# THE FIRST "FIRE PROOF" BUILDINGS IN ENGLAND
## A CONTRIBUTION ON THE EARLY HISTORY OF CAST IRON IN BUILDING CONSTRUCTION

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In the accounts of the history of architecture, but also of building construction, cast-iron construction or construction elements in industrial functional buildings (factory buildings, warehouses) from the early phase of the Industrial Revolution in Great Britain have attracted little attention up to now. This may be due to the fact that in this type of structure neither the artistic decoration of the new construction material nor the monumentality were present which were to be found in railway stations and market halls, exhibition and greenhouse pavilions, but also in some of the engine houses for steam engines,in the heyday of cast-iron construction in the second quarter of the nineteenth century. Factory buildings and warehouses were simple functional structures and, in general, until the 1960's, they were neither objects for preservation as ancient monuments nor did they attract the attention of technical or economic historical research. Until about thirty years ago, even monographs dealing specially with the role of cast iron in architecture (Gloag-Bridgewater, 1948) only repeated what had been presented in contemporary periodicals in the nineteenth century. Namely: "The first successful application of cast-iron beams as construction elements in a building was in a cotton mill which was erected in Manchester in 1801 by Messrs. Philips and Lee". This is a reference to the Salford Twist Mill. The design of the construction was attributed to Boulton & Watt, also on the basis of contemporary statements from about 1850.

These claims, made by W. Fairbairn in 1854 in his classic work "On the Application of Cast and Wrought Iron to Building Purposes", the "Gospel of the British Building Industry", are, even today, the most natural basic truths in renowned histories of architecture (as for example in L. Bebevolo, DTV edition 1978, p. 52 or in the 5th. edition of the work by W. Giedion, Space, Time and Architecture, 1973,p.191 ff.), but also in histories of industrial architecture.

In the thirty years since the appearance of the work by Gloag-Bridgewater, our knowledge of the application of cast iron in factory buildings in England, as also about the personalities who played a decisive role in these first stages of the development of iron construction has been considerably enhanced. We would mention some of the studies which appeared in the leading specialist periodical Architectural Review by T. Bannister (1950); A.W.Skempton and H.R. Johnson (1957, 1962) and A.J.Pacey (1969). As a result of the increased interest in the history of the Industrial Revolution, technical and economic historians, also in the field of local history, contributed much new material and industrial archaeologists discovered objects still in existence and rescued them or at least documented them. Since 1970 we have at least a comprehensive account of factory buildings in Great Britain until the 1830's from the pen of J. Tann.

This research has:

1) Complemented the topography of the first factory buildings of cast-iron construction and exactly defined their chronology.
2) Brought new technical details of the construction to light.
3) Determined who the architects of these buildings were and finally
4) very impressively demonstrated that the textile industry, from which the first impulses to change production came, also played

a pioneering role in the application of iron to architecture. Just like the new construction of the theatre in the Palais Royal in Paris, which was carried out between 1785 and 1790 by Victor Louis, the first impulse for the application of iron in factory buildings was less an attempt to attain new forms and improved static parameters than, rather, an attempt at reducing the danger of fire by the elimination of wood, that most important construction material in the construction of functional buildings for the textile industry.
The factory buildings of the Arkwright type, the predecessor of which was the famous silk yarn mill in Derby (1719-1721), and in the 1770's cotton mills with water wheel drive were generally spread in Derbyshire, solid 3-4 storey structures with solid, bearing exterior walls in stone and/or brick. In order to accomodate the machines and transmissions the floor surface area on each storey had to be undivided; they consisted of wooden rafter ceilings which were carried by supports also in wood. The span width of the beams restricted the breadth, the possibilities for optimal power transmission (from the power source to the working machines) and the length of the building to about 7.6 to 9.1 m (25-30 ft) and 21.3 to 23.4 m (70-80 ft). The costs of such a factory (just the main building with about 1000 spindles and the power source) amounted to about £ 3000 and with a building of double the length, about £ 5000. With the use of steam power from the 1790's onwards and the raising of the height of the building to seven storeys, the costs rose up to £ 10,000.

