Better than Steel? (Part 2): Tall Wooden Factories and the Invention of "Slow-burning" Heavy Timber Construction

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ABSTRACT: This paper continues the historical analysis of tall wooden buildings started in the author's ICSA2010 Keynote paper, *Better than Steel? The use of timber for large and tall buildings from Ancient Times until the Present* (Langenbach 2010)

The Industrial Revolution began in Great Britain with the mechanized manufacture of textiles, which led to changes in both the scale and technology of building construction. In the United States, where wood was plentiful, the interior structure of the multi-story textile mills was of timber hidden behind the brick or stone exterior walls. The need for water power to drive the machines prior to electricity demanded that the construction be located in multistory buildings adjacent to rivers, which dictated their form. During the 1820's and 30's, traditional timber framing with beams and closely-spaced joists was rapidly replaced with heavy timber construction in which joists were eliminated in favor of 2.5 to 3 inch (6 cm-7.5cm) planks grooved and splined together and spanning from beam to beam, a distance of about 8 to 10 feet (2.4-3.0m) on center. To qualify as slow-burning, the beams were a minimum of 12 inches (30cm) thick in either vertical or horizontal thickness. This system of construction was later identified and promoted as "slow-burning," also referred to as "mill construction".

Historically, the risk of fire in cotton mills was high because friction and frequent sparks from foreign matter getting into the rotating machines would easily ignite the cotton dust. Although this multi-story heavy timber construction has been commonly thought to have been developed because of its fire-resistive qualities, historical research appears to support the finding that it originally emerged because of its economy and practicality, even with the increase in the amount of wood it used. At this same time there was a need for the increased strength and stiffness that it provided. The historical records show that it was somewhat later that it was found to offer significant advantages in reducing the spread of fires as well as significantly delaying the collapse of burning floors in mills, after which it became known as "slow-burning construction". This paper describes the attributes and the history of what is the precursor of "Type IV, Heavy Timber" in the IBC, the current building code in North America.

1 INTRODUCTION

No one can forget the vivid images of the collapse of each of the World Trade Center towers. At first there were expressions of disbelief even by the TV commentator, not yet trusting his eyes that the sudden billowing of the dust and smoke was actually the onset of the complete pancake collapse of the burning towers. Towers one and two – the iconic pair – were followed hours later by the collapse of # 7, which was caused by fire injected into it by the collapses of Towers #1 & 2. "*Never before had a steel frame highrise building been collapsed by fire"* was the often repeated observation that then became the bedrock for the claim by the conspiracy theorists that the towers, or at least Tower #7, had been blown up from within by forces or terrorists not yet identified.

The record for highrise steel frame buildings has indeed been remarkable. There have been some very serious fires high up in skyscrapers in other places, including both China and the United States, but when unprotected or imperfectly protected steel has been exposed to sustained blazes, buildings have collapsed. That is the condition that the analysts determined was the case for the World Trade Center towers, where the shredded airplane and subsequent explosion stripped off much of the protective fireproofing. (Figure 2) This also included Tower #7, which was damaged only from the debris falling from the other two.

Figure 1. World Trade Center Tower 5 days before 9/11. *Photo © by author.*

Figure 2. Onset of collapse of World Trade Center South Tower. *Photo: Still image from private video of unknown source.*

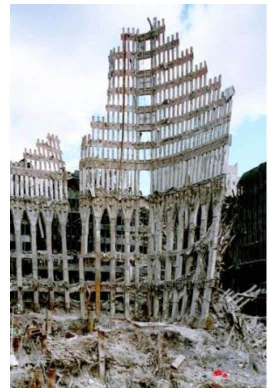

Figure 3. Ruins of North Tower six weeks after 9/11. *Photo © by author.*

I begin with this contemporary event because as we move back in time to the beginning of the nineteenth century, it is interesting to realize that the issues of safety and collapse prevention in ever taller multi-story buildings are just as profound today, even though the scale of the structures and the materials involved were very different.

Figure 4. Triangle Shirtwaist Factory on fire in the Asch Building, N.Y.C., March 25, 1911. *Photo: Wikipedia Commons.*

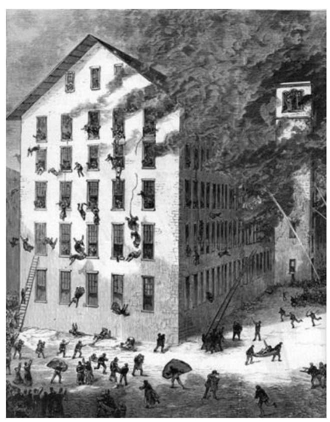

Figure 5. Granite Mill #1, Fall River, MA., on fire in 1874. *Engraving from Harpers Weekly*

Figure 6. Granite Mill #1 with top two floors burnt out in 1874, showing that the fire was prevented from spreading to lower floors. *Photo: (ATHM web).*

More than 90 years prior to the World Trade Center collapses, there was another seminal and influential fire event in New York City – the Triangle Shirtwaist Factory Fire. The building known as the Asch Building was not 100 stories, but it may just as well have been because the access to the interior stairways were locked or blocked, and the windows were higher than the longest reach of the firemen's ladders of the time. One hundred and sixty seven people died, one hundred and twenty nine of whom were women. The tragedy did at least have the benefit of leading to more stringent labor laws (Wikipedia). The building itself was of fireproof iron and masonry construction (Fire Engineering, web). Triangle occupied the top three floors. It was the cotton rags, clothes and dust which fueled the flames in the rapid, but hot, fire. The blaze began on the 8th floor, but spread upstairs to the other two floors of the factory. Unlike the World Trade Center towers, the Asch building in which the Triangle company was a tenant still exists as a part of New York University, but the searing image of people falling as if from the sky to their deaths on the pavement below remains embedded in the city's historic consciousness. Both this and 9/11 are memorialized by the New York Fire Department each year (Cangro 2011).

Looking back further to 1874, we can find another iconic blaze in the textile mill town of Fall River, Massachusetts, where the large and modern textile mill called Granite Mill #1 caught fire – probably from friction in one of the spinning mules on the 4th floor of the 5 ½ story building. As in the Triangle fire, the firemen's ladders could not reach the fire floors and many of the workers were trapped and forced to jump to their deaths or face being burnt alive. This time the searing scene of the falling workers, most of whom were women, with their long dresses spread in the wind, was captured in an engraving published in Harper's Weekly. The mill was constructed in 1864 with stone exterior walls, and with heavy timber floors (ATHM web), well after the adoption and promulgation of what then or later became known as slow-burning timber construction. So, the question must be asked, if it was '*slow-burning'* why wasn't the fire spread slow enough for the people to escape? Indeed – what is meant by '*slow-burning construction*' and what has been gained by its almost universal adoption for factory construction in the United States during the nineteenth and early 20th centuries?

