DEVELOPMENT STRUCTURES IN 19th CENTURY IRON ARCHITECTURE FROM BRIDGE TO HALL CONSTRUCTION

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Iron architecture in the 19th century did not develop in a straight line. Its possibilities of implementation were linked to economic and technical preconditions, which experienced some fluctuations in the course of the century and differed greatly in the countries concerned. This contribution will outline some of the major specific development structures on the background of their underlying causes.

Conditions, Influences

The historic development of iron architecture as the most important, and also most typical, expression of building construction in the 19th century depends on some major components:

(1) the economic and technical course of industrialization in the wake of the Industrial Revolution starting in England,
(2) the qualitative and quantitative improvement in iron production,
(3) the improved scientific methods of stress analysis calculation of the new structural material, iron,
(4) the emergence of new architectural problems.

Industrialization

The advancing process of industrial revolution had entailed fundamental changes in manufacturing techniques since the end of the 18th century. Mechanized production, increase in the output of industrial products, concentration of the population in cities, increasing traffic and transport problems are some of the determining factors initiating economic, social and cultural changes and new developments in the 19th century. As a consequence of industrialization in general and the technical and scientific reorientation of production connected with it, new physical principles were established also for building construction.

The possibility to produce large quantities of iron by greatly improved fabrication techniques drew attention to a material whose importance had already been pointed out, with some euphoria, by the French chemist Fourroy right after the turn of the century: "Working iron in its various development stages of perfection precisely marks the progress of our entire civilization".

Iron as a new structural material occupied an increasingly more dominating position in civil engineering in the course of the 19th century by setting new qualitative standards in building construction and architectural design. However, it did not simply remain an "ersatz" material replacing customary buildings of stone and timber. Instead, iron was the first new material to influence traditional architecture, both with respect to architectural problems and design. Iron construction as a special sector of building construction created the preconditions for solving, on the basis of scientific and technical building methods, new architectural problems evolving from changing needs.

Aesthetics and Engineering

The more clearly technical development lines emerged in architecture, the more urgent became the problem of their design consequences. Accordingly, the new trends in building construction were accompanied by theoretical debates, such as

- the need for a rationale behind aesthetic arguments,
- the conflict between architect and engineer, between historism and

rationalism.

The fundamental changes in building techniques brought about by the new construction possibilities of iron were bound to conflict with established design principles; doubt began to invade traditional architectural theories.

Already in the early 19th century, for instance, Henri Labrouste, one of the few exceptions among architects dealing logically with the technological development in building construction, argued in 1830 that "... in architecture, form must always correspond to the function for which it has been designed". He also felt that design expression had to be achieved by construction based on the proper choice and use of materials. Arguments of such far reaching impact began to appeal to many. Justified doubt about the validity of classic doctrines of beauty led to discussions, throughout the century, about the question of a "new style", which were started by Hübsch in 1828, also about the dominance of form or content, the distinction found by Bötticher in 1844 between "original form" and "art form", to mention just a few examples of the way in which a new rational basis of the aesthetics of architecture was considered to be a major precondition for the desired renewal of building construction.

These debates about architectural theory were increasingly influenced by the division of labour between architects and engineers. This development began in the 19th century as a result of the need arising in iron construction to specialize professionally in the technical and scientific sectors. The distinction this created between architecture and engineering construction at that time was tantamount to the separation of art and science.

Design and Calculation

While architects continued to regard as their primary duty the artistic design of a building, engineers were compelled to devote their attention to the structural part of building in accordance with the changing methods of building construction introduced by the use of iron. Hence, the growing bulk of technical problems created by the new architectural problems had to be solved by theories of calculation based on science and had to be converted into practical terms of building construction. Soon after the invention of modern building statics, the dimensioning of structural components, in Navier's "Mechanics of Building Construction" published in France in 1826 and in Germany in 1851, this field developed into an independent branch of building. The pretension of statics to a status equal to that of architecture is documented, for instance, by a statement made by the engineer Schwedler around 1865: "Design is the result of science; it is the element of truth in a building structure".

