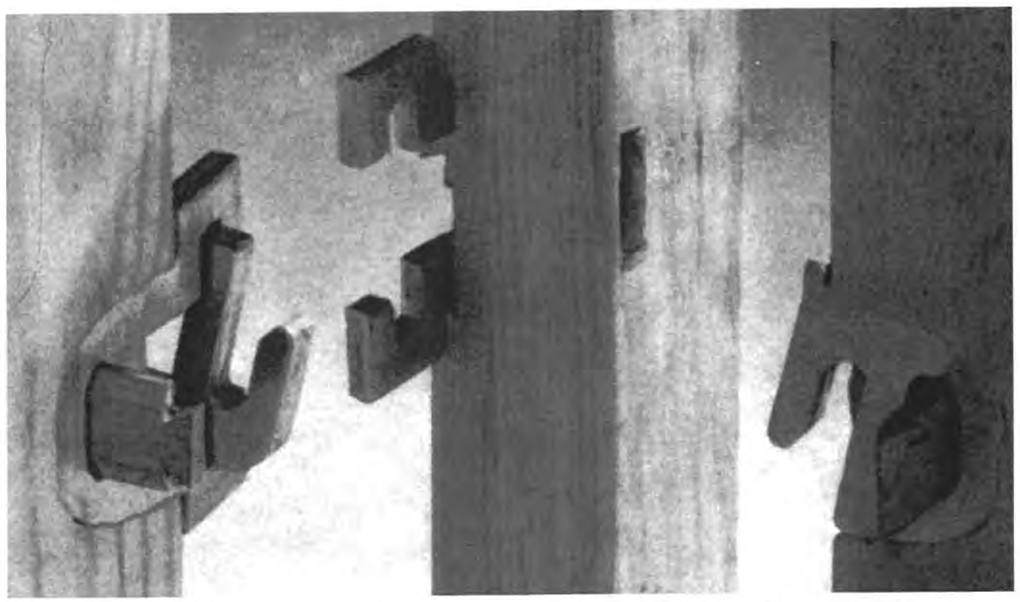

Figure 5. Packaged House System, 1942. Details. (© Sparks Co Inc NY / Wachsmann Wendepunkt im Bauen, Krausskopf, 1959)

On the other hand, Jean Prouvé the ironworker adapted the techniques of metal construction for use with timber, when it was not appropriate to use metal. Developing a logic for industrialised composite timber construction that was not based on the skills and techniques of the joiner led to new approaches to detailing and assembly that were foreign to the traditional joiner's workshop. Prouvé was able to develop assemblies of timber panels with metal connecting profiles from those he had developed for the military barracks in 1939 (Fig. 1), to the joints he used later for his curtain walls. These metal connecting profiles had a clear advantage in terms of watertightness over the interlocking assemblies of Wachsmann: they allow for the use of compressed continuous flexible joints in the connections.

Both designers were faced with the same problem regarding the edges of composite panels: How to connect two perpendicular panels mechanically while ensuring continuity of sealing and insulation? Wachsmann opted for using edge profiles to connect panels (Fig. 4), but Prouvé was unsatisfied with this type of solution. He experimented with his first prototypes in 1954 at his home in Nancy. He finally found a convincing alternative for the *Maison des Jours Meilleurs,* built for Father Pierre in 1956. The corners of the façade and the continuity of the envelope was achieved using the same kind of panels – in this case Bakelite plywood – which were curved with a radius of about 30 cm. (Fig. 6) This continuous and rounded corner solution gave an aesthetic intentionally taken from the automobile and aircraft industrial production.

Figure 6. Maison des Jours Meilleurs, Paris 1956. View of the corner panel and roof panel. (© Centre Pompidou, Bibliothèque Kandinsky)

If Prouvé adapted his solutions to the unique architectural choices of individual projects, the construction system of the *General Panel Corporation* of Wachsmann presented an 'ideal' construction model, able to form any type of plan corresponding the principles of industrialization of 'grouped product ownership'. Their thoughts on prefabrication and industrialization led to the development of noticeably different construction logics, designed ad-hoc, project after project by Prouvé, or theorized as a general system of geometric sophistication by Wachsmann. Wachsmann's *Packaged House System* was an 'all inclusive' model. In this system, architecture tended towards a logic of 'product'. On the other hand, the assembly of subsystems that is characteristic of Prouvé's work allowed various construction elements to be put together in unique architectural configurations. In this work, architectural design remained a 'service' even when it did not consist in transforming raw materials through craftsmanship, but in assembling industrialized subsystems in Meccano-like logic.

Systematization of construction by prefabricated panels in the work of Jean Prouvé
The use of prefabricated modular panels incorporating doors and windows, pre-assembled in the factory to save time and achieve high quality, as covered in a course given by Prouvé at the CNAM[12] between 1957 and 1970. In this class he continued to develop the comparison of the current way that mass-produced artefacts were manufactured and the way that buildings should be produced. He thus never ceased associating the object from its method of production (material, tools, machines, processes).

He designed most of his houses based on this system, using many variations of the surface finishes, including both plywood and metal. As he once said: "I found it friendly to enable people to live in wood; it is a material that is easy to maintain, it can be scratched and refurbished, it smells good, it breathes".[13] Thus, Prouvé, who was famous for his use of metal and industrial processes, was fully aware of the acceptability of the materials and their sensory qualities. For example, one can identify at least seven houses made from prefabricated timber-coated panels with roofs made of cross-laminated timber panels, which are discussed in more detail below in the section *Span / cover*.

