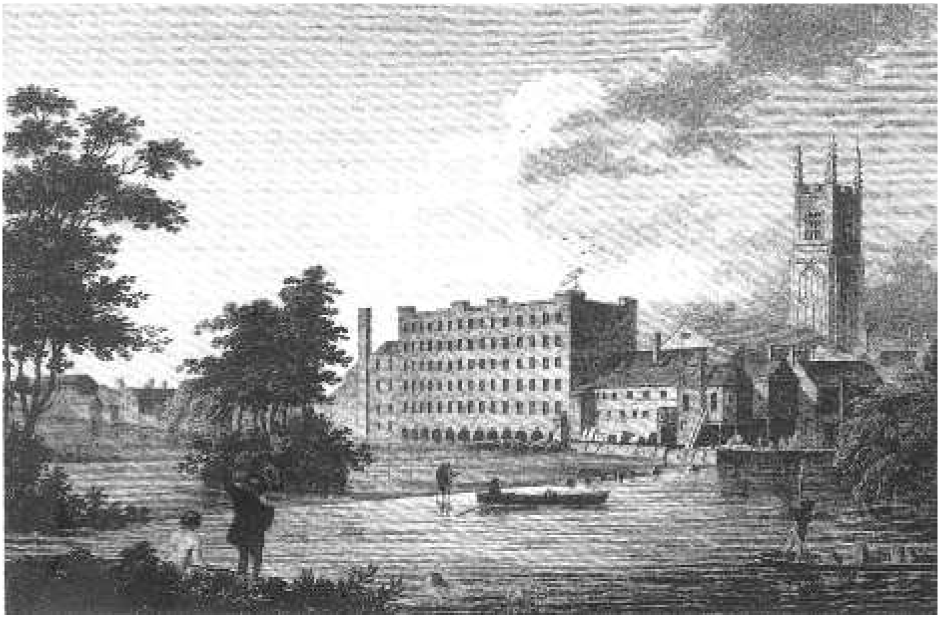
4 Factory as Innovator

> As soon as we know how to use the material which industry supplies us with we shall be able to create an architecture of our own.
>
> Theophile Gautier, 1850[1]

The history of invention and innovation is imprinted with the faint shadows of those who hesitated and lost their moment, as well as those who moved too fast. Some years after the fire at the Albion Mill in London, that most public failure, the elderly James Watt admitted that the project had been too ambitious. ‘It was’, he said, ‘too great, too new’.

Almost a century before, in the 1720s, while making a lengthy tour of Great Britain, Daniel Defoe was stopped in his tracks as he crossed the River Derwent at Derby by a newly built silk mill, ‘a curiosity in trade worth observing’, since its water wheel was powering machinery. The water wheel was hardly a novelty, but the scale of the building and the way in which the manufacture was being carried out were quite new. Defoe observed that the mill produced no handmade items, ‘yet it turns the other work, and performs the labour of many hands. Whether it answers the expense or not, that is not my business.’[2]

The austere five-storey mill, built by John Lombe in 1717, was probably the first mechanized factory in the world, and its advances were based on Lombe’s observations of Italian silk manufacture. A single water wheel of heroic proportions drove the thicket of winding and twisting machines overhead. Yet an almost 50-year interval fell between the establishment of Lombe’s mill and



the beginning of wider-scale industrial activity, based on mechanized processes of manufacture. The length of that pause is still not satisfactorily explained. But once the revolution began, 'the form of the shell of the archetypal mill grew logically from internal forces like a soap bubble'.[3]

Once the steam engine entered the picture there was no longer any need to site factories close to waterfalls or for them to be entirely dependent on the vagaries of wind and weather. Location was dictated by proximity to the supply of essential materials and ease of distribution. Those northern cities in Britain served by canals and, soon after, railways answered the need. The introduction of the hard, bright light of coal gas meant that floor size could be dramatically increased, matching the expanding size and weight of the looms. Long, low buildings were needed instead of squat,

The Lombe brothers' silk mill at Derby, 1717–19. The engineer George Sorocold had already built a smaller version, but this is the one described by Daniel Defoe in the early 1720s.

high ones; the search was on for a roof form that would allow natural top lighting.

The first wave of new industrial enterprises was pioneering too in matters such as time-keeping, quality control, safety, careful bookkeeping and cleanliness, those overt indicators of orderliness and efficiency, while, necessarily, working practice was to be a major determinant of the physical planning of the factory floor. As early as the 1760s, at Josiah Wedgwood's Etruria pottery in Staffordshire, the linear arrangement of the works mirrored the sequence of production, while careful consideration was given to optimizing sources of natural light in areas where wheels and lathes were operated.[4]

At their Soho Foundry in Birmingham, built in 1796, Matthew Boulton and James Watt, makers of the first steam engines, developed the benefits of 'a definite systematic and preconceived plan'.[5] This was in marked contrast to Boulton's and John Fothergill's Soho Manufactory built thirty years before, which more closely resembled a sizeable country house, an appropriate enough image for a works given to the production of silver plate and domestic ornamental objects.

