Lightweight construction

1 Introduction

Between 2004 and 2006 I earned a Master's Degree in Safety Engineering, which encompasses a course on occupational safety and health. In the context of this course I wrote a thesis on occupational safety in the fire service of Oostkamp, the station at which I serve as a voluntary firefighter. In order to get a good grip on the subject matter, I studied numerous cases of incidents in the US where firefighters lost their lives. One thing I noticed was the large number of firefighters that died because they fell through a floor into the room in which the fire was raging.

Personally, I had never heard of such an incident occurring in Belgium or in the neighboring countries. I did not really understand what it was, that was so different in the US. Over the years, I started to realize that the construction methods are radically different from ours. In North America, a lot of houses are built using wood. This in contrast to the brick masonry buildings we find here.

In the past, large dimensional lumber was primarily used for residential construction. Building materials are expensive however. A large solid wooden beam costs more than a wooden rafter. In the US, building methods shifted from using wooden beams to using rafters, I-joists and even small trusses. This particular way of building is called lightweight construction.

There are a number of advantages when building this way. First and foremost, it is cheap. Next, it is also lightweight. This leads to the possibility of using lightweight construction in apartment buildings, as is the case in the US. Finally, there is also an environmental factor. Less wood is needed.

Figure 1 Wooden trusses *(Photo: NIST)*

However, aside from all the benefits, there are some disadvantages as well. One of these, is the behavior of the building during a fire. This article tries to illustrate the problems of lightweight construction.

2 Risks

2.1 Stability

In Dutch, there is a term used among civil engineers which translates into "massivity". It is used to define the volume to perimeter ratio. Internationally, the surface to volume ratio (S/V) is more commonly used, which is the inverse of the above function.

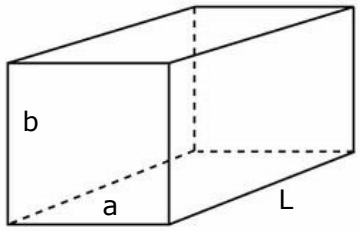

Figure 2 Schematic drawing of beam

The volume of a beam is equal to the section of the beam multiplied by the length. The surface area of a beam is equal to the perimeter of its section multiplied by the length. Therefore, the ratio of volume to surface area equals the ratio of the section to the perimeter of that section.

$$V = S \times L \qquad S = a \times b = section \qquad A = (2 \times a + 2 \times b) \times L = perimeter \times L$$

$$\frac{V}{A} = \frac{S \times L}{(2 \times a + 2 \times b) \times L} = \frac{section \times L}{perimeter \times L}$$

$$\frac{V}{A} = \frac{section}{perimeter}$$

Figure 3 shows the section of an I-joist. This building element can be made up of wood as well as steel. The drawing helps us to get an idea on its massivity. The drawing depicts the volume (V) as the section. The surface area (A) is shown as the perimeter of the section.

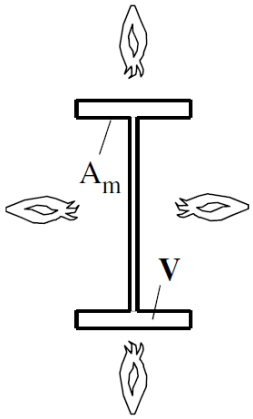

Figure 3 The section of an I-joist. *(Drawing: Rudy Van Impe)*

Now compare the massivity of the I-joist to that of the beam. A beam has a much larger section. More matter is present. A beam also has a smaller surface area. The inner matter of the beam is protected from the fire. The fire has to burn through the outer layers before it can reach the inside of the beam. During this time, the inside of the beam can continue to fulfill its load bearing function.

The web of the I-joist connects the top and bottom flange. In *cold conditions,* it is possible to create an I-joist that is as strong as a wooden beam. Wooden I-joists sometimes have webs that are thinner than 7 millimeters. In a fire however, meaning in *warm conditions*, the two building elements behave entirely different. The I-joist has a larger perimeter, meaning much more wood is attacked simultaneously by the fire. As soon as the web fails, the element will collapse. It is now clear that I-joists are not at all fire resistant.

In the US, numerous studies have been conducted into this field. A number of tests showed that wooden floors with lightweight wooden supports have a fire-resistance of 8

minutes. This means that the floor will collapse (or that a firefighter will fall through) shortly after the fire has started.

