9TH CENTURY GREENHOUSES - A CONTRIBUTION TO GLASS-IRON ARCHITECTURE

Ruth-Maria Ullrich

On the Designs of Greenhouses

In his book published 1976, "A History of Building Types," Sir Nikolaus Pevsner classifies greenhouses under the category of "market halls, conservatories and exhibition buildings," in which the characteristic 19th century glass-iron structures had matured into comprehensive structural systems encompassing all load carrying and space enclosing components. Among those buildings, greenhouses flooded with light were only at the beginning of their development. Their transparent skeleton structures made them a novelty in the history of architecture whose functional and aesthetic possibilities have been taken up again only recently.
Alfred Gotthold Meyer's entry, in 1907, under the heading of "Iron Buildings, their History and Aesthetics," that "all architecture made of iron and glass .... stems from plant houses," is certainly true, above all, with respect to their importance as a thesaurus of proven structures and architectural solutions. The example of the first universal exhibition building of 1851 in London Hyde Park, whose iron frame filled with glass panes on all sides was called "The Great Metropolitan Conservatory" at its time, is a case in point (Great Exhibition Building, London, 1851).
Under the 245 entries for the competition for this building there were three outstanding drafts which encompassed the experience available in glass and iron structures for greenhouses: the prize-winning draft proposed by the French architect Hector Horeau (Projet d'Edifice pour l'Exposition Universelle de Londres, 1851), the builder of the Lyons Jardin d'Hiver of 1847; then there was the design by the engineer Richard Turner, which also was awarded a prize (Great Exhibition Competition of 1850); his company had also built the early greenhouses of the Dublin Botanic Gardens, of Regent's Park, the Royal Botanic Gardens Kew; finally, there were the plans drafted with a delay of ten days by Joseph Paxton, landscape architect and practising experimental designer of greenhouses. Since his design of a glazed iron skeletal frame was based on mass production of a small number of proven basic elements and, hence, could be executed at short notice, it was accepted for implementation in preference to the rather time consuming brick structures of the Royal Commissioners.

In Paxton's design of the roof structure of the exhibition building, which was 560 m long, the ridge-and-furrow system was to be used which he had developed into a patented invention in the Water Lily House of Chatsworth (Water Lily House, 1849-1850). Also subsequent requirements imposed by the Royal Commission, i.e., to include a high transept in order to preserve the old elms in the park, were easily met by Paxton by using the arched truss system of the Great Stove tested in Chatsworth (Great Stove, 1836-1840, model).
When, one year later, Hyde Park had to be returned to its original condition, another advantage of the new type of building construction became evident, namely the possibility of fast disassembly. In the reconstruction of Crystal Palace in Sydenham in 1852 (Sydenham Crystal Palace, interior), on almost twice the original scale and with a winter garden in the nave, most of the old structure was re-used.
This development of glass and iron structures into industrial products greatly helped a new branch of industry, the so-called hothouse builders, to offer, at fixed prices and on a catalogue basis, single structural elements (MacFarlane's Castings, Glasgow, 1870-1880),

greenhouses for all strata of the population (J.W.Thomson, Kew and Windsor, hothouse designer; John Weeks & Company, Chelsea, Horticultural Builders; Henry Ormson, Chelsea, Hothouse Builder, approximately 1860), and to offer also modular buildings for various uses (MacFarlane Castings, Application to Building Construction, 1870-1880).

The use of glass and iron, which spread like a fashion, was based on the manifold possibilities offered by this new way of construction compared with the stagnating architectural and structural development: faster and cheaper building by using a small number of types and by prefabrication of the structural elements; addition of ornaments at no great extra cost, because decorations were made of cast iron; large spans, yet extreme lightness of the structural members; light from all sides and from the top; all of which were properties precisely tailored to the new architectural problems of the period, i.e. exhibition buildings (Dublin Exhibition Building of 1853), market halls (Smithfield Market, London, 1866-1868), railway stations (Paddington Station, London, 1850) and arcades (Barton Arcade, Manchester, 1870).
In addition, the outward appearance of greenhouses also influenced such other new 19th century creations as libraries, museums and theatres. Having passed through solid, palace-type architecture the visitor is surprised by light, transparent iron structures in the interior reminiscent of the characteristic structures of greenhouses (Göggingen near Augsburg Theatre, 1885-1887; Oxford University Museum, 1860; Leipzig Concert Hall, 1882).
In a number of buildings designed as concert halls, complete identity is achieved with the greenhouse example (Buxton Pavilions, Derbyshire, 1870-1871; Bournemouth Pavilion, Hampshire, 1893; Albert Palace, Battersea Park, London, 1884-1885). That these buildings could be put to various uses is also proved by the building history of Kibble Palace, Glasgow. Originally, the building had been designed as a conservatory, but after its expansion in 1872 it served as art palace and concert hall and, as Glasgow Botanic Gardens, is now a popular exhibition hall of plants (Kibble Palace, Glasgow, 1872).

