Ministry of Economics
Republic of Latvia

Apmācību semināru cikls

«Moderno koka konstrukciju projektēšana un ugunsaizsardzība»

ID Nr. EM 2021/42

Rīga, 2021

Ministry of Economics
Republic of Latvia

Training seminar / Apmācību seminārs

Fire Design of Timber Structures

Koka konstrukciju ugunsdrošība

October 26, 2021, Riga

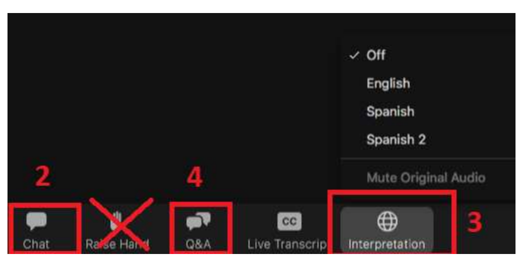
Michael Klippel (ETH Zürich, Switzerland)

Agenda

09:00 – 10:00	**Registration**
10:00 – 11:30	Introduction Timber/glulam/CLT/other wood-based construction products cross-sections charring rates calculation methods and calculation methods of fire resistance of these elements Delamination of glulam and CLT structures in fire Calculation of additional protection (gypsum board, etc.), the effect on timber/glulam/CLT elements fire resistance
11:30 – 12:00	**Coffee break**
12:00 – 13:30	Fire resistance of connections in timber structures; Insight in advanced calculations methods of fire resistance of timber structures; Case studies of timber building fire design
13:30 – 14:00	**Lunch break**
14:00 – 15:30	Fire protection strategies in mid-rise and high-rise timber buildings – required fire resistances and combustibility, timber structures additional fire protection, additional measures, etc. Fire protection solutions for mid-rise and high-rise timber buildings, examples; Questions and answers
15:30 – 16:00	**Question and answer session**

Technical information

1. Write your full name in participants list
2. Register your name using chat (write your full name and surname)
3. Interpretation available in Latvian
4. For questions use the Q&A functionality
5. Do not use the reactions or raise hand



Introduction of lecturer

Dr. Michael Klippel

Current position:

- Lecturer at **ETH Zurich** and head of research group «Fire and Timber»
- Co-founder and partner of **IGNIS – Fire Design Consulting**