But the ultimate challenge was to build an invulnerable, fireproof, mill. A multi-storeyed building lit by banks of candles or by oil lamps was an inevitable fire risk, since spilled wax built up under foot and continuous oil leaks saturated the floors, while inflammable waste materials and wooden machinery waited nearby to fuel the flames. The tendency of water power to fail in periods of drought or harsh frost meant even longer hours in which exhausted workers struggled to make up production targets under artificial light, with the increased risk of accident. Being held to ransom by fire or water was in the nature of the manufacturer's life.

William Strutt, the engineer son of Jedediah Strutt, was determined to crack the problem. The solution seemed to him to lie in the use of brick or hollow pots to replace timber and the introduction of lighter and more tensile wrought-iron tie-rods to strengthen the fabric. At their pioneering Derby mill of 1792–3, the Strutts introduced cast-iron columns (already used in churches) to support a brick frame and encased the wooden beams in plaster. The structure was repeated at a larger scale for their enormous Belper West Mill, begun in 1793.[6] The urgency of their quest was regularly underlined by mill fires, at least five occurring within an 80-kilometre radius of Derby in the 1790s. Between 1795 and 1843 the cost of factory, warehouse and mill losses by fire were estimated to amount to some £2,250,000, much of it met by the insurance companies.

In 1796 a new flax mill opened in Shrewsbury, Shropshire. A local newspaper celebrated the completion of the first building in the world to use cast iron for both columns and beams: 'Messrs

The Etruria pottery, Hanley, Stoke-on-Trent, Staffordshire, an early attempt to design a symmetrical and architecturally coherent factory. Built in 1769 by architect Joseph Pickford and his clients Josiah Wedgwood and Thomas Bentley. Viewed in the 1770s by Stebbing Shaw.

Benyon & Bage . . . have just finished a spacious Flax-spinning Mill, which is *fire-proof*. The materials consist wholly of brick and iron; the floors being arched, and the beams and pillars being formed of cast iron.' William Strutt quickly called in Charles Bage to build North Mill, Belper, Derbyshire (1803), along the same lines. He also improved working conditions by using the steam that powered the machinery to heat the building, via the iron columns.

Within a small circle, initially that of men based around Coalbrookdale and the textiles centres of the Midlands and the Pennines, iron masters shaded into mechanical engineers, mechanical engineers into builders, builders into architects and developers. Word passed around among them, publications and learned papers circulated, one man's experiment became the next man's investment.[7]

The Strutts' continual alertness towards new and improved structures also led to their adoption of a version of the Panopticon, in the form of a polygonal textiles mill at Belper built between 1803 and 1813.[8] Bentham, in his publication of 1791, had extended his plan for workhouses and prisons to factories organized on the 'ordinary plan of freedom'. He had emphasized the practicality of partitions (which at Belper became firescreens), as well as the need for supervision. At Belper, this came from an overseer who sat upon a revolving central upper chamber, driven by wind or hand as the conditions allowed. The Strutts' round building did not fall victim to fire, but neither was it practical, either for machinery or workforce. (Round or polygonal buildings did, however, have their uses; it was a form that came into its own for the assembly of heavy items, such as pianos, which could be rolled down ramps.)

Of all materials, iron was the key to the century of transformation, 1750 to 1850. The engineer and historian James Sutherland points out that the Industrial Revolution could equally well be called the Iron Revolution.[9] The continuing refinement of iron, in particular rolled sections, and the next revolutionary introduction, that of cheap mass-produced steel, were driven on by the rapid spread and development of the railway network. Although the steel-making processes invented by Henry Bessemer, William Siemens and others in the 1850s and ’60s did not bear fruit until the 1880s, its potential was already clear. Meanwhile, ship- and bridge-building suggested ways of greatly augmenting lengths and spans in ironwork, while railway stations, exhibition halls and arcades offered advances in the use of iron tie-rods and trusses (replacing timber), as well as modular systems of glazing – the predecessors of the top-lit factory floor space. What would now be termed technology transfer enabled new ideas to cross frontiers, to change in scale and application, despite the fact that the journey from the engineering workshop to the construction site was often a lengthy one.

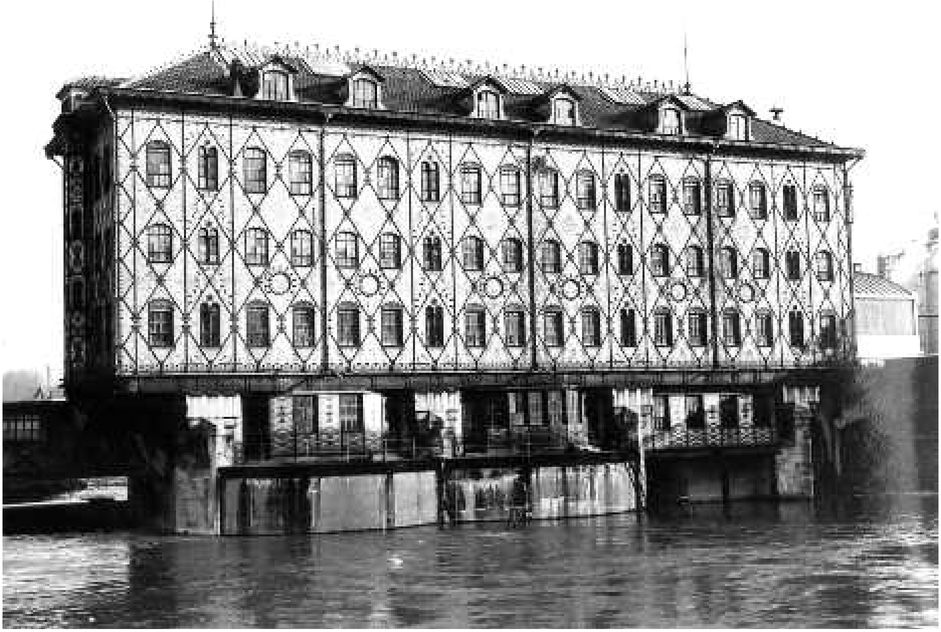
Necessity drove experiment. The naval dockyards and munitions establishments of the main European powers had been the unwitting pioneers in industrial building, both in form and technology – as they had been earlier in organized labour and production. The need for quality control and the presence of a disciplined and organized workforce, as well as the skills and innovations that were forced into being at times of war, made them ideal test-beds for the civilian world of industry. At Sheerness in Kent, one building tells the story.

