Fire Protection as a Mean to Increase the Sustainability of Wood Structures

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Abstract. Timber has been rediscovered as the building material of choice in recent years, especially in industrialised countries, with the shift of focus on attitudes towards sustainability that include use of natural resources and reduction of CO2 emissions in manufacturing building materials. The environmental qualities of wood (energy-efficiency, healthly building material, ability to be recycled) are matched by few materials used in constructions nowadays, making it suitable for a wide range of applications. The combustibility of wood is limiting its use in construction, an important weakness in terms of sustainability, as health and cost issues constitute essential conditions in sustainability assessment methods. Arguably, fire safety constitutes the foremost precondition in choosing wood as the building material. In the case of fire, wood burns on the surface, releases energy and contributes to the fire propagation and spread of smoke. In order to ensure greater safety for timber constructions, both passive and active measures of fire protection can be implemented, with the main objectives of improving the security of occupants, limitation of financial loss, protection of the environment in the case of fire. Despite the fear of using wood, the material has a better behavior in terms of fire than assumed, and even with structures more susceptible to fire risks, such as platform framing, measures can be taken in order to improve safety, as further explained in the article. The article analyses the concept of sustainability and the extent to which timber constructions observe these criteria, focusing on the means of increasing safety by fire protection methods with respect to the environment.

Keywords: timber, sustainable, fire protection, wood structure, safety.

INTRODUCTION

Sustainability has been an essential issue in the field of construction in the past decade, as this industry alone is responsible for more than 40% of CO2 emissions in the atmosphere if we take into consideration “cradle to grave” scenarios: erection, use and demolition (Frattari, 2005). Among others, the environmental qualities of wood, that are unrivaled by any other construction material, have triggered a renewed interest for its use. New technologies are developed, old techniques are perfected and updated and we are witnessing, especially in Central and Northern Europe, a revitalized use of timber in construction.

The combustibility of wood may affect the life cycle of this material in terms of duration of use in a finished construction, although LCA methods do not account for this type of risk. Fire safety constitutes the foremost precondition in choosing wood as the building material. In the case of fire, wood burns on the surface, releases energy and contributes to the fire propagation and development of smoke. The combustibility of wood is one of the main reasons why most building codes strictly limit the use of timber as building material (Frangi and Fontana, 2010). Fire has been historically the first argument for discarding wood as the material of choice for buildings. In Great Britain statistics show that fire is the number one fear regarding constructions determining a directly proportional amount of studies on the
Ample research on the matter has revealed though, that the fire resistance of timber structures is in reality much better than is perceived by the public, in fact, wood structures demonstrate better behavior than metal structures in the case of fire, because wood looses its structural properties at a controlled rate. After a certain temperature (around 300°C), steel looses its mechanical properties instantly as opposed to wood that chars at a constant rate, with the mechanical properties in the residual section remaining virtually unchanged.

Fire is in itself a subject in the context of sustainability, as it relates to issues such as: health, life cycle, costs. Beyond the fact that fire is a real problem for wood buildings, especially the types of constructions that use elements with small sections, the fact that “customer demand” is undermined by “fear factor” makes wood a less sustainable material. No matter how many qualities a material has in terms of sustainability, it won’t meet this criteria unless it is versatile and practical enough to be put into work and bottom line, “in demand”.

In order to insure a longer life cycle for timber constructions, both passive and active measures of protection can be implemented, with the objective of improving the safety of occupants and fire brigades, the safety of neighbors and their property, limitations of financial loss, protection of the environment in the case of fire (SR-EN 1995-1-2). The improvements in the passive systems (sprinkler and fire detection systems) for fire safety allow the safe use of wood in a wider field of applications for buildings. Many European countries have liberalized the use of wood for buildings in the past decade by introducing regulations that allow for the use of timber on the basis of performance (Frangi and Fontana, 2010). As active measures of fire protection, it is important to clad the structural timber elements with fire resistant materials and to a lesser degree treat wood elements with fire retardant solutions.

This article focuses on the relation between sustainability assessment criteria and fire as an issue for sustainability. It centers on analyzing different types of platform framing configurations for walls, seeking ways to improve their performance in terms of fire without impacting the environment.