2 BEAM-AND-PLANK TIMBER MILL CONSTRUCTION IN THE UNITED STATES

2.1 *The establishment of the textile industry in America*

What later came to be called '*slow-burning construction'* had its origins in the 1820's. It is a product of several important geographic and historical attributes. From the first settlements in New England after the arrival of the Mayflower in 1620, braced frame construction common in late medieval Britain was characteristic of colonial New England, with one exception: rather than brick or stone or wattle and daub infill, the exterior walls were from an early date most often clad with clapboards made from split wood, and later from sawn wood.

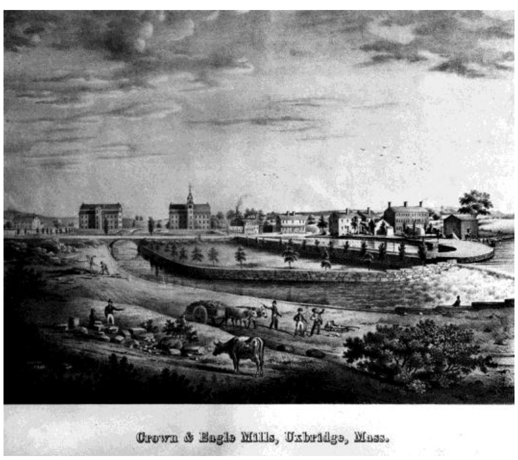

Figure 7. Ca.1830 view by James Kidder of the Crown and Eagle Mills, North Uxbridge, MA. The 1825 Crown Mill was constructed with joists, and the 1827 Eagle Mill was constructed with beam-and-plank floors. *Photo of print from Library of Congress HABS collections.*

Figure 8. The Crown and Eagle Mills was perhaps America's most beautiful textile mill complex, named to celebrate the owner Robert Rogerson's connection to England and the U.S. The Crown Mill is the one on the right with the bell tower. *Photo by the Author taken in 1966 for HABS (Historic American Buildings Survey, Library of Congress)*

The abundance of wood made timber significantly less costly than cast and wrought iron, as well as the cost of brick used for the floor vaults, in addition to the walls in early '*fireproof'* construction. This resulted in a social acceptance of timber as the primary structural and enclosure material for houses and also many commercial buildings, an acceptance that did not exist to the same degree in Britain.

Moving forward to the first years after independence and the War of 1812, entrepreneurs in New England began to invest in the fledgling textile industry. As agriculture moved to more fertile lands further west, this industry soon became the economic driver of the region. Despite the wars, there was an increasingly close communication between the early industrialists in England and those of New England, as the British saw their American colleagues as valued customers for their products. The first mills were clustered in New England and around Philadelphia. They had to be clustered because of the need to tap the water power directly at locations of waterfalls, or "privileges" as they were known at that time – a term which indicated the particular value of such locations as sources of power for water wheels and later for turbines, and eventually then for electrical power. The characteristics of the tapping and delivery of power in that age is important to the subject of this paper because the need to build tall multi-story structures is its result. The mill with all of its machines had to be close to the river, with water supplied by a canal to the waterwheels and turbines that were connected to the machines by shafts and leather belts. (Figure 7 & 8)

2.2 *Beam-and-joist floor construction*

Fires were common in the early textile mills because the cotton stock was flammable, and the process produced a lot of dust on the equipment – which at that time had many wooden parts. The drive belts were a particular source of friction that could start fires in the pervasive cotton dust. Metal debris hidden in the raw cotton would throw so many sparks in the scutching and picking machines that these processes were often in America placed in separate buildings called "picker houses," just to limit the loss should a fire erupt. Firefighting apparatus at that time was primitive, so there was a short window of time during which a fire could be successfully suppressed before spreading throughout the building.

Most of the fires were quickly extinguished with buckets and hoses hooked up to roof level water tanks, but when they got out of control, a mill could quickly be consumed as occurred with the Fall River Granite Mill #1 described above. The risk to the occupants as witnessed in that conflagration was still true for the occupants a half century later with the Triangle Shirtwaist Factory Fire, which spread quickly despite the fact that the building was of fireproof construction. Thus, the question of life safety must be distinguished from that of property protection when dealing with the question of fire risks.

Figure 9. Harris Mill #1, Harrisville, N.H. in 1969. *Photos by Jack Boucher for HABS.*

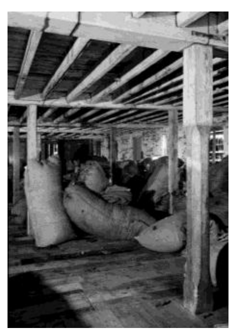

Figure 10. Interior showing beam-and-joist construction.

Figure 11. Interior of attic story showing characteristic fire-prone light frame gable roof construction.

Most of the 19th century mills were of masonry on the exterior, but the American mills, as well as many British mills, had timber floors. The construction was first a direct derivation of the heavy timber construction used for houses and commercial buildings – with heavy timber beams supporting joists which were nearly square in cross-section and mortised into the beams 18 inches to 2 feet apart (45 to 60 cm) on center. The floor itself consisted of two layers of 1 inch (2.5 cm) sawn planks, often laid with a layer of mortar in between the layers to resist the downward spread of fire. This timber construction was resting in pockets in the masonry walls, with iron rods with plates installed to hold the beams to the walls. These rods kept the vibrations of the machines from shaking the buildings apart. (Figure 9, 10, 11)

2.3 *Beam-and-plank floor construction*

Beginning in the mid-1820's this standard construction system for textile mills changed quite rapidly. Many have attributed the change to Rhode Island entrepreneur and mill owner, Zachariah Allen, but historian Richard Candee disputes this because of a lack of physical evidence of this change in Allen's own Allendale mill until he constructed a new wing in 1839. Also, there was no reference to this new system of construction has been found in his own writings, despite his singular interest in fire safety and fire insurance. Candee however did find an interesting open letter written by a Manchester, England industrialist identified only as "R" dated February 13, 1825 in the April 9th issue of London's "*Mechanics Magazine".* This same letter was republished verbatim only four months later in the August 20 issue of *American Mechanics Magazine*. This letter, among other things describes two ways of improving on *"the imperfection of the old construction of floors for the purposes of machinery… [that] instead of joists, flooring-boards, tiering underneath, &c…two planks (sic), of quite a different nature, have been adopted, vis. fire-proof and plank floors".* (Candee 1989)

For the fireproof example, he describes jack-arch construction with cast iron beams and columns held together with wrought-iron bars that did indeed become popular for the better class of British factories. For "*plank floors*" he says: *"iron columns and beams are used".* It is interesting to note that iron, not timber, was used for the beams. (Figure 12 & 13) He continues with: *"but the beams are flat on their upper side for the planks to lay upon; three inch planks are then jointed and ploughed [grooved] on the edges, for the purpose of admitting slips of sheet iron (called tongues) to enter half way into each plank, so that no dust may get through from the upper side."* He then offers his own ideas for making the system better - ideas not seen in practice in any of the examples I have come across, but what he described is what is found to have almost universally adopted in New England in the late 1820's.