There was a danger of fire both from the raw materials employed in the production (cotton, wool, flax, spinning oil; also the lubricants for the machines) and the open flames, as also from the conditions of work (up to 16 hours of work per day, over-fatigue of the workers, room temperatures of about 25°C). No matter what the reason for the fire, the construction material then provided an excellent source of fuel, particularly the beam ceilings soaked in the continuously dripping oil and the wooden supports. Because the raw materials used could not be replaced by something else and as only few entrepreneurs contemplated an improvement in working conditions, the attempt was made to deal with the problem at the most delicate point in the construction, in the supports and wooden ceilings.
Even if fire catastrophes which are said to have caused damage worth £ 45,000 in a factory (factory buildings with machines and raw materials, storage areas with stores) were an exception, fires in textile mills were nothing out of the ordinary. In 1792 there were reports of twelve mill fires in a radius of fifty miles around Derby alone; a year before the proud structure of the Albion Flour Mills in London burnt down. Entrepreneurs in the textile branch started looking more energetically than before for other new construction materials or methods of construction. A further reason for this energy was probably also the need for more space for machines and working space for new machines.
William Strutt, the son of Arkwright's partner and one of the great entrepreneurs of that period, dealt with the project for a completely new factory in Derby in 1791, the so-called Calico Mill which was built in 1792/93. This factory building, which was demolished about 1860, was the first functional building in which cast iron was employed as a construction element. The six-storey building, with the external dimensions 9.45 x 35.05 m (31 x 115 ft) and an internal width of 8.23 m (25 ft) had the following characteristics.
The supporting brick walls were 0.61 to 0.33 m thick. The brick vaulting dividing up the space was borne on crossbeams supported by two rows of 2.5 m high cast-iron pillars. This produced three spans of 2.94 m (9 ft) each, the span of the brick vaulting amounting to



2.44 m (8 ft) and 2.74 (9 ft) respectively. The ceiling of the sixth storey was made of wooden brick vaulting supported on the rafters of the roof structures.
The new feature of this building construction was the employment of cast-iron supports and the elimination of the beam ceilings by the brick vaulting borne on wooden beams with transversal cantilever. There are no details about the flooring, but on the basis of the warehouse built about the same time in nearby Milford (Derbyshire), also by W. Strutt, it is, however, to be presumed that the technique of tiles laid on a layer of sand was also employed in Derby.
The warehouse in Milford, just mentioned, was built in 1792/93 and later equipped as a cotton mill and, apart from the ground plan, also shows the same construction characteristics. The only important difference was that here the supports for the first storey were not cast iron, but stone pillars. The remarkable thing about this construction is the link between supports, beams and tie rods. At the joints the wooden beam was set in a cast-iron connecting piece borne on top of a pedestal. Through the central axis of this connecting piece, an iron pivot ran through the precisely pre-bored beams. These ties were fixed at its top end and above was the base-plate of the upper pedestal. The cast-iron connecting piece served both as a cantilever for the brick arch as a base plate for the support and as a connection for the tie rods.

W. Strutt had these two buildings, which were specially conceived to increase fire-proofedness, followed by a further one in the years 1783-1795 in the centre of his cotton mills, in Belper (Derbyshire), later known as West Mills, a factory building with six storeys. This building with external measurements of 9.1 x 57.9 m (30 x 150 ft) shows those now so well-tried construction characteristics, only that stone was used as construction material up to the third floor and brick pillars as supports for the first storey. The cast-iron supports had the same cross sections which had been well tried in Milford and were supplied, in part at least, by the renowned foundry of Ebenezer Smith & Co. of Chesterfield (Derbyshire). To increase the fire resistance, the wooden beams were also faced in metal sheet as in Milford and plastered from underneath. The costs for the building were £ 4689, i.e. about 25 % greater than for traditional wood construction.
In these first multi-storeyed "fire proof" factory buildings, the designs and construction elements for which came from William Strutt, the building material cast iron was used for supports for the first time in construction work. The remaining construction elements which were intended to increase fire safety, namely the replacement of the beamed ceilings by brick vaults, as well as the employment of hollow bricks, had already been used by Victor Louis in the theatre of the Palais Royal and also in some buildings in England between 1788 and 1792. In 1792, W. Strutt had made efforts to obtain sketches of Louis' construction and samples of the hollow bricks, but had to be content with a description of the construction. This Strutt type of building construction of factory buildings, which in practice only replaced the wood in part but retained the principles of wooden building construction, was very often employed in factory buildings, at least in the first half of the nineteenth century, despite the sinking price for cast iron.

