Fire in Timber Structures

Roberto Tomasi

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Overview

1. Introduction and fire safety
2. Timber Fire Behaviour
3. Timber fire design standard methods
The Great Fear of Fire

*Myths and fallacies of timber engineering*

Small pieces of wood burn well...
The Great Fear of Fire

Myths and fallacies of timber engineering
...but a timber structure with an appropriate design can offer equal or more fire resistance than the usual structures made with steel or concrete.
References

*Bibioteca Tecnica Hoepli*

MAURIZIO PIAZZA ROBERTO TOMASI ROBERTO MODENA

**Strutture in legno**

Materiale, calcolo e progetto secondo le nuove normative europee

*HOEPLI*

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**Fire safety in timber buildings**

Technical guideline

EU flag
Flashover is the transition in the burning period, it can be estimated having $T \approx 400 \div 600^\circ C$
Design Concepts of Fire Prevention

There must be a number of **active** and **passive** provisions against fire.

**Active Provisions** refer to *control* of fire through actions taken by persons or by automatic devices, e.g.: automatic detection, emergency exit, active control of smoke (by fans or other devices), fire extinguishers, automatic sprinkler systems, fire alarm, firefighters etc.

The **structural performance** of a structure vs Fire is defined in terms of **TIME**, e.g. R60 means that the resistance is guaranteed until 60 minutes.
Design Concepts of Fire Prevention

There must be a number of **active** and **passive** provisions against fire.

**Passive Provisions** refer to *control* by systems built into the structure, not requiring any operation by people or by automatic controls e.g. selection of materials, fire resistance of structures, containment of fire (preventing fire spread), party walls, compartment

The **structural performance** of a structure vs Fire is defined in terms of **TIME**, e.g. R60 means that the resistance is guaranteed until 60 minutes.
Simplifying, passive provisions follow a structural approach, active provisions are based on fire monitoring and all fire extinguisher systems.
Fire safety and current regulations

Fire safety involves prevention, detection, evacuation, containment, and extinguishment.

**Fire prevention basically means preventing the sustained ignition of combustible materials by controlling either the source of heat or the combustible materials.**

Two main categories can be:

**material requirements** include such things as combustibility, flame spread, and fire resistance.

**building requirements** include area and height limitations, firestops and draftstops, doors and other exits, automatic sprinklers, fire detectors.

Code officials should be consulted early in the design of a building because the codes offer alternatives.

**Adherence to codes will result in improved fire safety (?)**
Fire safety and current regulations

Construction Products Regulation (305/2011/EU - CPR)

Subject to normal maintenance, construction works must satisfy these basic requirements for construction works for an economically reasonable working life.


Fundamental difference between CPR 305/2011 and CPD 89/106/EEC

The Declaration of Performance (DoP) is the key concept in the Construction Products Regulation (CPR).

The DoP gives the manufacturer the opportunity to deliver the information about the essential characteristics of his product he wants to deliver to the market. The manufacturer shall draw up a Declaration of Performance when a product covered by a harmonised standard (hEN) or a European Technical Assessment (ETA) is placed on the market.

The manufacturer, by drawing up his DoP, assumes the responsibility for the conformity of the construction product with the declared performance.
Role and Importance of a Standard Fire

The standard temperature-time curve for direct testing in furnace given in EN 1363-1 is the so-called ISO 834 curve: \( T_t = 345 \log(8t + 1) + 20 \)

EN 1363-2 specifies alternative heating conditions, to be used under special circumstances. As said, Standard Fire allows to:

- determine Fire resistance
- determine Material Characteristics as a function of Temperature (for concrete, masonry, steel . . .)

. . . on a Standardized basis!
Terms and Definitions

Reaction to fire refers to *material behaviour*, the product shall be classified on the basis of its reaction-to-fire performance, including such things as combustibility, flame spread etc., having regard to the classification system based on *class of reaction-to-fire*.

