Construction History Vol. 9. 1993

The Development of Fireproof Construction in Great Britain and the United States in the Nineteenth Century

SARA WERMIEL

Introduction

Although the word "fireproof" has disappeared from the builder's lexicon, nineteenth century architecture and engineering journals routinely discussed fireproof construction. To modern ears, "fireproof building" is an oxymoron, since, as I am frequently told, it is the contents of a building that burn, not the structure. But this is true only for certain buildings – in fact, only for fireproof buildings. The vast majority of homes in the United States are not fireproof and burn very well. On the other hand, new buildings in city centres generally are fireproof, as they are compelled to be by building laws. Today, because most buildings which the public can enter are, in the nineteenth century sense, "fireproof", there is no reason to distinguish them from "non-fireproof" buildings, and so the designation has fallen out of use. The predominance of fireproof buildings is a twentieth century phenomenon. In 1800, only a handful of buildings that could be called fireproof existed in Great Britain and the United States. By the end of the century, fireproof construction was standard for tall buildings in the United States, a type which increasingly dominated the downtowns of large American cities, and a great variety of systems for constructing fire-resisting buildings was available in both nations. As fireproof buildings replaced buildings of ordinary construction, the danger of general conflagration decreased. After the first decade of the twentieth century, the era of great urban conflagrations in the United States was over.

What, then, is a fireproof building? In nineteenth century terms, it was a building constructed of incombustible materials; in other words, wood was not used structurally or if used, was protected with some non-inflammable material. The discarding of wood applied particularly to the interior of structures – to the spanning parts – since exterior walls were easily made incombustible. Indeed, since the seventeenth century, public authorities in London and Boston, Massachusetts, for example, required that walls of buildings in the town centres be made of brick or stone, as a fire protection measure.[1] Yet the interiors of even masonry-walled buildings – the floors, partitions, and roofs – were made of wood, as well as the window frames, doors, cornices, and so forth, which could communicate a fire on the outside of a building to the inside.

Despite steady development in practice, and contrary to popular belief, a fireproof building conferred no magic immunity from harm. "Fireproof construction must not be understood to mean a mode of constructing buildings in which no fire can arise; nor does it even imply that the buildings so called fireproof are absolutely safe from destruction or damage by fire", *Building News* explained in 1861. Rather, "fire-proof construction ... is little more than construction in which incombustible materials only are employed."[2] Likewise, Peter B. Wight, an American architect and authority on fireproof construction, observed in 1879 that "the most that can be attained by the best known systems of fire-proofing – and this is the main thing after all – (is) the preservation of the constructive portions of a building".[3] In so defining the term, neither writer meant to minimise the importance of fireproof construction but rather to caution what a fireproof building could and could not do. Fireproof buildings were intended to check the spread of a fire and eliminate the structure itself as a source of fuel. The building should be designed so that the floors and roof act as horizontal firebreaks, just as masonry party walls and parapets made vertical firebreaks. By creating fire-resisting compartments, and thus containing a blaze, a fireproof building bought time, for occupants to escape and firefighters to do their work. Thus, fireproof buildings had to be more than merely compositions of uninflammable materials, and they had to be backed up by a means of suppressing a fire. Ideas about what constituted best or prudent practice changed over the course of the century, as understanding of the performance of materials and the relative value of certain design features and fire protection appliances increased.

In this paper, I trace the development of, and attempt to account for differences between, fireproof construction practices in Great Britain and the United States in the nineteenth century. To know what in theory constituted the best fireproof construction I rely on contemporary authorities – the architects, engineers, fire insurance underwriters, and construction materials manufacturers who studied, worked on, and wrote about fireproof buildings.

Fireproof Buildings Before Iron and Brick Arched Floors

The British engineer Charles Sylvester, commenting on developments in structural fire protection in an 1819 pamphlet, wrote that before the introduction of the iron and brick system, fireproof buildings had been made "with ceilings and roofs of stone". Already in the mid-eighteenth century the architectural writer Batty Langley proposed a solid masonry building system "to prevent the sad consequences of fire in dwelling-houses". It consisted of "brick floors, with arches, groined, or coved ceilings", as well as stucco trim, stone staircases, brick interior partition, and lead covering for the roof.[4] Whether or not dwellings were built this way, at least some small industrial buildings at the Royal Dockyards were constructed with brick vaulted roofs for fire protection. Also at the dockyards, cellars in buildings for holding flammable stores were covered with brick vaults.[5] While evidence is very scanty as to how extensively the system was used in Britain, it is probably safe to take Sylvester's word that "such buildings are very uncommon, very expensive, and the principle upon which they are constructed is not at all adapted for the common purposes of life".[6] However, vaulted cellars continued to be built in Britain in the nineteenth century for secure storage.[7]

In the last quarter of the eighteenth century, fires occurred in London with "alarming frequency", prompting calls for public intervention.[8] In the first significant revision of London's building laws since the Great Fire over one hundred years before, the Act of 1774 added metal, artificial stone (concrete), and tile to the list of materials allowed in exterior walls, which materials came to be the principal ones used in new systems of fireproof construction.[9] At this time in Britain, however, no one had yet proposed a substitute for wood in floors (save for impractical vaults).

Rather, invention went in the direction of better protecting wood, thereby creating fire barriers. One invention, patented by David Hartley in 1773, wrapped wood floor members in thin sheets of iron called "fire-plates".[10] Although Hartley tested his invention in a building known as the Fireproof House, the plates were a way of making ordinary construction slower burning, not of making a fireproof, or incombustible, building. The plates were used in public and industrial buildings – for example, at storehouses in the Royal Dockyards in the 1780s[11] – and dwellings. While Hartley's plates seem to have gone out of use by the turn of the century, some building owners continued to wrap sheet iron around wood structural members for fire protection. For example, in 1807, the roof timbers of an existing corn mill, which became a wing of the new fireproof Armley textile mill in Leeds, were wrapped in thin sheets of iron.[12] A second proposal was an application of a kind of concrete, such as was used to deaden floors, to fire protection. In 1778, Lord Mahon proposed that the spaces between joists be filled with a mixture of lime, sand, and chopped hay to a depth of about one and one half inches.[13] Like Hartley's plates, this system could be applied to existing buildings. In the same vein, building owners sometimes placed plaster around beams and under flooring with the idea of making floors more fire resistant. But

such measures could create structural problems. While common lime plaster was found not to exclude air from wood, plaster (a natural material, so of varying compositions) could cause dry rot unless the wood beneath was ventilated, as could sheets of iron tightly wrapped around wood.[14] Various methods for protecting wood were improvised over the years: wire lath and plaster, paints made with alum, interlocking tile plates, and slabs of "fibrous plaster". But to make a truly fireproof building a substitute for wood had to be found.

By the 1790s, just as British building owners started experimenting with iron joinery, solid masonry fireproof buildings began to appear in the United States. The masonry system continued to be the method of building fireproof in the United States until the late 1840s. Unlike in Britain, where extant examples suggest that such buildings were small, the American masonry fireproof buildings were relatively large public buildings. Commissioned by federal and state governments for the most part, they often were several storeys high, with floors formed of brick barrel or intersecting arches carried on exterior walls and interior partitions or columns of stone or brick, levelled with concrete, and covered with stone or terracotta tiles. The system probably was first used in Philadelphia, where a prominent early example was the Bank of Pennsylvania, designed in 1789 by Benjamin Latrobe. Latrobe had recently immigrated to America, having apprenticed and practised architecture in his native England, and probably brought knowledge of this method of construction with him.[15] Latrobe's apprentices, Robert Mills and William Strickland, and Strickland's student Thomas U. Walter, went on to design most of the fireproof buildings erected in the United States in the first half of the nineteenth century.

Robert Mills was especially prolific, designing many fireproof buildings while serving as architect and engineer for the state of South Carolina in the 1820s, and later as architect and engineer for the national government. Several of his fireproof custom houses and court houses still stand, as do his Treasury, Patent Office, and Post Office buildings in Washington, DC, the last three built between 1836 and 1842. (Fig 1.) Despite his experience designing such buildings and attempts at innovation, Mills was unable to overcome the limitations of the system. For example, in the U.S. Treasury building, he tried to make the exterior walls thinner by constructing the floor arches with "hydraulic cement", which he believed "constitute them like

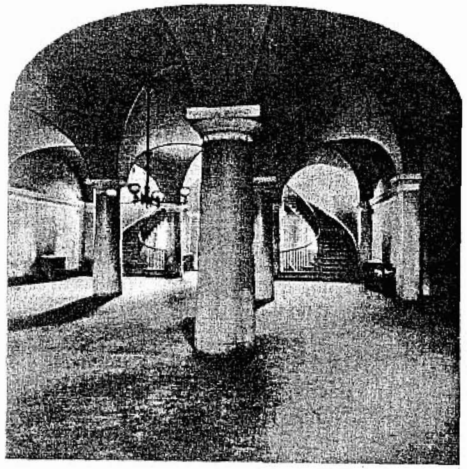

Fig 1: Stone columns and fireproof vaults in the Old U.S. Patent Office, Washington, D.C., built 1836–40 (Collection of the National Portrait Gallery, Smithsonian Institution).

one mass of masonry, relieving the lateral, and increasing the perpendicular press of the arches". This building became the target of a Congressional committee, inquiring whether it was unsafe and Mills incompetent.[16] While politics and professional rivalry muddled the investigation, nevertheless it seems that there was no settled practice for constructing such buildings. And indeed, these cave-like buildings were not very practical. An unhappy resident of Newburyport, Massachusetts, described Mills' damp custom house fifty years after it was built: "...there was not in the city a more dreary and desolate place than the Custom House".[17] But although unsatisfactory as buildings, they undoubtedly were fire resistant.