WOOD AS A SUSTAINABLE MATERIAL

„Sustainable” is defined in the Sustainable Building Technical Manual (1996) as „the condition of being able to meet the needs of present generations without compromising those needs for future generations. Achieving a balance among extraction and renewal and environmental inputs and outputs, as to cause no overall net environmental burden or deficit. To be truly sustainable, a human community must not decrease biodiversity, must not consume resources faster than they are renewed, must recycle and reuse virtually all materials, and must rely primarily on resources of its own region.”

In terms of material use, the embedded energy represents more than 15-20% of the entire energy consumed by a building in 50 years. The embedded energy becomes more and more important in reducing the “building carbon footprint” as the growing concern for the reduction of energy consumption over the life of a building leads to the implementation of new and more efficient systems for energy conservation (Georgescu and Dumitrescu, 2011). McLeod (2009) observes that, in recent years, timber has been rediscovered, especially in Central and Northern Europe, with the shift of focus on attitudes towards energy conservation and recycling that included use of natural resources and energy reduction in manufacturing building materials. Unlike other high-tech, synthetic building materials, wood is completely recyclable. In its cut form, timber is returned to the natural cycle, without contributing additional energy. “Few materials currently used in construction have the environmental qualities of wood. Not only is the material most widely used in construction, but also, its
qualities make it suitable for a wide range of applications (General Technical Report FPL-GTR-190, 2010).”

Wood has a sum of qualities, which recommends it for a sustainable architecture:

- **Wood stores solar energy.**
- **Wood reduces the global consumption of carbon dioxide.**
- **Wood is an energy-efficient material.**
- **Wood is a healthy building material.**
- **Wood can be recycled as raw material for paper, chemicals or energy source.**

![Fig 1. The cycle of carbon dioxide of wood in construction](http://www.machielsbuildingsolutions.be/en/wood-closed-co2_cycle.asp?nav=10)

The contribution to climate protection of timber products is significant, as the use of wood reduces non-renewable fossil fuel consumption, throughout the cycle of CO₂ as figure 1 depicts. Trees store carbon dioxide throughout their life. If the tree is used to produce wood products, these products store carbon while in use, for the entire life of the building. If burned or mulched, at the end of the building’s life, stored carbon is released, essentially in the reverse process of photosynthesis. Wood is a material with low-embodied energy (the quantity of energy required to harvest, mine, manufacture and transport, to the point of use, a material or product) as demonstrated by comparative calculations (General Technical Report FPL-GTR-190, 2010). Wood products (engineered wood products) require more processing steps, need more energy to produce but still require significantly less energy than other construction materials. Carbon emitted to produce a ton of concrete is about eight times the one emitted to produce a ton of framing lumber. The production of steel emits about 21 times as much carbon as an equal weight of framing lumber. Kiln drying is the most energy consumptive process of lumber manufacturing that also includes log and lumber transport, sawing, planing and milling. However, in most of the cases, bioenergy from a mill’s waste wood is used to heat the kilns, resulting in a carbon neutral energy use.

The composition of wood cells, whose cavities provide thermal insulation and whose cell walls absorb and release moisture, provides benefits by ensuring a healthy indoor climate for wood construction.

After its use in construction, wood products can be recycled: wood fibers can be converted into paper by modern and environmentally friendly processes, made into synthetic materials, or simply used as fuel either in its natural form or as processed material (Herzog et. Al., 2005).
While sustainability is an important agenda considered in the field of constructions nowadays, fire safety and protection is not explicitly included in this framework. It can be argued, though, that fire is a key sustainability issue, both in its own right and as a secondary issue with respect to new technologies and materials.

In terms of quality of life, the need to protect against death or injury from fire might be expected to be as significant an issue, as that of security. About 700 deaths occur each year in the United Kingdom as result of fire in all types of buildings. The physical and emotional injuries from fire may require long-term medical care and can severely affect the victim’s quality of life and that of their family (Shipp, 2007). Studies examining causes for fatalities in residential buildings show that in majority of cases, the combustible contents are the first to be ignited and the smoke and flame generated by these cause about 90% of the deaths. Only 0.2% of deaths in homes were attributed to structural collapse (www.cwc.ca). This statistical fact further demonstrates that it is not the structure of the building itself that presents the most risks, but other aspects, as such statistically wood structures do not account for larger number of casualties than other types of structures, deemed safer.