Fire resistance refers to *structure behaviour*, the load-bearing function must be maintained during the required time of fire exposure, therefore it is specified in terms of *minutes*. 
Terms and Definitions

The classification of performance of building elements is achieved with codes:

**R-EI-REI** (labels) + **30-60-90-...** (Resistance in minutes)

ex. R30; EI90; REI60

<table>
<thead>
<tr>
<th>Label</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td><strong>Load Bearing</strong>: ability to sustain the applied load at some point during fire</td>
</tr>
<tr>
<td>E</td>
<td><strong>Integrity</strong>: ability to stop the passage of flame or hot gases</td>
</tr>
<tr>
<td>I</td>
<td><strong>Insulation</strong>: ability to restrict the temperature rise of the unexposed face of the element to below specified levels.</td>
</tr>
</tbody>
</table>
## Terms and Definitions

<table>
<thead>
<tr>
<th>Label</th>
<th>Definition</th>
<th>Fire surfaces</th>
<th>1D Elements</th>
<th>2D Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>Load bearing elements, without &quot;compartment&quot; function</td>
<td>1, 2, 3</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>EI</td>
<td>Non-Load bearing elements, with &quot;compartment&quot; function</td>
<td>1</td>
<td><img src="image3.png" alt="Image" /></td>
<td>-</td>
</tr>
<tr>
<td>REI</td>
<td>Load bearing elements, with &quot;compartment&quot; function</td>
<td>1</td>
<td>-</td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
</tbody>
</table>
Thermal degradation of wood

Pyrolysis
- charcoal

Pyrolysis is a thermochemical decomposition of organic material at elevated temperatures in the absence of oxygen (or with few oxygen)

Complete combustion
+ ash

Complete combustion requires adequate oxygen and the 3 T’s:
- Time,
- Temperature,
- Turbulence

Energy released

- ≈ 1.3 MJ/kg

+ ≈ 20 MJ/kg
Thermal degradation of wood

**Sequence of combustion phenomena**

Scheme of the temperature sequence of the involved phenomena.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Phenomena</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 °C</td>
<td>Sample temperature before ignition</td>
</tr>
<tr>
<td>100 °C</td>
<td>Water Loss</td>
</tr>
<tr>
<td>120 °C</td>
<td>Decay begins (lignin plasticization)</td>
</tr>
<tr>
<td>170 °C</td>
<td>Pyrolysis begins</td>
</tr>
<tr>
<td>Over 170 °C</td>
<td>Pyrolysis products combustion</td>
</tr>
<tr>
<td>300 °C</td>
<td>EC5 Isotherm of <em>not returning point</em></td>
</tr>
</tbody>
</table>

Eurocode 5 fixes another *not return point*, where it places the charring theoretical line on the 300 °C isotherm inside the wood mass: from this line the strength and modulus of wood must be taken as zero value.
Thermal degradation of wood

Aspects of thermal decay

The combustion (and thermal demolition) of wood proceeds from its exposed outer surface towards the inside of its mass with a determined finite rate, so the process is not instantaneous. This velocity depends mainly on the wood species, while, among environmental factors, temperature, heat contribution and ventilation are determining. Among the material conditions, the most significant ones are moisture content and treatments that the material may have undergone.
Thermal degradation of wood

Aspects of thermal decay

It can therefore be said that, in a fire, the depth of destroyed material is approx. proportional to the exposure time (more exactly, to the duration of the charring process). Another important point to be remarked is that “normal wood” exhibits temperatures below 100 °C, except for a small layer (10÷20mm) next to the pyrolysis zone. Charring rate $\sim 0.6 \div 0.7$ mm/min
Thermal degradation of wood
Timber vs. other construction materials

Why choose a combustible material, such as timber/glulam/CLT, for structural elements that must ensure a given level of fire resistance?

Let us observe the gradual change (evolution) of the mechanical properties of some building materials when exposed to a standard fire. The parameters are measured with reference to the performance of physically defined elements.

For all materials but wood, the test piece size and shape do not have a significant effect: for these materials, moreover at any time a temperature constant over the whole section can be hypothesized, slightly lower than the environment temperature, and it is therefore correct to think that all material properties vary accordingly.

In wood instead, under the charred layer, there is no significant temperature increase and the material properties consequently remain unchanged.