Figure 12. Mill under demolition in 1969 in West Riding area of Yorkshire, England showing iron frame with joist pockets visible on beams for wooden joists. *Photo © by author.*

Figure 13. Mill under demolition in 1969 in Huddersfield, Yorkshire, England showing 'fireproof' iron frame with masonry jack-arch construction. *Photo © by author.*

The question then is whether this one letter to the *Mechanics Magazine* may have influenced the adoption of a radical change in practice in the US, or whether there were other simultaneous influences. More interesting is the question of whether or not fire resistance had anything initially to do with its initial adoption at this time. Since "R" was describing a construction type in the above quote that he claims was already in practice to some extent in Manchester, England, it seems more likely that Zachariah Allen (who was in Britain when this small article was published in the U.S.), as well as other visiting American merchants and manufacturers, would have seen examples in mills visited there and thus may have recommended the practice to others, (even though in the case of Zachariah Allen, he was not ready for a new mill until 1839.) Interestingly, "R" never describes the "plank" construction as fire resistant. The term "*slow-burning"* is believed not to have come into use until a half-century later (Candee 1989) when it appears to have been coined by Factory Mutual Insurance Company President Edward Atkinson, whose role is described below. However, there is plenty of physical evidence that it was adopted quite rapidly throughout New England. For example, the two mill buildings of the Crown and Eagle Mills illustrated in Figure 7 & 8 were constructed only four years apart, but the first in 1825 was of joist construction, while the second constructed in 1829 was of beam-and-plank construction.

In my research for this paper, I have not been able to find evidence that the rapid adoption of "beam-and-plank" construction in New England was a product of its fire-resistant qualities. The possibility that it was stimulated by a single small article in the American Mechanics Magazine – an article that fails to describe the system in any detail – is intriguing, but seems unconvincing. More likely than a single vector like this article or even observations by a single individual is the simple evolution of the structural system brought on by improvements in the sawing and processing of timber with the need for stronger and stiffer factory floors to support the increasingly heavy vibrating machinery.

In Britain, among those mills that were not of fireproof construction, the traditional beam-and-joist construction continued to be more common than the beam-and-plank construction described in the "R" letter. This was most likely because supplies of wood in Britain of the necessary length and cross-section were insufficient to support the widespread use of that system.

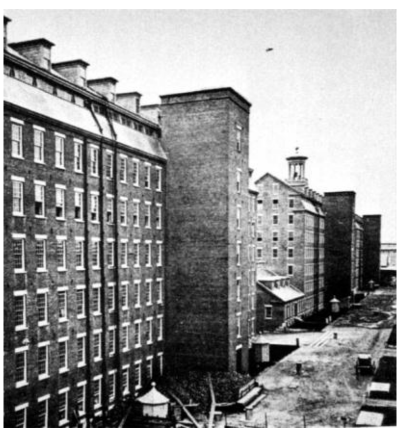

Figure 14. The ca. 1845 Bay State Mills in Lawrence MA. These mills, 9 stories including the two floor levels in the gambrel roof, may have been the tallest U.S. 19th century mills ever constructed. They were demolished only 36 years after they were built. Late 19th century mills were not so high in part because of inability to reach this height with hoses and ladders. In the 20th century, the height limit was restricted to 65 feet (20 meters). *Photo from (Langenbach 1981)*

Figure 15. Interior of Stark Mill #2, Amoskeag Millyard, Manchester, N.H. showing beam-and-plank "slow-burning" construction, ca. 1840, before the term *"slow-burning"* was coined. This view shows an example of this system with a finished wood board ceiling nailed directly to the planks, with the 1"thick boards nailed crossways to the planks, parallel to the beams. *Photo by the author for HABS.*

Figure 16. View of Carding Machine Room in the Jefferson Mill, Amoskeag Millyard. This view is of a mill ca. 1880, and shows beam and plank '*slow-burning'* construction. *HABS copy photo.*

It appears more convincing that the rapid adoption of the beam-and-plank system in the U.S. occurred because it represented both a structural improvement together with a dramatic saving in construction labor time and costs over the traditional beam-and-joist system it replaced. North America is where it could gain a foothold because of the untapped forests of old growth longleaf yellow pine that could be milled into the huge numbers of long thick planks needed for each mill. The timing of its adoption was probably also stimulated by improvements in the sawing and planing of wood that made the production of long and wide boards of this thickness to a level of finish adequate to make a level and smooth sub-floor practical. Moreover, only by then were there routers sufficient to cut the groove necessary for the spline and groove used to connect them together lengthwise structurally, and to prevent the penetration of dust and oil onto fabric on the machines below.

The structural improvement and cost savings can be explained because of a number of advantages. With the elimination of the joists, the mortising of the beams for joist pockets was no longer necessary. These pockets weaken the beam without significantly reducing its weight, so their elimination improved the strength and stiffness of the main beams significantly. Also, the joists themselves are subject to splitting if they were notched to fit into the joist mortises. In addition, because the handiwork of the notching of the beams and shaping and placing of the joists was no longer needed, the speed and ease of construction must have improved dramatically. However, for this beam-and-plank system to be viable, the cutting, planing, and cutting the groove in the 2 ½" to 3" thick pine planks itself had to be industrialized so that the already cut, planed and dressed timbers could be delivered to the site together with the wood splines ready to install (Candee 1989). (Figure 17 & 18)

Above the planks, a finished floor was customarily laid either on the diagonal or crosswise to the direction of the planks. This usually consisted of a layer of tongue and grooved 1" thick hardwood flooring. Sometimes, under the planks a ceiling of thin boards was nailed directly to the underside of the planks parallel to the beams. (Figure 15) Once finished and in use, this layered flooring system proved to be a much stiffer, stronger, and vibration-dampening floor, which was necessary for the increasingly heavy machinery that was also rapidly being improved in that era.

In a book comparing cotton textile manufacturing in United States with that in Britain in 1840, James Montgomery described this new system as if it had been widely accepted by that date. Montgomery was a Scotsman with experience as a mill manager who had migrated to the United States. At the time of his writing the book, he was Superintendent of the mills in York, Maine, so his remarks comparing British and American manufacturing practices and economics were from personal experience.

> *"Though the Mills in this country are not so high as those in Great Britain, they are generally very strong and durable. Instead of joists for supporting the floors, there are large beams about 14 inches by 12, extending across from side to side, having each end fastened to the side wall by a bolt and wall plate: these beams are about five feet apart, and supported in the centre by wooden pillars, with a double floor above. The under floor consists of planks three inches thick; the upper floor of one inch board. Some have the planks dressed on the underside, others have them lathed and plastered: the floor being in all four inches thick, is very strong and stiff. The average thickness of the side walls may be from twenty to twenty-four inches, and they are generally built of bricks. There are very few stone walls, free stone being scarce in this country."* (Montgomery 1840)

What is interesting about this statement is that there is no connection made in his book between the floor system and a reduction in the risk of fire compared to those mills with joists. His description deals with structural attributes, not fire resistance.