As early as 1954, for his own house in Nancy, Jean Prouvé designed a load-bearing structure composed of heterogeneous modular panels picked up in his workshops in Maxéville just before his departure. In the spirit of Levi-Strauss' 'handyman',[14] he proceeded from a limited number of available elements and adapted or diverted them to new purposes, in contrast to the spirit of the *engineer* who thoroughly conceptualizes the object before designing the elements required for its construction. Thus, in Prouvé's house we find timber-faced panels of the type used in the *Ferembal factory*, combined with aluminium panels with perforated oculi of the type used in the *Tropical house*, and, for the first time, using industrial cross-laminated timber panels, diverted from their original use as panels for grain silos, for the load-bearing structure at the back of the house and for the roof. The architectural design here invents the potential compatibilities of these pre-existing industrial sub-systems in a logic of experimental development.

In 1956, at the *Maison des Jours Meilleurs*, Prouvé introduced the curved thermoformed plywood edge strips, linking façade panels made of Bakelite plywood glued onto a chipboard frame. Again, these panels included doors and windows installed in the factory, reducing the amount of on-site assembly. Later, he used this panelised façade system connected with curved edges, in all his houses as an optimal industrial solution with an ideal aesthetic solution. Only the constitution of panels and their coverings continued to evolve: aluminium for Maison Degott in Epfig, Alsace in 1958 and the Maison du Dr Gauthier in Saint Dié, Vosges in 1961; mahogany for the Villa Seynave in the Domaine de Beauvallon, near Saint-Tropez in 1960 (Fig. 7); wooden cladding for Maison Bosquet in Cordon, Haute Savoie in 1962.[15]

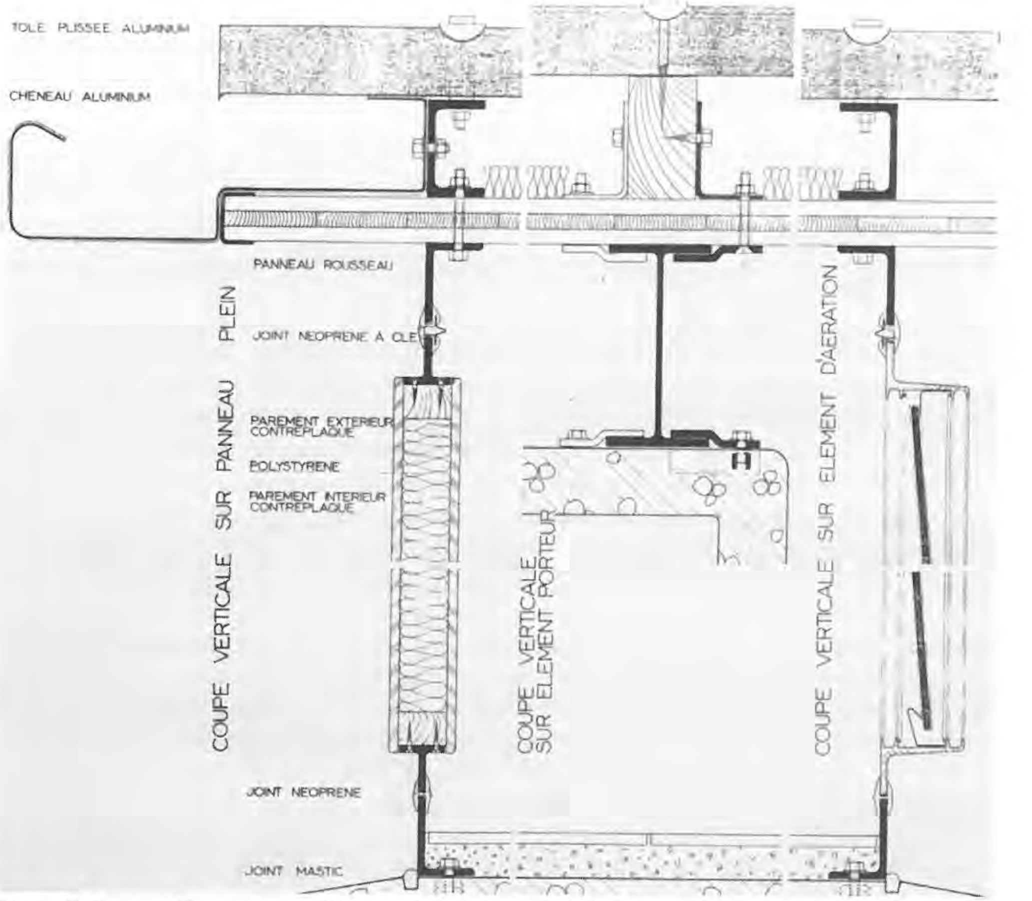

Figure 7. Seynave House, Beauvallon, South-east France, 1960. Jean Prouvé with Neil Hutchinson, architect. Details. (© Centre Pompidou, Bibliothèque Kandinsky)

After using solid timber in his first constructions for the army or for the victims of war, Jean Prouvé developed his technical devices, to incorporate industrially-produced, processed wood, such as plywood or cross-laminated timber. The size of these industrial products allowed for their integration as façade panels without additional joints. Their isotropic nature (the wood grains of laminated timber or plywood panels are crossed) enabled the façade panels to have equal structural properties in both directions.