Wood seems therefore to feature a better pattern, but what is being observed is not the temperature induced evolution of the material properties, but the evolution of performances for an element with a given (here 50 mm × 50 mm) initial cross section, that is the decrease of the resisting section during the exposure to fire. The advantage, when utilising wood, does not lie in the variation of its mechanical parameters with temperature, but in the slow and somehow predictable mass thermal evolution.
Timber vs. other construction materials

Evolution of the mechanical properties of some building materials when exposed to a standard fire

![Graph showing the evolution of temperature and strength reduction factor over time for different materials: Temperature, Wood (50x50 mm), Steel, and Aluminium alloy.](image)
Thermal degradation of wood

Evolution of the mechanical properties vs temperature of wood and steel

Wood

Steel
Thermal degradation of wood

Evolution of the mechanical properties vs temperature of wood and steel

Wood

Steel

\[ \sigma \quad t_R \quad Time \]

\[ f_R \quad Time \]

\[ \sigma \quad t_R \quad Time \]

\[ f_R \]
Frame Safety Requirements

Design of Fire Resistance

1. **Requirement** ⇒ Definition of $R_d$ (REI) in terms of time $T$ (see EN 1991-1-2)

<table>
<thead>
<tr>
<th>REI</th>
<th>15</th>
<th>20</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>90</th>
<th>120</th>
<th>180</th>
<th>240</th>
<th>360</th>
</tr>
</thead>
</table>

2. **Check of fire resistance** ⇒ Check $t \geq t_{req}$ (see EN 1995-1-2)

Concerning the Requirement it is necessary to refer to:

- **fire load density** (defined hereinafter), either based on *measurements* or based on fire resistance *requirements given in National regulations*
- specific *National Regulations* regarding occupancies (e.g. offices, hotel, residence, manufactories . . . )
Fire Safety Requirements

Requirements
The fire load density $q_{f,d}$ used in calculations should be a design value, either based on measurements or in special cases based on fire resistance requirements given in national regulations.

The design value may be determined

- from a national fire load classification of occupancies
- specific for individual project by performing a fire load survey

\[
q_{f,d} = \delta_{q1} \cdot \delta_{q2} \cdot \delta_n \cdot q_{f,k} \quad [MJ/m^2]
\]

Fire Load Density

$q_{f,k} \quad [MJ/m^2]$ characteristic fire load density per unit floor area

$\delta_{q1} \quad [1 \div 2]$ depending on the risk due to the size of compartment

$\delta_{q2} \quad [0, 8 \div 1, 2]$ depending on the risk due to the type of occupancy

$\delta_n = \prod_{i=1}^{10} \delta_{ni}$ depending on the different fire fighting measures,

with $\delta_{ni} = [0, 6 \div 0, 9]$
Fire Safety Requirements

Requirements
EN 1991-1-2: different values can be found in the national annex of single EU countries.

<table>
<thead>
<tr>
<th>Factor $\delta_{q1}$</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compartment floor area [$m^2$]</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>1,10</td>
</tr>
<tr>
<td>250</td>
<td>1,50</td>
</tr>
<tr>
<td>2500</td>
<td>1,90</td>
</tr>
<tr>
<td>5000</td>
<td>2,00</td>
</tr>
<tr>
<td>$\geq$10000</td>
<td>2,13</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ex. of occupancies</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artgallery, museum, swimming pool</td>
<td>0,78</td>
</tr>
<tr>
<td>Offices, hotel, residence</td>
<td>1,00</td>
</tr>
<tr>
<td>Manufactory for engines and machinery</td>
<td>1,22</td>
</tr>
<tr>
<td>Chemical lab, painting workshop</td>
<td>1,44</td>
</tr>
<tr>
<td>Manufactory of fireworks or paints</td>
<td>1,66</td>
</tr>
</tbody>
</table>
Fire Safety Requirements

Requirements

\[
\delta_n = \prod_{i=1}^{\frac{1}{10}} \delta_{ni}
\]

δni are Functions of Active Fire Fighting Measures

<table>
<thead>
<tr>
<th>Automatic Fire Suppression</th>
<th>Automatic Fire Detection</th>
<th>Manual Fire Suppression</th>
</tr>
</thead>
</table>
| δn₁ | δn₂ | δn₃ /
| 0,61 | 1,0 - 0,87 - 0,7 | 0,87 or 0,73 |
| δn₄ | δn₅ | δn₆ /
| 0,87 | 0,61 or 0,78 | 0,61 or 1,0 or 1,5 |
| δn₇ | δn₈ | δn₉ /
| 0,9 or 1,0 or 1,5 | 1,0 or 1,5 | 1,0 or 1,5 |
| δn₁₀ | | |