The Boat Store, which ‘from a distance . . . looks like an admirably crisp piece of work from the 1950s’,[10] is an iron-framed structure designed by a man born in 1807. Colonel Godfrey Greene was the Director of Engineering and Architectural Works at the Admiralty from 1850 until 1864, and the building, hidden away in a secure naval dockyard – where the conversion from sail to steam

had meant an introduction to advanced technology – remained undiscovered until the mid-twentieth century. Until then, Jules Saulnier's mill, built in 1871 for Chocolat Menier at Noisiel-sur-Marne, with its turbines feeding power to the factory overhead, had been celebrated as the pioneer of this form of iron construction.[11] There, the upper storeys were supported on iron box girders, and arched roof trusses permitted uninterrupted floor space for machinery at the upper level. The building's highly decorative skin of brickwork and ceramic panels seemed at odds with the ingenious engineering within, and the radical use of iron as a structural frame.

The Sheerness Boat Store, built between 1858 and 1860, had no need of such disguise. The rigour of its external appearance was at one with the innovation of its structure, in a fashion that might have been disturbingly bald to the Victorian eye had it been in a

The proto-modernist iron-framed Boat Store, Sheerness Naval Dockyard, Kent, designed in 1858 by architect Godfrey Greene.



more accessible location. Greene dispensed altogether with load-bearing walls and, by using an iron frame (cast and wrought iron for, respectively, column and beam) and lightweight corrugated iron infill panels, he pointed the way ahead to the steel-framed, panelled sheds of late twentieth-century industry.[12] The frame system that Greene used had clear advantages over conventional construction: it was quick to build, accommodated larger windows and did not require such heavy foundations. His ingenuity lay in the application of newly formulated standard sections and better quality metalwork to the well-tried, and deservedly admired, system of timber framing that had long served dockyards and mills in the south-eastern counties of England.

Looking back almost fifty years in his memoirs, the distinguished engineer Sir William Fairbairn pointed to the most dramatic change of all. In 1814 machinery had been made entirely by

An ornamental skin disguises a pioneering use of an iron frame. The Menier chocolate factory, Noisiel-sur-Marne, 1871, architect Jules Saulnier.

hand, largely of timber, but by the mid-nineteenth century iron tool-making had itself grown into a major industry: mechanization had begat mechanization. Originally a millwright, Fairbairn's own fortunes were founded on the manufacture of steam engines, water wheels, locomotives and mill gearing, and his own foundry and factory in Manchester was widely admired for its model working system in which 'each mechanic appears to have his peculiar description of work assigned, with the utmost economical subdivision of labour'. The production line itself was under development, along with the technology.

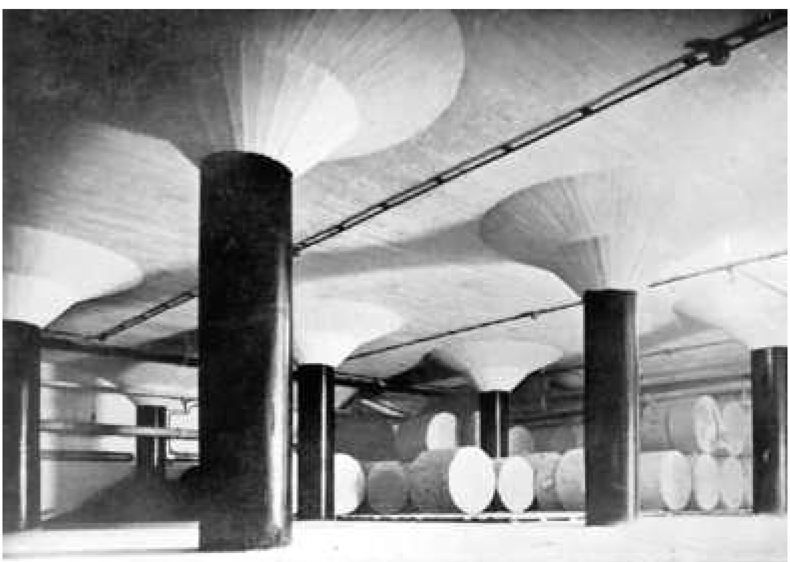
Science and technology, so long divided by 'the anomalous separation of theory and practice', had become, in Fairbairn's view and experience, an indivisible whole. Yet his fellow engineers and architects and their clients were still failing to exploit the possibilities of cast and wrought iron in buildings. As he wrote, 'experimentalists and mathematicians have provided the knowledge; but practitioners, I fear, have in a great degree failed to avail themselves of it'.[13]