Soon after this first step taken in the then centre of machine spinning on the path to the "structural revolution which leads to the skyscrapers of Chicago a century later" (Skempton-Johnson,1962) there came the second, the complete elimination of wood as construction material in building construction. It was again a factory building, but the scene was not Salford near Manchester in 1801, but, as F. Bannister has shown (1950), in 1796/97 in Shrewsbury in Shropshire, about twelve miles from Coalbrookdale, the birthplace of the coke-fired blast furnace, the modern foundry and also the cast-iron bridge. The architect and construction engineer was Charles Bage (1752-1822), a wealthy wine merchant in Shrewsbury, well known in the town for his great interest for everything which would nowadays be described as engineering structures.

The impulse for the construction of the flax mill in Shrewsbury came, even if indirectly from one of the leading innovators and entrepreneurs in flax spinning, from John Marshall in Leeds. While looking for financial backing for his too rapidly expanding spinning mill in Leeds in 1793, John Marshall gained the support to two wealthy wool merchants and agents for cottage weaving, Thomas and Benjamin Benyon from Shrewsbury, as partners for the construction of a new flax mill in Leeds. The Benyons invested £ 9000 in the deal, moved their offices to Leeds, but, in 1796, on account of their evaluation of the prospects of success, they insisted on the foundation of a flax mill in Shrewsbury. As they pushed their project through against the will of J. Marshall - Marshall did not invest a penny until 1800, but was, nevertheless, a shareholder with 25 % - they were without technical advisers for the problem of the factory building. It was difficult for them to resort to J. Murray, Marshall's technical adviser. They did not want a traditional factory building -- shortly beforehand, at the beginning of 1796, a mill burnt down completely on their factory site in Leeds. The new factory building should thus be "fire proof". While looking for an architect or construction engineer, the Benyons discovered Charles Bage. It was not feasible to offer him wages for his services, so the Benyons offered him a partnership with a one eighth share. Charles Bage accepted the offer in June 1796 and within a few months he designed the structure of the factory building for the flax mill, Benyon, Bage & Marshall in Castle Foregate in the suburb of Ditherington, the first cast-iron construction ever in the building industry. The building works, which were begun in October 1796, did not even last a year: in September 1797 the building was completely finished. The honour of rescuing this building, which is still standing today and has served as a malt store since the 1890's, from oblivion is to be accorded to J. Bannister (1950), A.W.Skempton and H.R. Johnson (1962) have given more precision to his details by additional measurements on the spot. The five storey building is 12.03 m wide and 53.95 m long (39' 6" by 177') and together with the (southern) engine house which was completed in 1797 and which also served as a staircase, the total length is 59.43 m (195 ft). The external supporting walls, built in bricks, decrease in thickness symmetrically from the base upwards (from 58.42 to 33.02 cm; 23 to 13 in). Originally, the first three storeys were divided into two parts by a partition wall, probably for reasons of fire safety. The ceilings in brick vaulting rest on cast-iron beams which lie on the longitudinal external walls and are supported by three cast-iron supports.