On the one hand, the history of iron building construction is the history of new aesthetics in architecture. On the other hand, however, it is also the history of the most important period in statics.

Materials, Designs, Architectural Problems

These conditions, interdependences and discussions were not mere fleeting phenomena, but major aspects in the development of iron architecture. They are indicative of the physical and theoretical changes on which the results of this architecture are based which are so typical of the 19th century. On this background it is possible to add the dimension of time to these development lines by indicating more aspects of specific architectural phenomena. The main points of development and their emergence in the course of time can be determined most appropriately in the light of three criteria which are mutually interdependent:

(1) Materials and their different structural properties,
(2) structural design as the basis for implementation under the new conditions imposed by materials,
(3) architectural problems based on newly emerging functional needs; their solutions are a consequence of structural design.

Cast Iron

Until the middle of the century cast iron had been the dominating material. Because of its brittle structure it could be used for structural purposes only where high compression forces had to be transmitted. Accordingly, most bridges and buildings contained arches composed of rod-type ribs or a number of segments. A schematic diagram explains this dominance in the first half of the 19th century, which was later replaced by girder and arched truss structures of wrought iron.

The great importance of the Coalbrookdale bridge design lies in the recognition that it was possible to make a building all of cast iron. The positive outcome of this first attempt to substitute conventional methods of timber and stone construction is evidenced by the ensuing increased use of iron in bridge construction, with logical consequences arising for building construction and architecture as a whole.

Some comparable bridge structures are these:

Coalbrookdale Bridge	1775 - 79
Sunderland Bridge	1793 - 96
Laasan Bridge	1794 - 96
Kupfergrabenbrücke, Berlin	1797
Chepstow Bridge	approx. 1800
Pont des arts, Paris	1803
Aberdare Bridge	1811.

These bridge constructions initiated the use of the first iron roof trusses in building construction. Since they were not covered, but remained visible, they constituted a new design element with technical overtones, as is shown by the following examples of different building projects:

Granary, Paris	1811 - 12
Stanley Mill, Stonehouse	1813
Foundry Hall of Sayn	1824 - 30
Dianabad, Vienna	1841 - 43
Bibliothèque Ste. Geneviève, Paris	1844 - 50
Stock Exchange, Antwerp	1851
Market Hall, Lyons	1858 - 59

Wrought Iron

Only the introduction, in the thirties, of wrought iron which could be shaped in rolling processes allowed iron building construction to enter into its most important development phase. Because of its better structural properties, tensile and bending strengths, wrought iron was far superior to cast iron and gradually replaced it in span structures. Although already in the late 18th century roof structures were made of arched wrought iron flat bars, such as the roof of the Théâtre Français of Paris in 1786 with its considerable span of 24 m, the decisive breakthrough was not achieved until the production of rolled sectional sheets and, in particular, T-beams after 1830 and I-beams after 1845.

Now it became possible to erect structures with larger spans consuming less material. Solid-walled arched trusses of rolled sectional sheet metal were used in bridge building and building construction in the middle of the century, such as in

Ouse Bridge near Lendal	1860
Severn Bridge-Albert Edward	1862
Paddington Station, London	1848
Crystal Palace, Amsterdam	1857
New Market Hall, Derby	1865.

Truss Structures

Under the influence of the changes brought about by the new material and the new possibilities opened up by wrought iron, also the structural principles of truss designs received attention. This principle not only improved the range of application of iron building construction, but raised it to a higher level of quality. The increasing use of truss structures marks the most important period in the development of the typical independent characteristics of iron structures. Iron truss structures represent an advancement over traditional half timber structures, adding particularly good economics because of the minimum materials requirement involved.