2.4 *Sprinklers and flat roofs*

Sprinklers came into use after the 1850's. At first a valve had to be opened manually, and then a couple of decades later, automatic sprinkler heads were invented and installed. Sprinklers were a profound improvement, but as we have seen over the years of the decline of the textile industry and the deterioration and abandonment of many of the mill buildings (Figure 32 & 35), they are only good as long as they are maintained in service.

Also in the 1850's, the formerly ubiquitous steeply sloped gable roofs with dormers or monitor windows ceased to be built, and many were soon removed largely because of the fire spread hazard, as fires would rapidly extend up to the roof - either through internal penetrations or through the windows catching the eves on fire. Fires in the attic, not being easily attacked, would quickly get out of control. This floor would be almost level with the water tank used for fighting fires limiting water pressure, and it would quickly be dangerous for firemen to enter. Such fires would then be impossible to fight from the ground level as hose pressures would have been too weak. It is probably at this time – just prior and subsequent to the American Civil War – that the fire-spread resistance of the beam-and-plank system began to be realized at the same time that gable roofs were eliminated.

The necessary precursor to the substitution of nominally 'flat' roofs for the steeply pitched gable roofs was the development of a roofing membrane technology that could be installed on a nearly flat surface behind a masonry parapet. A short and inconspicuous article in the very same issue of the *American Mechanics Magazine* as the letter by "R" about *"plank floors"* provides an early clue to the breakthrough technology for flat roof membranes. Finding this article felt to me like spotting a bottle with a note in it on a beach at the edge of the sea. In this case, the metaphorical sea is the modern Internet which had brought to my desk in California an image of this rare publication that otherwise lay hidden in Harvard University's rare book library three thousand miles away. This note in the 'bottle' is entitled "*Covering for Flat Roofs*" and it describes:

> *"a cheap and permanent covering for a flat roof" that involves "spread[ing] on, while warm, a composition of pitch with a little tar in it, carefully melted: over that lay[ing]…sheets of strong…paper; then again another layer of the composition and again the paper, and so on alternately as often as may be deemed necessary, taking care to have a layer of the composition last, over which…very fine gravel or sand should be sifted: the whole should then be kept covered (say an inch or so thick) with gravel."*

A quarter of a century after that small article was published, flat roofs for mills had become standard, and this roofing system is still in common use today. Such roofs are not exactly flat, as they have a shallow pitch to a drain located within the confines of the roof itself, thus not requiring a gutter connected to fire-vulnerable wooden overhanging eves. Before the invention of that roofing membrane technology, flat roofs of this type were not possible – at least not roofs the size of football fields atop five or six story buildings in wet northern climates.

Figure 17. Reconstruction of Amoskeag Mill #4 and #5, 1899. This shows the last of the gable roofed mills in the Amoskeag Millyard being replaced with an updated mill that is wider than, but not as high as, the earlier mills. *HABS copy photo.*

Figure 18. Detail of #17 showing the sawn and dressed heavy timber beams with cast iron seats already attached ready for erection. *HABS copy photo. (Most copy photos from Manchester Historic*

Figure 19. Interior of Stark Mill #3, Amoskeag Millyard, the day before it was demolished under "Urban Renewal". This shows the "slow-burning" heavy timber flat roof that was retrofitted onto this building after the earlier gable roof was removed. *Photo © by the author.*

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It was also in the latter half of the nineteenth century that the large cotton mill complexes in New England began to merge into continuous buildings with internal firewalls replacing the rows of individual mill buildings that had characterized the first phase. These great complexes in Lowell, and Lawrence, Massachusetts, and Manchester and Nashua, New Hampshire, and Biddeford and Lewiston, Maine became dramatic and impressive examples of the urban design potential of large cities of the industrial era. (Figure 20 & 21)

Figure 20. Aerial view of the Amoskeag Millyard in 1967 showing the canals on two levels. *Photo taken in 1967 by the author for HABS.*

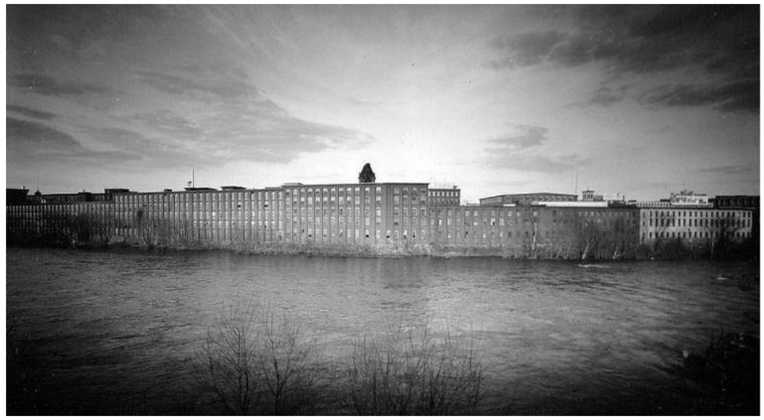


Figure 21. The southern end of the Amoskeag Millyard from across the Merrimack River. The original millyard had many separate "Lowell style" gable-roofed mills, but during the 2nd half of the 19th century, with improved firefighting equipment and full 'slow-burning' construction, the later buildings were joined together with internal firewalls. *Photo © taken in 1968 by the author.*

2.5 *Bhutan and India Kashmir examples*

It is worth straying for a moment from the subject of New England factory construction to the other side of the planet to illustrate the importance of some of the issues – particularly that of interconnected light framed wooden pitched roofs – in a world context. This also takes us back to a seemingly pre-industrial era. During this past year the danger of fire-spread through timber roofs has been brought to our attention by two tragic fires in present and former kingdoms in the Himalayan Mountains. They occurred within than 24 hours of each other, and both resulted in the complete destruction of historic structures of international significance. (Figure 22 & 24)

Figure 22. The 375 year old Wangdue Dzong in Bhutan before and during the fire of 24 June 2012 from a short circuit that destroyed this World Heritage quality complex. *Photos (left) Stephen Kelley for World Monuments fund; (right) Keunsel-BhutanNews*

These structures lacked sprinklers and other modern utilities, and comparatively primitive apparatus was used by the firemen, so these fires recall the conditions that were universal prior to the late-nineteenth century. It was situations such as these that stimulated changes to building construction in the early industrial period, and which can today still help to inform ways to improve fire resistance in heritage structures.