Fireproof Construction in Britain, 1790–1860

The search for less expensive and more practical systems for constructing horizontal fire barriers, principally floors, went in several directions in Britain in the late eighteenth century. One was brick floors, springing from cast iron beams; a second was floors of hollow clay products, supported by walls or iron beams; and a third was floors of concrete, with or without embedded iron joists. Iron first began to be used for structural members at this time. Improved methods of smelting iron ore, using coke rather than charcoal, spread rapidly in the last quarter of the eighteenth century, contributing to a much increased output of pig iron and its use for a greater variety of purposes, including construction materials. Iron was considered fireproof because it could not burn, and became an important component of the new systems of fireproof construction.

Iron and Brick

In the 1790s, the iron and brick arch system of construction, which came to define fireproof construction, was introduced by William Strutt and Charles Bage in their multi-storey, mechanically powered textile mills. A considerable literature on the history of this system in mill buildings in Great Britain is available, so I shall only mention a few points about them.[18] Fireproof mills appeared in the major textile areas of Lancashire and Yorkshire, though because they were much more expensive to build than ordinary timber mills, only well capitalized manufacturers built them.[19] Often fireproof mills were built to replace mills that had burned down. Not until the end of the nineteenth century did fireproof construction become standard for new mills.

The mills were built with bearing walls of brick or stone, typically in a rectangular shape. Cast iron beams ran across the narrow dimension, resting on the exterior walls and in between on one or two rows of cast iron columns. Brick segmental arches, which sprang from the beams, were levelled with sand, ash[20] or "hard rubbish" and at this time were paved with tiles or flags.[21] The shallow arches reduced the thickness of the floor but created narrow bays. Improvements in beam design were in the direction of using metal more efficiently and creating wider bays, but all beams had an angle or flange projecting from their lower portions to start brick arches or carry the skewbacks for an arch. Typically, the roofs of fireproof mills were built of wood, covered with slates.

A second system of fireproof mill construction, developed perhaps to increase the span between beams as well as to reduce the weight and depth of the floors, consisted of an iron framework filled in with large flag stones, making a flat floor. A number of mills and warehouses constructed this way date from the 1820s and 1830s, of which the Beehive Mill, Manchester, is an extant example.[22] Also in the 1830s, a Mr. Farrow patented a version of this type of floor, using small wrought, rather than cast, iron joists in the shape of an inverted T such as were being rolled in France, on which were placed stones of the depth of the joist, which

could form either the floors or roofs of fire-resistant buildings. These floors were used in some sugar refineries – a very hazardous business.[23] However, experience soon showed that stone was not a satisfactory material for fireproof buildings, since most kinds could be badly damaged in a fire.[24]

Space in textile mills and warehouses could be compartmentalized with relative ease; not so the non-industrial buildings which were constructed with brick and iron fireproof floors, beginning in the 1820s and 1830s. Mills needed vertical openings for little besides the stairways, lifts, power, water service, and heat pipes, all of which could be walled off from the main floor, or in the case of staircases, put in a separate tower. Architects of public and institutional buildings, the type which tended to be built fireproof, generally relied on the incombustibility of the materials to protect the buildings rather than compartmentalizaion.[25] Charles Barry designed a number of buildings in which incombustible materials were used for the sake of fire protection, but the buildings as a whole probably were not conceived as fireproof structures. For example, only after his design for the Houses of Parliament was accepted did the Government order the building to be built fireproof. This was accomplished "by substitution of iron girders and brick arches for ordinary floors, and iron roofs instead of slated coverings" – the latter modelled on roofs of public buildings in France, according to the architect's son, Edward Barry. He also described the floors of the tower as "fire proof receptacles for records and papers of value".[26] Thus the building was compartmentalized where necessary, but not generally. Office buildings, not containing the kinds of flammable contents found in warehouses or mills, were considered low risk structures. Parts of Charles Barry's Reform Club (1838-41), such as the floors over the basement where the kitchen was located and over the first floor, were made of iron beams and brick arches; and the public stairways were enclosed, though whether this was for fire protection, I can not say. At the same time, the servants' stairs, roof, some partitions, and finishes were made of wood, so the building was not thoroughly fireproof.[27]

Hollow Tile

A 1793 report of a committee of architects, which tested David Hartley's and Lord Mahon's fireproofing systems, mentioned a hollow tile which also could be used for fireproof floors: "Arches of Cones, or Bricks, or Tiles ... will answer the purpose, but they are more weighty and expensive." Tile is the general name for materials made of fired clay, with the exception of brick. "The advantage arising from the use of Cones, when compared with Bricks, is their superior lightness (being twice the bulk and only half the weight) and their being applicable to Arches of a very small rise".[28] The cones referred to were made by a pottery near London. The top floor of William Strutt's fireproof mill in Derby, under construction in that year, was made of hollow pots manufactured in Britain. Pots also formed the top floor, of two other pioneer fireproof buildings: a warehouse in Milford built in 1793, and West Mill in Belper built in 1795.[29]

The pot idea probably came from France, where floors of brick arches carried by timber beams – like those first introduced in Britain by Strutt, save for the shape of the beam – were being built in the late eighteenth century. Benjamin Franklin described them in a 1771 letter: "In some of the Paris Buildings the Floors are thus formed. The Joists are large and square, & laid with two of their Corners up and down, whereby their sloping Sides afford Butments for the intermediate Arches of Brick. Over the whole is laid an Inch or two of Loom, and on that the Tiles of the Floor..." The joists were tied with iron bars and a ceiling under the joists made of lath and plaster. "But it is heavy, taking up more Room, requires great strength of Timber and is I suppose more expensive than Boards".[30] It may have been the longer experience

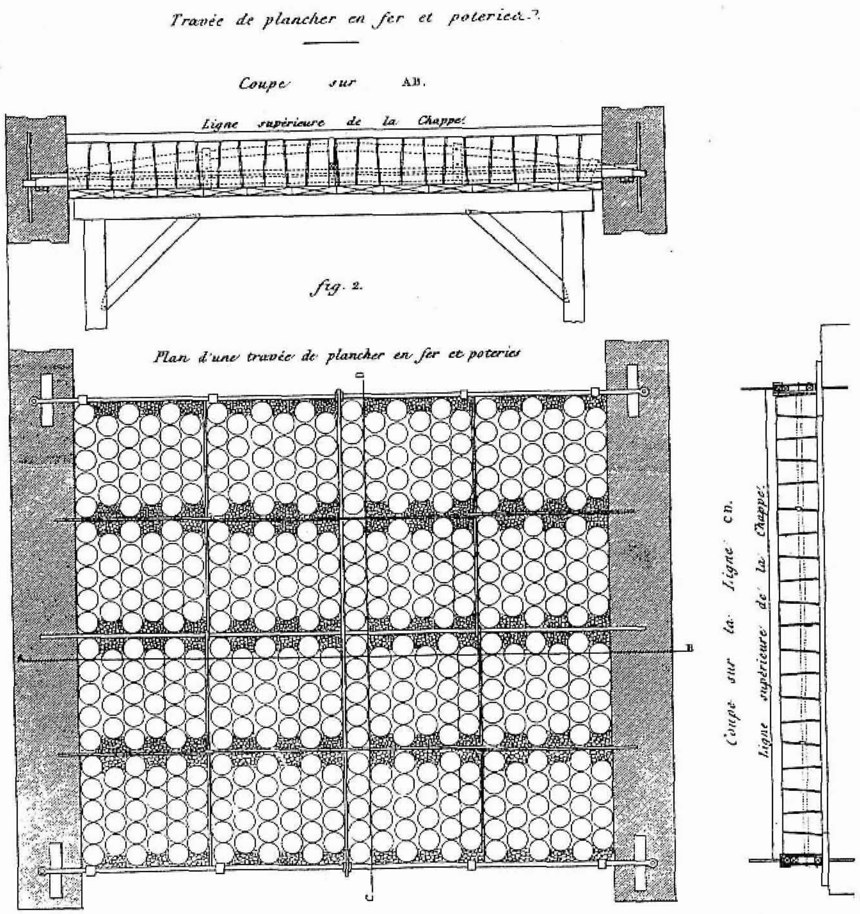

Fig 2: French method of constructing a floor of hollow pots and iron beams (from Charles Eck, *Traité de Construction en Poteries et Fer*, 1836).