The span of the arches of the brick vaulting measures 304.8 cm (10 ft) regularly to the north of the former partition wall and 320 cm (10' 6") to the south of it, and 365,8 cm (12 ft) in the case of one arch. The arch thickness is 33 cm (13 in) at the beginning, 22.8 cm (9 in) at the crown. The cast-iron beams are 548.6 cm (18 ft) long, thus two beams were necessary for the complete span, being connected above the central support by flanges and bolts. The actual span width was just 274.3 cm (9 ft) as a result of the three supports. The cross section of the support is a trapezoid measuring 27.9 cm (11 in)in



height, the foot 12.7 cm (5 in) in width, the fillet of the support 3.7 cm (1,5 in) at the bottom and 2.54 cm (1 in) at the top. The cast-iron supports have full cruciform cross sections, just like those in Belper. A typical sign is the entasis: the pillars are thickest at the centre and grow progressively more slender towards either end. The height of the supports is uniformly 297.4 cm (9' 2"). The cross section of the supports is uniformly 15.24 cm (16 in),but in the centre row of supports on the ground floor it measures 17.15 cm (6,75 in). The bifurcation of the supports in the centre row does not fulfil any static functions, but is intended for the transmission system from the steam engine to the working machine.
The roof construction consists of brick vaults on cast-iron supports which are, however, here only supported by a cast-iron support in the centre row (thus the span width here was 548.68 cm - 18 ft).The window frames of all 160 windows (16 on each storey along the longitudinal sides) were also in cast iron. All cast-iron elements were constructed by a local foundry, the Hazledine Foundry.
As we can see, in this construction Charles Bage has completely dispensed with wood, he has also eliminated it from the roof and windows. Although this was still not a skeleton construction -- the exterior walls still had a supporting function because otherwise there were no longitudinal beams -- the building in Shrewsbury was an important step in this direction, "the elements of iron skeleton construction are born" (Schädlich).

With this structure, Charles Bage revealed himself to be a superb structural engineer. Even the brevity of the period available to him from the time of his "engagement" in June 1796 until commencement of the building works in October 1796, for the design and working out of the construction elements, is proof of the fact that he was not dealing with the problem of cast iron as a construction material for the first time. He is said to have himself already employed cast-iron supports in his church construction in the same year (Bannister, 1950), Telford built a cast-iron bridge and a cast-iron aqueduct for the Shrewsbury Canal in the vicinity of Shrewsbury in 1795 and 1796. Bage knew W. Strutt and it is inconceivable that he did not know of the use of cast-iron supports in Derby and Belper. There were thus impulses enough for the use of cast iron in structural work and at a first glance the employment of cast-iron beams in structural work seems to have been the only really new thing in construction work which can be attributed to Charles Bage. His reputed dependence on Strutt was, however, refuted by the letters from Bage carefully kept by Strutt and preserved among the latter's papers. From them we can see, as Skempton (1956), Skempton and Johnson (1957) and also J.Tann (1970) have related, that Charles Bage was one of the first to deal theoretically with the problem of stability and loading capacity of cast iron as early as 1796, and finally produced his calculations on the solidity of cast-iron beams in 1803 which reached the same conclusions as those published by the famous mathematician, E. Hodginson in 1831 (Skempton 1956). The form of the supports is the same as that employed by W. Strutt but was not just adopted as a piece of luck, but after the loading capacity had been calculated.

Not only are further factory buildings in Leeds and Shrewsbury proof of the recognition for his capabilities as a structural engineer -- as an entrepreneur in the textile trade he was not very highly esteemed by his colleagues. When the famous Telford-Douglas project for a cast-iron arched bridge with a single opening measuring 183 m (600 ft) was the subject of an expertise by a parliamentary committee of inquiry in 1801, among the experts summoned were -- apart from six mathematicians and eight engineers (including

W. Jessop, J. Rennie, J. Watt) -- a three-man group of "persons having had long and extensive experience in the nature and construction of works of iron" John Reynolds from Coalbrookdale and John Wilkinson from Bradley together with Charles Bage (Barrington 1950). Despite this recognition by contemporaries, Charles Bage, who never published his ideas, was forgotten just as much as his factory building which is still in existence today, and his pioneer work, the first iron construction in structural engineering, was attributed to Messrs. Boulton & Watt. Rediscovered as a result of extensive research by Bannister, Skempton and Johnson some time ago, he has still not been included in the major histories of architecture, not even in the "History of Industrial Architecture" (Drebusch 1976). In the great "History of Technology" by Singer (1958), his name only appears on one drawing, in Kranzberg and Pursell's "Technology in Western Civilisation" (1967), however, his name and his factory building in Shrewsbury were mentioned.