For example, the absence of firewalls with functional automatic fire doors in both the Bhutan and Indian Kashmir buildings was particularly tragic as they could so easily have been installed. Ironically, in the case of the Kashmir building, when the fire was extinguished the heavy timber structure of the building was still extant – and even found to be of sufficient strength to allow its reuse in a restoration, although I have been informed that this will not be done (Hakim 2012). The timbers remained sound through the long hot blaze because of the insulating effect of the charring of the exposed surfaces of the beams. As the oversized beams char, the charred surface serves to protect the wood beneath, and prevent the total consumption of the timber in the blaze. (Figure 24)

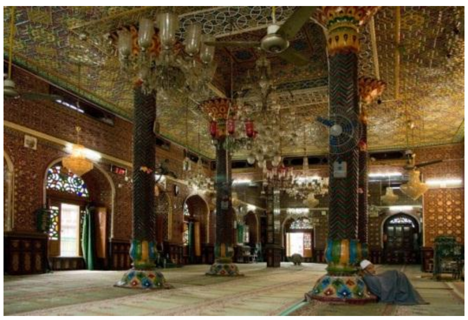


Figure 23. Interior of Peer Gastgir Sahib Shrine before fire which gutted the building on 25 June 2012, less than 24 hours after the Wangdue Dzong fire in Bhutan. *Photo by Jason Pemberton, Photopedia.com*

Figure 24. View of the fire and a view of the same space as in #24 after the fire destroyed the entire interior, leaving the heavy timbers charred but structurally sound. Needless to say, the loss of the artistic ornamental interior is a tragedy. The columns in the distance are two of those seen in the center of figure 23. *Photo (center) Kashmir Monitor, (right) Hakim Sameer for INTACH.*

This is also one of the critical features of "slow-burning" construction, because the protective charring of the oversized timbers can either prevent, or at least dramatically slow, the collapse of such structures in conflagrations. This then serves to save the lives of those escaping and particularly of the firemen fighting the blaze. It is also perhaps something that was discovered to have been true after the system was invented, when it was discovered that fires were easier to put out, and the fire damaged mills were found to be still structurally sound. This would perhaps explain why the *'slow-burning'* attribute of the beam-and-plank system only later came into clear enough focus to be codified and promulgated by the insurance companies not just for factories, but for urban commercial buildings as well.

Returning our attention to 19th century New England, it is noteworthy that the first known references to beam-and-plank construction as "*slow-burning*" does not come until 1879, over half a century later than the first known examples of the construction technology in 1827. It was also a quarter of a century after steep raftered roofs were eliminated in favor of beam-and-plank flat roofs, indicating that the fire-resistance was most likely well understood earlier than when the term *'slow-burning'* was coined. It simply takes a period of history for such values to become known from experience, and then codified and recorded in the press and given a name. The fires that are successfully put out before becoming conflagrations did not make it into the newspapers, but presumably they became known by word of mouth among the small circle of mill owners and operatives, and also by the *"mutual"* fire insurance companies. (The term "mutual" was reference to the fact that they were founded and collectively owned by those insured – the manufacturing companies themselves.)

It is those insurance companies that then codified and promulgated the system not just for factories, but later also for warehouses and commercial buildings – especially in the years after the Great Chicago Fire of 1871 and the Boston Fire of 1872 – both of which spread through windows, wooden eves, wood-trimmed mansard roofs, and internally through open pocket stud walls and behind ceilings – all of which had first been eliminated in the New England factories.

2.6 *Zachariah Allen and the Associated Factory Mutual Fire Insurance Companies*

Zachariah Allen founded the first mutual insurance company devoted solely to textile mills in 1835, after he was turned down for a discount on his insurance with another company despite having installed pumps, pipes and hoses in his mill. He organized the establishment of this new company, Manufacturers Mutual Fire Insurance Company, with other mill owners. It then spawned other companies which eventually joined together as the Associated Factory Mutual Fire Insurance Companies. This later merged into The Factory Mutual Insurance Company, whichnow conducts business as FM GLOBAL (www.FMGlobal.com).

The impact of this insurance collective in codifying and promulgating construction practices became increasingly significant as buildings became more complex, and experiences with fires added to the collective knowledge. It is interesting to note that the 1935 book *The Factory Mutuals, 1835-1935*, published by the company founded by Zachariah Allen on its centennial, reports that woolen mills had a much higher loss record than did cotton mills in the period from 1857 to 1872, despite the fact that cotton dust is considerably more flammable. They attribute this to their collective efforts at reducing fire hazards and improving firefighting capacity. (The Factory Mutuals 1935 p76) This did not mean that fire hazards were eliminated, but only that the collective property losses were contained through practices that kept most fires from getting out of control, as small "*flashy"* fires were reported to be quite common (Insurance Engineering Experiment Station 1908 p6).

Serious fires still did occur, as was shown by the Granite Mill #1 fire in Fall River with the graphic engraving in Harpers of the millworkers jumping to their deaths, skirts wafting up in the wind. The effects of events like that helped to speed the elimination of gable roofs in favor of beam-and-plank flat roofs, but that very same fire demonstrates the effectiveness of the beam-and-plank floor system by showing that the fire did not destroy the building below the floor where it started. The mill was rebuilt with a flat roof, but the unburnt floors visible in Figure 6 above were kept and repaired, rather than replaced.

2.7 *Edward Atkinson, the Factory Mutuals, and the use of the term* "slow-burning"

Edward Atkinson, the outspoken president of Boston Manufacturers Mutual Fire Insurance Co. is most likely the one who coined the term "*slow-burning construction".* Over the years of his tenure as President, he was a forceful promoter of the technology both with instructions to the insured and in magazines distributed to architects and engineers. It is in one such article that one can find the earliest reference to *"slow-burning construction,"* at least the earliest that historian Richard Candee came across (Candee 1989). It is in a letter to the editor signed "E.A." published in June 7, 1879 issue of *The American Architect and Building News*. From reading this magazine, it seems that the custom of the time was for correspondents to maintain anonymity by using initials, but "E.A." is Edward Atkinson (E.A. 1879). His long letter is entitled "*Slow-Burning Construction".* In addition to the title, he uses the term in this sentence: *"Our mills are not fire-proof, but if kept clean and in good order they are* slow-burning. *The contents may burn with great rapidity, but the structures themselves are built with a view to slow combustion."* Atkinson put "*slow-burning"* in italics.

Interestingly, there is another short article on the subject just a couple of pages earlier in the same magazine. It is reproduced from a paper "read before the New York State Association of Supervising and Adjusting Insurance Agents, at Syracuse on May 20, 1879 by P.B. Wright, Architect". It is entitled *On The Relation of Architecture to Underwriting* in which there is a description of the system using "*heavy wood for all interior constructions, and avoidance of all concealed spaces which fire may traverse unseen…"* This article makes clear that *"such is the system of building sought to be enforced in factories by the mutual insurance companies of Massachusetts and Rhode Island".* Interestingly, the term "*slow-burning*" is not used in this description, but is used once much later in the article when the use of oak wood is recommended for columns and girders because of its *"slow-burning and non-conducting properties"* This article even recommends that wood is suitable as a protective encasement for iron columns (yes – wood is here recommended as a cover to prevent fire from causing the early collapse of iron columns and beams!) (Wright 1879).

It is also important to note some architects wrote critiques of Atkinson's letter. One said: *"we do not think that the methods of mill building could be applied to any of the buildings which our correspondent mentions, except the plainest of warehouses, without increasing their cost, unless at the expense of a homeliness that would not be tolerated.* (This was the height of the Victorian era in architectural design.) He goes on to point out the (quite valid) problems with the residential use of such a system as it would allow unacceptable levels of sound transmission and it transmits more heat and cold. Moreover, dry rot can occur if, to give a more finished appearance, the timbers are plastered without an air gap (Eds. Am. Architect 1879). Another architect identified only as "C" compares the construction system to the unfinished interior of summer cottages in Oak Bluffs, an island summer resort, (which misses the point about the importance of heavy timber (C. 1879).)