In his own search for non-combustible buildings, Fairbairn had also come 'fortuitously close', as Kenneth Frampton puts it, to inventing reinforced concrete. In Fairbairn's publication of 1854, *On the Application of Cast and Wrought Iron to Building Purposes*, he proposed a system of iron beams supporting vaults formed of sheet iron, with concrete above. Within the concrete were embedded wrought-iron tie-rods, harking back to the tie bars of an earlier generation of conventional, masonry-built mills. To put metal reinforcement within the artificial stone compound, the latter the subject of much experiment from the early nineteenth century,[14] was extraordinarily prescient. The sticking point was to provide elasticity in the material, to deal with the stresses set up by the load of conventional post-and-lintel construction and which, overlooked, would inevitably lead to cracking and probably structural collapse.

Functional timber buildings, exemplified by Courtauld's 18th-century weaving sheds at Halstead, Essex, pointed ahead to further structural innovation, particularly in naval dockyards.

The breakthrough needed came from a particular joint, invented by François Hennebique and patented in 1892. His 'monolithic joint' was relatively flexible and resistant to stress. It worked by binding together the reinforcement bars of the various horizontal and vertical members of the structure at their junction. The effectiveness of the joint meant that a reliable concrete frame was possible, although it remained awkward looking. The application of the monolithic joint to industrial buildings, reducing fire risk, vibration and cost, was obvious, and in 1895 Hennebique successfully built the Charles Six spinning mill in Tourcoing in Belgium. Two years later he and his partner Le Brun designed the first reinforced concrete building in Britain, a flour mill in Swansea in South Wales, erected by the Hennebique method. By 1900 the firm had become a huge international concern. Among the licensees for the system were the Perret brothers, one of whom, Auguste, was to exploit the architectural possibilities for concrete much further. Now the race was on, and other patents, each differentiated by the precise geometry of the system of reinforcement, were developed both in Europe and the USA.

Unlike architects, who were held back from business ventures by their professional rules of disengagement, entrepreneurial structural engineers remained at the forefront of development. The Swiss Robert Maillart had built his first concrete bridge in 1898. In 1909, now running his own company, he patented a system in which the columns appeared to flow into the lightweight floor slab via a sinuous column head or capital, an elegant, fluid solution which simplified the traditional and now irrelevant junction between post, ceiling slab, joist and beam that perpetuated the forms of wooden or metal structures. The following year Maillart built a five-storey warehouse in Zurich, the first to exemplify his 'flat slab' system.[15] There the mushroom-headed or dendriform column, pressed into shape by wooden forming boards, which left an attractive imprint, proved to be an aesthetically pleasing and efficient solution to an awkward structural conundrum. In so doing, it can be seen as an apt metaphor for the practical achievement and architectural vision achieved by such pioneering engineers, yet little acknowledged by their professional peers or, until recently, by historians. As David Billington sees it, Robert Maillart epitomizes the 'design' view of engineering as against the 'applied science' view.[16] The new forms also offered tempting possibilities for alert architects. The young Finnish architect Alvar Aalto was among the first to embrace the robust possibilities of reinforced concrete in the huge mushroom-headed columns that supported the storage cellars below the offices of the Turku newspaper *Turun Sanomat*, built in the late 1920s. Aalto's friendship with many leading international artists and critics ensured that his work was quickly appreciated (and published) well beyond Scandinavia.



The paper storage cellars at the Turun Sanomat printworks, Turku, Finland, 1927–9, architect Alvar Aalto, with reinforced concrete, mushroom-headed columns of a type pioneered years earlier by Robert Maillart.

At the beginning of the twentieth century the modern factory could be seen as the perfectly functional building, built with improved or new materials and building technology, expressive of efficient procedures and management systems, owing its plan and its form to the specific nature and organization of the industrial process. Most significantly of all, it would be powered by electricity, becoming clean, bright and pleasant. Hidden behind all this was the reality for the workforce, which had to weigh a better environment and improved pay and hours against an increasingly dehumanized routine of repetitive and unstimulating labour.

Paradoxically enough, electricity and motor vehicles, those epitomes of the new age, were often produced in steel-framed and reinforced concrete buildings constructed to the latest specification but buried beneath masonry cladding and conventional ornament. When the American architects Wallis & Goodwillie were commissioned, well before the First World War, to build the General Electrical Company's headquarters at Nela Park in Cleveland, Ohio, their first action was to set sail for England. There, they toured Salisbury, Bath and Wells and steeped themselves in early eighteenth-century architecture. They returned with a portfolio of useful details plucked from examples such as Pulteney Bridge in Bath and the Judge's House in Salisbury, as well as 'coach houses and offices of old English estates'. The brickwork was beautifully detailed, the stonework carved with care, the Engineering Laboratory was a Wrennaissance masterpiece and the 200-foot-high (60.96 m) chimney had 'a delightful entasis and Doric cap'. The architecture suggested an unimpeachable pedigree, suitably reassuring while commercial electricity was still uncharted territory.[17]

