(B29) *To Engineer is Human*

The role of failure in successful design

Henry Petroski (Prof of Civil Engineering at Duke University)

Vintage Books(First Ed 1992) ISBN: 0-679-73416-3

"More than a series of fascinating case studies, *To Engineer is Human* is a work that looks at our deepest notions of progress and perfection, tracing the fine connection between the quantifiable realm of science and the chaotic realities of everyday life."

Chapter 12

INTERLUDE:

THE SUCCESS STORY

OF THE CRYSTAL PALACE

Innovation in engineering, as in everything, involves risk and is an invitation for something to go wrong. But it does not follow that innovation must lead to failure. And because there have always been dramatic engineering projects that have proved the nay-sayers wrong about this or that daring new design, today's engineers are not acting irresponsibly when they want to use an untried material or structural design to build a bridge longer or a skyscraper taller than any one extant. They are merely following in the tradition of the great nineteenth-century builders of daring structures that outlived their opponents. And one of the most ambitious and innovative structures of the Victorian era was not a bridge or a tower but the vast building constructed to house the Great Exhibition in London in 1851. The story of the Crystal Palace is a fascinating one that bears repeating, for it shows that no matter how innovative an engineering structure may be and no matter how many opponents it may have, the proof is in the putting up and in the testing of it.

Joseph Paxton was born in 1801, the son of a farmer in Bedfordshire. As a young man he became a gardener, employed by the Duke of Devonshire, and by 1826 Paxton was superintendent of the gardens at Chatsworth, the Duke's Derbyshire estate. Paxton also displayed a special talent for structural design, and by 1840 he had built a greenhouse enclosing an acre of ground. This Great Conservatory at Chatsworth was considered a contemporary marvel, and Paxton was firmly established as an engineer in practice and in spirit if not in name, for his Great Conservatory was to serve as a model for the Great Palm House in Kew Gardens, the Royal Botanic Gardens near London, and he was to go on to create many other structures of his own.

It was into one of the heated tanks at Chatsworth that Paxton first placed a cutting of a giant water lily obtained from Kew Gardens. The seeds had been brought back from tropical British Guiana in 1837, but the plant did not thrive at Kew. Under Paxton's care, however, the plant developed the huge leaves and beautiful flowers characteristic of such lilies. He named the flower Victoria regia (now properly called Victoria amazonica, since the plant had been so named before Paxton's involvement with it) and presented a bud to the queen.

As the lily continued to grow, Paxton designed a building especially for the plant, patterning the structure of the lily house after the structure of the lily leaves themselves. He once demonstrated the strength of the natural ribbed structure by placing his young daughter on one of the floating leaves, which measured five feet in diameter. It easily supported her weight without sinking, and it later became a Victorian fad to be photographed on one of the giant water lily pads with the characteristic lip around the edge that makes them look like baking dishes for enormous quiches. Paxton observed that the large leaf owed its strength and stiffness to the geometric pattern of ribs and cross-ribs on its underside, and he took that as a model. The result was a lily house at Chatsworth measuring 47 feet by 60 feet (about 3,000 square feet), with a glass roof resting on wooden beams set across iron girders supported by iron columns. This light and airy building eventually provided the idea for the Crystal Palace, which would measure over 400 feet by 1,800 feet (almost 750,000 square feet) and shelter the 100,000 exhibits of the Great Exhibition of the Works of Industry of All Nations, as the first world's fair was officially designated.

Just as the world of commerce was ready at mid-century for the first international exhibition of the works of industry, so was the world of technology ready to build the Crystal Palace. The British government had repealed the century-old glass excise tax in 1845, removing any fiscal impediment to using almost 300,000 panes of glass in the building. The United Kingdom was producing about five million tons of cast iron and wrought iron annually, more than 1,000 times the amount required for the exhibition building, which at 4,500 tons was still an enormous quantity. And although the scale of the Crystal Palace was indeed grand, the engineering experience gained in developing Britain's railroad system, which included hundreds of iron bridges, provided the knowledge about the strength of materials necessary to execute the bold design. (Even though at the time bridges were failing at an alarming enough rate for a Royal Commission to have been appointed to look into the use of iron as an engineering material, there appears to have been sufficient confidence in using iron in a gigantic static structure that would not be subjected to the pounding of railroad wheels and the higher and higher loads of evolving rolling stock.) Nevertheless, the Great Exhibition came to be housed in the Crystal Palace only at the eleventh hour.