* For normal Fire Fighting Measures in staircases δni=1, if not present δni=1,5
Fire Safety Requirements

Requirements

The fire load can be determined either

- from a fire load classification of occupancies (given by classification or calculated for the building)
- specific for individual project

The characteristic fire load density is defined as:

\[ Q_{fi,k} = \sum M_{k,i} \cdot H_{u,i} \cdot \Psi_i = \sum Q_{fi,k,i} \, [MJ] \quad q_{f,k} = Q_{fi,k}/A \, [MJ/m^2] \]

- \( M_{k,i} \, [kg] \) amount of i-th combustible material
- \( H_{u,i} \, [MJ/kg] \) net calorific value of i-th combustible material
- \( \Psi_i \) optional factor, to take into account "protected" combustible materials (usually \( \Psi_i = 1 \))
- \( A \, [m^2] \) floor area of the fire compartment
Fire Safety Requirements

**Requirements**

Examples of standard fire load densities $q_{f,k} \text{ [MJ/m}^2\text{]}$ for different occupancies.

Values valid for $\delta_{q,2} = 1, 0$

Fire loads "from the building" should be added if relevant.

<table>
<thead>
<tr>
<th>Occupancy</th>
<th>Average value</th>
<th>80% fractile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dwelling</td>
<td>780</td>
<td>948</td>
</tr>
<tr>
<td>Hospital (room)</td>
<td>230</td>
<td>280</td>
</tr>
<tr>
<td>Hotel (room)</td>
<td>310</td>
<td>377</td>
</tr>
<tr>
<td>Library</td>
<td>1500</td>
<td>1824</td>
</tr>
<tr>
<td>Office</td>
<td>420</td>
<td>511</td>
</tr>
<tr>
<td>Classroom of a school</td>
<td>285</td>
<td>347</td>
</tr>
<tr>
<td>Shopping centre</td>
<td>600</td>
<td>730</td>
</tr>
<tr>
<td>Theatre (cinema)</td>
<td>300</td>
<td>365</td>
</tr>
<tr>
<td>Transport (public space)</td>
<td>100</td>
<td>122</td>
</tr>
</tbody>
</table>
It is especially interesting to study a wooden structure, undergoing a fire, analysing parts of the structure, imposing the accidental action of fire and verifying that for each of them the following condition is satisfied:

\[ A_{d,fi}(t) \leq R_{d,fi}(t) \]

where \( A_{d,fi} \) is the design value of the effect of action under fire conditions, \( R_{d,fi} \) the corresponding design resistance under the same conditions, and \( t \) the duration of fire exposure.
Fire Safety of Timber Structures and Standards

For the effects of the direct actions acting on the structure, the combination rule for the so-called exceptional combinations is adopted, that can be written as follows:

\[ G_k + \psi_{1,1} \cdot Q_{k,1} + \sum_{i} \psi_{2,i} \cdot Q_{k,i} \]

- \( G_k \) characteristic value of permanent actions;
- \( Q_{k,1} \) characteristic value of variable (principal) action;
- \( Q_{k,i} \) characteristic values of other variable actions;
- \( \psi_{1,1} \) combination coefficient for the variable action assumed as principal;
- \( \psi_{2,i} \) generic combination coefficient for other variable actions.

The values for the combination coefficients \( \psi \) are given as functions of the different categories of use for the different areas in buildings (EN 1991-1-1), and usually range between 0 and 0.7. Caution should be used in those cases in which the maximum action can be foreseen during the fire event (e.g. libraries, archives and stores).
Fire Safety of Timber Structures and Standards

A simplified method to calculate $A_{d,fi}$ when conditions are unchanged during the fire is available. Starting from the fundamental combination of actions $A_d$ for normal temperature design, the values $A_{d,fi}$ can be calculated using the following equation:

$$A_{d,fi} = \eta_{fi} \cdot A_d$$

$\eta_{fi}$ depends on the different safety factors $\gamma_G$ and $\gamma_Q$ (characteristic permanent and variable actions), as well as on the combination factor $\Psi_{fi}$ for frequent values of variable actions in the fire situation, given either by $\Psi_{1,1}$ or $\Psi_{2,1}$ (EN 1991-1-2), and it can be written as:

$$\eta_{fi} = \frac{G_k + \Psi_{fi} \cdot Q_{k,1}}{\gamma_G \cdot G_k + \gamma_{Q,1} \cdot Q_{k,1}} = \frac{1 + \Psi_{fi} \cdot \xi}{\gamma_G + \gamma_{Q,1} \cdot \xi}$$