The outbreak of the First World War gave reinforced concrete systems, among them Julius Kahn's well proved and heavily promoted version, the boost needed. Owen Williams's career began in 1911 with the American Indented Bar and Concrete Engineering Company, and the following year he moved to Truscon's London office to become their chief estimating engineer, designing innumerable civil factories before turning to the massive establishments required for armaments and defence hardware during the war. In 1914 Truscon began to publish *Kahn-crete Engineering*, a bimonthly magazine that extolled the product and provided practical information, as their French competitors had done for many years. There remained a need for reassurance; as late as 1919 the *Architectural Record* was reminding its (American) readers of the early history of concrete and a series 'of most lamentable accidents. These were due to causes which those properly experienced with concrete now know how to avoid.'

Fast, economic and adaptable, reinforced concrete had become readily available at just that moment when shortages of traditional materials, the relaxation of building regulations and flexibility made its virtues most persuasive. In Britain between 1913 and 1917 the Danish practice of Christiani & Nielsen designed ranks of undisguised reinforced concrete silos and warehouses for the British Oil and Cake Mills at Erith on the Thames estuary, while in France Eugène Freysinnet had spent the war years building arms and munitions factories, glass and steelworks all to gargantuan scale driven by the urgency of the moment.

In the USA the notions of the systems engineer also came to the fore in wartime, conclusively influencing the forms and materials of industrial buildings. The ideas of Frederick Taylor, who died in 1915, had been applied to a wide range of industries, from steel to munitions, reinforced concrete to machine-tool engineering. His *Principles of Scientific Management* (1911) played a considerable part in revolutionizing the Ford manufacturing process, although it can be argued that Albert Kahn and Ernest Wilby had already established 'the typological characteristics of the modern factory' in their work for the Pierce automobile plant in Buffalo, designed from 1906, in which self-contained work cycles were housed in single-storey, steel-framed, top-lit, sawtooth-glazed buildings.[18]

At Highland Park, Detroit, a new workshop had opened on New Year's Day of 1910 for the production of the Model T Ford. It was a four-storey block, each floor being entirely un-subdivided and served by freight elevators around the perimeter. Being long and narrow, it turned out to be ideally adaptable. With sizeable extensions to the original block and reordering of the entire site to cope with the increasingly specialized nature of each operation, three years later Highland Park became the site of the world's first moving assembly line. Parts travelled past operatives on a conveyor belt, enabling them to perform a single efficient task: gravity-fed car production was dead. By 1915 a quarter of a million Model T Fords were pouring out of Highland Park annually.

The logical extension of this thinking was to integrate the entire process, from the arrival of the raw materials – coal and iron ore, in particular – to the shipping out of completed models. The huge extent of the Rouge River marshes at Dearborn, Michigan, gave Ford the opportunity for an enterprise on such an all-embracing scale, and in 1918 he set up an assembly plant for the Eagle torpedo boat. Albert Kahn's Building B was half a mile (800 metres) long. Working to the adage 'An Eagle a Day, Keeps the Kaiser Away', the labour force soon adapted to post-war manufacture of car bodies. Single-storey buildings were far less vulnerable to fire and did not suffer from vibration, while steel frames meant fast construction. Kahn's vast complex was fathered by the Pierce building of 1906, while the deployment of robotics in manufacture would be the obvious next step, since repetitive, demoralizing work and escalating labour costs combined to often explosive effect in the mid-twentieth century – as caricatured by Charlie Chaplin in his film *Modern Times* (1936), the automaton-worker even being fed by machine.

Eugène Freysinnet's hangar of 1921 at Orly airport outside Paris, its arches based on the catenary principle used by Christopher Wren on the dome of St Paul's Cathedral, demonstrated the scale and impressive dimensions that reinforced concrete could achieve in the hands of the generation of innovative and radical engineers who had risen so impressively to the imperative of war. Equally, Auguste Perret's Esders clothing factory of 1919 in Paris, with its glazed roof and clear space supported by concrete arches, transformed the notion of the top-lit workshop into a great hall. Meanwhile, Owen Williams benefited from his experience with Truscon and set up Williams Concrete Structures Ltd to market his own patent, 'Fabricrete', before being appointed the leading engineer to the British Empire Exhibition of 1924 at Wembley, where he applied his wartime experience of large-scale buildings and fast construction, gaining a knighthood at a very young age for his efforts.

The purposeful austerity of Perret's industrial work of the immediate post-war years, often combining pre-cast elements with *in situ* concrete, would be shared by his later civic commissions; for, as he put it, 'how can we build palaces, if we do not build our factories the same way?'[19] Freysinnet worked on in his search to a solution to what he termed the 'dissonant deformations' of concrete and steel, that is, their antipathy under conditions of stress. In 1928 he wound up his business partnership and began to experiment with pre-stressed concrete, inducing stresses artificially in the reinforcing rods before insertion in the concrete. His efforts were vindicated when he was brought in to deal with subsidence at the Marine Terminal at Le Havre in 1933. Pre-stressed concrete was applied as a last resort, and found to be highly effective.