How long does it take before the fire is noticed by someone? How long does it take to send out the alarm? How long does the fire service need to get on scene? On scene, how long does it take to stretch and charge hose lines and start an interior attack?

It is obvious that the floor will be severely weakened by the time the crew starts the interior attack. When facing a basement fire, an attack crew advancing a hose line signifies a very heavy load on the already weakened floor. An attack crew of two firefighters, wearing BA's and carrying equipment, can easily exceed 200 kg. This explains why so many firefighters in the US have fallen through floors.

The same reasoning can be applied to ceilings. When firefighters are operating on the same floor as the fire, they have to be mindful of a possible collapse of the ceiling. In these situations, the mechanisms behind the collapse are even more complex. The wooden joists inside the ceiling could collapse, but also columns or walls supporting the ceiling could fail.

All in all, lightweight constructions hold up very poorly in a fire. They are serious threat to fire crews.

2.2 Fire spread and flame spread

Belgian building codes allow for the use of lightweight wooden constructions in detached houses (and in row houses as well as long as there is a fire-resistant wall between the different dwellings).

Luckily in Belgium there is something as the Royal Decree on "Basic norms". This decree stipulates a large number of demands which have to be met when building apartment buildings, office buildings, … One of these demands elaborates on the fire-resistance of structural building elements. The fire-resistance required, will allow to construction to maintain structural integrity for some time during a fire. That way, fire crews can operate safely inside the building. Fire-resistance norms also cause the fire to be trapped inside a compartment. The compartment walls will counter fire spread for some time.

Walls and floors are usually made up of materials like concrete or brick (for walls). These walls and floors are therefore a formidable barrier for the fire to pass. Because of these building methods, there are relatively few collapses at fires in Belgium.

It is simply not possible to achieve the same result using wooden walls and wooden floors. In order to build a fire resistant wooden wall, the wall would have to be protected. This can be achieved by adding protective sheathing such as plaster boards.

Nowadays in North America, apartment buildings are made up almost entirely using wood. It is possible to do this at a low cost. And when it's cheap, there is always someone willing to do it. In Belgium, it is not that cheap since all the walls and floors would have to be protected to achieve the necessary fire-resistance. Still, it happens now and then.

In the Nieuwstraat in Brussels, a construction company was raising an apartment building. The idea was to add around 200 apartment units on top of an existing building. If this was to be done using concrete, it would cause problems in terms of the load bearing capacities of the original building. By using wood, it became possible to add several floors to the construction. The plan stipulated adding protective sheathing to the wood. However, a fire started during the construction at a time when the sheathing had not yet been installed. The fire service of Brussels found themselves facing a massive blaze. The fire quickly spread throughout the entire building. After all, there were no measures in place to stop the fire spread. During construction (building, renovating or demolishing) lightweight wooden constructions signify a very large fire hazard. And when a fire reaches a certain size, the fire service can no longer operate safely.

Figure 4 and Figure 5 Two photos show the progress of a fire in a wooden apartment building. *(© Footage: Karen Jones)*

On YouTube, there is a dramatic video of a fire in Houston, Texas. The clip shows a construction worker that is trapped on a balcony of a wooden apartment building under construction (use search terms "man on balcony in burning building").

At the start of the clip, we can see that the man has fled onto the balcony. Apparently, there was no time to escape down the stairs. The film clearly shows how fast the fire is spreading. In no time at all, the fire has engulfed the entire top floor.

The man is eventually saved by the fire service using a ladder truck. During this rescue effort, the wall of the top floor collapses. Both screenshots were taken with only a minute and half in between.

2.3 Construction fires

Lightweight constructions such as these, also carry a higher risk for construction fires. In such buildings, all electrical installation (wiring, outlets, …) are built into the walls, as is the same for brick buildings. The difference is that brick is nonflammable. An electrical installation is a source of ignition. When something goes wrong in the electrical circuit, temperatures can rise very high in certain locations. In a brick wall, this is not that much of a problem. In a wooden wall, a smoldering fire can develop. It will turn into a fire that difficult to access and that is slowly spreading. When the fire has spread into the

construction itself, it had become a *construction fire*. This is a very challenging situation for the fire service.