Edward Atkinson followed this letter to the editor with a number of articles and books over his career, and also, soon after his 1879 publication, Charles Woodbury, Inspector for the Factory Mutual Insurance Companies, published a book *Fire Protection of Mills* in which he says: "*A fire-proof mill is a commercial impossibility"* and goes on to advocate: *"making buildings Slow burning, rather than striving to make them fire-proof".* This book includes a description of well-designed heavy timber slow-burning mill construction. It also describes a design for encasing iron columns with wood for fire protection mentioned above. (It also includes other methods of iron column protection which use ceramics).

FIG. 1

UNDESIRABLE CONSTRUCTION

Note the large expanse of wooden surfaces exposed to fire and the fact that a slight fire which may burn no more than ½ inch from each side of the joists practically destroys their strength, whereas a similar fire burning under purlins or timbers illustrated in Figs. 2 and 3 may do but little injury to them.

FIG. 2 **FIG. 3**

GOOD TYPES OF CONSTRUCTION

Figure 2 illustrates plank directly on timbers or girders not usually over 10 feet on centres.

Figure 3 is a type where trusses, posts, or girders are widely spaced, necessitating use of purlins to support planks.

Note that an 8 x 12 inch purlin has an equivalent amount of wood to six 2 x 8 inch joists spaced as in Fig. 1, and that the latter expose 108 square inches of surface to a fire as compared with 32 square inches in the former.

Figure 25. Illustration from *Report No. 5: Slow Burning or Mill Construction.* Published by The Boston Manufacturers Mutual Fire Insurance Co in 1902 under the direction of Edward Atkinson. (Insurance Engineering Experiment Station 1902)

Edward Atkinson himself published a more detailed description of *"Mill or Slow-burning Construction"* in *American Architect Magazine* in 1893 and again in 1901 under the subtitle *"What It Is; What It Is Not".* (Atkinson 1901) He lists four essential attributes, the first of which is "*so disposing the timber and plank in heavy solid masses as to expose the least number of corners or ignitable projections to fire...also that when fire occurs it may be most readily reached by water from sprinklers or hose".* The others include (2) incombustible fire stops covering any floor to floor openings (scuppers to the exterior are needed to drain fire hose and sprinkler water from a fire floor), (3) protecting ceilings above especially hazardous processes with lime plaster or other non-combustible protection without any airspace between the covering and the timbers behind, and (4) providing firewalls or protective gaps between buildings. In a 1894 article in *Engineering Magazine*, he added another attribute: (5) placing *"mortar, plaster-board, or some other fire-retardant between [the floorboards and roof boards] and the planks, where maximum safety is to be attained".* (Atkinson 1894)

In the "*what mill-construction is not*" list, Atkinson describes most of the common attributes of standard beam-and-joist and pocket wall construction that was still common in many central urban areas. In this list, he includes buildings without sprinklers and other firefighting pumps and equipment, and so, by reference, covers this gap in his list of what mill construction is.

In his 1894 *Engineering Magazine* article, Atkinson observes that *"it became apparent to the officers of these factory mutual insurance companies that (1) there is no such thing as a fireproof factory building and (2) that if there were, it would cost too much to construct it."* He goes on to say that the European textile mills "*commonly known as "fireproof factories," the combustion of the contents has frequently occasioned complete destruction"* of these brick and iron buildings. On structural members of iron, he has this to say:

> *"Iron is one of the most treacherous of all building materials when suddenly exposed to high heat…Iron posts have been crippled or sprung by heat a great many times at an early period in a fire. A wooden post of suitable size has never burned off until other parts of the building were already destroyed. They have in one instance resisted for hours fire which destroyed granite posts near them by reducing them to sand – the granite measuring 12 by 12 inches…Wherever the mill-floor, suitably constructed of three-inch plank, grooved and splined, covered with one-inch top boarding, laid on timbers eight or ten feet on centers, has been made continuous, - that is to say, without any break for belt-holes, open elevators, or open stairways, it has never been burned through by a fire upon the floor or by fire passing through the floor above, except in one instance, and that was in a warehouse where a pile of jute bales took fire in a place where it could not be reached"* (The fires described in this paper above all suffered from floor penetrations, but the Cocheco Mill fire described below, which happened 13 years later than this quote, most probably would have to be added alongside his bales of jute example.) *"To repeat, the mill-floor properly constructed and rightly guarded has sufficed to hold fires, not only in the building but in the room in which they have originated, until the mill fire-department or the public fire-department could extinguish the fire."* (Atkinson 1894, p605)

The risk of collapse of iron structures is even more interestingly described by the President of the Continental Insurance Company, Francis C. Moore, in a book published by that New York based company: *"The iron or steel used in a modern building has, in its time, been smelted in a furnace which presented no greater capacity for running metal into pigs than some of our modern buildings, whose interior openings from cellar to roof correspond to the chimney of a furnace and the front door to its tuyere. Indeed if a pyrometer could be adjusted during the progress of a fire it would be found to rise quite as high as in any forge* (Moore 1899). These quotes are noteworthy, considering that New York City was filled with cast and wrought iron buildings at that time, which was just in the first decades of steel skeleton frame construction, which also, as we know, required fireproofing to avoid or forestall collapse in fires.

2.8 *The 1907 Cocheco Mill fire*

'Slow-burning' does not mean fireproof, nor does it mean the fire will go out on its own. Rather, it can lengthen the time during which the fire crew can gain the upper hand. Also, once a fire is brought under control, it is less likely to flare up again as it can do if areas were to be hidden behind walls or ceilings. Once a conflagration gets established, it is hard to put it out. This was demonstrated in a subtle yet profound way in the burning of the Cocheco Mill in Dover, N.H. in 1907 when on a bitterly cold winter day a fire proved that what had been thought to be 'slow-burning' construction had an unanticipated fatal flaw which allowed the spreading of the fire and made it difficult to put out.

For structural reasons in this mill, the beams were parallel pairs of timbers bolted together side by side. To avoid the rotting of the timbers (textile manufacture requires high humidity), they were spaced ¾ of an inch apart. The fire was hot and it became lodged in between the beams, which then behaved like adjacent logs in a fireplace. The fire between the beams was out of the reach of the sprinklers and the firemen could not reach the fire in the narrow slot between the beams. Because the beams were themselves continuing to burn, the firemen were at increasingly greater risk from collapse of the structure because the charring found to protect single beams failed to do so between the double beams. Six people died in the fire.