From then on, pre-stressed concrete was used for almost all heavy engineering projects, dams, bridges, wind tunnels, landing strips and lighthouses. Its lightness (the concrete section could now afford to be extremely slender) and adaptability made it ideal for forming cones and parabolas – while it proved reassuringly durable. According to one leading engineer, pre-stressed concrete was 'the most revolutionary idea in twentieth century structural engineering'.[20] Post-war, the Spanish-born but Mexican-based architect Felix Candela and the Italian structural engineer Pier Luigi Nervi experimented inventively and to extraordinary effect with both *in situ* and pre-cast concrete to create complex industrial and public buildings, folding, slashing and piercing the material into cones, parabolas, tentlike roofs and swooping vaults.

Concrete vaulting and columns for the Gatti Wool Mill, Rome, 1951, engineer Pier Luigi Nervi. Elsewhere Nervi mastered spanning of large expanses with reinforced concrete, for hangars, sports stadia and exhibition halls.

Until the Second World War, the three modern materials – steel framework, reinforced concrete and glass – had offered, in Albert Kahn's words, 'a straight-forward attack of the problem' in which 'simplicity and proper respect for cost of maintenance make for a type which, though strictly utilitarian and functional, has distinct architectural merit'. For Henry Ford, the continual challenge was hyper-efficiency and super-productivity; there was no time for reflection or consolidation, for 'a thing is obsolete, no matter how good it is, the moment something better appears', as William Cameron, his public relations and spokesman, put it.[21] Thus a power plant that had cost $20 million was summarily replaced in 1937 when requirements changed.

In his book Moritz Kahn emphasized the importance of lighting quality within the factory, both 'physiologically and psychologically'. In recognition of this, long before, Matthew Boulton had insisted on whitewashing the walls of the Albion Mill, both to improve the rough interiors and to reflect more light. Kahn advocated the use of translucent upper panes and clear low ones, to alleviate the strain of continually looking at one object and to help diffuse the natural light. Although Kahn did not mention safety, it was well known that poor lighting was a major cause of industrial accidents. Since the late nineteenth century, different combinations of glazing and roofing material on single-storeyed work sheds had led to various standard roof profiles which included sawtoothed, butterfly and monitor lights.

Glass offered benefits as well as difficulties. Generous glazing led to overheating – curtains, blinds and opaque paint were quickly introduced at Walter Gropius's Faguswerk (1912–14) in Alfeld-an-der-Leine and, later, awnings – but the symbolism of a transparent building, both in terms of modernity and accessibility, was potent. In 1931 Le Corbusier was transfixed by the Van Nelle

Factory in Rotterdam, begun in 1925 and recently completed. He considered Brinkman and Van der Vlugt's work (assisted by the young Mart Stam) a notable creation of the new age. An eight-storey tower rose above the lower, curving administration building. Everything was glazed and 'open to the outside'. The company packaged foodstuffs, including tea, cocoa and coffee, and an essential message to their customers was conveyed in the cleanliness and transparency of the building. The curtain walls and diagonal conveyor belts, the mushroom columns and concrete slab floors, were all part of the visible modernity of the Van Nelle factory – as were the white ceramic wall tiles, stainless-steel handrails, rubber floors and radiators tucked beneath sill level. When Howard Robertson and the architectural photographer Frank Yerbury visited the still-incomplete building for the *Architecture and Building News* in the spring of 1930 they noted that 'the factory [had] a human atmosphere of gaiety and joy'.[22] On Tuesday and Friday evenings the lights were left on in the building, ensuring that the great glittering ship of glass became a highly visible landmark across the city. The company well knew the effect that their eye-catching, illuminated new building would have on sales.

For Owen Williams, the 300-acre (121.4 ha) greenfield site that Boots wished to develop in the late 1920s outside Nottingham, at Beeston, offered a rare opportunity to design a factory as a factory was meant to be – 'a place protected from wind and weather where things, most unnecessary, are made most efficiently'. In order to be able to keep full control of the design, he registered himself as an architect in 1930.

As so often with the leading industrial buildings of the early twentieth century in Europe, the client was American, the United Drugs Company having bought Jesse Boot's firm. The plan was to build a huge manufacturing plant in three phases. In the event the

building, known as the 'Wets', which referred to its function in manufacturing, packing and distributing pharmaceutical liquids, pastes and creams, did not expand. By the time that Boots asked Williams to design another building, the 'Drys' (for powders and tablets), the firm had returned to British ownership. The second building followed a very different brief, and discarded the glass curtain wall for a more solid masonry structure. The external image of the two buildings provides a metaphor for the cultural gulf that existed between confident Machine Age America and cautious inter-war Britain.

An early 1930s night-time view of the Van Nelle factory, Rotterdam, 1925–9, architects J. A. Brinkman and L. C. van der Vlugt. Illuminated glass-walled buildings, whether factories or department stores, were a commercial gift.

With his wide experience, a programme largely defined by the production and engineering team held no fears for Williams. As the souvenir brochure expressed it, ‘as a constructional engineer free from the superficial restrictions of the fashions of the building trade, he became sensitive to the living, productive organism which is Boots’. Williams was working to a precise brief, since the client team presented him with flow lines, the optimum accommodation for each operation and the necessary linkages between the many processes. His triumphant achievement was to visualize all this within a complex of two immense atria, around which everything else revolved.