An exhibition of international scope, featuring the application of art to industry, was first suggested by Henry Cole, a public servant and art patron whose indefatigable energies and interests made him a driving force behind Victorian architecture and industrial design. Unlike his contemporary John Ruskin, who did not look favorably upon the common products of the Industrial Revolution, Cole's vision was to combine the fine arts and engineering. Thus Cole's idea of a Great Exhibition was a natural extension of the views he expressed before the Society of Arts in 1847:

> Of high art in this country there is abundance, of mechanical industry and invention an unparalleled profusion. The thing still remaining to be done is to effect the combination of the two, to wed high art with mechanical skill.

Prince Albert immediately embraced the idea of a Great Exhibition and agreed that Hyde Park would be the best site. Early in 1850 the prince became chairman of a Royal Commission to promote the project, and soon a building committee was appointed. This committee envisioned a temporary structure covering sixteen acres and announced an open competition to select the design. However, the committee found none of the 245 entries acceptable and proceeded to cannibalize them for what it considered the best features to produce its own design. A rendering of the committee's "camel" of a building was published in the Illustrated London News in June and was panned immediately by the Times.

Critics described the proposed structure as a "vast pile of masonry" that they feared would never be removed and would become a "permanent mutilation of Hyde Park." Indeed, the committee's mal-proportioned behemoth would have required the laying of fifteen million bricks and the construction of a dome two hundred feet in diameter, considerably larger than that of St. Paul's Cathedral. The mortar would not have been expected to be dry in time for the opening of the exhibition, then less than a year away.

Meanwhile, the exhibition itself and its location were debated in Parliament. Xenophobic opponents feared the effects of foreign competition on the sale of British goods at home and abroad, while others cited less commercial concerns, including overcrowding, rowdiness, and disease. One particularly vocal opponent was Colonel Charles Sibthorp, a protectionist who also had opposed the Public Libraries Act of 1850 because, among other reasons, he "had not liked reading at all." His most celebrated objection to the exhibition site involved a small clump of elm trees marked to be cut down. Reason prevailed in Parliament, however, and the protests of Colonel Sibthorp and his sympathizers were for the moment suppressed, though the environmental impact issue never did entirely disappear.

Paxton did not enter the original competition because, according to his own account, he took it for granted that the building committee would select a suitable design without his help. But he was disappointed in the proffered plans, which were being discussed more or less publicly, and wondered if it was too late to put forth an idea. Although he approached exhibition officials only a fortnight before the building committee's final choice was formally to be announced, Paxton persuaded them to allow another entry. The commitment was obtained on June 11, 1850, and on that day Paxton left London for the Menai Straits in northwestern Wales to see the third iron tube girder of the Britannia Bridge set in place. He was distracted during a board meeting that he attended while away from London by the thought of a building for the Great Exhibition, and it was at that meeting that he made on a blotter his famous sketches of what was to become the Crystal Palace. During the following week, with the help of Peter Barlow, a railroad engineer, the columns and girders were sized and the design completed. When Paxton showed them to Robert Stephenson, whom he met on the way back to London, the bridge engineer was enthusiastic.

At first the building committee pooh-poohed the new proposal, but it gradually gained support. And after a rendering of the design was prematurely published in the Illustrated London News of July 6, the committee soon abandoned its own design and unanimously embraced Paxton's "ferro-vitreous' '-iron and glass-concept. Among the advantages were the building's extreme simplicity, the speed with which it could be assembled, its absence of internal walls, and the fact that the materials could be reused. The economic advantages of lower construction costs and high salvage value seemed to clinch the design's choice. (Indeed, the Great Exhibition - unlike virtually all subsequent world's fairs and international exhibitions - made a handsome profit, certainly in part because of the economy and smoothness of construction of the Crystal Palace.)