Span / cover: Industrial timber as roofing

The Rousseau panels
From 1954, with the design of his own house in Nancy, Jean Prouvé further developed the use of cross-laminated timber panels (*Rousseau panels*) for the roofs of his buildings. The Rousseau carpentry factory, located at La Charité-sur-Loire in central France, and specializing in agricultural sheds, manufactured the panels by pressing and gluing three boards with a total thickness of 40 mm. These were forerunners of modern *cross-laminated timber*, before the post-war breakthroughs in adhesives and, especially, the mechanical joints that enable their modern use. The cross-laminated timber Rousseau panels were designed and developed in the early 1950s following the research on glued timber led by Pierre Gauthier, an engineer who brought his scientific knowledge to the contractor.[16] These panels,

patented in 1952, consisted of an innovation similar to modern glue-laminated timber. This was a very innovative approach in 1954, and also very risky. In fact, the quality of the urea-formaldehyde (UF) glue used in France at that time was poor, being very sensitive to heat and moisture. This was a weakness of the new material and it was not until 1958, when American resorcinol glues arrived in France through the *Borden Chemical Company* that glued timber was able to develop fully, using glues that were more resistant to heat and moisture than the wood itself. It was no coincidence that the first significant use of glue laminated timber took off with the Brussels World's Fair in 1958, thanks to the national pavilions for Norway (architect Sverre Fehn), Finland (architect Reima Pietilä) and the United Kingdom (architect Howard Lobb and engineer Felix Samuely).

Prouvé in fact, took a second risk in using the *Rousseau panels* in a different way as spanning elements in a roof rather than as vertical load-bearing elements. The excellent mechanical strength of the panels eliminated the need for secondary spanning elements, such as rafters, using only a few primary beams and the loadbearing façade panels. Furthermore the roof panels formed a surface, acting as a thin diaphragm of bracing in the plane of the roof. Another advantage of these laminated panels was that their underside that was considered attractive, clean and uniform enough to form an exposed, internal ceiling in the house. This system gained internal height and optimized both the amount of material required and the construction time.

All the houses mentioned above have a roof made of Rousseau panels, resting on modular wall panels. Following experiments with his own house in Nancy in 1954, Prouvé cross-laminated timber panels supported on a central steel beam and façade panels, as a structural system in all his houses, including the *Maison des Jours Meilleurs*. Nevertheless, each bespoke house was designed to meet the individual contingencies of sites, functions and aspirations of clients. The variety he achieved in these houses demonstrates that using industrialized sub-systems does not need to inhibit imaginative solutions or necessary impose standardised repetition in architectural objects.

From curved roof to stressed skin in the Evian Pump Room

Finally, these large composite panels (up to 13 metres in length) had a flexibility which allowed the construction of curved roofs, making thin concave or convex veils, by the bending of the material. These curved surfaces provided more than a slope to drain water: they opened up for Jean Prouvé a new relationship between form and structure.

Starting with his own house in Nancy in 1954, he took the opportunity of experimenting for the first time in bending these elements on large spans. (Figs 8 & 9) The roof of this house is supported on the rear sloped side, by a large piece of furniture made of Rousseau panels and on the front aspect, by modular panels of various types. Between these two ends, 13 metres apart, an intermediate steel beam gives the point of inflexion of the S-shaped curve. These laminated panels, 40 mm thick, are then dressed on the outer face with an insulating layer and an aluminium sheet to ensure waterproofing.

Figure 8. Jean Prouvé's own house, Nancy,1954. Building under construction. (© Centre Pompidou, Bibliothèque Kandinsky)