The ‘Wets’ was revolutionary in its scale – at 695,000 square feet (645,655.5 sq. m) it approached the scale of car factories and munitions works. The four-storeyed slab structure is supported by mushroom-headed columns spaced within a grid and wrapped by a sweep of glass and steel curtain walling. Nothing like it had been seen in Britain, and overseas only the Van Nelle factory in Rotterdam could be compared to it.

An early photograph of Boots' 'Wets' factory, Beeston, Nottinghamshire. 1930–32, architect–engineer Owen Williams. After an extensive restoration, it remains as impressive as ever and is still in working use.

The production area is illuminated from above, where an immense expanse of bull's-eye glazing forms the covering of the atria. From the beginning, everything possible was mechanized: the finished products were hoisted up to the packing department by lift and came down to the ground floor on chutes. The entire organization was linear, running south to north through the building – raw materials to finished products. The benefits of the new building enabled Boots to become the first company in the country to introduce a five-day week for its staff, with no reduction of pay.

The 'Wets', completed in 1932, was officially opened by the chairman's wife on 27 July 1933. As if she were launching an ocean-going liner, Lady Trent hurled a bottle of perfume against the wall. As a contributor to the *Manchester Guardian* wrote: 'It suggests what the factory of the future may be when architects, with the new materials now at their disposal, have further revealed their ideas of industrial design.' The 'Wets' was hailed with

An early photograph of the packing hall in Boots' 'Wets' factory. Note the shutes.

The packing hall at Boots' 'Wets' factory, seen in 2001. The shutes have gone and an enclosed ground-floor area has been added, bottom left, but there are few other major changes, 70 years on.

Boots' 'Drys' factory, Beeston, 1937–8. Owen Williams's second building on the site was a more conventional structure due, in part, to the change of ownership from American to British.

warranted journalistic hyperbole in the *Glasgow Evening News* as 'the wonder factory of the world' and an 'industrial crystal palace where thousands of men and women work in the full daylight under conditions that must be the envy of every man and woman employed in the orthodox factory'.

After extensive renovation work in the mid-1990s, the main floor area of the 'Wets' still functions much as designed, amply justifying all the claims for it and a remaining an utterly compelling architectural *tour de force*, exerting a Machine Age thrill 70 years later.[23]

Yet, despite such an occasional exception, and usually only where American business partners were involved, British industry of the inter-war period remained firmly locked into the Victorian era. In the architectural magazines of the early 1930s, strenuous advertising of products such as white reflective tiles, pale 'Midhurst white' bricks and 'Snowcrete' cement did little to brighten the picture. One report in the early 1930s reported that some 30,000 factories did not even have electric light. The pioneering Wedgwood pottery works in Etruria struggled on in the eighteenth-century premises that H. G. Wells had considered sadly run-down 60 years before. Not until the late 1930s did the company commission their new works at Barlaston from Keith Murray.

As in the previous war, the shortages and restrictions brought about by the priorities of defence and essential production during the Second World War galvanized the construction industry to experiment. In the USA the stocks of traditional materials had been exhausted by mid-1942. Steel was reserved for armaments, so that reinforced concrete and timber byproducts, such as plywood, came into their own. Despite a certain initial nervousness in the face of the unfamiliar – 'Unusual materials, designs and methods of fabrication . . . are entirely justified under prevailing conditions' – the economies and lightness of pre-stressed concrete and the dependability of columns and trusses of laminated timber turned out to be admirable. Synthetic materials, from rubber to resin glues, proved practical adjuncts to these novel building materials.[24]

After the war, the immense US defence infrastructure fell largely redundant, and Federal funding was directed, through a government agency, the Defense Plant Corporation, to the task of converting the plants to domestic industry. Aircraft engine and tank plants became car factories, notably the Willow Run bomber assembly plant at Ypsilanti, Michigan, which produced the (unsuccessful) Kaiser Frazer car before reverting to building transport planes for the Korean War.

Some plants were converted to produce industrialized buildings, in particular much-needed prefabricated housing, feeding on the over-supply of aluminium and steel. An artificial demand for newly developed materials was sustained by, for example, legislation in Congress that synthetic rubber must be used in preference to natural rubber. But the domestic market proved predictably resistant to such new products as the Lustron, an enamel-coated steel house. With peacetime and prosperity, the impetus to explore further drained away, a waste of what Martin Pawley has termed a 'temporary coincidence of science and building'.