An additional major risk is formed, when the fire progresses and manages to ignite a piece of furniture in a room. This could be a couch that is close to the wall. Then – on top of the construction fire – a ventilated or under ventilated fire will develop as well. At that point, it will become very difficult to save the building.

2.4 Size up

In Belgium, we have a tradition of building brick houses. There is a Belgian proverb which loosely translates into: "A Belgian is born with a brick in his stomach". Brick houses are very standard to us. Next to that, status matters a lot too. People want to build a house cheap, but don't want everyone to see it. So even as the number of wooden houses is increasing, it is not visible in the average Belgian streets. The majority of wooden houses have a brick wall as outer finishing. The wooden construction is therefore very difficult to distinguish from a classic brick building.

Figure 6 Construction of a wooden house. *(Photo: Nathalie Van Moorter)*

Figure 7 The same house once finished. Brick was chosen as the finishing outer layer. The house looks the same as a traditional building. *(Photo: Nathalie Van Moorter)*

If a fire were to start in such a house, there is the risk that firefighters will be caught off guard. Upon arrival, nothing would immediately indicate that there is a wooden house involved. At a ventilated fire, fire crews would likely face a fire exiting from windows and doors. Such a fire signifies a massive thermal attack onto the walls and ceiling. Experience tells fire crews that this is not a problem for a brick and concrete building. This is not the same however for wooden houses. When the fire service is faced with a fire on the ground floor during nighttime, performing search & rescue on the upper floor is not without risks. Possibly the fire has weakened the construction to a degree that the search crew could fall through the floor. In that case, they could fall directly into the fire room.

In a house with brick walls and concrete floors, it is perfectly possible to direct one crew to perform fire attack while a second crew starts searching for victims on the floor above in the bedrooms for instance. The concrete floor guarantees structural stability. This is not the case in wooden houses.

In a wooden house, the fire can spread into the walls as well. The fire will then be able to spread into the entire construction. Especially the floors situated above and the attic, are likely to become involved in the fire. As soon as the fire spreads into the attic and/or roof, it will become very hard to save the house. In the situations where there is a brick facade, the fire service will likely not consider that possibility at first. When faced with a fire in a single room in growth stage, firefighters will knock down the fire quickly. In a brick house, that typically takes care of most of the problem. In a wooden house, firefighters will have to make sure whether or not the fire has spread into the construction.

3 Cases

3.1 Houston, Texas: roof collapse

On May 31st, 2013 around 12h08, the Houston fire department is called out to a fire in an attic of a restaurant. The Houston fire department is a career department of 3800 firefighters protecting over 2 million people in an area of 1600 km². That's about twice the population of Brussels in an area ten times as large.

The first engine on scene, engine 51, confirms heavy smoke buildup visible while they were still riding out towards the fire ground. They arrive at 12h12 and start an interior attack. The TIC indicates a ceiling temperature of 84 °C. The time is 12h15. The attack crew enters about 3 meters into the structure and starts extinguishment using a 70-mm line. They describe the inside conditions as "not warm but zero visibility". Because of a possible problem with the water supply, they come back out at 12h18. Two minutes later, the engine 51 crew resumes the interior attack, aided by a crew of the second engine, engine 68. A second attack line is stretched into the building. At around 12h23, part of the building collapses. Four firefighters perish. 15 others are (severely) injured. At that point, engine 51 has only been on scene for 12 minutes.

This tragic incident has been studied extensively. An engineering firm was asked to examine the stability of the building structure. The roof was supported by trusses. Figure 8 shows the schematic of that truss. Such constructions are very popular because they are very strong. With a limited amount of materials, it is possible to span a large distance. In our parts, trusses are typically used in the steel industry. In rooms that span large distances, these elements are sometimes used.

The downside to this is that these elements are very fragile. Because each truss has a low *massivity*, it will collapse very quickly when there is a fire. On top of that, the plates used to connect truss chords require special attention when dealing with wooden trusses. The chords and webs are often connected by truss plates or nail plates. These are no more than a thin metal plate with a grid of nails on top of it. These plates are attached to the chords and that's how the entire truss retains its shape. What is dangerous is that these plates tend to fall off during a fire. They warp and are pulled out of the wood due to the heat like a banana peel. As soon as the truss plate no longer sufficiently joins the chords and web, collapse can occur. The restaurant in Houston had undergone renovation. The roof had initially consisted of roofing. Later, concrete roof tiles had been placed on top of this. This extra load of course, had caused the collapse to occur even sooner than it would have otherwise.