However, the fate of the elms in Hyde Park still cast a threatening shadow, and Paxton added to his original design a central transept that would enclose the ninety-foot-tall trees. Construction began even without a firm agreement with the contractor, Messrs. Fox, Henderson, and Co., and a contract was not signed until more than a month later. The price agreed upon was £79,800 to erect and later dismantle the building, with the contractor owning the materials. The final cost of the Crystal Palace, including modifications such as the transept and other additions, was £200,000. Still, this works out to about £25 per hundred square feet of covered ground, a bargain even in the mid-nineteenth century.

Workers fenced in the construction site in August, with the same wooden planks that would be used later for the floors and galleries. Completion of the project was scheduled for January 1851, which allowed just over twenty weeks to enclose with massive amounts of iron and glass an exhibition floor whose requirements had grown to nineteen acres. The ground was leveled, foundations and iron drainpipes were laid, and the first column was erected on September 26. Construction proceeded quickly, by the light of bonfires at night, and on one Saturday Paxton reported seeing two columns and three girders put up by two men in only sixteen minutes. What was to be the first large and truly significant building constructed of metal and glass would be erected in only seventeen weeks!

The mathematical regularity of the proportions of the Crystal Palace helped simplify construction. Paxton determined the basic unit of length for the building not by some. aesthetically based "golden section," but by the requirements of the exhibition space and a fundamental technological constraint: in 1850, sheets of glass longer than about four feet were not only very costly to manufacture but also were very unwieldy to install. Thus, panes forty-nine inches long were mounted on the roof in a gently sloping "ridge-and-valley" pattern that was not only pleasing to the eye but also provided good drainage. To simplify construction, workers installed the glass as they moved along in trolleys that rolled on wheels set in the grooves of "Paxton gutters." These were installed in the valleys to carry rain and condensation to the hollow iron columns that doubled as drainpipes. The gutters were placed at eight-foot intervals, a length dictated by the combined span of two sheets of properly inclined glass. Roughly three times this dimension, or about twenty-four feet, was a convenient length for the cast-iron girders, and their supporting iron columns were placed at twenty-four-foot intervals. Thus, twenty-four feet became the basic unit of scale in the plan for the entire Crystal Palace.

Wide interior "avenues" that stretched the length of the building were spanned by wrought-iron trusses forty-eight-feet long. And the spectacular Central Avenue was spanned by trusses three-units, or seventy-two-feet long. The arched central transept was also seventy-two-feet wide. This bare and simple geometric regularity no doubt contributed to the structure's graceful appearance, just as the repetition of basic units of glass or marble facing work so effectively in modern architecture. The seventy-seven twenty-four-foot units along the south facade of the Crystal Palace were also numerous enough to distract all but the most observant and counting eye from the fact that the central transept was not central at all, but was off center by one unit to accommodate Colonel Sibthorp's elms.

The uncommon depth of the girders and trusses - roughly three feet - added to the grace of the Crystal Palace when a visitor looked down one of the long avenues. And in Paxton's usual custom, this aesthetic feature served a structural purpose as well: attaching the trusses and girders to the supporting iron columns not only at the top but also at their relatively deep bottom provided a great stiffness against wind and other lateral forces. The structural advantage of the deep girders can be appreciated by comparing the flimsiness of a card table having thin folding legs with the rigidity of an old kitchen table whose top is supported on deep wooden side beams attached solidly along their entire depth to firm legs.

The construction techniques, like the building design, also speeded up progress. For example, workers used special machines developed by Paxton to cut several wooden sash bars simultaneously out of a single plank, grooving and beveling their edges at the same time. Workers used circular saws to notch and bevel the ends of the sash bars, which would hold the panes of glass in place, and pierced nail holes with revolving augers driven by a steam engine. Altogether 600,000 cubic feet of timber were used in the Crystal Palace, including twenty-four miles of Paxton gutters.

Increasing the scale of something from a relatively modest lily house to a grand exhibition building can be tricky business, for in engineering as in nature bigger is not necessarily a better or even a good idea. Thus, besides the environmentalists who feared the ravishment of Hyde Park, the health officials who worried about sanitation and disease, and others who worried about fire, comfort, and crime among the millions of visitors expected at the Great Exhibition, there were those who simply did not think the structure itself was safe. When the King of Prussia inquired about the safety of visiting London during the Great Exhibition, Prince Albert wrote an ironic letter of caution. He recited all the dire prophecy and confessed that "Mathematicians have calculated that the Crystal Palace will blow down in the first strong gale; Engineers that the galleries would crash in and destroy the visitors."