Although it is true to say that building with glass and iron originated from greenhouses, this certainly does not apply to the iron structures proper. Only in 1816, J.C. Loudon had developed sash bars of wrought iron, i.e., the load carrying glazing sections in greenhouses, and tested them in his experimental glazed buildings of Bayswater, London (curvilinear glass houses, Bayswater, 1817-1818). The large first rotunda based on this principle was erected at Bretton Hall in 1827 (Bretton Hall, Yorkshire, Conservatory of 1827). It had a diameter of 30 m and a height of 18 m.
As early as in 1806-1811, Bélanger and Brunet had erected a dome covered with copper plates over the Paris Halle au blé which, with its ribs and support rings of cast iron segments bolted together, already spanned 40 m (Rondelet, Traité théorique, Halle au blé). At an even earlier date the first wide-span structures were built, such as Coalbrookdale Bridge of 1773-1779 (detail of Coalbrookdale Bridge, Salop). In building construction, this was followed by the roof structure of the Théâtre Français by Victor Louis, 1786, made of wrought iron (Rondelet, Traité théorique, Le Théâtre Français), and by William Strutt's Mill of 1792-1793, the first multistorey mill building having an iron frame (details: Benyon, Marshall and Bage, Flax Mill, Ditherington, Shrewsbury, 1797 and King's Stanley Mill, Gloucestershire, 1812-1813). Only because of the alleged fire resistance the considerably higher costs of an iron structure were tolerated, an aspect which was of no importance in greenhouses. Only after iron had become cheaper as a result of its increased use, it was employed in greenhouse construction on a larger scale.

The Space Programme

Greenhouses exerted a far reaching influence not only because of their construction of glass and steel. The very programme behind these structures, which embodies the old dream of eternal spring, retained its magic attraction throughout the 19th century. Such names as "Jardin d'Hiver, Palais des Fleurs, Palais Végétal, Floral Temple, Winter Garden" are expressions of this enthusiasm. It was initiated by the strange beauty of innumerable exotic plants introduced into Europe which suffer no interruption in vegetation during the winter and, for this reason, require a climate composed of much light, heat and humidity throughout the year. This atmosphere of tropic heat and floral fragrance, a vegetation strange to the eye under a glass roof abandoning the fixed boundaries of space, created an incomparable contrast to the dying nature outside in the winter in northern latitudes.
Accordingly, greenhouses set up in urban environments soon fulfilled important fuctions as social meeting points, public winter gardens: promenading to the strains of music in gardens decorates with works of art, romantic garden scenes and fountains created a euphoric mood which promoted human contacts much more readily than did theatre performances, concerts, art exhibitions and banquets (Jardin d'Hiver, Paris, 1847; Jardin d'Hiver, Lyons, 1847; Le Palais d'Hiver, Jardin d'Acclimatation, Paris, 1891-1892).
One characteristic of the increasing number of types of greenhouses is their assignment to different building programmes: As a private winter garden the greenhouse was standard in buildings erected by the nobility and members of the upper class, in palaces (Syon Park Conservatory, 1827-1830), estates (Broughton Hall, West Riding, 1853-1854), mansions (Jardin d'Hiver de la Princess Mathilde, Paris, approx. 1869) and town houses (Tour en fer et verre, Paris, approx. 1870; Dach Conservatory, London).
Greenhouses in botanic gardens (Louvain, Serres du Jardin de l'Université, 1827), public parks (Liverpool, Sefton Park, Palm House, 1896), universal exhibitions (International Exhibition of 1862, Conservatory of the Royal Horticultural Society) and horticultural exhibitions (Regent's Park, London, Conservatory of the Royal Botanic Society, 1845-1846) catered to an interested public and, at the same time, served scientific research. They were maintained by universities, royal courts, municipalities, horticultural firms and the spreading horticultural societies of the 19th century.
A peak in this development are the public winter gardens appearing in almost all municipal building programmes and wherever social communication was desires: in the big cities, such as London and Paris (London, the Royal Aquarium and Summer and Winter Garden, Westminster, 1875-1876; London, Muswell Hill, Alexandra Palace, 1858, 1865-1869, 1873-1875; Paris, Bois de Boulogne, Le Palais d'Hiver, 1891-1892, floor plan); in the large seaside resorts mostly in connection with aquariums, skating rinks, billiard and reading rooms (Great Yarmouth, Winter Garden and Aquarium, 1875-1876), casinos (Pau, Le Palais d'Hiver, 1898), in hydros (Matlock Bank, Derbyshire, Smedley's Hydro, Winter Garden, approximately 1890), even in hospitals (Leeds, Winter Garden of the Infirmary, 1868). Winter gardens added to the educational facilities available, i.e., theatres (Eden-Théâtre, Paris, Jardin d'Hiver, 1882-1893), museums (The People's Palace and Winter Garden, Glasgow, 1898), zoological gardens (Anvers, Jardin d'Hiver de la Société Royale de Zoologie, 1897), and polytechnic schools (The People's Palace for East, London, 1886-1891). Even hotels (Charing Cross Hotel, London, approx. 1860) and bazaars (The Pantheon Bazaar Conservatory, London, 1834) gained in attraction.