The "first building designed in the new cast-iron technique" (Drebusch 1970), the "prototype of the factory building with interior cast-iron support structure" (Schädlich 1966) was thus the second application of this type of construction and was produced three years later, this time in Lancashire, in the centre of the cotton spinning trade, in Salford near Manchester. We are here referring to the Salford Twist Mill of Messrs. Philips and Lee, erected between 1799 and 1801, according to J. Tann between 1800 and 1802. In the construction there are important differences in comparison with Bage's Flax Mill in Shrewsbury, these changes are to be found in the construction elements (in the form and the measurements of the supports and beams and the connecting system) and in the measurements of the building.
Before we begin with the measurements, a brief note. For technical laymen, such as myself, it is actually astonishing how it was possible for incorrect measurement details which were quoted simultaneously with a ground plan and elevation drawn to scale to be maintained for so long. They have been available since Fairbairn (1854), but Gloag-Bridgewater (1948), Giedion (1941 to 1967) and finally Drebusch (1976) still, quote the length of the building incorrectly as 42.6 m (140 ft) instead of 72.5 m (238 ft); the width is quoted as 12.8 m (42 ft), which is correct for the interior space. Despite the fact that the most important details for the calculation of the basic measurements can be seen from the elevation and ground plan, just a comparison of the length and width on the ground plan is sufficient, even without knowing the scale employed, to determine that one of the figures quoted must be wrong. The relationship L:W in the ground plan is namely approximately 5:1; with a length of 42.6 m, however, just 3:1. This just by the way when dealing with sources.

According to Skempton-Johnson (1962) who re-measured the bases of the building which was destroyed in an air raid in 1940, these details agree with the ground plan and elevation mentioned from the archive of Boulton & Watt, the seven-storeyed factory building (with the engine house and an ante-room) measured 72.54 m long and 14.32 m wide (238 x 42 ft). The outer walls were approx. 0.76 m (30 in) thick. The actual production area had interior measurements of 63.09 x 12.8 m (207 x 42 ft). The height of the seven-storeyed building with roof was about 24.7 m (81 ft), the clear height (from beam to beam) was 335 cm (11 ft) on the ground floor and 305 cm (10 ft) elsewhere.
Transverse beams (two cast-iron beams of 670 cm - 22 ft - length, joined by a flange and bolt link) supported on the exterior walls



and on the two cast-iron supports at a distance of 426.7 cm (14 ft) from one another, whereby the span width of the beams is also given. In the longitudinal direction, the distance between beams and supports was 274 cm (9 ft) and this was the span width of the brick vaulting which divided up the space and rested on the broad-flanged beams.

Apart from the exterior measurements, the building was not only considerably longer than any previously known examples, but also exceeded them in width; something new and in part also a pointer for the further development of cast-iron structural buildings were the supports and beams employed by G. Lee (1761-1821).
In contrast to all cast-iron supports previously employed (cruciform cross section and solid casting), Lee employed cylindrical supports with a diameter of 16.51 cm (6.5 in) on the ground floor and first storey and a diameter of 13.57 cm (5.5 in) elsewhere. The wall of the supports was 1.9 cm (0,75 in) thick, the length of the supports was, according to Skempton, 297.4 cm (9' 2"), that is the same as that employed in Shrewsbury. The supports were mounted on top of one another and carried up through a cylindrical opening in the beams; in view of the diameter of this opening (approx. 8.25 cm - 3.25 in) the connection between the upper and the lower support must have been released with a pin.
The new feature of the cast-iron beams was their profile, which, deviating from the Shrewsbury type, showed a clear step forward to the inverted T-profile beam. The spanning of the width with two beams and their support by just two supports is also a new element. G. Lee, was not to be deterred from the idea of a just two-part beam, not even by Boulton & Watt, who advised him to adopt three-part beams. Remarkable also is the elimination of the contral row of supports. This meant 23 supports less per storey and together with the use of hollow cast supports this meant a considerable reduction of the deadweight of the structure. Furthermore, this also brought the additional advantage that in each storey three areas 4.27 m (14 ft) wide and about 63 m long were created, that is to say a division of space which was more favourable for the erection of production equipment. In one respect this building lagged behind parameters already in existence; it was given a roof construction in wood.