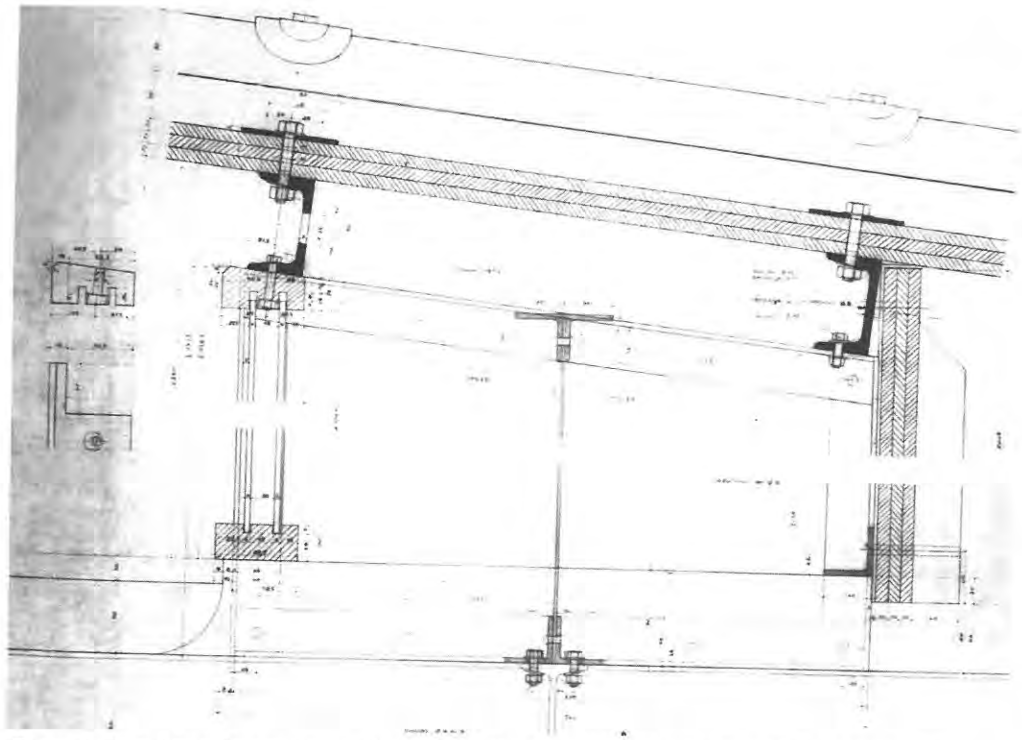

Figure 9. Jean Prouvé's own house, Nancy,1954. Roof detail. (© Centre Pompidou, Bibliothèque Kandinsky)

Two other projects with curved roofs of laminated panels were begun in 1956. First the nomadic school for the city of Villejuif whose structure consisted of a row of steel Y-support set off from the longitudinal axis and carrying two intermediate purlins. (Fig. 10) Cross-laminated timber panels provided the roofing and are continuous from one façade to the other, forming a curve defined by the levels of the intermediate supports and with a span of 8.75 metres. These panels were, as in the houses, covered with insulation and aluminium sheet. Inside, the panels form the exposed ceiling of the classrooms. Late projects for nomadic schools and the Air France holiday camp in Arbonne were designed in the same way. (Fig. 11)

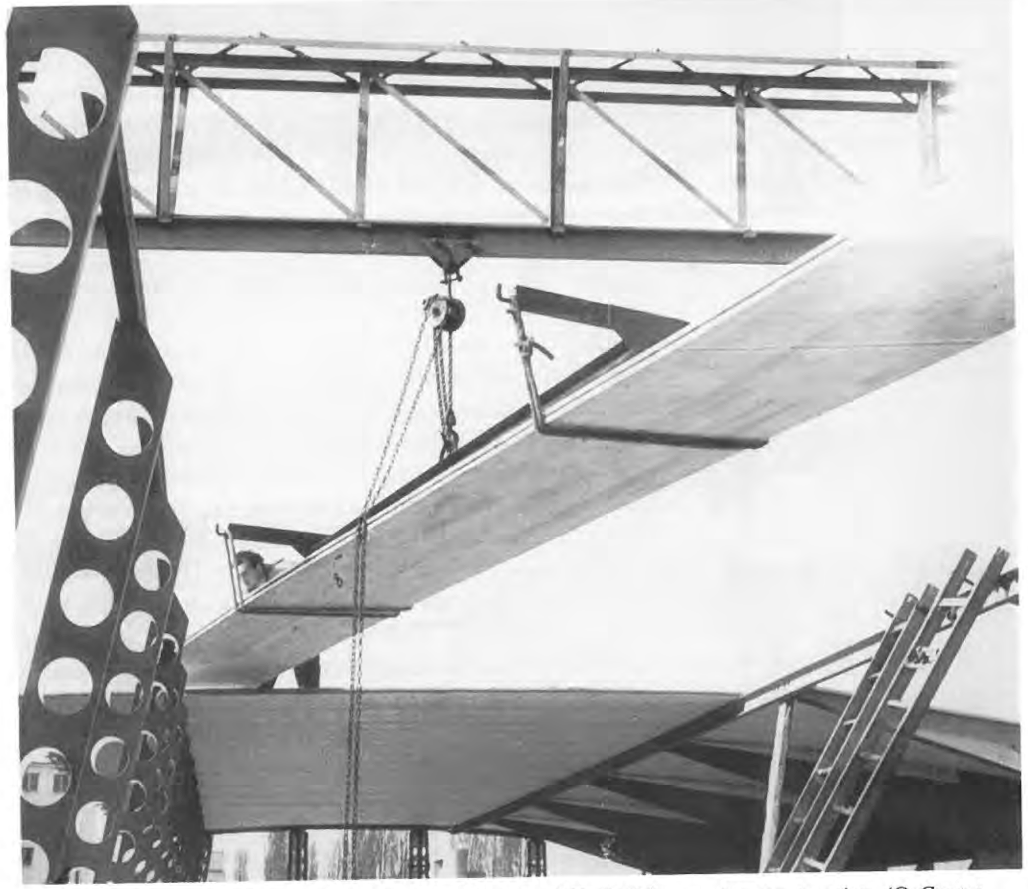

Figure 10. Nomadic School, Villejuif (Val de Marne), 1956. Building under construction. (© Centre Pompidou, Bibliothèque Kandinsky)