French builders had with these heavy floors that prompted a search for a lighter structural clay product. At any rate, hollow pots – a rediscovery of an old method of construction – appear in about the 1780s, and soon were used in conjunction with rolled iron in a system of fireproof construction known as "poteries et fer". The pots, wrote architect Charles Eck in his 1836 treatise on the system, in combination with iron, created very light, solid and absolutely fireproof masses, and could be used in the construction of partitions, roofing, vaults, floors and stairs. He illustrated examples of the system, as used in theatres, government buildings, and market halls in France.[31] Several kinds of tiles are illustrated in Eck's book, but the "cone" type was narrower at one end than the other; they were placed alternately right side up and up side down to form a flat floor, or narrow side down to form an arch. The pots were made by hand, thrown on a potter's wheel. (Fig. 2)

Hollow pots springing from stone skewbacks resting on iron beams were used for fireproof floors in buildings in England from about the 1790s to the 1840s, including several government buildings, a mansion or two, and the domed roof of Soane's Bank of England. But they were never used in as many buildings, or applied to as many structural purposes, in Britain as in France. This may be because, as built in Britain, they offered no great advantage over brick: pot floors were relatively deep and average spans, at 4½ – 7½ feet, were less than those of brick arch floors.[32] In addition to pots, hollow bricks also were used in France and a couple hollow brick systems were introduced in Britain, but they were little used.[33]

John Webster, in his comprehensive 1890 survey of fireproof construction materials, was probably correct when he suggested that the ability to produce hollow tiles by machine was important to the success of this system. He gave 1845 as the date of the first successful tile forming machine.[34] But there is evidence of machine-made hollow tiles at an earlier date, though the specific product may not have been widely used. In the 1830s, a builder, James Frost, introduced square, hollow tubes "made by a machine" for constructing floors and flat roofs. The "machine" may have been like the sewer pipe press used to make hollow tiles in the U.S. some five decades later. Frost's tubes, 2½ inches square and a foot long, were laid flat in two layers at right angles to each other, bonded with a "cement" of chalk and clay, and topped with mortar. While the floors were only perhaps 6-7 inches deep and comparatively light, they were not designed to have intermediate supports, so apparently were intended for small rooms.[35] The desideratum of lightness combined with greater span was not accomplished until Joseph Bunnett patented his hollow tile system in 1858.

Concrete

Probably the first fireproof concrete floor in Britain was that installed by Henry Fox in the 1830s at his private asylum near Bristol. The floors of this building are made of cast iron joists, of inverted T section, with heavy laths resting on the bottom flange, forming a permanent centering. A layer of mortar covered the laths, and then a thicker layer of mortar mixed with an aggregate, followed with a finish layer of lime and sand.[36] Although patented in 1844, the system seems not to have been used until some years later, after Fox joined with James Barrett, a building contractor, who promoted the system. Barrett claimed his floor weighed 78 pounds per foot, comparable to a floor made of half-size brick arches but about two-thirds the weight of full-size brick arches. By his calculation, in 1853, a 63 x 28 foot mill floor built his way cost about 40 per cent less than a brick and iron floor.[37] In the 1850s, Barrett began using rolled iron joists rather than cast iron; however the joists continued to be closely spaced, about 1½ feet apart. The eventual product, known as the "Fox and Barrett" floor, was installed in hospitals, residences and office buildings.[38]

Also by the 1850s, French methods of constructing concrete floors began to receive attention in Britain. For example, in 1854, H. H. Burnell read a paper at the R.I.B.A. on the French "iron floors". He described two systems used in Paris, both of which consisted of closely spaced rolled iron joists which carried small iron bars; the iron was covered with plaster. These floors apparently had not been developed in France as a fire protection measure; rather, they were improved versions of floors which came into general use following a carpenters' strike in the previous decade.[39]

Thus, in Britain by mid-century, the cast iron and brick arch system was well established, a number of patented systems of floor and roof construction were in use, and certain principles of fireproof construction – the concept of compartmentalization and the need for fire breaks in wall cavities – had been discussed in print in several places.[40] However, few kinds of buildings were built fireproof – mainly prominent government and institutional buildings, the better capitalized textile factories, some warehouses, and model housing. London's building laws did not require any building to be wholly fireproof. Rather, the Building Act of 1844 codified the tendency to concentrate fireproof materials where they might, theoretically, do the most good. Thus access ways in the public building class, and stairs in multi-unit buildings in the dwelling class, were required to be fireproof. Large buildings such as warehouses could not exceed 200,000 cubic feet, although openings in party walls between warehouses were allowed, if protected with iron doors.[41]

In American cities, such building regulations as existed were concerned with exterior materials of construction. Very few fireproof buildings existed, mainly the solid masonry type, built mainly for government or institutional owners. Manufacturers did not build fireproof buildings. Iron and brick construction was just beginning to be taken up. Not until the 1840s did American iron production increase to the point where it could be used extensively in building construction. Before this time, cast iron columns were imported.[42]

Introduction of the Iron and Brick Fireproof Building in the United States, 1850 – 1870

The American production of castings for buildings increased considerably by mid-century, as urban foundries – what became known as architectural iron works – began to manufacture building facades, columns, lintels, stairways and so forth. In the late 1840s, a few fireproof buildings modelled on the British iron and brick fireproof non-industrial type were commissioned by government clients. By 1854, one of the nation's leading iron manufacturers – Trenton Iron Works in Trenton, New Jersey – succeeded in rolling T shaped beams, referred to by contemporaries as "deck beams" since they were shaped like those used in iron ships.[43] This new product came on the market at a propitious time, when the U.S. Congress was busy voting approbations for the construction of government buildings in newly settled regions as well as replacements for out-dated buildings in the East. Between 1854 and 1857, about seventy custom houses, court houses, post offices, marine hospitals, and specialised buildings were authorised. All were fireproof, and all were built with internal iron structures, using the new beams from

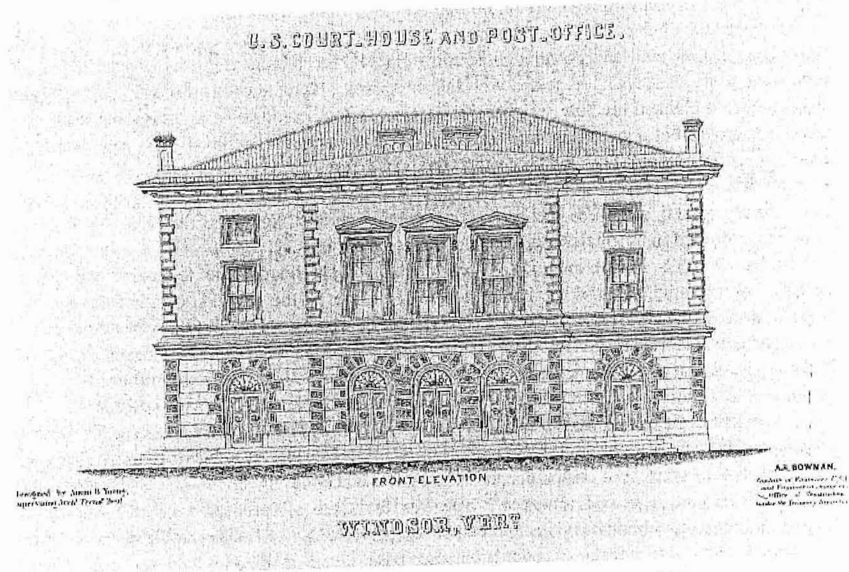

Fig 3: Court House at Windsor Vermont (from *Plans of Public Buildings*, 1856).

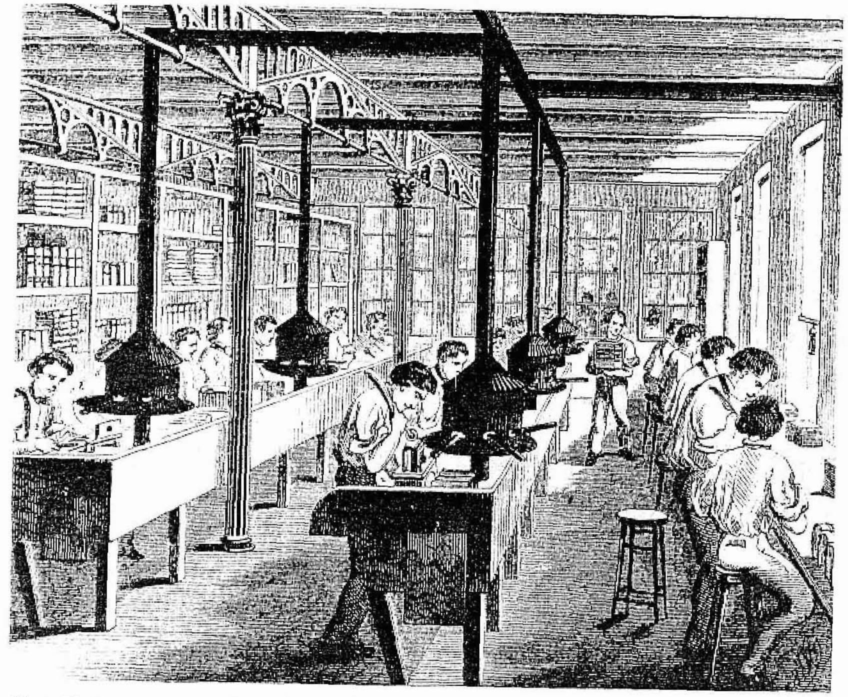

Fig 4: Workroom on the upper floor of Harper's Publishing House, 1855 (from Jacob Abbot, *The Harper Establishment*, 1855).

Trenton. Also, interestingly, all were built from designs of one architect, Ammi Burnham Young, who was employed by the U.S. Treasury Department – the agency responsible for building these structures (Fig. 3). Unlike the masonry system, the iron and brick system also began to be used by owners of commercial buildings to a comparatively large extent.

The girders used in the American iron and brick buildings came in a variety of sections. One of the earliest was in the form of an arch made of cast iron with the ends tied by a rod of wrought iron (Fig. 4). This girder was used in the Harper Brothers' publishing house of 1855 and one of the first brick and iron fireproof buildings in the U.S. to use "solid" – as contemporaries called them – wrought iron beams. The girders designed for the Treasury Department buildings were made of rolled plates, channels, and double beams. Girders could be manufactured in large sizes, such as the 30 inch deep, 41½ foot, 6,600 pound girder shipped from Trenton in 1857. The dimensions of rolled beams increased rapidly, from a 7 inch deep bulb headed beam to a 9 inch I shaped beam about two years later (Figs. 5-6). Both sizes weighed about 31 pounds per foot, and could be made in lengths of 20 feet and more.[44] As with rails, the long lengths were made by "piling" and rolling puddled bar iron. Other mills began producing rolled iron beams, although only the largest were able to do so. These products were developed primarily for fireproof buildings. At this time, the firms that bid on contracts for manufacturing and erecting the iron work in these buildings were architectural iron works.[45] They or the builder (often a masonry contractor) ordered the rolled beams and girders from the few companies that made them, and then iron workers from the foundry firm did the set up.