While questions about the strength and stability of the Crystal Palace arose from the beginning, its design and construction made no compromises with safety. Wherever the girders and trusses did not provide sufficient lateral stiffness, slender diagonal rods were installed in cross patterns. These rods were used extensively in the arched central transept and their oblique pattern broke up what might even have been the monotony of the great space. Workers tested all cast-iron girders as they arrived at the construction site using a hydraulic press made for the purpose and achieved a degree of quality control rarely matched even today. They also tested the double- and triple-length wrought-iron trusses, but needed to test only one of each type since the wrought iron by its nature could be counted on to be of uniform quality as surely as the cast iron could not.

Criticism continued throughout construction, however, and nay-sayers warned that wind and hail would bring the glass box down, or that heat and humidity would make it unbearable in the London summer. Neither happened, though one parody in Punch, which was generally supportive of the great building that it christened the Crystal Palace, was a biting piece narrated by a cucumber who knew what it was like in a hot glass house on a steaming July day. But the Crystal Palace withstood the elements and proved to be as cool (thanks to canvas suspended over the roof and adjustable louvers in the walls) and dry (thanks to the Paxton gutters) as one could wish. But, said the predictors of doom, if the forces of nature would not be the undoing of the Crystal Palace, the masses of visitors would.

Extensive galleries were planned to provide an additional 200,000 square feet of promenade and exhibit space, but the elevated walkways were attacked as unsafe months before the opening of the Great Exhibition. After all, during this time iron railway bridges were failing at a rate of almost one in four, and suspension bridges were collapsing under marching soldiers. The safety of the Crystal Palace galleries had yet to be demonstrated. As a test, a twenty-four-foot-square section of gallery was constructed just off the floor on four cast-iron girders. Inclined gangways of wooden planks served as approaches to the test floor. Queen Victoria, on one of her inspection tours, witnessed with her entourage the following proof test, as reported in the Illustrated London News of March 1, 1851:

> The first experiment was that of placing a dead load of about 42,000 lb., consisting of 300 of the workmen of the contractors, on the floor and the adjoining approaches.
>
> The second test was that of crowding the men together in the smallest possible space; but in neither case was there any appreciable effect produced in the shape of deflection. So much for dead weight.
>
> The third experiment - which was that of a moving load of 42,000 lb. in different conditions - consisted in the same party of workmen walking first in regular step, then in irregular step, and afterwards running over the floor, the result of which was equally satisfactory.
>
> The fourth experiment - and that which may be considered the most severe test which could possibly be applied, considering the use to be made of the gallery floors when the Exhibition is opened to the public - was that of packing closely the same load of men, and causing them to jump up and down together for some time: the greatest amount of deflection was found to be not more than a quarter of an inch at any interval.
>
> The third experiment was then repeated, substituting, however, the Sappers and Miners engaged at the works, for the workmen of Messrs. Fox, Henderson, and Co.; and this last trial, which was quite as satisfactory as the others to all present, is represented in our illustration.

The specimen gallery withstood it all, and the Illustrated News went on to hope that the fears about the safety of the building had

> "by this time, been entirely rejected from the minds of those who have gone so far as to predict that the 1st of May would but prove fatal to the thousands who will enter the great Industrial Palace on that occasion."

The successful testing of the galleries served also as the basis for a Tenniel cartoon in Punch, which declared itself a proud "Sponsor of the Crystal Palace." In the cartoon the specimen section of the gallery is shown supporting a great ball labeled "THE WORLD" and Punch himself is beaming atop it. The gallery floor shows not the slightest strain and the crowd witnessing the event is all smiles, with their hands raised in triumph and their hats off to the Crystal Palace.

The Crystal Palace was unique not only in its structural details but also in its maintenance and decoration. The floor, for example, was laid with a space between the boards so that dirt and debris could fall or be swept into the cracks, preserving a neat and dustless promenade. Floor-sweeping machines were originally to be used to push the dust into the half-inch spaces between the boards, but they proved unnecessary as women's dresses accomplished the same end. Small boys were employed to crawl beneath the floor boards and collect bits of paper that might otherwise accumulate and present a fire hazard.