Figure 26. Ruins of Cocheco Mill #1 after the fire of 26 January 1907 destroyed most of the mill, in part because of the double beams. This is also a good example of the effectiveness of having "fire cuts" on the ends of the heavy timbers, most of which collapsed. *Photo Dover Public Library Web.*

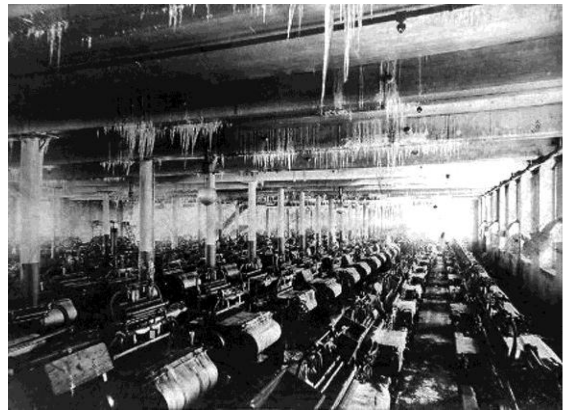
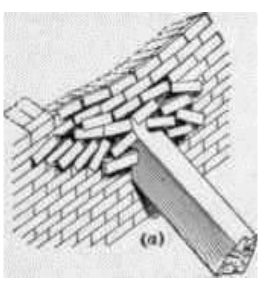


Figure 27. View of the weave room after the fire in the Cocheco Mill #1, showing an intact floor with "slow-burning" construction below the floors where the fire destroyed the structure. *Photo Dover Public Library Web.*

Repeated inspections by the Mutual Insurance Companies prior to the fire had reported the mill and its equipment at "excellent" and the firefighting commenced soon after the fire was discovered in the morning of the 26th of January 1907, but because of a leak in a sprinkler head, the sprinkler system was at that very time turned off to for repair. This was just the kind of head start that the fire needed to quickly begin to spread. By the time that the sprinklers were quickly turned back on, so many sprinklers had melted off that it had again to be turned off to enable adequate water pressure in the standpipes for the fire hoses. The fire continued at a slow pace, without ever becoming a big blaze all at once, but it burned through the night and the following day, with the firemen fighting it in unusually cold -15C temperatures. First the roof and upper floor collapsed and then, with the weight of all of the machinery, collapses continued as beams were weakened by the fire between them until in parts of the mill only the ground floor remained intact. An account of this event published by the Dover Public Library read like a screen play for a dramatic movie, rather than a real event (Fish web).



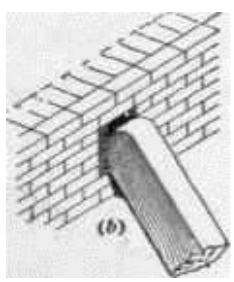


Figure 30. & 31. Illustrations published in 1899 illustrating effectiveness of fire cuts on the ends of the beams in case of a collapse of floors in a fire. *From (Colliery Co. 1899)*

Figure 32. Abandoned Buck Hosiery Mill fire 9 April 2012. Effectiveness of fire cuts shown. *From ABClocal.go.com*

Figure 33. London Blitz fire in 1942 showing danger of outward falling walls. *Image from Retronaut.com*

After the fire, the six story walls for the most part remained standing – which actually demonstrates one of the most important features of this carefully codified heavy timber construction that I have not yet mentioned, as it is not designed to mitigate against fires, but to protect the firemen and surrounding property when out-of-control fires do occur. It is what is called the "*fire cut*" on the end of each beam where it enters the masonry wall. (Figure 30 –

33) In the event of a fire, it is designed to be able to rotate downward when the floors collapse without jacking the masonry wall up, and thus causing it to fall over outward, which would crush the firemen and their equipment (Crosby et al 1918).

2.9 *Subsequent improvements*

There were a number of improvements made after this fire, such as redesigning the hoses so they would not clog or leak all over the firemen in freezing weather, but the most significant structural realization was that two beams with a ¾ inch (2cm) gap between them allowed the fire to continue to burn until the floors collapsed even when attacked with fire hoses. In a 1918 edition of the Crosby-Fiske-Forster *Hand-Book of Fire Protection* (and probably in earlier editions as well) these double beams, called *"double stick girders,"* are listed as *"not approved"* and it is specified that *"where the loads require two or more timbers, they should spiked together"* (Crosby *et al* 1918). (Figure 28)

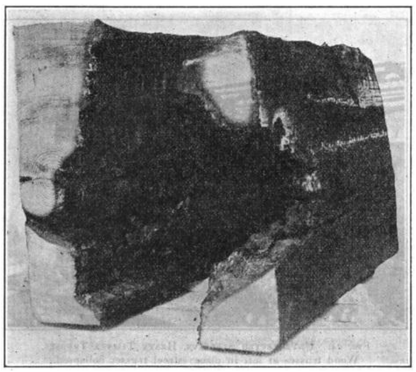


Figure 28. Cross-section cut from a double beam with ¾" space like that contributed to the extent of the conflagration in the Cocheco Mill #1 in 1907. *From (Crosby et al 1918)*

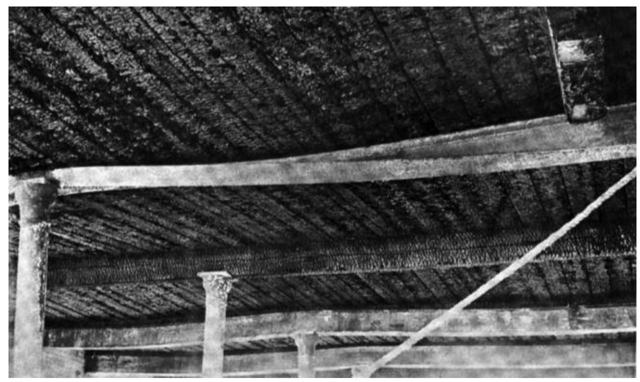


Figure 29. Wood beams next to steel beams after a 1898 mill fire in Arlington, N.J. The caption reads: *The stability of the wooden timber was not affected although the ten-inch steel beams sagged and were twisted to a degree which required rebuilding. From* (Insurance Engineering Experiment Station 1902)

The history of response to fire risk in building construction is filled with such surprises and counter-intuitive findings, resulting in an empirical process that has led to changes in construction. The idea that heavy timber is safer construction in a fire than unprotected steel was something that is not self-evident, but proved to be true as illustrated in Figure 29. Slow-burning mill construction is now recognized in the modern North American building code as Type IV, Heavy Timber Construction, and it continues to have a favorable fire rating.

Another example of a counter-intuitive finding is that fire doors made out of wood are far better than those made out of iron. Fire doors have been made out of thick wooden boards cross-laminated to make the door panel, which is then clad with thin sheets of metal. The reason why the iron doors failed while the wooden ones worked is that the iron expanded and warped, while the metal cladding on the wood kept the wood from combusting (Woodbury 1882). The warping of the iron doors presented two problems – one is that the door would jamb, trapping occupants and preventing the firemen from opening them, and the other is that on a number of documented occasions, including in the Cocheco Mill fire, the warped iron doors allowed the fire to pass through the firewall to destroy the next section of the building (Fish, web).