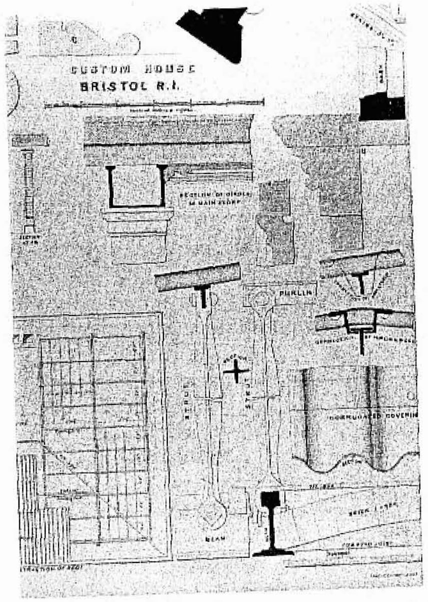

Fig 5: Ironwork in the Custom House at Bristol, Rhode Island (from *Plans of Public Buildings*, 1856)

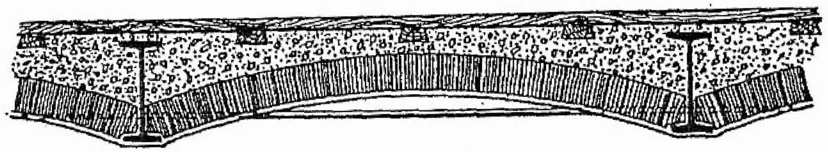

Fig 6: Typical American iron and brick fireproof floor (from J.K. Freitag, *The Fireproofing of Steel Buildings*, 1899)

By the time American iron and brick fireproof buildings began to be built, the system had fallen out of favour for new institutional buildings in Great Britain, although it continued to be the system for constructing industrial buildings until the end of the century. Nevertheless, the American system differed from the British iron mill in a number of respects. First, American floors were made of iron girders carrying smaller iron joists, with brick arches springing from the joists. British mills used girders only, and therefore required more columns. Second, the brick arches in the government buildings usually were filled with cement concrete, like the arches in the earlier masonry fireproof buildings. Concrete did not begin to be used in this way in British mills until the 1860s.[46] Third, the roofs of the American buildings were made of iron, with cast and rolled iron supports and corrugated iron covering (Fig. 7). The roofs of British mills usually were framed in wood. Lastly, as little wood as possible was used in the American buildings: thus the window frames and stairways were made of iron, and floors were covered with stone or tile. The buildings also were supplied with iron shutters unlike British fireproof mills.

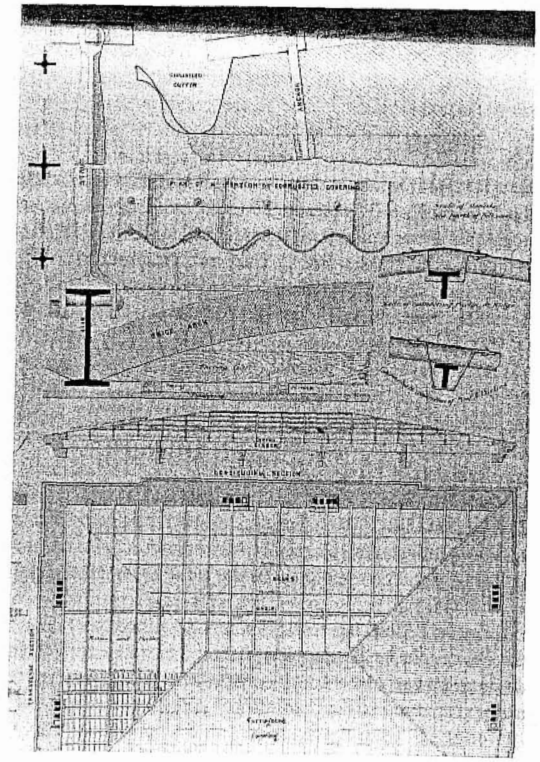

Fig 7: Details of the roof, Custom House, Portsmouth, New Hampshire (from *Plans of Public Buildings*, 1856).

Why wrought iron beams, which were available in Britain in the 1840s, were not more used in British iron and brick mill buildings – as joists, as in the non-industrial buildings, or as girders – is something of a mystery. Even the most exemplary plants, for example the huge integrated mill in Yorkshire built 1850-53 by William Fairbairn for Titus Salt, was constructed with cast iron beams carried on columns.[47] Fairbairn's important book on the construction of fireproof buildings, published in 1854, discussed the superiority of wrought iron over cast iron for beams, but did not suggest that they might be used as joists in combination with girders.[48] The girder and beam system began to be used in railway warehouses in Manchester in the later 1850s or 18609s[49], and in textile factories in Lancashire by the last decade of the century.[50] Nevertheless factories throughout the century continued to use cast iron.

Fireproof buildings were built around the country, but especially in New York, which was located near to Trenton. The example of the government buildings undoubtedly helped popularize the system. Fireproof buildings built for commercial clients in the 1850s and 1860s include the American Exchange Bank, Continental Bank, Hupfel's Brewery, Metropolitan Gas Works, and Mutual Life Insurance Co. Building in New York City; the Chicago Historical Society and the Tribune Building in Chicago. Nevertheless, the number of fireproof buildings constructed was small. Iron was still an expensive material in America compared with wood. Moreover, American-made rolled beams were sold at fixed prices, and imported iron was taxed.

Construction of iron and brick buildings slowed after 1857, when the nation's economy took a dive, and dried up in the first part of the 1860s during the American Civil War and the inflation that followed.

Rise of Fireproofing – the 1870s

Already in the 1840s in Britain, iron was under attack as a building material. James Braidwood, Superintendent of the London Fire Brigade, argued that cast iron beams and columns when used in large buildings with open expanses, staircases, and wells, and filled with combustible goods, "are not, practically speaking, fireproof". Cast iron, he observed, was liable to fail for many reasons, including flawed casting or weakness from over- loading; girders, when expanded by the heat of a fire, could push out walls; iron tie rods might give when softened in a fire; and heated iron might fracture when cold water was thrown on it. "For these and similar reasons, the firemen are not permitted to go into warehouses supported by iron, when once fairly on fire".[51]

Braidwood met his death in 1861, crushed by a falling wall while fighting what was perhaps London's most serious conflagration since 1666 – the Tooley Street fire. The fire started in and spread among the dreaded iron warehouses, many of which had been very well built. Calls for new laws to protect the public typically follow such tragedies. Parliament passed the Metropolitan Fire Act, providing for a fire department under government administration to replace the organization Braidwood led, which was financed by fire insurance companies. However, no clamour was raised for revisions to the building regulations. Rather, criticism of structural iron increased. The Tooley Street fire showed dramatically what could happen to iron in a serious blaze. As a *Building News* reporter described the fire scene: "The greater part of the premises...now lie in shapeless hills of bricks, broken and half-melted columns, girders, iron doors... Such a heap of broken ironwork as that here collected is seldom to be seen – girders from two to three feet deep are broken into short lengths, others, half melted, have run into strange forms..."[52] Even the insurance offices considered iron a more dangerous material than wood.[53] The solution to the iron problem was either to avoid using it, or to protect it.

In the iron-avoidance camp was the redoubtable Capt. E. M. Shaw, who next headed London's firefighting organization and repeated his predecessor's warnings about the unreliability of iron. He wrote that hardwood posts with girders and joists filled with cement were preferable to iron combined with brick.[54] Shaw, in fact, was highly sceptical of the idea of fireproof construction. He condemned the use of stone, the usual material for making stairways in London in compliance with the Building Act, and thought hollow brick could crack when the heated air in the cavity expanded.[55] He recommended limiting the size of buildings – height and volume – instead of trying to make them fireproof. Regarded as a hero and unimpeachable authority, his views were cited and echoed by writers in the architectural press for years to come. As the architect T. Hayter Lewis concluded in a 1865 paper: "Nothing short of diminishing the size of warehouses and other such buildings, or protecting them with brick arches or brick piers (as in solid masonry buildings), will render them secure; ...the common method of brick arches on iron girders is the most dangerous that can be used."[56]

By the mid-1860s several new methods of building fireproof floors came on the market, most of which were made of concrete, a less expensive material in Britain than clay products. British inventors also addressed the problem of how to protect iron beams. Iron columns received less attention, perhaps because the new fireproof floor systems tended to be used in situations where walls and partitions rather than columns and girders carried the floor slabs. In an 1872 article in *Building News* on "how to build scientifically with the aid of modern inventions," a writer listed Phillips' and Dennett's fire resisting floors as the kinds most generally used.[57] Phillips' floor was like Fox and Barret's, with small T iron replacing wood lath between rolled iron joists, and the concrete made with Portland cement.[58] But with joists spaced two feet apart, the floor required a great deal of iron. Dennett's consisted of gypsum combined with an aggregate to make "Nottingham concrete", and was shaped in an arch usually, but was not reinforced with iron although it sometimes was built between iron girders. This floor was used in a "long list of buildings", including government buildings, St. Thomas's Hospital, and at least one Yorkshire mill in the 1870s.[59] As well, a type of concrete arch floor, unreinforced like Dennett's, or with reinforcement when constructed flat for landings or corridors, made by W. B. Wilkinson & Co. was installed in railway stations, a building at Edinburgh University, and "in many warehouses and stables".[60] These new floors led one writer to exclaim: "What changes have not come over the meaning of fire-proof! Among my early experiences no building was considered fire-proof that had not iron joists and brick arches ... Now it is generally admitted that no floor can be called ... fire-proof that has iron used in its construction – such is the present position of iron".[61] Somehow, though, these new truths had passed by mill designers and owners, as they continued to build with iron, unprotected.