The Building Structure

Orangeries: Most court-type orangeries in the 17th and 18th centuries were detached rectangular buildings with solid walls and with high single windows on the south side opening into an architectural garden (Margam Abbey, South Wales, Orangery, 1786-1790). As winter places for citrus plants these buildings were merely supposed to protect from frost. In summer the empty orangeries were used as garden halls for festivities and banquets. Other designs, such as a semi-permanent Seville orange houses, terraced orangeries and orangery palaces, had little influence on the development of glass building in the 19th century.

Greenhouses: With the introduction of exotic plants growing the whole year round, plant houses had to be found which, unlike orangeries, collected a maximum of light and solar heat in the cold and dark seasons. This resulted in the development of greenhouses with large glazed areas in the roofs and walls. These acted as heat sinks, admitting short-wave light and preventing reflected long-wave radiation from escaping. Since there was no exchange of air between the inside and the outside, except for variable ventilation sections, the interior heated up much more quickly than the air outside, thus producing the so-called greenhouse effect.
The first greenhouses in the 19th century built with solid walls, the architectural conservatories, are almost identical with orangeries. Only the flat, slightly inclined gable roofs are glazed as additional light sources and screened behind stone balustrades (Belton House, Lincolnshire, 1811-1819; Shrubland Park, Suffolk, 1830-1832). At Camellia House, Woburn Abbey, Bedfordshire,(approx.1816) the interior is spanned by decorated cast iron trusses. At Aroid House, Kew, Middlesex (after 1836) there are two additional supporting rows of stanchions.
In the next phase, iron structures became independent, for instance, at The Grange, Hampshire (1824-1825), standing as independent engineering structures behind brick fronts adapted to the architectural style of residental houses, in this case the Greek Revival style.
In the conservatories of Alton Towers, Staffordshire (1824) and Syon House, Middlesex (1827-1830) also the iron structures of the glazed domes are included in the composition of the building. When designing Syon Park Conservatory, Charles Fowler translated the ornaments of the supporting ring of cast iron colonnades into the thesaurus of Italian Renaissance forms. In matching the structure to the surrounding stone building he used hollow sections to create volume and perforated them, a logical and economic step to save material, i.e., iron (Syon House Conservatory, interior). Up to the end of the century other important buildings were erected in this style, such as the Palm House by Friedrich Ohmann (Vienna, Burggarten, 1901), with elements of stone and iron construction, decoration and building sculpture constituting an overall concept.
In contrast to the architectural conservatory style, the structural engineering architecture of greenhouses developed around 1815 from functional concepts based on the habitats of exotic plants. The earliest reports about this new technology were published in "Transactions of the Horticultural Society:" G.S. Mackenzie (1815)and T.A.Knight (1822) reported about their experiments in new floor plans and cross sections, bent glazed areas and the use of cast iron and wrought iron instead of timber. In 1817 and 1818, J.C.Loudon published his theoretical studies of the relation between the angle of insulation and the inclination of glass areas. Spherical glass areas following the position of the sun (G. Mackenzie, Quarter-sphere Hothouse,1815) and ridge-and-furrow roofs (Somerleyton Hall,Suffolk,Paxton's ridge-

and-furrow houses) were tested in some experimental buildings which ensured early and permanent heating when inclined east and west.