The environmental impact of fires is well established, as the releases of CO₂ and other chemicals, notably H₂S, CO, SO₂, etc., can contribute to a great extent to air pollution. Fires that compromise large buildings or complexes can affect the air quality in the city impacted for many days. The contamination of the water table and rivers by water used in firefighting has been recognized as a problem for many years now.

Fig 2. Platform framing dwelling wrapped in flames. (http://www.rothcpa.com/archives/007664.php)

In terms of social problems, fire loss at some premises - sports centers, schools, theatres, etc.- can affect the whole community, as local inhabitants may have to travel to alternative, more distant venues and social structures may be disrupted.

The direct financial losses due to fire are very significant. A statistic estimated that the total cost of fire in United Kingdom in 2004 has been estimated at £7.03 billion. Of this, £2.52 billion are attributed to the consequences of fire (including criminal justice costs), the others are those “in anticipation of fire”, for example, the fire service. Regarding the businesses, as well as the direct losses from fire, consequential losses can be greater. These
can include long-term loss of client confidence, loss of clients to competitors, health service costs and legal fees.

In terms of material use, fire is a secondary sustainability issue. There are concerns especially regarding the increased use of highly combustible, recycled, non-conventional and non-traditional materials, such as rubber tires, bales of hay or straw, where fire safety implications do not appear to be fully formed. Lightweight constructions methods are gaining in popularity and respect the principles of sustainability especially regarding the rational use of resources and costs. The use of combustible materials, timber with a small cross-section, can determine a low resistance in a fire as opposed to wood elements with big sections that perform well when exposed to fire. (Shipp, 2007) This aspect accentuates the need of protecting wood in such structures especially by means of cladding with gypsum boarding.

BARRIERS TO THE ENHANCED USE OF WOOD IN EUROPE

Although wood has many inherent qualities, especially in respect to sustainability criteria, there are many limitations to the use of wood in construction in Europe, not only for generic wood-framed building types, but also for innovative wood-based construction products that may form the future of the wood construction industry. In a European report on barriers in the use of wood for construction, durability was identified as the main technical limitation, while risks (especially fire) was identified as the second economic barrier in order of importance. One of the main regulatory limitations to the enhanced use of wood-based products in residential construction relate to fire resistance specifications when building elements are used in multi-storey residential construction. The requirements throughout Europe differ, but all relate to the compartmentalization of fires and the restriction of fire spread, ensuring the safe use of means of escape routes. The performance requirements for structural walls and wall lining elements are directly dependent on the building height and are also related to the use of the building, especially with multiple occupancies. With the exception of flooring zone in escape routes, the use of wood-based products is generally possible throughout Europe, giving the fire insulation requirements are met. In some European countries, the use of any wood-based materials in escape routes is prohibited. Generally, in single family housing timber products can be used in the wall, slab and roof constructions without any limitations (de Jaeger, 2003).

Human societies value so-called “building of antiquity”, especially those deemed to have historical significance. However, not every building is held in such high regard, and, in fact, the majority of buildings are commonly deemed to be perfectly satisfactory if they have a service life of 50 years, typically because they become functionally obsolete as opposed to becoming structurally deficient. Modern wooden structures achieve with ease a life expectancy of 50 years, that, in correlation with the ease with which timber structures can be dismantled and the materials recycled, and the fact that the rotation period for the harvesting of plantation timbers is also typically 50 years are solid arguments for the sustainability of wood as a building material (Millner, 2009). Many historic wood buildings have proven that the life cycle of wood in construction can be up to a millennium, the wooden churches of Transilvania, a Unesco World Heritage Site, proving that local soft wood from Romanian forests can last more than 400 years in the fabric of a building without significant damages. Although statics are made regularly it is difficult to determine how the risk of a fire affects the life cycle of any construction, and to compute that risk in a life cycle assessment. This is why no sustainable assessment method includes fire in the framework of criteria. Improving the fire resistance of a construction, especially one more prone to the hazard of fire such as platform framing, insures that in an estimated time for occupancy of 50 years, this risk is
 minimal, provides the code requirements for implementing such constructions and reassures the occupancies of the safety implications regarding their dwelling.

**IMPROVING FIRE RESISTANCE OF WOOD FRAME CONSTRUCTIONS**

Unprotected light-frame wood buildings do not have the natural fire resistance achieved with heavier wood members. In these, as in all buildings, attention to good construction details is important to minimize fire hazards (General Technical Report FPL-GTR-190 2010). This is the reason why this article focuses on platform framing structures, a type of modern wood construction that is becoming more popular in Romania.