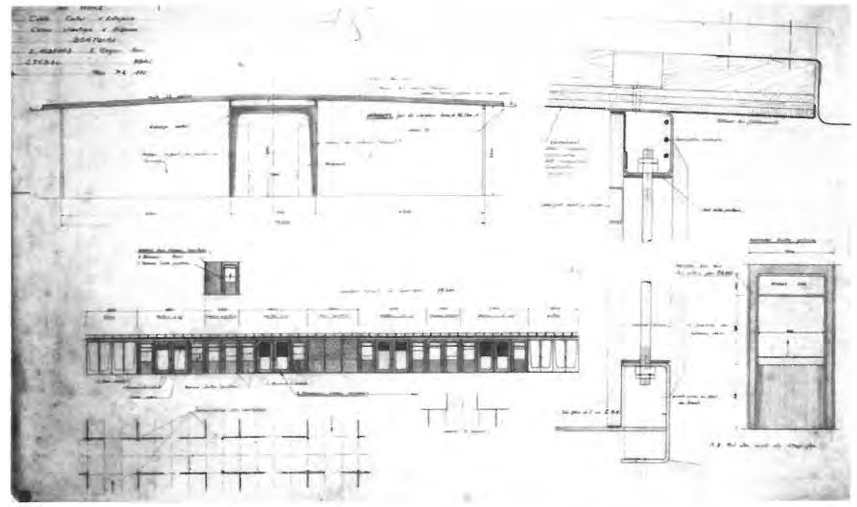

Figure 11. Air France Holiday Camp in Arbonne, 1956. Cross section and detail. (© Centre Pompidou, Bibliothèque Kandinsky)

In a similar design but on a larger scale, the pump room of the *source Cachat* in Evian also has a curved roof supported on Y-columns. Here, the curve of the roof is reversed, the bearing point on the façade panels being higher than the one on the central Y-columns. The change in scale and the increase of span imposed a more complex structure. One-piece panels, spanning the entire width of the building, were reinforced with curved, prefabricated timber I-section beams. These beams support rafters below the metallic roofing. Construction photographs show that the curve of the roof was obtained with the 'natural' catenary of the panels resting on their supports. (Fig. 12) The curved beams were installed after the panels to stiffen the construction. (Figs 13 & 14) They were also used to lift the cantilevered panels slightly beyond the end support and maintain a continuous line of the roof. Again, the panels form the visible ceiling underneath the roof.

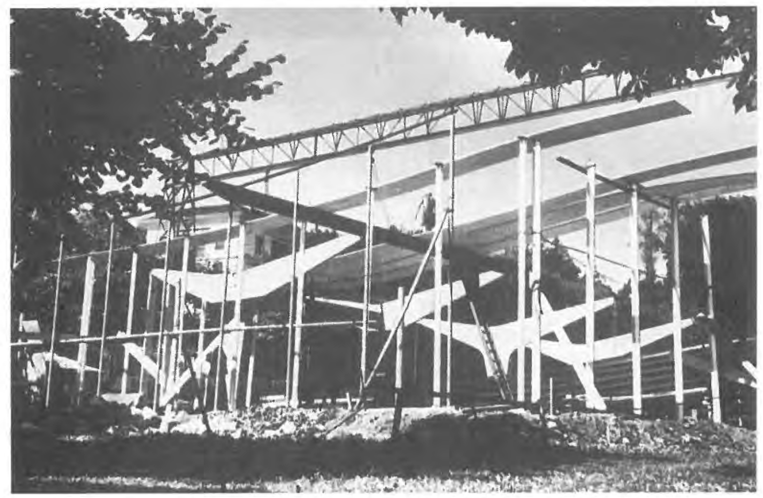

Figure 12. Pump Room, Evian (Haute-Savoie), 1956. Jean Prouvé with Maurice Novarina, architect. Building under construction. (© Centre Pompidou, Bibliothèque Kandinsky)