$\xi$ is the ratio $Q_{k,1}/G_k$
Values for $\eta_{fi}$ as a function of permanent/variable actions ratio $\xi$

Diagrams $\eta_{fi}$ as a function of ratio $\xi$ and for different values of the combination coefficient $\Psi_{1,1}$, assuming $\gamma_G = 1,35$, $\gamma_Q = 1,5$. Values 0,9, 0,7 and 0,5 correspond to category E (areas susceptible to accumulation of goods), C/D (meeting and shopping areas), A/B (areas for domestic and residential activities, and office areas). High values of the ratio are usually featured by the so called "lightweight" structures, such as the wooden ones.
Residual and effective cross section methods, definition (EN 1995-1-2)

**The European Standard approach**

Thermal decay of wood as previously described justifies a standardised approach that, however simplified, allows satisfactory design evaluations and verifications. The following terms will then be utilised:

- **char line**: transition area between charred layer and the residual cross section;
- **residual cross section**: initial cross section minus the thickness of the charred layer;
- **effective cross section**: initial cross section minus the thickness of the charred layer and that of a under-laying layer whose strength and stiffness are assumed to be zero.
The European Standard approach

In EN 1995-1-2, three different design approaches with increasing complexity are envisaged:

- **effective cross section** method;
- **reduced properties method** (reduced strength and modulus) method;
- **advanced calculation methods**, with reference to charring models, temperature profile and moisture gradient over the cross section and to wood strength and modulus variations with temperature and moisture.

The first method entails both simplicity of analysis and consistency with the physical development of the phenomenon.
Effective cross section method

In this method, an effective cross section is calculated by subtracting from the initial cross section the thickness of an effective charring depth $d_{ef}$ given by:

$$d_{ef} = d_{char,n} + k_0 \cdot \beta_0$$

$d_{char,n} = \beta_n \cdot t$ is the notional charring depth, $\beta_n$ is the notional charring rate, including the negative effects of shakes and corner rounding.

$k_0$ is a coefficient ranging between 0 and 1 (to be defined further on).

$\beta_0 = 7 \text{mm}$, is highest difference between residual and effective cross section.
### Fire Safety of Timber Structures and Standards

**β₀ and βₙ values for wood and wood based materials (EN 1995-1-2)**

<table>
<thead>
<tr>
<th>Material</th>
<th>β₀ (mm/min)</th>
<th>βₙ (mm/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Softwood and beech</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glued laminated timber with characteristic density ≥ 290 kg/m³</td>
<td>0.65</td>
<td>0.70</td>
</tr>
<tr>
<td>Solid timber with characteristic density ≥ 290 kg/m³</td>
<td>0.65</td>
<td>0.80</td>
</tr>
<tr>
<td>b) Hardwood (beech excluded)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid/glued laminated timber with characteristic density value of 290 kg/m³</td>
<td>0.65</td>
<td>0.70</td>
</tr>
<tr>
<td>Solid or glued laminated timber with characteristic density value ≥ 450 kg/m³</td>
<td>0.50</td>
<td>0.55</td>
</tr>
<tr>
<td>c) LVL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>with characteristic density value ≥ 480 kg/m³</td>
<td>0.65</td>
<td>0.70</td>
</tr>
<tr>
<td>d) Wood-based panels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood panelling</td>
<td>0.90*</td>
<td>–</td>
</tr>
<tr>
<td>Plywood</td>
<td>1.00*</td>
<td>–</td>
</tr>
<tr>
<td>Wood-based panels other than plywood</td>
<td>0.90*</td>
<td>–</td>
</tr>
</tbody>
</table>

* These values apply to boards with a characteristic density value of 450 kg/m³ and a thickness of 20 mm. European Standard EN 1995-1-2 provides methods to derive values for different densities and thicknesses.
Fire Safety of Timber Structures and Standards