As far as the design of the building, indeed of the whole construction, is concerned, as also the individual construction elements, the structural engineer was George Lee and not Boulton and Watt. From 1796 on, G. Lee had been toying with the idea of entering the flax spinning business and also considered the idea of taking on Watt Jr. as a partner and called in Messrs. Boulton & Watt, who were to supply the steam engine, for consultation on his own construction plans. Because he originally considered a flax mill, it is to be presumed that some time between 1798 and 1800 he collected information on the "fire proof" building in Shrewsbury. The consultations with Boulton & Watt, which are still available in the Boulton & Watt Archive, as also the plan still extant there for the Twist Mill, tempted W.Fairbairn to assert that the design and construction were by Boulton & Watt. According to the research findings of Bannister, Skempton and Johnson (1962) and of J. Tann, exactly the opposite was the case. G.Lee consulted with Boulton & Watt about his own plan, but did not accept the majority of critical objections (to the two-part beams and their connection); the plans in the Boulton & Watt papers -- the most important collection concerning early factory buildings -- are not building projects for this factory building, but sketches and plans of the already existing building. The outcome: "Although Boulton & Watt's opinions were valued by Lee, on major points their advice was rejected and on the available evidence it must be said that Boulton & Watt did not play a major role in the design of the Salford Twist Mill" (J.Tann). Thus in statements, such as that e.g. last formulated by Drebusch in 1976 -- "even the first factory building designed in accordance with the new cast-iron techniques came from two technicians: in 1801, Watt, together with his partner Matthew Boulton, conceived a cotton mill for Messrs. Philip & Lee in Salford" nothing agrees with the facts. However, it is plainly a very wearisome task to expunge widely known facts from specialist literature, however wrong they might be, by means of well-founded special studies and monographs (Bannister, Skempton, Tann).

Nonetheless, Lee's Salford Twist Mill was a very important step for the spread of cast-iron construction in the textile industry, for it was the first factory of this sort in the centre of the cotton trade, in Lancashire. With the innovations already emphasised (supports in hollow casting, greater width of the building and better division of space by the use of just two supports per beam), this factory building concluded the first phase of the application of cast iron in building construction.

Together with the type of construction developed by Charles Bage, which was improved with the construction of the factory building in Meadow Lane in Leeds (1802-1803) by Bage himself and with the construction of the North Mill in Belper (1803-1804) by W. Strutt, in some details (beam profile, link between beams and supports), these two methods of cast-iron beam construction dominated factory construction in Great Britain for roughly the next thirty years. Although cast-iron construction in building, in factory buildings or workshops, did also produce more artistic forms with the new construction material in individual cases (e.g. Stanley Mill in Stonehouse near Stroud in Gloucestershire - 1813; main hall of the Blockmills in the Royal Naval Dockyard in Portsmouth, built by S. Bentham, 1803 to 1808), these forms, which Carl Friedrich Schinkel had also accepted as architecture, remained the exception. Mainly in the industrial conurbations, such as in Lancashire and in West Yorkshire, simple and unpretentious functional structures predominated among the factory buildings and warehouses of whatever construction they might be: "the huge structural masses, just from a master builder, without any architecture, carried out for the simplest of needs in red brick" (C.F.Schinkel in 1826).
It will hardly be possible to determine the exact proportion of cast-iron buildings in the mass of factory buildings, even just in the textile trade in Great Britain, despite considerable research into that industry. After such construction techniques had ceased to be something entirely novel, they were only registered in exceptional cases. Thus, for instance, in the event of the collapse of a building, a danger which was especially great in view of the lack of certain methods of checking material in hollow cast products (thus in cylindrical supports). Descriptions of factory buildings by contemporaries, analyses of capital expenses in the textile trade and of the costs of cast-iron construction support the opinion that the technique of completely iron construction had not completely gained the upper hand and that even in new structures from the 1820's to 1850's, the Strutt type of "fire proof" building (cast-iron supports, wooden transverse beams and brick vaulting) was preferred. Thus in a letter from C.P.W. Beuth to C.F.Schinkel in 1826 we can read: "Such a structure is eight, even nine storeys high,often has forty windows longitudinally and roughly four windows depth. Each storey is twelve feet high, all are vaulted, namely with a nine foot space for the entire length. The columns are in iron.The beam which lies on it also; walls and external walls like sheets of



