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PROTAGONISTS OF IRON BUILDING CONSTRUCTION IN THE SECOND HALF OF THE NINETEENTH CENTURY

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Protagonists of iron building construction are characterized less by so-called inventions of a technical or artistic nature than by their ability to absorb the existing historic substance of architecture, namely structure and space, and adapt it to changed social conditions in the light of new problems.
What is called progress in architecture basically stems from modest, but specific, interventions by individuals step by step elevating building design to higher technical and aesthetic levels and creating new, different spaces.
Thus, the use of iron as a building material in architecture per se does not constitute progress. It all depends on the way in which the very nature of this material is conceived and brought into harmony with the essence of a building.
In a fundamental distinction relative to stone and wood building, iron construction can develop only in an existing industrial production environment, as is well known. At a certain level, the nature of iron is developed not only by intuition, but by the exact sciences initiating and controlling its production process. The work incorporated in a structural component made of iron assigns to that part a high value, thus forcing it to be used only sparingly in most applications, i.e., restricted to the optimum structural minimum. Where iron is used in building construction, new problems are involved: The needs for enlarged spans and reduced structural cross sections as required for bridges, railway station halls, markets, factory halls. The ability of iron to accommodate high tensile, compression and bending forces and the possibility to shape iron and thus, as in the parabolic arc, almost retrace the flow of forces inside the material, has enabled this material to fulfill these new duties.
In solving these problems, the man to control iron construction from the beginning was not the architect, but the engineer. For only he was accustomed to making full technical use of the characteristics of a material not yet fully investigated and, in doing so, proceed along unconventional lines: He dared to risk experiments. Above all, however, he was always able to build as a function of the material. Nevertheless, the right way towards developing an iron architecture fitting the needs and characteristics of the material and having a correspondingly useful thesaurus of forms was not at all clear from the outset.

Unencumbered with questions of style, the designing, as a function of the material, of such structural parts as beams, arches and girders, the shaping of sections with optimum load bearing characteristics, but also the aesthetic appearance were debated violently and controversially. The results obtained in practical building construction were very rapidly publicized in the engineering journals and included in the theoretical discussion. A particular position in engineering designs made of iron was held by the girder and beam systems made of cast iron or wrought iron and the lattice work known for a long time in timber construction. Initially, the correct shape of a beam as a ceiling support played a main role. The shape was the I-beam with a web, a top and a bottom flange, whose load carrying behavior could be improved even further by shaping it as an arch when using brittle cast iron of low tensile strength.
Although spans were then still relatively modest, straight beams could be extended by bottom trusses consisting of a central stiffener and a round bar. This type of beam, a fixed triangle, was combined by

Camille Polonceau into the system of roof girders bearing his name. Long and Howe also experimented with fixed triangles, but of timber, which were combined into parallel lattice girders. Both designs became prototypes of lattice work structures, which Culmann made calculable around 1850.
Although these structures were quite progressive in that they made the most efficient use of material in relation to their large spans, they still owed much to timber, straight girder systems, and beams.
At the same time, architecturally speaking, the limits of lattice work structures became apparant: The single and double pitch roofs they had to carry covered a space traversed by tensile members and rafters. In addition, the roof structure and the support structure were separate systems, as in stone and timber construction. Throughout the nineteenth century it was quite customary to rest iron roof structures on solid brickwork. The only positive effect of these designs was the possibility to create well lighted rooms, but the shapes of these enclosed spaces remained essentially the same as those known throughout the history of building (basilica). As Meyer stated in 1907, the lattice work structures were "rigid and terribly practical" designs for covering spaces. About the rotunda of the Vienna World Exhibition, which was 80 meters high, he wrote: "The motive of the tent roof,which had played a role in the history of styles especially as the outer roof of Bramantesque Renaissance domes, became independent in the Vienna exhibition building and was enlarged to a tremendous scale."(Meyer, 1907, p. 121).
In lattice structures, iron was used "as a function of the materials," the system of girders with rigid and movable bearings, separated into tensile and compression functions, was minimized in the extreme, for the basis of this engineering structure was statics, while the calculations were not an aesthetic dimension allowing viewers to experience the nature of iron.
Polonceau, an engineer, stated in 1840: "Each structural design system must meet the dual conditions of longevity and economy or, in other words, all materials used in a structural system must be arranged in accordance with their strengths in such a way that they can be given the smallest possible dimensions and their combination is of the greatest simplicity," (C. Polonceau, RGA, Paris, 1840, column 27).