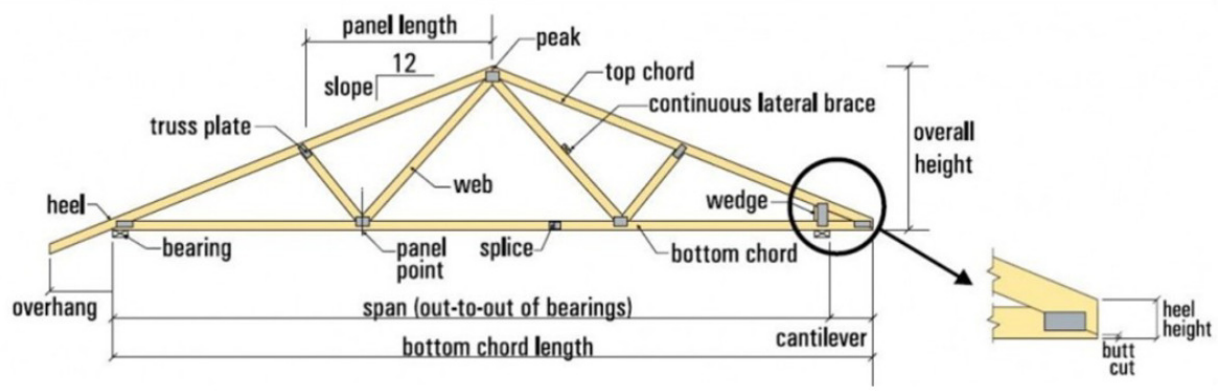

Figure 8 A wooden truss of the Houston restaurant. Trusses like these are made up of chords and webs being joined together by truss plates. *(Drawing: [1])*

Investigation afterwards showed that employees of the restaurant had already been noticing a smell of something burning for about three hours earlier. Several quick searches had been done for a possible fire, but nothing had been found. Probably, a construction fire was smoldering. It was not until the fire exited the construction, that it was noticed. Only then was the fire service alarmed … while all that time, the fire was allowed for 3 hours to smolder and spread in the wooden walls.

3.2 Colerain Township, Ohio: firefighters fall through a floor

On April 4th, 2008, the Colerain Township fire department is called out to a fire in detached house. This particular fire department is made up of 60 career and 150 volunteer firefighters protecting 60.000 inhabitants in an area of 117 km².

At 6h11 in the morning, firefighters respond to an automatic fire alarm. At 6h20 the fire is confirmed by the dispatch. The first engine arrives 3 minutes later. The crews arriving on scene are told by the owner that there was a fire in the basement. He also tells them that everyone is outside of the house. Two firefighters (a captain and a firefighter) start an interior attack using a 45-mm hose line. The conditions inside are described as *moderate smoke in the doorway*. It takes some time to advance the hose line into the building. A third firefighters steps up to help the crew. The attack crew descends the stairs into the basement. The third firefighter goes back outside to gather some more hose. When he comes back to the door, he is ordered to stay outside by the captain. The attack crew has run into trouble.

The rescue effort to save the attack crew is started at 06h37. This is 14 minutes after the arrival of the first engine. The rescue crew notices that the ground floor has partially collapsed. The two firefighters of the attack crew sadly lost their lives to this collapse.

The investigation afterwards showed that the attack crew entered the structure 16 minutes after the fire alarm went off. At that time, the fire had only been burning for 16 minutes at most. The beams supporting the wooden floor of the ground level, were 5 cm wide and 25 cm high. Still they collapsed because they had been severely weakened by the fire. Investigators assumed that the fire crew was forced to withdraw back out

because of the intense heat in the basement. Then they likely crossed the room towards the backdoor. The combined weight of the attack crew was too much for the weakened supportive beams and the floor collapsed. The attack crew fell into the burning room.