The spectacular examples of complete destruction of brick and heavy timber mills inject an element of realism and caution into the discussion. Although fires have been rare, the resulting ruins prove that not all fires were could be extinguished – even when sprinklers and standpipes were functional. In one such case, as if chosen by God to nip any over-confidence, a well fitted large mill, the Royal Mill in Riverpoint, Rhode Island caught fire in 1919 in the only part of the building not protected by sprinklers – the ornamental tower roof. When this roof collapsed, a heavy ornamental ball on top crashed through several floors of the mill, severing the sprinklers. The mill burned to the ground.

When the sprinklers were turned off, and the standpipes are broken, as was so often the case when one-by-one, the textile companies went out of business and the mills were abandoned, many have been burned, often from fires lit by vandals or vagrants. The saddest loss of such a mill I have seen is the complete destruction in 1975 of the Crown and Eagle Mills, which had already been recognized by the mid-20th century as the most beautiful of all of the New England mills, just as it had been so honored when it was constructed a century and a half earlier. It was unused at the time, with sprinklers turned off, but for half a century, it had been carefully preserved by its last owner – until vandals succeeded in burning it down. (Figure 35. *Also shown in Figure 7 & 8).*

Figure 34. Crown and Eagle Mills, North Uxbridge, MA. in 1968. (see also Figure #7 & #8) *Photo © by the author.*

Figure 35. View of the Crown and Eagle Mills after vandals lit the vacant mill on fire in 1975. The ruins were subsequently rebuilt with modern materials as senior housing. The bell tower was not restored. *Photo © by the author.*

3 CONCLUSION: MODERN DAY LESSONS

By the end of the 2nd decade of the 20th century, as reported in the 1918 *Hand-book of Fire Protection, "the cost of timber has materially increased…"* making moot the economic advantage that Atkinson had cited as the reason for its use. Heavy timber mill construction gradually went out of favor compared to non-flammable "fire-resistive" construction – namely reinforced concrete (Crosby *et al* 1918 p156). Coming to the present, one wonders what can be learned from this history, now that we are at the very beginning of an era when the idea of building highrise structures out of wood is being explored. Is there any lesson here? Are there aspects of this construction that can be ported over into cross-laminated timber multistory construction or any other tall wooden building construction?

On the positive side, the history of this construction and of the emergence of the Factory Mutual Insurance Companies and their compilation and dissemination of data and information did result in a remarkably good record of a minimum of losses. In the citation above about the higher losses in the woolen mills – which were usually smaller companies located in older buildings with less of an organized internal system of fire risk mitigation – the insurance payouts amounted to 80% of the premiums received, while in the cotton mills, the losses were only 25% of the premiums.

From a technical standpoint, the finding that timber construction configured into large members and thick plank floors can retain its structural integrity through a significant fire without collapsing because of the protective layer of charred surface that helps to insulate against further progress of the fire, is not something that would have been intuitively thought of until it was observed after a number of fires. It is of significance to other structural uses of wood in multi-story buildings, but to determine the minimum thicknesses of the timber elements and the nature of the protective finishes on the wood needs to be worked on experimentally before findings can be made. In the case of cross-laminated timber panels, the history of fire-door research and experience is certainly relevant, as the wood in such doors under the sheet metal cladding was itself cross-laminated: *"two thicknesses of tongued and grooved 1" boards laid diagonally across each other…"* (Woodbury 1882). Woodbury reports: *"an examination of such doors, after an exposure of several hours to the flames, shows that the wood had been slowly carbonized, the charcoal extending to a depth of only a fraction of an inch."* So, by this observation, the survival of the wood with the metal cladding preventing combustion is the same as why the carbonized wood in ancient Herculaneum has survived to this day when it was buried by the hot pyroclastic flow from Mount Vesuvius in 79 AD.

With the move towards reinforced concrete buildings, as well as the move of textile and piece-goods factories off-shore, the risk of the buildings being consumed by fires has reduced, but the risk to human life has not, as has been seen so tragically in recent fires in Bangladesh and Pakistan, (and even today, 27 January, 2013 – as I write – in a Santa Maria, Brazil, nightclub where 245 people died in a *"fast-spreading blaze,"* and another factory fire in Bangladesh killed 7.) In their carnage, these fires recall the Triangle Shirtwaist Fire of 1911, which reminds us of the speed with which factory fires can mushroom into conflagrations that extinguish the lives of scores and even hundreds of workers at a time. As recently as November 2012, 112 workers were burned to death in the Tazreen Fashions Factory in Bangladesh, and a staggering 289 people died in a single factory fire in Karachi, Pakistan on September 12, 2012 (Figures 36 & 37). A senior police official Amjad Farooqi said "*There were no safety measures taken in the building design. There was no emergency exit. All the people got trapped*" (TheNews.com.PK)

Figure 36. The Tazreen Fashions Factory, Bangladesh after the fire that killed 112 people. It appears from this image that the concrete structure was not even scorched, indicating that it was a flash fire that killed the people who could not get out. *Photo Abir Abdullah/European Press Photo Agency.*

Figure 37. View of the Ali Enterprises Factory in Karachi, Pakistan during which 289 people trapped behind barred windows and locked doors died. *Photo from blog.TheNews.com.PK*

This brings us back to the point where this story began. The World Trade Center towers were ultimately felled by the fire that was fueled by the contents, rather than the building materials themselves. The fires, including that in World Trade Center #7, were out of the reach of the fire department. Worse, was the fact that the leadership failed to understand the risk to the firemen of the potential for collapse of Towers #1 and #2, and thus 411 firemen and emergency personnel were killed in the collapse, along with the civilians who were trapped above the airplane impact and fire area, whom they could not rescue from below in any case.

It is interesting to contemplate the differences which exist with wooden structures. Wood is combustible, but it does not warp, expand or initially lose its strength when subjected to heat. It is the expansion, warping and loss of strength of the steel floor trusses left unprotected when the fireproofing was stripped off by the shredded airplane and airline fuel explosion that is what precipitated the collapses. Tower #2 collapsed 56 minutes after the attack and Tower #1, which was hit higher, lasted for 1 hour and 42 minutes before collapsing. While a 100 story wooden building is not on anybody's drawing board, ten to twenty stories are being contemplated using cross-laminated panels. If these are protected by plaster flush on the surface of the wood – in the way recommended by Edward Atkinson – then the performance of these buildings may meet our current expectations.

The above tragic stories of factory fires in other parts of the world are included to avoid the misleading impression that with the historical transition from "*slow-burning construction"* to fireproof construction in reinforced concrete, the problem has been solved. After a fire, the damage to concrete structures may require their demolition, but more important is to consider the message in my other ICSA2013 Keynote Address. Reinforced concrete construction can carry with it risks of structural collapse for other reasons – particularly from earthquakes.

Interestingly, cross-laminated timber midrise residential structures may stand as a remarkable potential solution to that problem if timber growing and production can be re-established in locations where it has been depleted. One thing is certain – such structures show great promise to be far more robust, with far less need for high quality construction training, quality control and supervision than is necessary for reliable earthquake resistant buildings of reinforced concrete. Because earthquakes come without warning, this fact alone could save many lives in the future.

ATHM web. American Textile History Museum website: http://blog.athm.org/?p=380

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