That iron is unreliable in a fire was amply demonstrated to Americans by the fire which consumed Chicago in 1871. It occurred a few weeks before the annual convention of the American Institute of Architects (A.I.A.), and was a hot topic at the meeting. Peter B. Wight, an architect with a great interest in fire protection, visited Chicago shortly after the fire and reported to the meeting on lessons learned from the destruction of Chicago's fireproof buildings. Wight held the cast iron columns responsible for the failure of the fireproof Post Office, believing that they shattered. Iron was again put to the conflagration test the following year, when the centre of Boston, Massachusetts, burned down. After surveying the Boston wreckage, R.G. Hatfield, an architect with an interest in technical aspects of construction, concluded "all iron had been proved untrustworthy; cast iron, however, had stood much better than wrought iron".[62] How did iron behave in a blaze?

American architects lacked technical information regarding new construction systems and materials. As one complained in 1869, architects did not have the means to test new products for themselves (though they often required manufacturers to perform load tests on items ordered, as did British architects), and manufacturers did not divulge complete information about their products.[63] Another remarked a few years later, "notwithstanding our seventy years' experience in iron, we now really know very little with certainty as to its action under varying circumstances of stress".[64] How American architects got information is still a question. The A.I.A. chapter and annual meetings were venues for discussing such topics and the New York chapter collected product samples, but the organisation was elitist and only a small number of all building designers were members. The papers read at the annual meeting were published in Proceedings. The first American architecture magazine to survive for more than a few years began publication in 1876, and it printed the papers given at A.I.A. meetings and articles on technical subjects. No doubt designers also relied on the material manufacturers, and the handbooks they published, to a great extent. Some read British periodicals. While still scanty, by the 1870s the sources of information on technical matters for architects at least were growing.

And their interest in fireproof construction was great, judging from the number of articles on the topic appearing in *American Architect and Building News* and the patents for fireproof materials – or, now, "fireproofing" materials, as the age of structural protection rather than incombustibility had arrived. Though the men who wrote the articles about fireproof construction were well acquainted with British hostility to iron, they also believed that the strength of iron, especially columns, was indispensable; rather, they too made the distinction between incombustible and fireproof, and emphasized that iron had to be protected. As Wight wrote in 1878, in an approving comment on the plans for a new city building in Chicago: "In its constructive features the materials are not alone incombustible – a word too often mistaken for fire-proof – but are to be made fire-proof in the true acceptation of the term. All the iron- work is to be protected".[65]

Two great problems of fireproof construction – how to make it affordable and how to protect iron – led to two different styles of fireproof building in the United States in the 1870s, both of which made use of an old material, clay, employed in a new way. The iron and brick fireproof building was very heavy, requiring extra material in the exterior walls and foundations. One way to lighten floors was to use hollow tiles rather than bricks. From this idea, the system of fireproof construction which became standard practice in America until the first decade of the twentieth century evolved. However rolled iron girders and joists were still very expensive, in part, contemporaries believed, because of price fixing by the manufacturers, the "mill pool", as well as tariffs on imported beams.[66] A more economical method of fire resisting construction was to protect ordinary wood floors by suspending ceiling tiles from them. A number of products for this purpose began to be patented in the 1870s. With respect to protecting iron, attention was first directed to protecting iron columns, perhaps because iron columns were used in buildings of all types, whereas iron beams were used principally in the few thoroughly fireproof buildings. Several methods were patented to protect columns; beam coverings were not used until the 1880s.

Tile fireproofing products first came into commercial use in the fireproof buildings constructed after the Chicago fire. Some months before the fire in 1871, George H. Johnson, a manger with the Architectural Iron Works in New York (and English by birth) and Balthasar Kreischer, a manufacturer of brick products, patented a large tile which spanned between iron floor beams. Their tile was shaped like a tile patented about 15 years before by the German born engineer and architect Frederick Peterson. Peterson's tile is unlike the pots, tubes and hollow bricks used in England. The Patent Office illustration shows a one piece unit, resting on the lower flanges of beams of Hodgkinson section, with an arched top and flat bottom. According to Peter Wight, these tiles were only ever used in the first storey of the Cooper Institute, designed by Peterson and built in the 1850s, where they were set between double 6 inch channel bars bolted together, 2 feet 6 inches on centre; they were made by hand of semi-fire clay.[67]

It was not this tile but one patented by Johnson a year later, in the shape of hollow voussoirs, that Johnson installed in the Kendall Building (1872-73) in Chicago, along with hollow block partitions, in the first instance of the use of this material in America.[68] (Fig. 8) Hollow voussoir-shaped tiles were being manufactured in France in the late 1860s.[69] Although the French blocks generally had interior webs, unlike the Chicago floor, they were probably the inspiration for Johnson's floor. Johnson may have received help selling the idea of hollow tile floors from the example of a 12 foot wide terracotta arch made from blocks sent over from England, put up on a

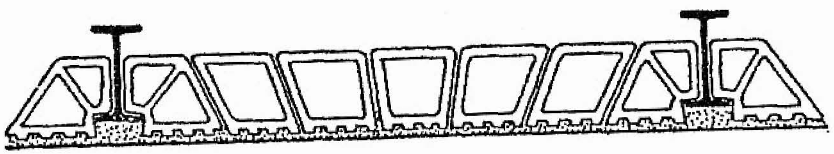

Fig 8: Hollow tile floor, as used in the Kendall Buildings, Chicago, 1872 (From J.K. Freitag, *The Firproofing of Steel Buildings*, 1899).

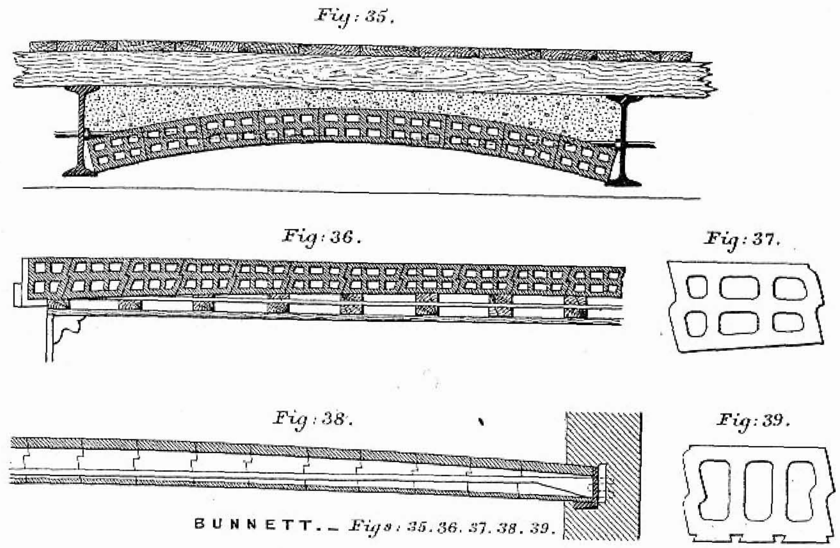

Fig 9: Joseph Bunnett's patent hollow tile floors (from *Minutes of the Proceedings of the Institution of Civil Engineers*, 1890–1).

vacant lot in Chicago after the fire."[70] (Fig. 9) Joseph Bunnett, inventor of this floor, patented his system some 13 years before, and it had been used in Grosvenor Hotel and the London and Brighton Railway Station, Pimlico.[71] His interlocking blocks tied with an iron rod could form spans of 21 feet, with a rise of only 2¾ inches. The blocks came in two patterns, one for a "side-pressure" arch – with the hollow cavity running perpendicular with the tie rod – and the other, an "end to pressure" arch – with the cavity running parallel to the tie rod. The tiles were made by machine, with the clay pressed through dies. Whether Bunnett ever sold his blocks in the United States is not known, but he made no headway in Chicago, in part because local firms had entered the hollow tile business, and in part because, in the hurry to rebuild Chicago, "there was no time to study up the subject" of fireproof building.

For owners who could not afford to build with iron – and most were in this group – inventors devised a new version of wood protection, à la Hartley and Mahon, in the form of interlocking ceiling tiles. A number of patents for such tiles were granted in this decade.[72] In addition, patents for the materials of which tiles were to be made were granted. Materials used in making tiles included ordinary clay, fire clay, and mixtures of different kinds of clay. The Fire-proof Building Co. of New York manufactured tile from a mixture of "French cement", plaster, and coke breeze, according to methods used in France. In Chicago, a method of making porous terracotta invented by the architect Sanford Loring and patented in 1874, consisted of clay mixed with sawdust or other vegetable matter which burned out in the firing.[73] Porous tile could be nailed and sawed, and was used rather than lath and plaster for ceilings under floor joists.

The problem of protecting iron columns was first addressed in the United States by Peter Wight and his partner William Drake (English by birth) who in 1874 patented a method of protecting cast iron columns of cruciform section with insulating wedges.[74] For larger columns, Wight came up with the idea of having small flanges cast on to cylinders to hold tile wedges.