All the decorative and ornamental details for the building were under the direction of Owen Jones, known as "Alhambra" Jones because of his great knowledge of Moorish architecture. In painting the structural elements, Jones applied his "science of color." His contemporaries did not universally applaud the result, but it is difficult to judge today because original hand-colored prints have long since faded. However, the colors have often been described in words.

Pale blue was the predominant color of the interior vertical metalwork, and this is believed to have enhanced the feeling of open space. The underside of every girder was painted strong red, a color repeated in screens against which many of the exhibits were to stand. Yellow was used on molded details and highlighted the fluted portions of the otherwise blue columns. All in all it must have been a striking palette. A further touch of color was added on the exterior by displaying flags of all nations on a thousand poles around the periphery of the. roof. (Sir Charles Barry, one of the organizers of the Great Exhibition, suggested this.) The flags had the remarkably pleasant effect of breaking up the monotonous straight line of the long roof in a most appropriate way.

Another example of Jones' attention to detail was an electric clock with a face twenty-four feet in diameter located above the south entrance of the central transept. The clock might have dominated and disfigured the transept had Jones not abandoned the traditional circular arrangement of the hours for a face that exploited the design of the transept itself. The numerals were arranged in a semicircular pattern on the transepts radiating structural components. Instead of a single hour hand that swept in a circle every twelve hours, the clock had an hour hand (really two hour hands) that looked like a propeller. It revolved only once every twenty-four hours, with one blade of the propeller indicating the hour at any given time. The minute hand was similarly designed.

If anything did not go off like clockwork in the Crystal Palace, it is hardly remembered. Just as we seem to remember nothing but the failure of an ill-fated design, forgetting what might have been its successful innovations, so we seem to remember nothing but good of those designs that succeed. "He builded wiser than he knew," wrote journalist Horace Greeley of Joseph Paxton, and the Crystal Palace seemed to succeed even beyond everyone's hope and expectation. The building itself stole the show from the exhibition's myriad displays of manufactured goods.

On May 1, 1851, Queen Victoria opened the Great Exhibition with much pomp and circumstance before an assembly that included numerous foreign officials and functionaries. More than six million people were to visit the exhibition during the 141 days it was open. (It was closed on Sundays.) The busiest day saw more than 100,000 visitors, with 90,000 people in the building at a single time. The galleries apparently never trembled, and there were no panics about the safety of the structure. The Queen herself returned to the Crystal Palace about fifty times before the Great Exhibition closed on October 15, 1851, and she seemed never to tire of spending hours methodically touring the exhibits. A retrospective entry from the Queen's journal for the closing day reads; "To think that this great and bright time is past, like a dream, after all its successes and triumphs."

Although the Crystal Palace was supposed to have been dismantled after the exhibition so that Hyde Park could be restored to its unimproved state, officials seriously considered leaving the scaled-up lily house where it was. Some wanted to turn the structure into a "winter garden" where people could ride and walk among flowers during the dreary days of the long London winters. The costs of adapting the building for permanent use in Hyde Park, as opposed to dismantling it and erecting it elsewhere, were compared in great detail. But Colonel Sibthorp, perhaps remembering the elms outside the transept that were cut down, opposed permanent installation. Various proposals for relocating the building were forthcoming.

Among the daring proposals for reusing the columns and girders was Prospect Tower, conceived to be a thousand feet tall. This tower would certainly have been an economical use of ground, as its designer pointed out, The tower would have sported a clock forty-five feet in diameter with numerals ten feet high, and proponents were sure its glass exterior would withstand the great forces of the wind. This vision of the modern skyscraper was aesthetically if not structurally a century ahead of its time and would compare favorably with the designs of today. However, it would certainly have taxed the elevator technology of the early 1850s, and it would surely have been a bolder leap in structural engineering than even the Crystal Palace and not likely to have succeeded as well.

Yet, although the true skyscraper did not really come into its own until the twentieth century, the Crystal Palace prefigured it in many important ways. The light, modular construction ingeniously stiffened against the wind is the essence of modern tall buildings. And the innovative means by which the walls of the Crystal Palace hung like curtains from discrete fastenings, rather than functioning as integral load-bearing parts of the structure, is the principle behind the so-called curtain wall of many modern facades.