The Romanian code P-118/1999, that considers buildings with structural walls protected with gypsum boarding of C2(CA2b) REI combustibility class (>30 minutes) and C1(CA2a) REI combustibility class (>60 minutes) for walls delimiting circulation areas to have a fire resistance rank of IV class in a V class rating system. In this system, platform framing structures generally fall in a fire resistance rank of IV, as this article will further present. The fire resistance of a building is the basis for all regulations in Romanian code P-118/1999, establishing the safety distances between constructions, lengths of evacuations routes, number of levels, etc. for different types of constructions depending on their function.

A number of configurations for interior walls were considered and analyzed according to the SR-EN-1995, the Romanian normative adapted from Eurocode 5 - Calculations for wood structures in fire scenarios.

The 3 types of walls, presented in figure 3, 4 and 5 represent the most commonly used configurations for platform framing constructions in Romania.

![Figure 3](image1.png)  
**Fig. 3.** Type of structural wood platform framing walls utilized in interior (top view). Type a. 100 mm structural wall with type A gypsum boarding on both sides: 1- plaster finish; 2-13 mm thick gypsum boarding; 3- soft wood stud 50x100 mm at 400 mm spacing; 4- mineral wool insulation. (Original figure)

![Figure 4](image2.png)  
**Fig. 4.** Type b. 150 mm structural wall for phonic insulation with 2 layers of type A gypsum boarding on both sides: 1- plaster finish; 2-2 layers of 13mm thick gypsum boarding; 3- soft wood stud 50x100 mm at 400 mm spacing; 4- mineral wool insulation. (Original figure)
Fig. 5. Type c. 100 mm structural wall with type A gypsum boarding on both sides and OSB panels: 1 - plaster finish; 2-13 mm thick gypsum boarding; 3- 12 mm thick OSB panel; 4- mineral wool insulation; 5- soft wood stud. (Original figure)

For the three types of walls presented in figure 3, 4 and 5, the fire resistance was calculated utilizing the formulas given by SR-EN-1995, the Romanian normative adapted from Eurocode 5- Calculations for wood structures in fire scenarios. The time for fire resistance of a wall was considered the minimal value of the time it takes for the fire to char the wood stud to a point of collapse and that of failure of the elements of the panel- gypsum boarding, mineral wall, OSB (1).

\[ t_{req} = t_{min}(t_A, t_B) \]  

where:

- \( t_{req} \) - Required time for fire resistance
- \( t_A \) - Required time for fire resistance through the wood elements
- \( t_B \) - Required time for fire resistance through the insulating elements

For the wood elements protected with gypsum boarding, \( t_{req} \) was considered the sum of \( t_{ch} \) (time of initiation of charring) and \( t \) (time of fire exposure) (2)

\[ t_A = t_{ch} + t \]  

The time for initiation of charring was calculated utilizing the formula:

\[ t_{ch} = 2.8 \ h_p - 14 \]  

where:

- \( h_p \) – the width of panel used for fire protection

For double layers of cladding, as in the case for the type b wall, \( h_p \) is considered as the sum of the width of the exterior layer and 50% of the width of the second layer.

Time of exposure was calculated with the formula:

\[ t = \frac{d_{char}}{\beta_0} \]  

where:

- \( d_{char} \) – width of charred layer
- \( \beta_0 \) – calculation value for basis burning speed for uni-directional standard conditions of exposure.
It was assumed the condition of a one-level house for which the value of \(d_{\text{char}}\) was considered of 12mm. The results of the calculations for the three types of walls are presented in Table 1.

For the insulating elements, \(t_B = t_{\text{ins}}\) was calculated using the formula:

\[
t_{\text{ins}} = \sum t_{\text{ins},0,i} k_{\text{pos}} k_j - \quad (5)
\]

Where:
- \(t_{\text{ins}}\) – time of temperature increase on the unexposed face of the wall
- \(t_{\text{ins},0,i}\) – the insulating value of layer “i”
- \(k_{\text{pos}}\) – coefficient for positioning in the wall structure
- \(k_j\) – coefficient for fixing elements

Using this verification method, the results are presented in Table 1.