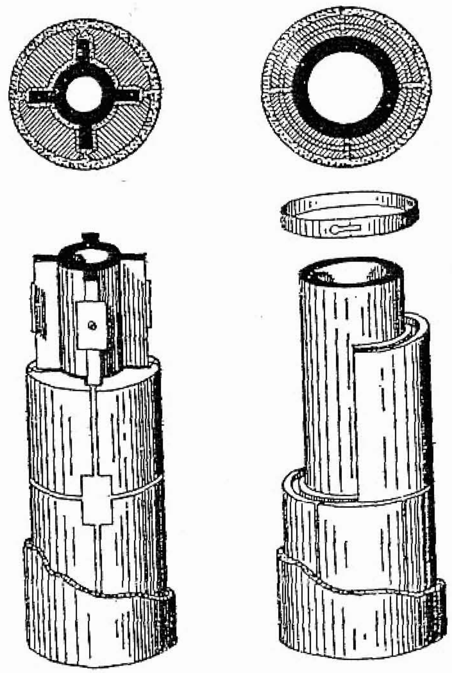

Fig 10: Peter Wright's systems of column fireproofing (from J.K. Freitag, *The Fireproofing of Steel Frame Buildings*, 1899)

Columns of this type were used in the 1880s in a variety of buildings. The tile wedges also were used to cover Phoenix columns, which were made of sections of rolled iron with flange joints. To meet the specifications for federal government buildings, which did not allow the flanged cast iron columns, Wight developed a system of tile rings with a groove, held in place with iron band.[75] (Fig. 10)

Many of these inventions appeared after the 1873 Panic and were not used in buildings in the 1870s, due to the general economic slowdown during the rest of the decade. Nevertheless, ideas for improving hollow tile floors continued to be patented, and the system developed in the direction of wider spans, made possible with terracotta of new compositions and the placement of reinforcing webs inside the blocks. Several New York area companies, in addition to Johnson's Illinois-based firm, entered the business, including Huvelman, Haven & Co. and the Fire-Proof Building Co. Tile manufacturers were the contractors for installation, although some also sold their products to builders, and their line of business came to be known as "fireproofing". Although these companies advertised in the national architectural press, few owners outside of New York City and Chicago (with the exception of the federal government) bought their products.

Why Americans did not adopt any of the concrete floor systems used in Britain, or even use concrete for making walls as was tried in the Peabody workers' houses in London in 1871, was a mystery to the British. In building construction, "concrete" of varying compositions, not always including cement, was used in America for foundations to some extent before the 1880s, and for levelling brick arches. A type of fireproof floor made of concrete or mortar poured over sheet iron plates, with or without corrugations, flat or arched, had been installed in a few buildings in America.[76] C.C. Dennett obtained a U.S. patent for his concrete arch in 1870.[77] But a writer in 1869 remarked that Americans lacked an understanding of "management of the material in large masses", and users found they ended up spending as much as if they had used brick.[78] Production of Portland cement did not begin in the United States until the 1870s, and even as domestic production increased, far more cement was imported, from England and Germany, at great expense, than was manufactured locally. As late as 1896, about twice as many barrels were imported as were produced in America.[79] The architect Richard Hunt, writing in 1877, believed, "with the experience gained by the more general use of these materials (concrete and beton) in this country, the same (uniform) results will undoubtedly be attained" as were achieved in Europe.[80] On the other hand, tile had much to recommend it. Clay was abundant in America, whereas concrete was a cheaper alternative to brick in Britain. In this period, tile floors took less time to install than did concrete floors, which was a selling point for time-conscious Americans.[81]

British inventiveness in the decade of the 1870s was also stimulated by the Chicago and Boston fires. Archibald Dawnay, "one of the pioneers of the flat or suspended concrete floor", began working on a concrete floor in 1868 when rolled iron joists were first imported to Britain.[82] His floor was a flat slab of cement concrete reinforced with bars or small joists of iron, and could be used to create spans up to 20 feet. It was used in "over 3000 buildings". Another slab, made of rolled joists embedded in concrete but with no other reinforcement, was patented in 1871 by Homan and Rodgers.[83] The Liverpool architect, Lewis Hornblower, invented a method of constructing floors, partitions and roofs which combined iron rods, hollow tiles, and concrete made of Portland cement and aggregate. The iron rods ran through tile tubes, between which larger tiles were suspended, forming a permanent centring which was covered with concrete.[84] This system was used in the Manchester Pantechnicon, the Liverpool Corn Exchange, and several buildings in Glasgow.[85] Hornblower also invented a method of fireproofing iron columns and girders in existing buildings by covering them with fire-clay tubes held in place with Portland cement concrete. Another form of column protection, available from Dennett and Co., consisted of concrete laid on to cast iron columns, held in place by longitudinal strips of corrugated iron or wire mesh on wood strips.[86] The objection to such coverings was that they increased the diameter of the column.

While London architects may have abandoned iron and brick arches for fireproof construction, mill architects did not. Some innovations were introduced to increase the span and reduce the depth of arches, for example A. H. Stott's iron column brackets, patented in 1871.[87] Iron in mills rarely was protected, a fact noticed by American fire insurance officials who visited English fireproof mills.[88] American mills in the nineteenth century rarely used structural iron, since large dimension wood for columns and beams was much less expensive.

The First and Second Waves of American Skyscrapers

The American economy picked up at the beginning of the 1880s, and the new fireproofing products were adopted in new buildings constructed in the brief booms that punctuated the decade. Production of fireproof products increased as new hollow tile, or "fireproofing" companies entered the business. The flat or curved arched floors made of terracotta were called "American floors" in Britain. Many of the buildings constructed in this decade were "office buildings", practically a new type of structure. Rental space in the commercial city before this time could be found in lofts comparable to what were called warehouses in Britain, which lacked facilities for the convenience of tenants. But demand for office space, coincident with the growing number and scale of some businesses, increased to the extent that ever larger buildings could be profitably filled; the new buildings had to have elevators, lavatories, and appointments to attract tenants. Even owners who built for their own use occupied only a few floors of their buildings and rented out the rest.[89] Such speculative office buildings apparently were not being built in Britain to the same extent.

American fireproof building of the 1880s was constructed of either incombustible materials or with wood floors protected with terracotta ceiling tiles. Many buildings were constructed in both styles until mid-century, after which they thoroughly incombustible style came to be preferred for first class buildings. A fire in the Grannis Block, a fireproofed wood floor type of building, in 1885 helped turn the tide in favour of using iron and tile exclusively for office buildings in Chicago. As Henry Ericsson, a builder and later building commissioner for the city, recalled: "In a real sense, more was learned from the burning of the Grannis than from the great fire of 1871; at least, its lessons were taken to heart and tenants became aware and alert as regards the perils of fire".[90] Also, the first wave of tall building construction had begun, and concerns were being raised over the safety of buildings which stood beyond the effective reach of fire hoses. By mid-decade, laws were passed both in New York and Chicago which forbade the constructive use of wood in buildings over a certain height within the fire limits.[91] After mid-decade, then, the progress of the tall building and the fireproof building became completely entwined. Tall buildings had to be built fireproof, by law if for no other reason, and fireproof buildings had to be tall, in order to return a significant rent to make their higher cost of construction affordable.

The story of the tall building has been told many times, but the fact that it is also the story of the fireproof building is not always appreciated. The tall fireproof buildings of the early 1880s were impressive for their height, but also for their weight. One of the first skyscrapers, the ten storey Montauk in Chicago (1878-82), was completely fireproofed by Wight Fireproofing Co. It was also notable for having rail grillage foundations on isolated footings, a new type of foundation made necessary because of the depth of bedrock under the city.[92] With grillage foundations, a heavy building would settle on the upper layers of clay, but evenly and not too far, and the basement would still have room for mechanical equipment. As Peter Wight explained the connections between fireproofing, height, weight and foundations in 1893:

> *"The use of steel (rails in) foundations, and later of steel- framed constructions, are the natural outcome of the use of light hollow fireproof blocks. In order to build fireproof structures and make them pay, they must be many storeys higher, so as to decrease the relative cost of the land to the improvement. Building higher on compressible soils necessitated economy in weights. Hollow materials only made this feasible. It was then found that the heights of buildings could be increased more and more by using steel frames, but only in case those frames were protected by the light fireproof material. Hence the latest and most improved buildings contain very few bricks, the exteriors being of cellular terracotta, and the interior faces of the exterior walls of hollow fire-clay blocks."*[93]

In 1883, construction began on the pioneer skeleton building, the Home Insurance Building in Chicago. It was actually of a type of construction that came to be known as a "cage", meaning that the frame carried the floors but the walls were self-supporting. Putting columns in the piers was a way of reducing the size and weight of the piers. This building was fireproofed by Wight. In the second half of the 1880s, many cage buildings were built in Chicago and New York.