As early as in the first half of the 19th century various truss systems had occasionally been tested in bridge building by Navier, Long and Howe on an empirical basis. The earliest example is the small bridge of St. Denis built by Bruyère in 1808. The clear superiority of truss structures over all other structural designs received theoretical backing only when Schwedler and Culmann published their theory of truss structures in 1851. This established a basis for increased use and advancement of this optimum system, both in terms of statics, economy and structural possibilities, especially in bridge building and building construction. Besides the suspension roofs also developed in the thirties, for instance by Wiegmann and Polonceau, it is mainly post and strut structures designed as girders and arched trusses which take their clearly dominating positions in the mid-19th century, thus becoming characteristics of iron architecture. Let me, first of all, present a few schematic diagrams to demonstrate the great variety of truss structures used in bridge construction whose repercussions on building construction soon emerged.

Here are some examples:

Bridge near St. Denis	1808
Mythe Bridge near Tewkesbury	1823 - 26
Great Bridge, St. Louis	1871
Maria Pia Bridge near Porto	1879
Bridge over the River Rhine near Coblence	1879.

Iron truss structures as designs determining form reached their peak in the sixties after the development of hinged girders and three-hinged arches. This allowed considerably greater distances to be spanned. In building construction they were preconditions for erecting large halls without supports and walls for a variety of uses.
That the development of iron construction (structures and systems) began in bridge building is due to the very purpose of these designs and not a result of chance. The first designs, and especially the great variety of elementary framed structures, clearly indicate that this very sector of building was the great experimental area in which to test technical possibilities throughout the 19th century. This is characterized also by the increase in spans: in 1779 distances spanned began at 30 m, in 1890 they ended at 521 m (Firth of Forth Bridge). By contrast, the spans attained in building construction seem to be small: in the early years, in 1786, they amounted to 24 m (Théâtre Français), the limit was reached at 112 m in 1893 (industrial building of the Chicago International Exhibition). However, the relation of spans is perhaps not the most suitable yardstick by which to measure the relations between bridge building and architecture. It would also be an oversimplification to say that the construction of iron bridges had a direct and absolute influence on the development of iron architecture. Bridge building served to test basic designs and, hence, pave the way for new possibilities of implementation in many other areas of architecture. Bridge building, above all, was the source of major findings in statics henceforth to be used on architectural problems. It is not the form and content of buildings which are compared here, but the functions of these designs relative to the architectural problems at hand.

Architectural Problems

If bridge building can be regarded as a complete, self-contained architectural problem for a specific use, building construction is the sum total of many different sub-problems with different conditions, uses and functions.
Although iron influenced design in almost all architectural areas, the new architectural problems arising after the middle of the century, especially in hall construction, constituted the most important and most cogent areas of its application. This is where design systems typical of the materials used more and more became the means of meeting the requirements raised by the new types of buildings, the market halls, railway stations, fabrication halls and exhibition halls. They are the best documentary evidence of the independence of iron architecture. It reaches its peak in the expensive exhibition buildings erected after 1851. The halls, most of which were temporary buildings, of the numerous industrial and universal exhibitions offered the best possibilities to test iron architecture and employ this experience in buildings for permanent use. The large areas of glass typical of iron architecture, expecially in the roof and wall areas, were most logically applied in exhibition halls, aside from greenhouses. The resolution of masses by rational, sparingly dimensioned structures supplemented by glass as an outer skin helped to overcome traditional space concepts in favour, for the first time, of an unobstructed transparency of space. The Crystal Palace built in 1851 marked the beginning and the prototype of this new, influential dimension of space.

Let me finally add a few more characteristic examples of this aspect of problems in iron architecture:

Crystal Palace, London	1851
Crystal Palace, New York	1853
Crystal Palace, Munich	1854
Central Market, Paris	after 1853
Industrial Palace, Paris	1855
St. Pancras Station, London	1863 - 65
Bibliothèque Nationale, Paris	1854 - 57
Retortenhaus, Berlin	1863
Machine Gallery, Paris	1878
Galerie des Machines, Paris	1889.

Iron architecture is the major innovation in 19th century building construction based on the materials, designs and architectural problems involved and characterized by the resolution of masses.
Its historic significance can be determined from the direct influence on 20th century construction up to the present. Analyses of its conditions and design varieties serve to judge the status of present architectural problems and assess historically what has been preserved of that architecture.