card, not even two and a half feet thick in the second storey".This was the so-called fire proof mill of the Strutt type (Derby 1792), and on the basis of what one can describe as certain knowledge, not even this structure would seem to have been the most wide-spread.A Handbook of Building and Machine Techniques for Cotton Mills from 1909, and also industrial archaeological research from the 1950's have determined that the majority of English textile mills from between 1825 and 1865, and in Preston until the last two decades of the nineteenth century, were, it is true, built with cast-iron supports, but with wooden beams and wooden ceilings. Basically, this is not surprising. Factory buildings were not built as pretentious structures by the majority of entrepreneurs; if money sufficed,there were the dwelling houses or the company's offices in the City for that purpose. The new construction technique only came fully into play where it seemed absolutely necessary, usually for production technique purposes (e.g. new machines which meant more space required and/or a greater load on the structure) and also if funds were available in order to be able to carry out long-term planning and investment. One can assume that the additional costs of about 25 % for a fire proof construction, as shown for the end of the eighteenth century, still continued to exist despite progress in iron production. And in this case, in these first iron constructions, the entrepreneur, the architect, the construction engineer and the owner were all one and the same person. One cannot attribute capabilities such as Strutt, Bage and Lee had to all entrepreneurs in the industry. For the majority of them, the new method of construction went beyond their capabilities, they would have decides for an iron construction and a design such as could only have been produced for payment. Thus, even for that reason, it was cheaper for them to keep to the old system in construction, for which there were specialists in their own company and for which, if necessary, old structural material could be used. This is a further sign that the importance in technical development does not have to go hand in hand with the degree of spread in the economy.

To summarise: While looking for ways and means to reduce the danger of fire in the textile mills with their increasingly complex machines, which also required ever more room for their erection and operation, the textile industry was the first to adopt a new building material, cast iron. The most important stages of the early history of cast-iron constructions in the building industry for production plants were:

1) The Calico Mill in Derby, built by William Strutt in 1792/93 with cast-iron supports but wooden transverse beams and with brick vaulting instead of wooden ceilings.
2) The Flax Mill of Messrs. Benyon, Bage & Marshall built in Castle Foregate in Shrewsbury (Ditherington) by Charles Bage in 1796/97 -- the first completely iron construction in the building industry. Cast-iron supports, beams, roof and windows, ceilings in brick vaulting, flooring in brick tile.
3) Salford Twist Mill of Messrs. Philips & Lee in Salford (Manchester), built by George Lee 1799-1801. Construction characteristics as in Shrewsbury, but the first application of cylindrical cast-iron supports. Wider span of the beams, thus larger standing and working areas, Considerably larger dimensions of the building.

These forst two structures with cast-iron construction (Shrewsbury and Salford) were not real iron skeleton structures, the external walls played an important part in the support. Their importance lies in the fact that they helped the new construction material, cast iron, which had previously had its home in bridge and canal construction, to achieve a breakthrough in building construction, by which means the new building material opened the way to a more purposeful employment of space and was thus decisive for the whole first half of the nineteenth century. They were, to exaggerate a little, also the precursors of erection work employing pre-fabricated parts: the cast-iron elements had to be produced industrially with exact measurements. It is difficult to establish to what degree they fulfilled the original purpose of increasing fire safety; the elimination of free standing wooden parts, thus of the supports, was obviously regarded as the most important change in this respect, which the frequent application of Strutt's construction (Derby 1792/93) in the nineteenth century would also seem to prove.