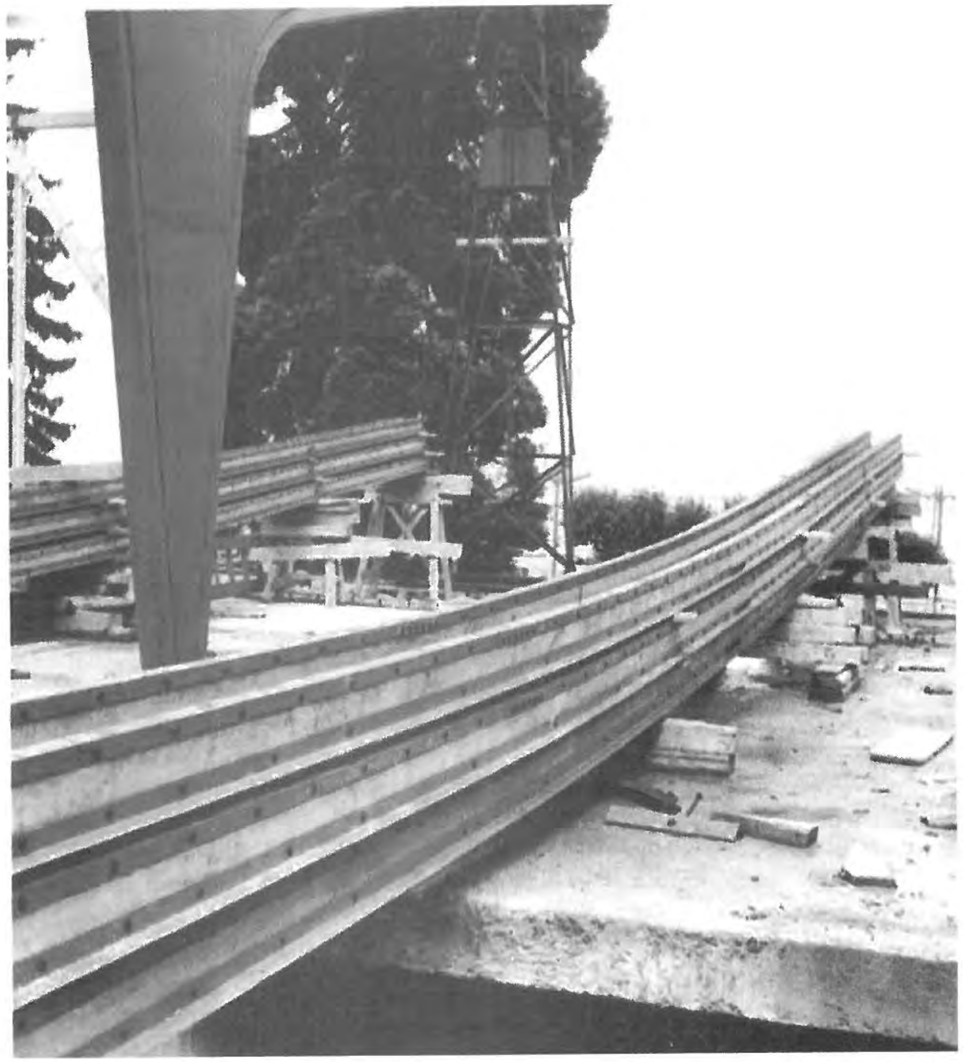

Figure 13. Pump Room, Evian (Haute-Savoie), 1956. Building under construction showing curved roof beam. (© Centre Pompidou, Bibliothèque Kandinsky)

Roof panels in curved plywood

A few years later, Prouvé also experimented with a new roof structure for the Youth Club at Ermont in Paris in 1966, using sandwich panels, which were light, curved and rigid, with an outer surface of aluminium, an inner face of plywood and a polyurethane core. (Figs 15 & 16) The cylindrical roof was composed exclusively of a series of preformed panels, about one metre wide, simply bolted together. Waterproofing was ensured by a neoprene joint applied during the on-site assembly. The eaves of these panels were timber boards, cut to the desired curve. They close the insulating core and serve as a support for bolted joints.

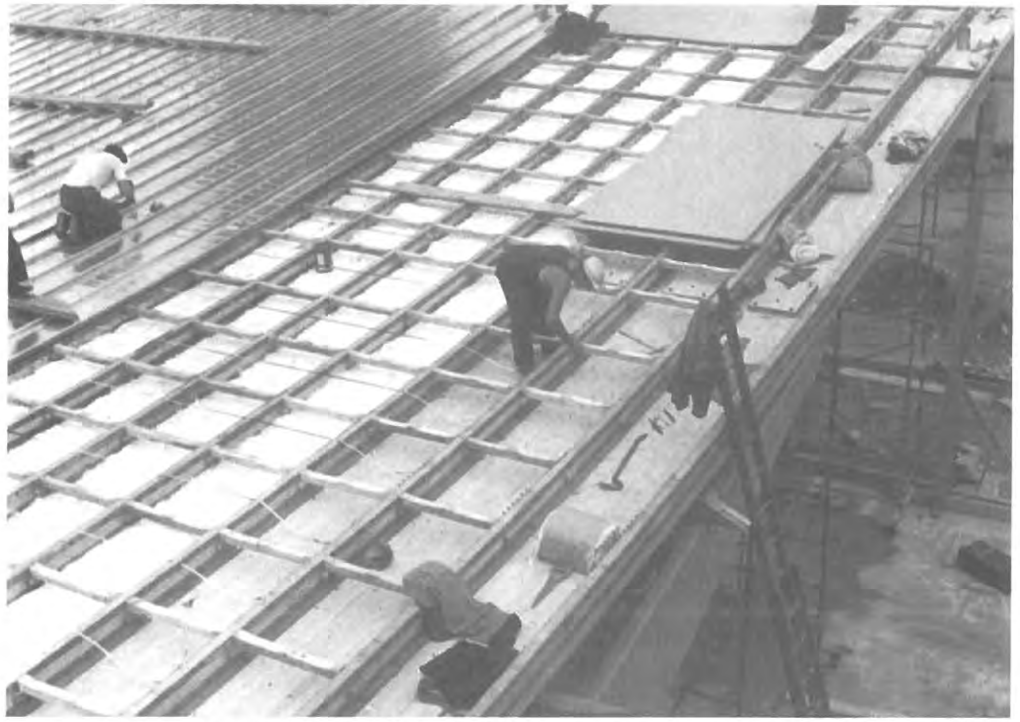

Figure 14. Pump Room, Evian (Haute-Savoie), 1956. Roof under construction. (© Centre Pompidou, Bibliothèque Kandinsky)

Figure 15. Youth Club, Ermont (Val d'Oise), 1966. (© Centre Pompidou, Bibliothèque Kandinsky)

Figure 16. Youth Club, Ermont (Val d'Oise), 1966. Building under construction. (© Centre Pompidou, Bibliothèque Kandinsky)

Jean Prouvé justified the choice of aluminium on the exterior for its resistance to corrosion; while plywood was flexible enough to follow the curve and be resistant to knocks and shocks caused by the activities in a Youth Club. The simplicity of the construction allowed youth associations to assemble these building themselves, and reduce the need for skilled labour; the prefabricated panel served as both envelope and structure, and the whole building was constructed using this single building element.