In the USA, with the availability of ample quantities of improved quality, lightweight-steel sections, firms such as Skidmore Owings & Merrill (SOM) developed a sophisticated gridded, highly serviced shed with an exposed steel frame which, before long, was being exported to Europe for industrial use – initially on behalf of American clients. As Mies van der Rohe put it, speaking in the USA in 1950, 'Technology is far more than a method, it is a world in itself.'[25] A newly elegant reinterpretation of pre-war European modernism, evoking Gropius's and Mies's own schemes, the image, whether as architecture or as polemic, was impressive. Nevertheless, the fine steel mouldings that delineated the slender frames offered no more support than might a plaster or timber trim, since fire regulations still required much of the structural steel to be masked. In Sweden, unscathed by war or materials shortages, the British-born architect Ralph Erskine built two factories in the early 1950s (one making mattresses at Köping, the other cardboard at Östenfors), using brick in an expressive and effective way on the exteriors.[26]

The next generation of metal-framed and heavily glazed buildings were to be the beneficiaries of new sealants developed for the car industry and tougher, oxidizing steel (Cor Ten) developed for freight wagons and heavy industrial plant. Other materials, in particular reflective glazing and pre-cast concrete, also proved adaptable to 1960s industrial buildings. Further refinements,

Neutral Sweden was able to gear itself up for production earlier than many other countries in post-war Europe. In the early 1950s architect Ralph Erskine used brick in an exuberant way for this cardboard factory at Östenfors.

especially profiled steel and aluminium cladding and plastic sealants, encouraged the shed to become ever lighter, while such features as masts, cables, braces and air conditioning plant became more explicit, often celebrated in bright colours or metallic finishes, leading to what became known as High Tech.

Later twentieth-century architect-designed industrial buildings lent themselves readily to what has been termed 'architectural engineering'[27] – the use of elements that rely more on external effect than structural reality. The now-demolished but much admired Reliance Controls factory outside Swindon in Wiltshire was built at high speed in 1965 by Team 4 Architects (the practice set up by Norman and Wendy Foster and Richard and Su Rogers) – a cheap and flexible shed with strongly marked bays that served as both factory and offices for an American electronics company. Its most visually memorable feature was the crisp cross-bracing on each bay of the external steel frame. Despite the contemporary nature of the clear structural logic of the grid, the expressed frame and its light steel and glass infill panels, the designers were prepared to admit that the bracing was there just 'for visual effect'.[28]

Rather more purposefully, the masted structures at Richard Rogers's Fleetguard Manufacturing Centre at Quimper in Brittany, for American clients, the Cummins Engine Company (with Ove Arup as engineers) in 1981, and at Inmos Microprocessors at Newport, South Wales, in 1982 (with Anthony Hunt, engineers), offered flexibility, the possibility of adding prefabricated parts along a central serviced spine. The Meccano-like elements of Foster Associate's Renault depot of 1983 at Swindon emphasized the 'toys for boys' element of the overt mechanistic references. The masts, brightly coloured, helped to establish the visual impact and image for these new factories, not markedly

dissimilar from many others in France or Britain except perhaps in their aesthetic ambitions.

In fact, the sophisticated serviced shed has become a relatively standardized item. In 1980 Michael Hopkins & Partners, architects who had already shown their potential in the field of industrial buildings, were commissioned to draw up a prototype small unit. Patera, as the system was named, is a steel-framed box with glazing, a prefabricated factory unit that could nourish that enduring modernist appetite for a building that comes off the assembly line, like a car. A handful were built but there was to be no mass production.

The latest materials are probably entirely out of sight: complex combinations of resins, fibres, metals and plastics, some of which

With its clean lines and taut bracing, the Reliance Controls Electronics factory, Swindon, WIltshire, became an influential building for an entire generation of sleek factory sheds. 1965–6, architects Team 4. Now demolished.

Masts and steel bracing rods around the building denoted new technology at the American-owned Fleetguard Manufacturing & Distribution Centre, Quimper, Brittany, 1979–81, architects Richard Rogers Partnership.

are replacing more traditional options, layered and sandwiched to insulate, seal and improve the environmental performance of the building. In theory, therefore, 'every building is a prototype with a choice of structure and materials'.[29]

The real innovations in the factory are equally unlikely to be visible, but hidden indoors where modern machine tools, robotics and laser technology have emptied the 'manufacturing facility' of people. Alterations in the face and pace of work, with modern ergonomic and spatial planning, have been fed into the design thinking.

Where people still remain a part of the process, a thoughtful brief and a well-considered plan can potentially change attitudes and break down hierarchies. A simple decision such as the provision of a unified canteen or a single entrance desegregates blue- and white-collar workers, improving labour relations and communications at a stroke. The Motorola factory near Swindon, built in 1998, is designed around an internal 'street', a sociable but undefined space in which employees can mingle. Sheppard Robson, the architects, have also been responsible for a number of research and development headquarters for leading biotechnological and pharmaceutical companies in Britain, arguably factories in a new guise – albeit staffed by highly qualified graduate staff. Their campus for the American pharmaceutical giant Pfizer at Walton Oaks in Surrey, opened in 2001, provides attractive, informal meeting places throughout the building, where people can swap ideas beyond the confines of office or laboratory.

Viewed in the round, a factory is not simply a well-oiled machine, nor an architectural set piece, but a complex social structure. As Jeremy Melvin writes, in a critique of the Ryder Company's exemplary Viasystems plant for printed circuit boards in North Tyneside, such a satisfactory result depends on 'the

manipulation of infrastructure, the capability for change, the understanding of different scales, and an almost ritualised regulation of the interplay between people, goods, waste and information. In short, factories are the closest phenomena to urban life . . . '.[30]

A sleek cigar of polished steel, the Motorola factory at Swindon, Wiltshire, was as mute about its function as its 'high tech' predecessors were voluble. 1998, architect Sheppard Robson.