The second wave of tall buildings, beginning at the end of the 1880s, was characterised by the introduction of the skeleton system and steel. Architects were aware of the potential advantages of steel, but had rarely used it before 1890, both because of cost and because of doubts about the reliability of Bessemer steel, then the principal kind.[94] But as steel prices fell in the 1890s and

production of open hearth steel increased, they began to use it to a greater extent. Cast iron continued to be used for columns, especially in cage-style buildings. But in the skeleton-style building – in which the exterior walls as well as floors are carried by the metal frame – rolled steel began to be used for the entire frame. Tile floors were standard for such buildings, with the end-pressure type gaining favour after well publicised tests of tile arches in 1890.[95] Although a number of concrete floor systems had been introduced, they were adopted to the largest extent in San Francisco, presumably because English Portland cement there was relatively cheap. These developments allowed buildings to be constructed ever taller. In major cities, tall buildings had to be fireproof. Indeed, building codes had the effect of spreading and standardising this system of construction. The codes in Boston, New York and Chicago, for example, contained much technical information, which gave guidance on such matters as the loads to be assumed in designing floors and roofs, the strength of wrought-iron and steel beams and cast iron columns, and formulas which should be used.[96]

The State of Structural Fire Protection at the Close of the Century

No similar surge of interest in new materials of construction occurred in Great Britain, although inventors continued to patent ideas for fireproof products in the last two decades of the century. Again, most of the fireproofing systems used concrete. Two systems, perhaps the most commonly used ones, combined hollow tile, in end-pressure, and concrete.[97] Homan and Rodgers' flat floor, patented in 1885, used hollow tubes which were shaped like trapezoids, spanning between rolled beams, and were covered in concrete. A similar idea was introduced by Mark Fawcett in 1888, and consisted of tile tubes with arched tops and flat soffits, laid diagonally on joists and covered with concrete. The tiles allowed an air space under the beam soffit.[98] These floors saved the cost of centring and were light; however, as joists were placed two feet apart, they required a good deal of iron compared with American hollow tile floors. Nevertheless, the Fawcett Ventilated Building Co. floors were installed in a number of American buildings, especially in Philadelphia and other Pennsylvania cities.[99]

Despite the variety of systems available for building fireproof, the kinds of buildings in which they were used continued to be those owned by institutions and government, textile factories and some warehouses. Americans found the British complacent about fire protection, as their relatively better fire record might lead them to be. For example, a writer who compared the English and American fire services found that the number of fires in London and New York was the same (in 1885) even though London had three times the population, five times the number of buildings, and three times the land area.[100] Yet the city's better fire loss record could not be due to its fire service, which he found very slow in responding to calls.

Rather than requiring that new buildings be constructed fireproof, London authorities relied on size limitation. The warehouse class of buildings had been limited to 200,000 cubic feet in the 1844 Building Act; 216,000 in the 1855 Act; and up to 450,000 cubic feet with permission and then limited to 60 feet high in the London County Council Act passed 1890, with a general height limitation of 90 feet plus two storeys in the roof. The architect Horace Cubitt compared London's laws with those of New York and Boston, and found American laws contained far more rules governing construction: fireproofing of certain buildings, stricter egress requirements, and detailed regulations for safe construction.[101] With respect to fireproof building in Britain, he noted that "the greater proportion of the best class of buildings (in Britain) are now erected of fire-resisting construction, but entirely at the option of the owners, professional opinion here apparently not having yet reached the point of considering compulsory measures desirable." A comprehensive revision of London's building laws in 1894 reduced the allowable height of buildings as a fire safety measure, with no objection from the R.I.B.A. committee formed to advise the code writers. But not everyone found this strategy satisfactory. Edwin O. Sachs, an architect and a leading figure in Britain's early fire protection engineering movement, was critical of London's Fire Brigade and of building construction in London. He helped form the British Fire Prevention Committee, an organisation devoted to increasing the adoption of "preventive measures" by conducting independent tests of materials, methods and appliances; publishing papers and reports; collecting information on fire prevention; and holding meetings.[102]

This committee got started following a tragedy, the fire in London's Cripplegate in 1897. Cripplegate was a district of warehouses that had been rebuilt in the 1870s, but the best practices of the period had not been observed, and the buildings were never updated. In a report about the fire, Sachs wrote that there were no fireproof buildings in the burned area: no fire- resisting doors, no protected iron work "as is generally understood today, either by plaster or terra-cotta", no fire shutters or sprinklers. Many buildings in the area were combined horizontally, and the fire doors installed to protect wall openings failed in the fire.[103]

How does one account for the variety of systems available and the fact that traditional methods continued to be used? In answering this question, I take a hint from Marian Bowley, who pondered the problem of why British architects were slow to adopt the steel frame:

"(The) developments of modern steel frame construction and of reinforced concrete were not necessary to fulfil any obvious requirements in the country in the late nineteenth century. They offered new and better ways of providing buildings to perform functions already performed by existing buildings".[104]

Was fire safety a problem that was not being addressed? Or was anxiety about fire safety low? Did the fact that much land in Britain was leased rather than owned by those who owned the improvements discourage construction of more substantial buildings? Were British fireproof materials too expensive? I do not know the ultimate reasons, only its manifestations: a building law in London that did not require fireproof construction, and little agitation to allow fireproof skeleton buildings.

This situation changed in the first decade of the twentieth century, when new laws in London addressed fire safety, and allowed skeleton frame construction. Also in this decade in the United States, concrete came to be used to a much greater extent in fireproof buildings, following favourable reports of its performance compared with terracotta in the great fires in Baltimore and San Francisco. Thus British and American construction practice began to look more similar, after a century of developing differently.

Conclusion

British building designers and construction materials manufacturers were leaders in introducing fireproof construction systems in the nineteenth century. American practices were adapted from or anticipated by British systems. However, fireproof construction became much more general in America than in Britain at the end of the nineteenth century. The question I address is why, having pioneered so many fireproof building systems, British inventiveness slowed down and adoption never spread beyond a limited set of clients, while the variety of fireproofing systems in America increased and fireproof construction became standard for many kinds of buildings. I conclude that the difference stems from different levels of anxiety with respect to the likelihood of general conflagration, which was reflected in the different building laws in the two nations. In both countries, building laws originated in order to control fire. American cities, unlike British cities, suffered serious fires throughout the nineteenth century. The approach to the problem eventually adopted by American cities was to require that buildings over a certain height within designated fire limits, or of a certain type (e.g. theatres), be constructed fireproof. But tall buildings had to be fireproof not only because of building laws; as a practical matter, there was no other way to build them, and thus the progress of the development of the tall building and the fireproof building became thoroughly intertwined in the last two decades of the century. In Britain, a distrust of large buildings, as fire hazards, long was embodied in building laws. Just as the first generation of skeleton frame buildings was going up in the United States, the allowable height of buildings in London was reduced, in an 1894 revision to the building laws, as a fire safety measure. In short, most Americans accepted tall buildings but wanted them fireproof, a situation which encouraged research and development in the field of structural fire protection. Britons forbade tall buildings for the sake of fire safety, and could protect the buildings that were allowed with the methods already at hand. The century ended with the apparently paradoxical situation of American cities having both more serious fires and yet more buildings being constructed fireproof, using the latest practice.

ACKNOWLEDGEMENTS

The author is particularly indebted to Lawrance Hurst and Arnold Pacey for previous information and for their many valuable insights regarding nineteenth century construction practice.

CORRESPONDENCE:

Sara Wermiel, 70A South Street, Jamaica Plain, MA 02130, U.S.A.

References

1. C. C. Knowles and P. H. Pitt, *The History of Building Regulation in London 1189-1972* (1972); *Records of the Governor and Company of the Massachusetts Bay ...* (1854), pp.239-40.
2. *Building News*, 7 (5 July 1861), p.557.
3. *American Architect and Building News*, 5 (7 June 1879), p.179.
4. Batty Langley, *The London Prices of Bricklayers Materials and Works* (1749), p.246.
5. J. G. Coad, "Two Early Attempts at Fire-Proofing in Royal Dockyards", *Post-Medieval Archaeology*, 7 (1973), p.88.
6. Charles Sylvester, *The Philosophy of Domestic Economy* (1819), footnote pp.7-8.
7. For example, the warehouses on Cotton's Wharf and Depot Wharf, built between 1840 and 1860, which burned in the Tooley Street fire. *Building News*, 7 (5 July 1861), p.573.
8. Associated Architects, *Resolutions of the Associated Architects: with the Report of a Committee ... To Consider the Causes of the frequent Fires ...* (1793), p.ii.
9. Knowles and Pitt, *Building Regulations.*
10. Frank Kelsall, "David Hartley's Fireplates" (unpublished paper, March 1991).
11. Coad, "Two Early Attempts", p.89.
12. The Leeds Industrial Museum, *Armley Mills* (Leeds n.d.), p.6.
13. Associated Architects, *Resolutions*, Appendix No. 1.
14. Manufactureres Mutual Fire Insurance Co., *Special Report No. 10*, April 1, 1882.
15. *Macmillan Encyclopedia of Architects*, vol. 2 (New York, 1982).
16. House of Representatives, "New Treasury and Post Office Buildings", Report No. 737, March 29, 1838. Mills' quote from . p24.
17. Article in the *Herald* of 23 Nov. 1873, quoted in B. Woodman, *A Customhouse for Newburyport* (privately published, 1985), p.20.
18. Recent publications include: Ron Fitzgerald, "The Development of the Cast Iron Frame in Textile Mills to 1850", *Industrial Archaeology Review*, 10 (Spring 1988), pp.127-145; Colum Giles and Ian Goodall, *Yorkshire Textile Mills*, 1992; and Mike Williams with D. A. Farnie, *Cotton Mills in Greater Manchester* (Preston, 1992).
19. Jennifer Tann, *The Development of the Factory* (1970).