Timber as an industrial material: a doctrine

Jean Prouvé's use of timber for its physical and mechanical properties, in association with other materials in a complementarity logic, was made explicit in the interview he gave at the exhibition 'Timber Houses' in the Centre Georges Pompidou-CCI in 1979.[17] Prouvé declared: "I do not use timber in a traditional way. I use it seeking industrialized elements that are shaped not as the carpenters used to, but by machines ... what matters with timber is having a fibrous material. By placing the fibres more advantageously, it enables the achievement of huge spans".

He also challenged architects at this exhibition on the revival of tradition wooden architecture: "These framed systems are abominable: it is uninteresting in our time to use timber in this way, while there are modern means of shaping the material that allow to get something else. If we are to begin to build timber houses in the same way as in the U.S.A., it has no interest compared to what can be achieved with a material like this. There is a significant intellectual poverty shown by some people".

His innovative approach was based on technical inventions (including processed timber materials), technology transferred from metallic constructions and new forms of organization - the industrialization of construction. This approach pretends to be clear of aesthetic premises and claims to set out the problem before solving it. In the thoughts of Jean Prouvé, materials combine, with pragmatism, based on the performance to be achieved. This approach is very different from the one, common among architects, to use only one material exclusively in pursuance of aesthetic radicalism: 'all timber', 'all steel' or 'all concrete'. Prouvé built with timber rather than in timber. And if an aesthetic emerges - and there is a Jean Prouvé style - it is one of modernity, fascinated by its technical objects, its cars, its planes, as well as by the new means of production in a design where things and signs are not dissociated.[18] We could say that the work of Jean Prouvé calls first upon nature as it is - the strength of timber, its fibrous nature, flexibility, lightness and thermal conductivity - and then as a symbolic representation - that timber can evoke healthy, green and warm sensations.

The engineer Peter Rice (1935-92) nicely formulated this same thought about the true nature of materials in design when he wrote, in *An engineer imagines*:

> "A design ... can be tactile when a material is used to express its inner nature with feeling and is clearly the work of a designer who, in thinking about the material, has made the perception of the material more real. ... The search for the authentic character of a material is at the heart of any approach to engineering design."[19]

In this respect, Prouvé's work with timber is no different from his more general commitment to imagine the industrial revolution in the construction field. His buildings question the original work of art in the light of the benefits of efficient industrial production.

It is interesting to note that in the seventies, the French government, inspired by the approach of Jean Prouvé, tried to transform the construction industry, dominated by reinforced concrete, through the financing of research and experimental works linked with the development of construction as an 'open industrialization',[20] using standardised dimensions and compatible connections between all the components produced by different manufacturing companies. The objective was twofold: first to break the monopoly position that the concrete industry had acquired in the post-war period by opening up opportunities in residential construction for other actors, in particular steel and timber manufacturers; and secondly to facilitate architectural diversity after the trauma of large, brutalist, repetitive residential buildings, yet without losing the benefits of industrialization. The 'open industrialization' was conceived as a sort of giant Meccano set, using industrial products from different catalogues, each compatible with the other, federated through common dimensional rules. In the many reports of research projects on this topic, Jean Prouvé is frequently mentioned as a pioneer, as a model to follow. However, this concept of 'open industrialization' or 'components policy' did not meet with success, beyond a few experimental subsidized projects.

While the revolutionary works of Jean Prouvé prefigured the industrialization and the mass production of building components, they remained prototype units or low-quantity batch production, built in a careful or pre-industrial way. They have not led to the industrialization of the construction as might be imagined, simply giving us a view of what it might have been. The 'reproducible technical object' that should have replaced the 'one-off piece' became a piece of work in itself. There is some historical irony in how Jean Prouvé prototypes are placed in art galleries and museums, while the architectural community wholeheartedly welcomes him in its Pantheon.

The fact remains that Jean Prouvé, in France, stands for the promoter of an outstanding endeavour to transform the technical culture within architecture, consistent with the new industrial tools of his epoch, and was perfectly illustrated through his use of timber, going beyond the craftsman culture of the carpenter to discover a modern material with a much higher level of performance. It is a reasonably safe bet that current environmental requirements for buildings, which demand higher performances from architecture particularly in terms of thermal and physical performance, will no longer allow us to be satisfied with symbolic ecology or 'greenwashing' and lead us to review again the lessons to be found in the work of Jean Prouvé.

Conclusion

In broad terms, four essential qualities can be isolated from Prouvé's experimental work.

The first is to bring timber into modernity, as an industrial material involved in the conception of construction sub-systems benefiting from the new physico-mechanical properties of transformed timber. The material is used in composite construction systems taking advantage of the natural qualities of wood and of its new qualities derived from its industrial processing. The value of timber panels is both mechanical, to brace the prefabricated panels, and thermal to remove the risk of condensation experienced in steel structures. The new rule was: 'use the right material in the right place'. Thus, Jean Prouvé broke the centuries-old traditions of timber carpentry and offered new outlets for the timber industry.

The second is to have been able to address the technical building issues in a creative way, in the sense given by Gilbert Simondon,[21] that is, through the ability to involve objects or unusual materials, to extract non-explicit properties, in order to solve problems in a quick, original and efficient way, such as in the use of Rousseau panels. It shows that in the industrial situations, architecture becomes the driver for experimentation and development of technical inventions, external to and independent of the project, its specific program, or the specific conditions of a place. The ability of these inventions to become innovations then depends on the ability of the designers to receive them and to bring them through the trial of architectural design. One may nevertheless wonder if our times, saturated with standards, rules and certification, can still allow the freedom to experiment such as Prouvé enjoyed.