During this very short time frame of 16 minutes, the wooden beams of 5 cm wide were so weakened that a collapse occurred. *Think about what this means if it were I-joists with a 7-millimeter web?*

3.3 Ukkel

In Belgium as well, there has been at least one incident where lightweight construction played an important part in the outcome of a fire ground operation. On August 30th, 2008 two Brussels firefighters lost their lives in a fire in Ukkel. The building on fire was made up of several different parts. The part in which the firefighters died, was a lightweight wooden construction. A smoke explosion caused the structure to partially collapse. The extreme fire behavior was the most determining factor of the outcome. The smoke explosion directly caused the collapse. The question remains whether the end result would have been the same in a concrete building. Would the smoke have spread so easily throughout the different parts of the building? Would a concrete building also have collapsed due to a smoke explosion?

4 Solutions

The problem posed by lightweight construction is difficult to solve. Luckily –for now- this type of building is rare in Belgium. Because of this, people will be reluctant to come up with different kinds of radical solutions. However, in the future, the amount of these buildings will continue to rise. Lightweight wooden construction is cheap. That is the reason why we can expect an increase of these buildings. Possible solutions to the problem are offered below.

4.1 Registry of the structure of buildings.

There is only one sure way to prevent a firefighter from getting hurt in a collapse. The only way is to stand outside and stay out of the possible collapse area of the building.

Preplanning can help immensely here. A registry can be made of buildings and their underlying structure. Dispatching would then be able to consult that registry upon receiving the alarm. Information on the type of structure could be communicated while driving to the scene. That way, firefighters know beforehand whether they are dealing with a lightweight construction. If needed, they can adjust their tactics. This is the only way to avoid incidents as described above. Of course, this is a project of massive undertaking, but it could prove useful in other ways as well. A lot of industrial buildings are constructed using steel. Steel is a building material that has very limited fire resistance when left unprotected. In these cases as well, it is advantageous for the fire crews to have this information at the beginning of their operation.

4.2 Training and education on Construction methods and collapse mechanisms

The fire service does not put much effort into educating their people, especially lower and middle ranks, on different construction methods. A course on different building methods could prove useful. Each type of construction has its specific advantages and disadvantages. Certain types of construction react very well during a fire. Others have very specific problems in case of a fire. For instance, brick walls and gables are known to fall outwards when their connection to the rest of the structure has burnt away. Accidents such as in Jodoigne in 2011, reveal that these collapse mechanisms are insufficiently known to firefighters. A training course on the matter could help.

If the fire service is able to identify the type of construction, it can better assess – when trained and knowledgeable on the matter – the different risks. In 2013, the 18th article in this series handled collapse. ("The building is your enemy"). This article was also an initial effort to increase firefighter knowledge on different types of structures. Knowledge on building methods will generally come in handy as well during construction fires.

4.3 Large impact

If there ever is a true shift towards wooden housing, then this will have a very large impact on how the fire service does business. In that perspective, it may be interesting to look at fire departments whose the response area houses are primarily wooden constructions. The fire service of Sydney is so organized, that the first engine is able to arrive on scene within 5 to 10 minutes after the alarm. They would then have to get the fire under control within the next 5 minutes if they are to save the house. Should the fire spread into the structure, then the house will be lost. In order to achieve this, a much larger career staffing is required. Personnel is stationed in firehouses with a single engine and four firefighters. Be doing this, a very tight network of fire stations is formed. Each firehouse has a small response area where it will be first on scene.

The same organization can be found in the US and Canada. Here, career firefighters protect the suburban areas so that they will be able to tackle a fire in a wooden quickly enough.

In Belgium, voluntary firefighters form the basis of the fire service in the suburbs. The response time of volunteer firefighters is generally a couple minutes longer than that of career crews. After all, they have to drive to the firehouse first. On top of that, Belgium is organized with less, but much larger fire stations. This means that the response time is even longer. Both of these factors imply that the fire service will often not reach the scene fast enough to stop a fire in a wooden house. It may well be that in the future, the fire service will be faced with more house fires where the building completely burns down to the ground.

5 I am still dreaming

In 2013, I quoted Martin Luther King in my article on collapse: *I have a dream.* It was a call for action. A call to start learning from incidents in Belgium. In most countries, each and every serious accident is thoroughly investigated. Reports are written up so people may learn as much as possible of what went wrong. Sometimes, literally thousands of

man hours are spent on analyzing an accident and writing up a clear report so that the tragic incident will not be repeated. No expense or effort is spared in order to make sure that the firefighters who lost their lives, did not do so in vain…

I am still dreaming …

6 Bibiography

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