A step forward compared with purely mathematically correct structural design is marked by a process resulting in a design, in which iron exhibits its load carrying function also for physical perception.This restores an aesthetic function demanded of architecture in the nineteenth century, which we do not want to miss even today.
"Art, however, wants to represent the battle between force and load as an easy, pleasant game, express its solution in a free interaction of parts and establish equilibrium as a peaceful, calming conclusion. Although the mere establishment of static conditions and forms will always result in a certain amount of regularity of the whole structure, firm basic conditions and symmetry, the mere knowledge that a building will not collapse does not evoke any response, does not cause any higher sensations. Such impressions are created however, if the structural members can be made to come alive, as it were, so that they voluntarily and gladly seem to exercise their functions easily and safely; these impressions are those of a battle between forces and loads come to an end and concluding in full peace," (Baumeister, 1866, p. 31).
In these quotations from a textbook on design for engineers,structural design is pathetically regarded as a living being able to develop forces in order to battle against loads. The inner play of forces is to be expressed aesthetically by designs of the bearings, stanchions

and gussets in such a way that even a viewer unskilled in the science of engineering will be able to surmise it.
Even if these sentences may also apply to the aesthetics of stone architecture, they do describe an open problem when applied to iron architecture: The laws of gravity cannot be expressed in filigree iron construction, in accordance with the viewing habits of the nineteenth century, as long as this structural design does not reveal its structural principles at a higher level than was incorporated in the traditional modes of architecture: the free spanning arch, whose curvature follows the flow of forces.
In an essay by Richard Lucaes entitled: "On the Power of Space in Architecture," which discusses the "giant vestibules" of the large cities, the halls of railway stations, we read: "The lasting effect on us created by this space is both the assurance with which the immense ceiling, supported only by the walls on both sides, hangs freely above our astonished eyes, and the bold conquering of distance in an undivided room without any supports. In one word, it is the grandiose. We feel that the genius which created this space is the same spirit which conquered it outside, in overcoming rivers and penetrating the Alps. However, it is the sheer size which almost exclusively makes its impact here, at least in most of the rooms so far developed in this category. They have been dedicated to such prosaic purposes that, except for some cases, it was felt that they could almost do without any art at all, and yet the other forces of space, especially light and form, if they were used for artistic purposes, could elevate even these rooms to a higher aesthetic level. Without idealizing in an unhealthy way its purpose for a very real side of our life, one could at the same time make the grandiose idea underlying the design of this type of ceiling an important ideal of beauty. Our eyes, which get lost in the stupefying maze of crisscrossing iron rods and iron cables, would come to a rest and find enjoyment, if the individual examples of this calculation expressed in iron could be concealed from our view and only the result,arranged in a clear system of sums, showed them visually in a fashion pleasant to the eye," (R. Lucae, 1869, pp. 398, 399).
This result, in which the sum total of forces appears to be concentrated in this case would be the wide arch of a railway station hall, such as St. Pancras of London, whose tension member is buried in the ground.
The semi-circular or parabolic arched trusses made of iron indeed not only represent a design principle born from iron, but also create a new type of space, the aesthetics of which reflect statics: This new type of space are the "domed buildings", whose shapes have been taken from solids of revolution, flat, parabolically curved roofs, sometimes reaching up to tall bell shapes, or longitudinal halls with the cross sections of an arch. The characteristic all these glazed structures have in common is the absence of any distinction between ceilings and walls. It is well known that these forms of spaces can be traced back to Loudon's modest experiments with curvilinear transoms, coming to a culminating point in the greenhouses and winter gardens of the nineteenth century. Another culminating point are the domed railway stations and exhibition halls, e.g., St. Pancras of London and the machine hall by Contamine and Dutert and, of course, the bridges representing a new shape as three dimensional lattice structures. In all these arched buildings we find embodied what engineers, in their language of symbols, call the "flow of forces within a loaded cross section." Indeed, load diagrams in most cases correspond to a flowing, parabolic line. Only for this reason, e.g., Gaudi, although he built in stone, was able to arrive at the curves of his arches in the Sacrada Familia church by using stressed cables.