Effective cross section method

If the corner rounding effect caused by simultaneous fire exposure on concurrent faces, the charring rate $\beta_0$ can be used. For a one-dimensional situation (e.g., a glued laminated beam), the charring depth can be calculated referring to a 0 charring rate, close to the results of (1-D) physical tests:

$$d_{\text{char},n} = \beta_n \cdot t$$

The rounding radius of the corner must be assumed to be equal to the charring depth $d_{\text{char},0}$. This is allowed as long as the minimum cross section dimension has a value greater than $b_{\text{min}}$, which is obtained from:

$$b_{\text{min}} = \begin{cases} 2 \cdot d_{\text{char},0} + 80 & \text{if } d_{\text{char},0} \geq 13\text{mm} \\ 8,15 \cdot d_{\text{char},0} & \text{if } d_{\text{char},0} < 13\text{mm} \end{cases}$$

If the minimum cross section dimension is or becomes smaller than $b_{\text{min}}$, the $\beta_n$ values apply instead.
Effective cross section method

What is the difference taking into account or not the corner rounding effect? The difference can be significant considering the final (reduced) cross-section, as shown in this simple example, in terms of section moduli.

\[ t = 60' \]

4 surfaces exposed, solid softwood

\[ \beta_0 = 0.65 \text{ mm/min} \]
\[ \beta_n = 0.8 \text{ mm/min} \]

with corner rounding

\[ (r = d_{\text{char},0}) \]

without rounding

\[ 29\% \cdot W_{\text{in}} \]
\[ 25\% \cdot W_{\text{in}} \]

+15%
Fire Safety of Timber Structures and Standards

CLT Products
Glued laminated and sawn timber (softwood and hardwood) are reported in EN 1995-1-2, but up to now CLT is not regulated within the European Standards!

Is it possible to think that, if the base-material (i.e. boards) is the same for assembling GLT and CLT, also the charring rate will be the same?

If the charring is beneath the first glue line, there is no problem (± until 30 minutes), the answer is YES! If the process goes on, influencing the 2nd layer, the charring rate for CLT is usually greater than for GLT. The problem is complicated by the glue usually employed by CLT producers! The PUR-bond glue has thermal characteristics different from the ones used for GLT, as an example the MUF glue.

There are ETAs (European Technical Approval) of some producers that seem to confirm this assumption.
The European Standard approach: Strength and Modulus of material
What are the values to be assumed for mechanical parameters during fire?

Strength

\[ f_{d,fi} = k_{\text{mod,fi}} \cdot \frac{f_k \cdot k_f}{\gamma_{M,fi}} \]

- \( k_f \) is the value for obtaining the 20 % fractile of a strength and modulus properties from the 5 % fractile value (at normal temperature):
  - Solid timber: 1,25
  - Glued-laminated timber: 1,15
  - Wood-based panels: 1,15
  - LVL: 1,1
  - Connections with fasteners in shear with side members of wood and wood-based panels: 1,15
  - Connections with fasteners in shear with side members of steel: 1,05
  - Connections with axially loaded fasteners: 1,05

Elastic modulus

\[ S_{d,fi} = k_{\text{mod,fi}} \cdot \frac{S_{05} \cdot k_f}{\gamma_{M,fi}} \]

Resistance of connections

\[ R_{d,fi} = \eta \cdot \frac{R_k \cdot k_f}{\gamma_{M,fi}} \]

- \( \gamma_{M,fi} \) is the partial safety factor for timber in fire (=1,0)
- \( k_{\text{mod,fi}} \) is the modification factor for fire (=1 for the effective cross section method)
Designing a fire resistant structure

Designing the protection

Wood is a fuel but it can be protected

Wood burns with a constant charring rate $\sim 0.7 \text{ mm/min}$

Timber section remains unchanged if the protection is designed accordingly
Designing a fire resistant structure

Designing the protection

Wood is a fuel *but* it can be protected

Wood burns with a constant charring rate $\sim 0.7 \text{ mm/min}$

Timber section is reduced, and its load carrying capacity (ULS) must be checked
Fire Safety of Timber Structures and Standards

Designing a fire resistant structure

Generally, a "stocky" timber structure (i.e. characterized by elements with low values of the ratio $A_{\text{exposed}}/V_{\text{element}}$) is inherently better than a light timber structure.

This is particularly true when stability issues (Euler buckling of column, lateral-torsional buckling of beam) are involved, since the resistant cross section decreases and the slenderness significantly increases.