20. Williams with Farnie, *Cotton Mills*, p.59.
21. Luke Hebert, *The Engineer's and Mechanic's Encyclopaedia* vol. 1 (1836), p.526.
22. Giles and Goodall, *Textile Mills*, p. 64; Williams with Farnie, *Cotton Mills*, p.61.
23. Hebert, pp.526-27.
24. For example, C. W. Pasley, *Observations on Limes...* (1838), p.168.
25. Edward Diestelkamp, "Architects and the Use of Iron", in Robert Thorne, ed., *The Iron Revolution* (1990), p.21.
26. Edward Barry, "An Account of the New Palace at Westminster", R.I.B.A. *Sessional Papers* (1857-58), pp.86, 90 – 91.
27. See descriptions in John Olly, "The Reform Club", *Architects' Journal*, 181 (27 Feb. 1985), pp.34-60.
28. Associated Architects, *Resolutions*, footnote on p. 11.
29. H. R. Johnson and A. W. Skempton, "William Strutt's Cotton Mills, 1793-1812", *Transactions of the Newcomen Society*, 30 (1955-56 and 1956-57), pp.179-205.
30. "Unpublished Letters of Benjamin Franklin", *The Pennsylvania Magazine*, 15 (1891), p.39 (cited in Philadelphia Museum of Art, Philadelphia, *Three Centuries of American Art*, (1976).
31. Charles Eck, *Traite de Construction en Poteries et Fer* (Paris 1836).
32. Pasley, *Observations*, p.164.
33. For example, Henry Roberts, hollow, wedge-shaped bricks, patented 1849, weighing with concrete fill 70 lbs/sq. ft., and William Fairbairn's jogged bricks, used at Saltaire Mills in 1854.
34. John J. Webster, "Fire-proof Construction", *Minutes of Proceedings of the Institution of Civil Engineers*, 105 (1890-91), p.264.
35. Pasley, *Observations*, p. 164, and Hebert, p.526.
36. Lawrance Hurst, "Fox and Barrett" (unpublished paper, March 1991).
37. James Barrett, *Minutes of the Proceedings of the Institution of Civil Engineers*, 7 (1852-53), pp.264-65.
38. Hurst, "Fox and Barrett".
39. William Ware, "On Middle-Class Houses in Paris and Central London", R.I.B.A. *Transactions* (1878), p.33.
40. For example, Builder, 7 (Nov. 1848), p.541.
41. Knowles and Pitt, *Building Regulations*, p.63.
42. P. B. Wright thought the first cast iron columns used in the U.S. had been imported from Scotland. (American Institute of Architects, *Proceedings*, 1877.) At a meeting of the Polytechnic Club in New York in 1860, a Mr Godwin commented that he had seen cast iron columns imported to the U.S. "a good many years". (*Architects' and Mechanics' Journal*, 2, (5 May 1860), pp.41-43.
43. *Architectural Review and American Builders' Journal*, 2 (Aug. 1869), p.102.
44. Day books, order books, and shipping records, 1852-1865, Cooper & Hewitt Collection, Manuscript Division, Library of Congress.
45. All iron work contracts at federal government buildings built in the 1850s went to iron founders (National Archives, Record Group 121, entry 6 and 26); for the later period, William Fryer in *A History of Real Estate in New York City* (1898, reprinted New York 1967), p.498.
46. Williams with Farnie, *Cotton Mills*, p.106.
47. Fitzgerald, "*The Cast Iron Frame*", p.142-43.
48. *On the Application of Cast and Wrought Iron to Building Purposes* (1854).
49. A. J. Pacey, "Technical Innovation in some late Nineteenth-Century Railway Warehouses" *Industrial Archaeology*, 5 (1968), pp.364-372.

50. Roger Holden, "Pear Mill, Stockport: An Edwardian Cotton Spinning Mill, "*Industrial Archaeology* Review" 10 (Spring 1988), p.163.
51. James Braidwood, *Fire Prevention and Fire Extinction* (1866), p.48.
52. *Building News*, 7 (5 July 1861), p.573.
53. Paper read by T. Hayter Lewis to the R.I.B.A., summarised in *Building News*, 12 (7 April 1865), pp.243-44.
54. From *Building News*, 12 (27 Jan. 1865), p.69.
55. *Building News*, 22 (29 March 1872), p.250.
56. *Building News*, 12 (7 April 1865), p.244.
57. *Building News*, 22 (29 March 1872), p.250.
58. *Building News*, 12 (29 Dec. 1865), p.925; *Building News*, 22, (29 March 1872), p.250.
59. *Building News*, 12 (7 April 1865), p.243; G. M. Lawford, "Fireproof Floors", Society of Engineers *Transactions for 1889* (1890), pp.45-46; Williams with Farnie, *Cotton Mills*, p.108.
60. Lawford, "Fireproof Floors", p.46.
61. *Building News*, 22 (29 March 1872), p.250.
62. American Institute of Architects, *Proceedings*, 1873, pp.18-19.
63. "The Office of the Supervising Architect: What it was, what it is, and what it ought to be", New York, 1869, signed "Civis".
64. N. H. Hutton, paper presented at 1873 A.I.A. convention, *American Architect and Building News*, 1 (5 Feb. 1876), p.43.
65. *American Architect and Building News*, 3 (8 Feb. 1878), p.43. 66. For example, Louis De Coppet Berg, *Architectural Record*, 1 (1891-92), p.461.
67. *Brickbuilder*, 6 (March 1897), p.54.
68. Patent 132, 292, Oct. 15, 1872, with W. Freeborn.
69. Wight, in *Brickbuilder*, 6 (March 1897), p.54.
70. *Brickbuilder*, 6 (March 1897), p.54.
71. Henry Eyton, *Journal of the Society of Arts*, 12 (20 Sept. 1864), p.722.
72. For example, 129,827, Isaac Hodson and William Brown and 133,448 Johnson and E. R. Hall, in 1872; 143,197, L. A Tartierre in 18 73; 156, 808, Henry Maurer in 1874.
73. American Architect and Building News, 1 (30 Dec 1876), p.421.
74. Peter Wight, writing in Brickbuilder, 6 (August, 1897), p.173.
75. 1874 patent 154 , 852 and 1878 patents 203, 972 and 204, 867.
76. Gilbert's patent ceiling, *Architectural Review and American Builders' Journal*, 1 (July 1868), p.62. The arched version was like a floor used by William Fairbairn in a refinery building, 1845; and the corrugated version was like Moreland's floor.
77. Patent 98,571, Jan. 4, 1870.
78. John Draffin, "A Brief History of Lime, Cement, Concrete and Reinforced Concrete", in *A Selection of Historic American Papers on Concrete 1876-1926* (Detroit: American Concrete Institute), p.11.
80. R. M. Hunt, "The Architectural Exhibits of the International Exhibition", *Reports of the United States Centennial Commission* (Philadelphia 1877-78).
81. *American Architect and Building News*, 16 (15 November 1884, p.232.
82. Arthur Cates, "Concrete and Fire-Resisting Construction", in R.I.B.A. *Sessional Papers* (1877-78), p. 308; Lawford, "Fireproof Floors", p.47.
83. Webster, "Fire-Proof Construction", p.267.
84. *Building News*, 22 (9 March 1872), p.193; 23 (8 Nov. 1872); 358–9.
85. Cates, "Concrete and Fire-Resisting Construction", p.298.
86. *Building News*, 26 (27 Feb. 1874), p.225.

87. Roger Holden, "Pear Mill, Stockport: An Edwardian Cotton Spinning Mill", *Industrial Archaeology Review*, 10 (Spring 1988), p.163.
88. Edward Atkinson, "Report on English Cotton-Mills and Methods", New England Cotton Manufacturers' Association, *Proceedings*, October 31, 1883, pp.33-55; J. R. Freeman, "Comparison of English and American Types of Factory Construction", reprint from the *Journal of the Association of Engineering Societies*, remarks presented Sept. 17, 1890.
89. Gail Fenske and Deryck Holdsworth, "Corporate Identity and the New York Office Building, 1985-1915", in Ward and Zunz, eds., *The Landscape of Modernity* (New York, 1992), pp.129-159.
90. Henry Ericsson, *Sixty Years a Builder: An Autobiography* (Chicago, 1942), p.227.
91. *Inland Architect and News Record*, 4 (April 1887), p. 32; William Fryer, "The New York Building Law", *A History of Real Estate, Building, and Architecture in New York City* (New York, 1898, reprinted 1967), p.292.
92. Ralph Peck, *History of Building Foundations in Chicago*, U. of Illinois Engineering Experiment Station, Bulletin Series No. 373 (Urbana, Illinois, 1948).
93. *American Architect and Building News*, 41 (19 Aug. 1893), p.114.
94. G. Henning, "Notes on Steel", A.S.M.E. *Transactions*, 4 (1882/83), p.410.
95. *Brickbuilder*, 6 (May 1897), p. 99.
96. As discussed by Frank Kidder in *American Architect and Building News*, 37 (21 Nov. 1892), pp.97-100.
97. Lawrance Hurst, "The Age of Fireproof Flooring", in Robert Thorne, Ed., *The Iron Revolution* (1990), p.37.
98. Lawford, "Fireproof Floors", pp.49-52.
99. The Fawcett Ventilated Building Co. Ltd. 1898 trade catalogue in the collection of the Hagley Museum and Library, Wilmington, Delaware.
100. H. D. Purroy, "English and American Fire Services", *The Forum*, 2 (1886), pp.299-307. It is impossible to get an accurate picture of fire loss in the 19th century because of the lack of data.
101. *American Architect*, 89 (12 May 1906).
102. "Objects of the Committee", printed in British Fire Prevention Committee, *Redbooks*.
103. *Engineering News* (London), 65 (1898), pp.355-357.
104. Marian Bowley, *The British Building Industry* (Cambridge, 1966), p.34.