Loudon's development of the sash bar made of wrought iron, which had served as a load carrying section supporting glazings in numerous early greenhouses and had given those houses their characteristic features (Bicton Gardens, Devonshire, around 1841), was based on a comparison of timber and iron as structural materials. While filigree iron structures admitted up to 75 % more light than solid timber structures, the drawbacks of the susceptability to corrosion of iron and the danger of wood deterioration by rotting were roughly equal. However, iron soon lost its leading position as a result of its higher conductivity, which resulted in building damage due to expansion and made greenhouses cool more quickly at low outside temperatures.

Finally, mixed structures using timber for the external sections of glass skin and iron for the inner structures settled the dispute about the most suitable building material for greenhouses which had been going on until well beyond the middle of the century (Temperate House, Kew, begun 1861, truss structure).
The most simply designed and, at the same time, most suitable cross section, as far as solar radiation was concerned, was incorporated in the so-called lean-to houses in which inclined sash bars were supported against a solid north wall. In order to store the collected solar energy and prevent cooling of the greenhouse at night, an excellent solution was found already in the 18th century; a building with inclined glazing of the south side, which improved the angle of insulation. The structure had a heat accumulating rear wall emitting heat at night and, at the same time, keeping away cold northerly winds (Seligenstadt, former abbey, greenhouse built around 1760). Its external distinguishing mark is the large projection of the cavetto-shaped swan neck. It protected the glass panes from rain, hail and air flows likely to cool the house.
Charles Rohault de Fleury, an advocate of the lean-to theory, had expanded the cross section in the two-storey gallery wing of the Serres of 1833-1835 (Jardin de Plantes, Paris) by bending the glazing sections into a quarter circle. This added to the useful space and improved the stability of the sections. Because of their elegance, curved glass areas were used again and again, all the more so since the imbricate installation of the small glass panels made no difficulties even at the curves. The greenhouses of Bicton Gardens, Devonshire (Bicton Gardens, around 1841), of Belfast (Belfast Botanic Gardens, Palm House, 1839-1840) are examples of this very popular style.
In contrast to the lean-to houses, iron structures with glazing on all sides proved to be better for uniform plant growth, but they were more difficult to stabilize, because of the absence of brick walls. Rotunda halls, in which the sections support each other like the rods of a tent, were still in the early stages of development. One of the first major rotunda structures made of glass and iron was Loudon's Conservatory of Bretton Hall (Bretton Hall, Yorkshire, 1827). The building began to vibrate even when exposed to minor gusts of wind and was stabilized properly only after it had been glazed. The dome of the Antheum, Hove near Brighton (Antheum, Palmeira Square, 1832-1833) collapsed because of instability at the time of inauguration. If one compares this with the huge dome structure of the Jardin d'Hiver of Laeken (Domaine Royal, Laeken near Brussels, Les Serres, 1876-1894), with its structure moved to the outside, one fully realizes the stage of technical development meanwhile reached in the construction of greenhouses.

The Palm House built for the municipal Sefton Park (Palm House, Sefton Park, Liverpool, 1896) showed a different variant of central structure. To save money, the dome was erected on top of an octagonal floor area, which greatly simplified the substructure and obviated the need for a conical cut of the glass panes and bending of the glass. The window panes were installed as plain panels. The curvature of the roof was achieved by bending at the joints of the panes, certainly a less elegant solution.
All buildings shown here have in common the basilica-type cross section. It was found to be particularly suitable both for round and for oblong greenhouses (cross section of Palm House, Kew, 1844-1848). The different heights of the naves and aisles lend themselves especially well to accommodating various categories of plants; the tallest varieties can be observed and attended to from the gallery around the aisle. In the upper lofts there are the venting panes accessible from the gallery. As in church construction, the aisles take up the thrust of the central glass dome, reinforcing the extended tubular supports of the glass dome which, at the same time, discharge the rainwater.
The Great Stove built by Joseph Paxton (Great Stove, Chatsworth, Derbyshire, 1836-1840), the largest greenhouse of its period, which served as a prototype for innumerable follow-on structures, was also built on the cross section of a basilica. The rounded surfaces are due to the technique of fabricating the laminated wood trusses bent and bolted over templates. They were supported by tubular cast iron supports and spanned 21 m with building dimensions of 37 x 84 m and a height of 19 m.