Apart from the chronology of the first cast-iron constructions in structural engineering, the research of the past thirty years has also corrected biographies. The architect and construction engineer of the first cast-iron construction were neither W. Strutt nor Boulton & Watt, but the newly arrived entrepreneur in the flax mill trade and private scholar in the field of engineering construction, Charles Bage. And the justifiably much admired Salford Twist Mill should be put on the account of the specialist knowledge of George Lee and not to the benefit of Boulton and Watt, who had no reason anyway to claim others' achievements as their own. The manifold aspect of W.Strutt's, C. Bage's and G.Lee's works fits in very well with this period of the first phase of the Industrial Revolution as basic knowledge in several fields was still to the fore in front of specialisation. Coupled with a degree of prosperity which ensured adequate leisure for such "pastimes", such firm basic knowledge sufficed for some personalities in order to produce above average work in several fields.
It is even less surprising that the works mentioned in the field of the application of iron construction in building construction were produced in the field of the textile trade. For it was in the spinning mill that complete transformation of traditional production techniques had begun which was an important characteristic of the Industrial Revolution. In the textile industry came the first massive employment of machines and a centralisation of production in factories, the traditional method of construction of which soon stood in the way of further centralisation. In contrast, for example, to iron foundries, one could not here just flee into workshops or halls in which the wind blew in and out; in order to be able to employ the new technology profitably, the textile industry, like no other, needed buildings which apart from static qualities equally good as the old ones, also provided more surface space and working area and also safety for the expensive equipment (rather than for the workers). It was thus little wonder that it was precisely in the textile industry that some entrepreneurs wracked their brains more about new construction techniques than was the case with constructions in general or with the foundry industry, and were more receptive for new ideas and finally also found the solution.

Notes

Ashmore, O., Industrial Archaeology of Lancashire, Newton Abbot,1969
Bannister, T., The First Iron-Framed Buildings; in: Architectural Review, 107 (1950).
Benevolo, L., Geschichte der Architektur des 19. und 20. Jahrhunderts (1960), DTV Ausgabe 1978.
Chapman, S.D., Fixed Capital Formation in the British Cotton Manufacturing Industry; in: Aspects of Capital Investment in Great Britain 1750-1850 (ed.Higgins-Pollard), London 1971.
Condit, C.W., Buildings and Construction; in: Technology in Western Civilization (ed.Kranzberg-Pursell) Bd. I, New York 1967.
Drebusch, G. Industrie-Architektur, München 1976.
Fairbairn, W., On the Application of Cast and Wrought Iron to Building Purposes, London 1854.
Giedion, S., Space, Time and Architecture Cambridge (Mass.)1967;
Glas und Eisenkonstruktionen des 19. Jhs. in Grossbritannien. Bericht über ein Seminar und eine Exkursion im WS 74/75. TH Darmstadt, Fachbereich Architektur Darmstadt 1975.
Gloag, J. - Bridgwater, D., A History of Cast-Iron in Architecture, London 1948.
Hamilton, S.B., The Use of Cast-Iron in Building; in: Transactions of the Newcomen Society XXI (L941/42). Building and Civil Engineering Construction; in: Singer Ch. u.a. (Hgg.), A History of Technology, Bd.IV. Oxford 1958.
Meyer, A.G., Eisenbauten. Ihre Geschichte und Aesthetik. Esslingen 1907.
Pacey, A.J., Earliest Cast-Iron Beams; in: Architectural Review, 145 (1969).
Rimmer, W.G., Castle Foregate Flax Mill; Shrewsbury Transactions Salop Arch. Society LVI 1957-58.
Schädlich, Ch., Das Eisen in der Architektur des 19. Jahrhunderts. Beitrag zur Geschichte eines neuen Baustoffes. Habilitationsschrift Weimar 1966.
Skempton, A.W. - Johnson, H.R., William Strutt's Cotton Mills 1793-1850; in: Transactions of the Newcomen Society, 30 (1955-1957). The First Iron Frames; in: Architectural Review, 131 (1962).
Skempton, A.W., The Origin of Iron Beams; in: Actes VIII International Conference of the History of Science, vol. 3, Florence 1956.
Tann, J., The Development of the Factory, London 1970.
Treue, W. - Pönicke, H. - Manegold, K.H., Quellen zur Geschichte der Industriellen Revolution, Göttingen 1966.