The Crystal Palace inspired much contemporary architecture, as the idea of international exhibitions spread quickly throughout the world. In 1853 New York hosted a world's fair in a cruciform iron-and-glass "palace" topped by a dome 168 feet high. Here Elisha Otis demonstrated a new safety device for elevators. He ascended in an elevator cage to dangerous heights above the floor and, before a gasping audience, cut the supporting rope. The elevator started to fall but was stopped by Otis' simple gravity-activated locking device that gripped the guide ropes. This was a milestone in mechanical engineering that, like the civil-engineering milestone of the Crystal Palace itself, was essential to the development of the true skyscraper.

Although the Crystal Palace was doomed in Hyde Park, Paxton had other plans for the building that had earned him knighthood. Dismantling began in the summer of 1852, and the columns and girders, gutters and glass, were transported to two hundred wooded acres atop Sydenham Hill, south of London. Paxton raised over half a million pounds to purchase the Sydenham site and the building's construction materials.

The Sydenham Crystal Palace was to be more than a re-creation of the original structure, however. The roof was vaulted along its entire length, and the central transept was greatly enlarged and doubled in width so as not to be overwhelmed by the new roof. The enlarged transept, in turn, demanded the addition of two stories and two end-transepts for balance. The final cost of the project, which included extensive gardens and fountains, was £1.3 million.

Part of the extra expense was for two tall water towers built to supply the elaborate fountains that were intended to rival those at Versailles. Not only did the towers store water, but also the South Tower housed the Crystal Palace Engineering School attended by, among others at the turn of the century, a young Geoffrey de Havilland. Years later Sir Geoffrey, the airplane manufacturer, recalled fondly in his autobiography that the building at Sydenham provided myriad diversions not only for engineering students but also for all Londoners.

Although fire destroyed the north transept in 1866, the remaining asymmetrical memorial to Joseph Paxton and the original Crystal Palace withstood wind and hail, if not waning interest, for many more years until another fire destroyed the entire structure in 1936. The two water towers remained standing until they were demolished in 1940, presumably because of concern that they might serve as beacons for enemy bombers looking for London. Today a television transmission tower stands on the site, and in its shadow is a bust of Sir Joseph Paxton atop a cracking stone column. Throughout nearby London, and throughout the world, architectural descendants of the Crystal Palace abound. But no matter how tall, they do not seem to approach the greatness of their progenitor.

While the Crystal Palace holds a secure though not unassailable place in the history of both engineering and architecture, whether it represented a triumph for either discipline was hotly debated in 1850. Although Paxton had been designing and overseeing the construction of parks, gardens, greenhouses, and conventional buildings for over two decades, his lack of professional training in either discipline caused his plans to receive a cool reception in some quarters. People, like the buildings they make, can have their failings. Distinguished members of the Institution of Civil Engineers were among the leading prophesiers of the collapse of the original Crystal Palace, and Paxton was never to receive the Royal Gold Medal in Architecture.

Victorian architects generally found the Crystal Palace lacking in a strong sense of form or organic integrity. They argued that Paxton's use of repeated modules was arbitrary and lacked artistic motivation or restraint. Indeed, there may be some validity to the criticism, for Paxton's first design was based on twenty-foot modules. He increased the size to twenty-four feet only when he learned that this was the minimum width for an exhibitor's stall. And the overall length of the building was coincidentally and whimsically 1,851 feet - the year of the exhibition - as Charles Dickens observed in his popular weekly, Household Words. But regardless of what professionals thought at the time, Paxton's Crystal Palace captured the hearts of London and the world in the mid-nineteenth century as few buildings or structures seem to have since.