Tab. 1

The time for fire resistance of a platform framing wall with different configurations.

<table>
<thead>
<tr>
<th>Type of Wall</th>
<th>(t_A) (minutes)</th>
<th>(t_B) (minutes)</th>
<th>(t_{\text{req}} = t_{\text{min}}(t_A, t_B))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type a wall</td>
<td>39.46</td>
<td>65.75</td>
<td>39.46</td>
</tr>
<tr>
<td>Type b wall</td>
<td>56.96</td>
<td>103</td>
<td>56.96</td>
</tr>
<tr>
<td>Type c wall</td>
<td>50.17</td>
<td>84.26</td>
<td>50.17</td>
</tr>
</tbody>
</table>

The American code accepted procedure, the component additive method (CAM), the fire rating of a light-frame assembly is also calculated by adding the tabulated times for the framing components. The American procedure is, by comparison, much simpler to use than the Eurocode. For instance, the fire resistance rating of a wood-stud wall with 16-mm-thick Type X gypsum board and rock wool insulation is computed by adding the 20 minutes listed for the stud wall, the 40 minutes listed for the gypsum board, and the 15 minutes listed for the rock wool insulation to obtain a rating for the assembly of 75 minutes (General Technical Report FPL-GTR-190, 2010).

Similarly, the component additive method in the Canadian Code, would give a fire resistance time of by adding 25 minutes for 12.7mm type X gypsum board, 20 minutes for wood studs at 400 mm centers and 15 minutes for rock fibre bats (Buchanan, 2002). These results, obtained using the American and Canadian codes are not comparable to the calculations made in this article, as we assumed the use of type A gypsum board, a more commonly used material in Romanian wood constructions. They simply illustrate the ease of use for these two codes as opposed to the much more complicated European procedure.

Light wood construction, including platform-framing type, has a high degree of ceasing fire by using gypsum panels on the inside of the structural walls. It is recommended in these types of structures the use of fire resistance gypsum panels, with fiberglass filaments that maintain intact the wood core during a fire. In comparison, a traditional gypsum board, without additional fire protection gives a fire resistance of 15 to 30 minutes (General Technical Report FPL-GTR-190, 2010). The time for initiation of charring \((t_{\text{ch}})\) was calculated in this paper with formula (3) at a value of 21 minutes for type A gypsum boarding of 12.5 mm width.

Fire resistance of wood elements can be improved, to a lesser extent with substances that delay the effects of fire, FRT (fire retardant treatments). Fire wood treatments have the effect of ignition delay, reduce heat generation and a slower spread of flame. Fire wood treatments do not make wood non-combustible nor change the heat potential, however some products cause a reduction in the amount of smoke emitted. Fire wood treatments generally
act by reducing the amount of released flammable volatiles or reducing the effective heat of combustion or by combining these two factors. Both actions result in a reduction in the heat generation curve, so it is possible that the wood is extinguished by itself when the heat source is removed.

The combination of salts used in fire retardant treatments proves cost effective and can be easily impregnated into the wood. In terms of toxicity to humans, an important criteria for sustainability, boric acid and boric salts are the best solution, as they do not contain copper or other heavy metals. A resurgence of the use of borate treated wood for and internal structural members has resulted from the recent interest in low toxicity timber for residential use, along with new regulations restricting some wood preservation agents (General Technical Report FPL-GTR-190, 2010).

CONCLUSIONS

Fire is not a main subject on the sustainability agenda, but it’s importance in respect to timber constructions, especially those that use elements with small sections, make it a foremost important topic in the framework of sustainability. This article analyzed different types of platform framing walls, in order to establish a better configuration for preventing fire hazards. These calculations demonstrate that is the failure of the wood studs with small sections, rather than the layers that compose the wall that lead to the collapse of the wall. As it was shown, via calculations done in compliance with the Eurocode 5, using double layers of type A gypsum boarding greatly contributes to the fire resistance of a wall. Gypsum boards are considered a sustainable solution, as they are a healthy solution, are also recyclable on the condition that are not contaminated with paint or adhesives, can incorporate recycled material, usually in a percentage of 10 to 15%. Considering the economic data in Romania, the cost of an extra layer of gypsum boarding will only increase the total cost of the panel by 5-10%, a reasonable amount, considering the benefits in respect to the security of occupants.

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