The third quality is to have been able to develop it's the construction sub-systems consistently, working step by step towards improving their internal consistency, to the autocorrelation of all their components to enhance their performance through functional synergies. this was exemplified by the evolution of the composite façade panels, from the first barracks in 1939 to the curved panels developed for the youth club in Ermont in 1966. In the same way, regarding the scale of the buildings themselves, the development of the architectural connections between these industrial sub-systems show a striking continuity of evolution. Jean Prouvé, as a manufacturer, was looking forward to the optimal solution, rather than building up works of art. This approach that we would today call 'experimental development' is particularly clear in the evolution of his houses, from his own house in 1954, to the house in Cordon in 1962. Moreover, the evolution of a typology toward its optimal technical solution was not achieved by imposing standards, nor did it lead to architectural impoverishment as many architects feared.

Finally, the fourth quality is to have been a pioneer in the transformation of timber architecture from the art of the carpenter to the art of the engineer,[22] culminating in the pump room at Evian, the first timber stressed surface used on a large scale. And it is no coincidence that Robert Lourdin, a French pioneer of timber construction engineering between 1960 and 1980, was a student of Jean Prouvé in CNAM.[23] He built many spatial structures in timber, following the inspiration of research by Le Ricolais[24], that were both technically innovative and architecturally remarkable.

Prouvé's work with timber followed his more general commitment to perceive an industrial revolution in the construction sector, totally in harmony with the narrative of modernity, perhaps more strongly than others, despite the strength of their claim for modernity.[25] His buildings challenged the uniqueness of the architectural work in favour of industrial production, performance and economy. This shift from liberal arts toward mechanical arts, as Antoine Picon describes it in *L'art de l'ingénieur,*[26] shows a new pre-eminence of concerns for welfare, efficiency and performance over the symbolic or spiritual issues with which the liberal arts were traditionally concerned. This shifting of the centre of gravity of architecture from the symbolic work of art to an ideal technical object was an innovative approach that aimed at adapting architecture to new production methods, to new working organisations, taken from the world of the industry whose achievements were admired at that time. In Prouvé's concept, the building was first thought of as a technical object in itself.

His approach to architecture is consistent with the definition of innovation expressed by Joseph Schumpeter in 1911 as "the carrying out of new combinations in production",[27] in Prouvé's case timber industrially transformed, prefabrication in construction and engineering knowledge, which converge and combine in contemporary works.

The role of experimental technical development, vital to innovation, is rarely stated explicitly in French architecture. Indeed, technology is considered as instrumental, and is usually relegated behind the issues of function, space and aesthetics. Jean Prouvé framed the role of the architect as an actor in construction innovation, involved in the evolution of techniques with his tools, methods, and creativity. His work reveals that architecture is not just a place for implementation of techniques but also an opportunity for their invention, improvement and renewal in complex situations.

The Author

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The SEAT Dining Hall in Barcelona, 1956: innovative approaches to structure, the use of aluminium, and building services

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Abstract

Completed in 1956, the SEAT Dining Hall in Barcelona was the first structure to use aluminium in Spanish civil engineering, and the building was awarded the first prize in the international competition held by the Reynolds Aluminium company in 1957.

The aim of this paper is to study the technical design and construction systems used in the SEAT Dining Hall building and their role as catalysts for its architectural design. Beginning by placing the building in its historical context and presenting its creators, the paper continues with an analysis of how its pioneering, externally-visible aluminium structure provides the backbone for the building's key requirements. The current building enclosure is studied with regard to its response to the climate in Barcelona. Finally, the building services system for hygrothermic conditioning, for which there are no graphical records, is reconstructed in order to evaluate its ground-breaking techniques and how it was integrated into the building.

The paper argues that the collaboration between the architects César Ortiz-Echagüe Rubio, Manuel Barbero Rebolledo and Rafael de la Joya Castro and the structural engineers R. Valle Benitez and H. Herrera, and building services engineer, Pedro Roca, was fundamental to the success of this building, which should be recognized as one of the most innovative and efficient modern structures which contributes to both Spanish and international building heritage in the 20th century.

Keywords

Aluminium, structure, air-conditioning, SEAT dining hall, Barcelona.

Historical context and the creators

The Sociedad Española de Automóviles de Turismo (SEAT) was founded in 1950 in the Free Trade Zone of Barcelona and began production in 1953. In 1956, Dining Halls were built to serve 2,000 meals daily in two sittings, for a total of 1,600 workmen, 300 clerks and a hundred engineers.[1] For the site, SEAT chose an area to the extreme south-east of the factory, the only area which would not be affected by the future plans for extension. The site measured 11,850 m^2, of which 3,420 m^2 were constructed, at a total cost of 11,128,348 pesetas (approx. 2.4 million Euros).[2] The architects of the SEAT Dining Halls were César Ortiz-Echagüe Rubio (b.1927), Manuel Barbero Rebolledo (1924-92) and Rafael de la Joya Castro (1921-2003). The structural engineers were R. Valle Benitez, an aeronautical engineer and H. Herrera (CASA) and the building services engineer is Pedro Roca (SEAT). (Fig. 1)