The central pavilion of Kew Palm House built by Burton and Turner, which is still fully functional today, contains most of Paxton's ideas, but transferred to a rolled arch girder structure (Palm House, Kew, structural view) and expanded by two added wings. The tubular stringers with tie rods on the inside then newly developed by Turner held the whole structure together. At the same time, they supported the iron ribs of the outer skin carrying the glazing (Palm House, Kew, structural design). At the very end of the century this design, which had been frequently varied in the meantime, was used once more by the Viennese architect Segenschmid in the Palm House of Schönbrunn, but this time with double glazing, in view of the Viennese climate (Wien-Schönbrunn, Palm House of 1882). The structural members, some of which were moved to the outside, and the architecturally developed pavilions decorated with ornamental arches are slightly reminiscent of the greenhouses of Laeken built only a couple of years earlier.
Richard Burton's second group of greenhouses in Kew Gardens, the Temperate House built in four stages between 1861 and 1899 (Temperate House, Kew, external view), were to exceed the earlier Palm House in size, height and span. Although Burton retained the basilica-type cross section, the arched areas were abandoned. Improvements over the old Palm House were seen in the hip-type variation of a saddle roof which saved the expense of bending the glass panes, the wooden frames for the glass, which were to prevent cooling of the greenhouse, and the truss structure, which saved material. According to contemporary critics, the architectural qualities of the more elegant older Palm House were in far higher public regard.
The description of the two lines of development of architectural and structural engineering-type greenhouses will be concluded with a few ideas on the architectural concepts of the architects Charles Fowler and Decimus Burton/Richard Turner.
At first sight, Fowler's Syon House Conservatory (Syon House Great Conservatory, floor plan and elevation) does not reveal that its architecture, closely related to Palladio's work, is based on strict rules of dimensions, proportions and layout of a kind typical of an

engineer's "analytical mind" (Benevolo). Fowler assigned to the individual parts of a building different sizes, depending on their roles in the overall composition, by grading them in the floor plan and the elevation which, when comparing the sectional areas of the wings, outer pavilions, the main building with and without the dome, are seen to double in a 1:2:4:8 ratio.
The numbers and sizes of matching building structures and structural elements are governed by the principle of a balance of forces. Two external pavilions 15.24 m long add up to a length of 30.48 m of one main building. Six arcade windows in the annexes to the main building are opposed by six windows of the same size in the central projection of the outer pavilions. Two smaller arched fields extending up into the gables correspond to the large arched field of the centre pavilion etc. They also interchange between central projections and annexes so that the large and the small structural components have distinct features of their own, although the basic elements are repetitive.

Fowler's method of combining a small number of basic elements so as to create individual buildings is also evident from his market buildings. As "hidden reason" (Chr.Beutler) it signalizes the transition to engineering concepts and industrial production.
Within structural engineering architecture in the 19th century the "pure" glass-iron structures of greenhouses occupy a special position.

The glass skin only a few millimetres thick surrounding the building and separating the inner sphere from the outside establishes complete agreement between the form of the room and the form of the building (Palm House, Kew Gardens). Never before was the structural skeleton with all its components so fully revealed by the transparency of areas of glass. Like veins the heavy iron structures permeate the filigree of the webs carrying the glass. They subdivide the building in the rhythm of the large module, which is a function of design, and the small module, which is a function of material. In Kew Palm House (floor plan and elevation) the large module is 3.81 m, which corresponds to 15 times the small module, the dimension dependent on the width of fabrication of the glass.
A single radius of 2 x 3.81 m repeated over and over again determines the form of the building: in the central pavilion it is superimposed in quarter arches and semi-arches, in the side wings it is both a semi-circular cross section and an apsidal termination of the floor area. Here are some other multiples of the large module: length and width of the central buildings, 11 and 8 x 3.81 m, respectively, length and width of the wings, 9 and 4 x 3.81 m, respectively, overall length of Palm House, 29 x 3.81 m.
Multiples of a single module, the preferred dimension for the installation of the glass panes, determine all parts of the floor plan. They limit the infinite number of possible dimensions to the series pertaining to the module (1 x m, 2 x m, 3 x m ....), with the resultant advantages of coordination of dimensions and limitation to a small number of different components. The series of modules enforces thinking in terms of combinations and additions which, in building construction, is tantamount to adding one or more widths of glass; in this way, it meets the most important prerequisites of industrial production.

Probably like no other architectural problem, greenhouses with their structures of glass and iron have made visible these correlations between design, production and architecture and thus furthered development.