Because Paxton was not steeped in the traditions of either engineering or architecture, he approached design problems without any academically ingrained propensity for a particular structural or aesthetic style. He solved the problems of housing a giant water lily and a great exhibition alike with buildings that departed both from conventional methods of construction. and architectural traditions. In short, Paxton, in his professional naïveté, struck out in brilliant new directions that produced models for the architects and engineers of the next century. The Crystal Palace was the first large and truly significant building to be made of metal and glass, the first major building to use outer wails that provided no structural strength, and the first building constructed using prefabricated, standardized units that were shipped to the construction site for rapid assembly. These practices are now commonplace in many large construction projects. Among the architectural breakthroughs of the Crystal Palace was the building's use of colossal space. The repetition of structural units-enhanced by interior decorator Owen Jones' color scheme of "yellow rounds, blue hollows, and red flats" - was a clear forerunner of much of modern architecture. The building also stands, or stood, as a success story in construction management. Although built in what may seem to have been a simpler age, the Crystal Palace was not without many of the same complications that can delay modern construction projects and cause them to fall years behind schedule. The project involved major planning, financial, management, and labor components. The amount of materials that had to be ordered, manufactured, delivered, processed, and erected was enormous even by today's standards. Social and political obstacles existed as well, for although an environmental impact statement was not required in 1850, Paxton still had to accommodate many objections, including those that today would be raised by environmentalists.

As the roles of architects and engineers moved further and further apart in the latter half of the century, the Crystal Palace served as a symbol of what could be but would not be again until the mid-twentieth century. Of course, conservatories and greenhouses continued to be built in the Paxton tradition. But for buildings designed to house solid institutions cultivating and preserving money, art, knowledge, and other relatively immortal commodities, heavy brick, stone, and cast-iron facades were the preferred style.

Perhaps the centennial of the Crystal Palace contributed to its architectural reincarnation. In 1951 seemingly countless exhibits were staged and books published on the Crystal Palace, and Joseph Paxton and his building began to be favorably reappraised. In the 1950s Lever House and the Seagram Building, both characterized by the non-structural "curtain wall," rose in New York City to epitomize the concept of the tall glass box that has since become ubiquitous. Indeed, Mies van der Rohe, who like Paxton had no formal architectural training, had actually anticipated in 1921 the multitude of successors to his Seagram Building with his then unrealized "Glass Skyscraper," whose facade was reflected in its own curved forms. And his apartment buildings in Chicago, with their strong exterior structural details carried to an extreme and using superfluous steel beams and columns for purely decorative effects, helped to reawaken the sense of the technological roots of architecture implicit in the Crystal Palace. The ultimate example of this concept may be the exposed structural and mechanical elements of the glass-walled Centre d'Art et de Culture Georges Pompidou in the Beaubourg section of Paris.

The influence of the Crystal Palace is especially strong today, as architects include large atriums and open public spaces in their designs of corporate headquarters and other urban buildings. The IBM Building in New York City has a four-story greenhouse, complete with bamboo trees green in winter beneath its saw-toothed roof, which cannot help but evoke Paxton's patented ridge-and-valley design. And the legacy of the Crystal Palace lives on today in more than an atrium in at least two major construction projects in this country. The new Infomart in Dallas is the world's first large-scale center for marketing computer products, and its appearance is as faithful to the original Crystal Palace as architect Martin Growald could make it. He even tried to match the Victorian color scheme of the building that housed the Great Exhibition, but unfaded prints and intact artifacts of the nineteenth-century structure are hard to come by.

Growald's Crystal Palace sits on the Stemmons Freeway among the more boxy and opaque buildings in the wholesale market complex known as the Dallas Market Center, built by the Trammel Crow

Company. The original concept for a computer market building called for a conventional structure with a rectangular shape, a granite and glass curtain wall, and a rooftop glass vault. When Growald was asked to design the building, he suggested to Trammel Crow that the computer market building be diametrically opposed to the other ones in the complex. The architect sees his design for the Infomart as ideal to serve as an exhibition and marketplace for computers, which he sees as the instruments for a continuation of the Industrial Revolution. However, the construction of a modern Crystal Palace proved to be a lot more expensive than one of today's more familiar market buildings, and the project was delayed while comparative economics were argued and wrestled with. The $85 million first phase, consisting of six stories of a projected fifteen, was finally approved and ground broken in May 1983. The building was ready for occupancy in January 1985. While this is a longer time than it took to complete Paxton's Crystal Palace, which did not need so many electrical outlets for computers, the Infomart was a relatively trouble-free construction project by modern standards.