The physical appearance of the flow of forces in a structure becomes the image of the formal abstract solution. This fact is particularly striking in bridge designs.
The technical background of these progressive iron structures was the process of riveting, which became accepted after 1860 and allowed the simplest mass produced units, such as flat iron bars, strips and plates, to be joined so as to withstand shear forces. In this respect, the most important process adopted in the Crystal Palace, namely the use of mass production and standards, did not stop there, but was further refined in the riveted large structures: A mass product available in every market, the semi-finished flat and section iron bars, could now be processed.
With the introduction of mass production technologies in steel making (Bessemer and open hearth processes) and of riveting after 1860, cast iron structures began to withdraw from applications in ceilings and roofs. They still survived, for a couple of decades, being used as stanchions, and around 1900 altogether disappeared from the structural systems of buildings. Basically, the possibilities of cast iron had been exhausted completely, both technically and aesthetically, already around the middle of the century. Absorbed into the history of building, it became a historic building material, much like the stone pillars and stone arches whose industrial replacement had been its early role.

What was passed on by cast iron construction was the industrial organization of work and its product, namely a mass product. In the rows of many millions of rivet heads and wrought iron structures of the second half of the century, this serial approach is exemplified. Originating from structural requirements, they at the same time fulfill the ornamental concept in the aesthetic rationalism of architecture, according to which ornaments help to explain a design.

As mentioned above, the essence of these frame structures, whose numerous subunits were combined into homogeneous entities, was expressed in the iron arch.
Many names stand for the completion of this line of iron construction. They revitalized iron architecture, which had got stuck in eclecticism, either imitating stone or covered with stone: Balat, Le Play and Krantz, Eiffel, Contamin and Dutert, Pergod, Barlow, Segenschmid and Wagner, etc. Let us only mention the work of Segenschmid and Wagner, the Palm House of Schönbrunn Palace built in 1882, because it marks an instance where a space design typical of this structural concept was implemented almost as an architectural manifesto, and because the building born out of this structural approach is already indicative of what is to come: iron and the laws of statics turned into aesthetic manifestations.
In a comtemporary report we find an illustrative description of the impact of this building:
"In the view of the experts, the artist has solved his difficult problem in a most fortunate way. The huge glass building has a most impressive effect; its harmonious structure and soft contours make it stand out against its green background in a manner transparent and powerful at the same time. Its curved glass panes glistening in the sunlight light it up and cause it to sparkle like a magic palace. Its dimensions make the Schönbrunn Palm House the largest of all greenhouses in Europe built in accordance with a uniform plan. The building owes its graceful character to the dominance of curvilinear and curved lines and the avoidance of forms found in stone architecture and wood construction, which are so frequently emulated in iron construction. Also with respect to style and structural design it marks an interesting step forward in the artistic development of iron construction which, in the absence of past models of architectural application of this modern structural material, is either found in the artless forms

of practical, but ugly industrial buildings, or is disguised in the masks of stone and wood constructions. In the Schönbrunn Palm House, as the excellent arts writer Ilg expresses it, the shape of the whole building matches the material; only the curve controls the contour. The overall aspect is that of an artistic impression, the cause for which we do not fully realize. It does express the artistic power of the material in this appropriate artistic treatment, but we do not yet understand the reasons underlying that impression. We are still at the beginning of a new, dark path in an unknown territory. However, looking at this building, I feel as if the rod of a diviner trying to find a spring of water had twitched ever so slightly," (Illustrierte Zeitung, April 22, 1882, vol. LXXVIII, No. 2025, pp. 325, 326).

Notes

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