The Crystal Palace of 1851 has also inspired the New York Convention Center, but its construction has been as beset by as many problems and delays as Paxton's and Growald's buildings escaped, though the re-erected building at Sydenham, whose design went beyond the technology of the original Crystal Palace, may be said to have prefigured what has happened with the New York project. Groundbreaking for the convention center took place in 1980 and construction was to proceed on a "fast track" for a 1983 opening. The sixteen-acre structure is of the same scale as the 1851 building that was erected in Hyde Park, but its design is strictly twentieth-century. Instead of girders bolted to columns, the New York Crystal Palace will have the world's largest space frame. Two expansion joints will be provided in the roof of the six-block long structure, which engineers believe will behave more like a bridge than a building, and the lessons learned from wind blowing across bridges were used to design features to counteract the uplifting forces. The space frame will be put together in Tinker-toy fashion from steel rods that fit at various angles into steel hubs full of holes.

The project was priced at $375 million when the design was revealed in late 1979, but in early 1983 the news broke that defects were discovered in many of the hub castings that were to be located at the eighteen thousand nodes of the space frame. X-ray tests of completed nodes turned up numerous cases of voids and hairline cracks in the metal that would make the components unable to carry as much load as they were expected to in the original design. Early reports projected that this unexpected trouble would add $5 million to the cost of the building, and one plan to keep the construction schedule from slipping too much called for using larger, defective hubs to substitute for some of the smaller Ones. In this way the twelve thousand parts that had already been cast, some sixty percent of which were weaker than specified, would not have to be discarded completely. This remedy was eventually rejected, however, and a totally new order was placed to have all hubs recast-at a cost of over a million dollars and a delay of more than a year. In the meantime, the tall, massive, welded-steel columns were the dominant features on a quiet construction site that looked like an abandoned garden whose pollarded trees were planted too far apart, in an arid field.

As soon as a completion date had been set for the Convention Center, space beneath what would be Manhattan's gigantic skylight began to be committed. Before construction problems became front-page news, more than fifty conventions were booked in the blocks-long dream-structure for the last half of. 1984 alone. The consequences of a delay have been disastrous not only for the lost revenue and lawsuits from conventions without a home, but also for the lost new bookings. After all, who is to say for sure when the troubled convention center will finally open? The governor of New York ordered a report on the delayed project, and when it came to him almost three months late it put the completion date in the summer of 1986. The projected cost was increased to $500 million, and that did not include the hundreds of millions of dollars of convention business lost to New York City for the years 1984 and 1985 that the center was to be opened and operating.

Fast-tracking was blamed for many of the delays experienced in the construction of the New York Convention Center. In this method of construction, where certain components are put in place before the whole design is complete; options can be limited rather than opened up, according to opponents of the method, and fast-tracking makes it impossible to know the final cost of a structure at the outset. Proponents counter with the claim that, by overlapping the design and construction steps of building, the system provides some protection against inflation, and can get a project finished sooner than if every design detail is completed before any construction begins. The fast-track method has been given good marks in Washington, D.C., where it was used in the construction of a convention center, and in San Francisco, where it was used in building the Moscone Center. The problems experienced in New York may not have been due to fast-tracking per se but to problems unique to the management of a large public construction project and to the lack of quality control as demonstrated in the problem of the cracked and defective hubs.

The difficulty of producing reliable structural components by casting was known to the builders of the original Crystal Palace, and that is why they had every cast girder tested before they accepted it for delivery at the construction site. They also knew that wrought iron is more dependable, and thus they only tested a few of the girders of that kind, taking the test results to be representative. The cast hubs for the New York Convention Center were sampled and tested, with statistics providing the confidence that the inspection of some but not all individual parts was sufficient. But. while sampling methods may have improved since the nineteenth century, the same inherent problems with castings remain, as the experience in New York has demonstrated.

Setbacks may seem to be the norm in construction, but as the historical example of the original Crystal Palace illustrates (the erection in fourteen months of the Empire State Building could serve as another positive case study), they are not inevitable. And even when problems do occur, they are often forgotten when the structure is complete. Innovation, whether it is in structural engineering design or in construction methods, can not only be a threat to success but also can cause the designers and builders to be more cautious in anticipating and eliminating trouble. Knowing they are bridging record distances or enclosing record volumes can call forth in engineers the attention to detail that made the Crystal Palace the symbol of success that it has come to be.

Top of page; Return to Background Index

Home

25/9/05 Last Updated 25/9/05