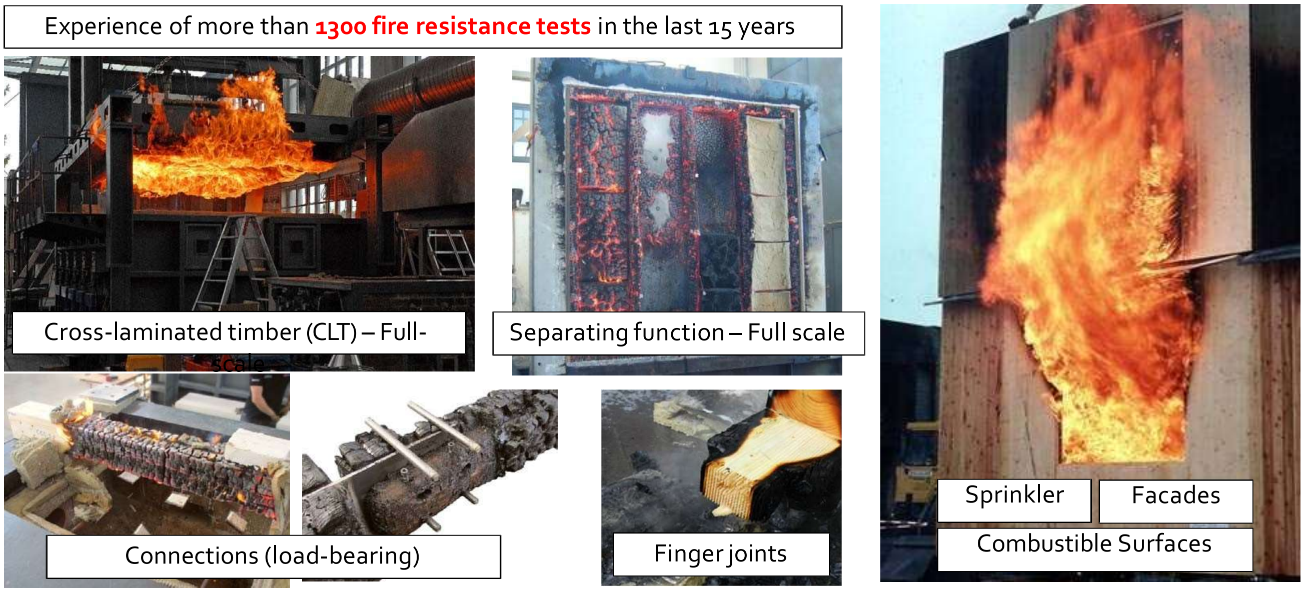
Business units of IGNIS

IGNIS
Fire · Design · Consulting

- **IGNIS-seminar**
  Education and Teaching
- **IGNIS-Tools**
  Software and Application
- **Fire Safety Engineering and Concepts**
  Building and Design
- **Fire Resistance Testing**
  Consulting and Performing
- **Fire Design of Structures**
  Design and Standardisation
- **Product Development**
  Consulting and Testing

Selection of performed fire resistance testing

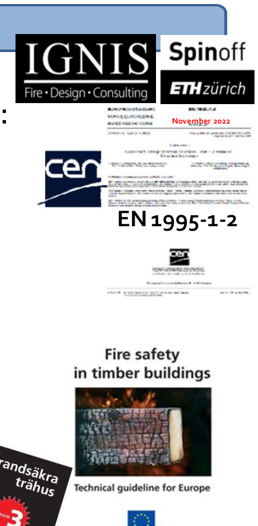
Experience of more than **1300 fire resistance tests** in the last 15 years



IGNIS contributions to selected documents

Contribution of **IGNIS** partners in *standardisation*, *guidelines* and *handbooks*:

- EN 1995-1-2 (Eurocode 5, fire part), DIN 4102-4, DIN 18234
- Fire safety in timber buildings – technical guideline for Europe
- COST FP 1404 Guidance documents, Swiss timber design guideline by Lignum
- «The CLT Handbook» in Sweden, «Building with CLT » in Germany
- Numerous PhD dissertations and research projects on «fire and timber» at ETH Zürich, TUM Munich and TalTech Estonia



Typical Services

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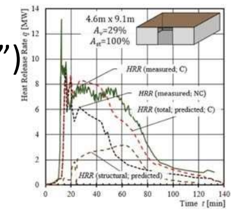
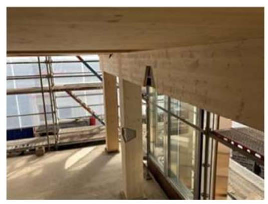
1. Fire resistance design (modelling and "smart testing")
2. Quality management for timber/composite structures
3. Product optimization
4. Fire dynamics calculation (consideration of structural timber as "fuel load")
5. Risk assessment/ evaluation of design deviations
6. Robustness
7. Review of FSE elements
8. Detailing





Application of expert knowledge // project selection

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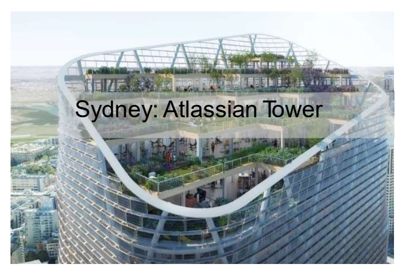


Please visit: www.menti.com

Agenda / 10:00 - 11:30

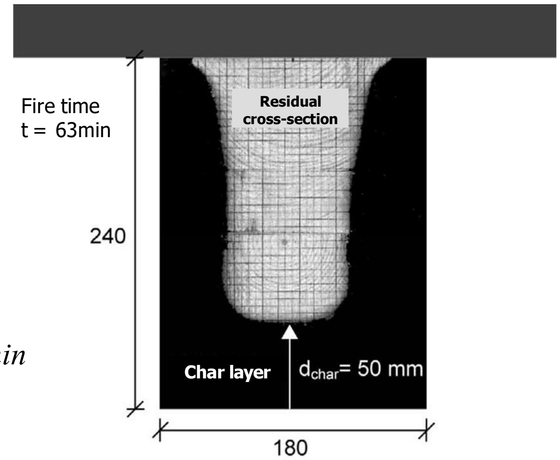
- Introduction
- Timber/glulam/CLT/other wood-based construction products cross-sections charring rates calculation methods and calculation methods of fire resistance of these elements
- Delamination of glulam and CLT structures in fire
- Calculation of additional protection (gypsum board, etc.), the effect on timber/glulam/CLT elements fire resistance

Timber behaviour in fire

- Pyrolysis: thermal degradation of wood producing combustible gases and accompanied by a loss in mass (starting from about 250°C)
- Charring rate β: Ratio between charring depth d_{char} and fire time t (in mm/min)

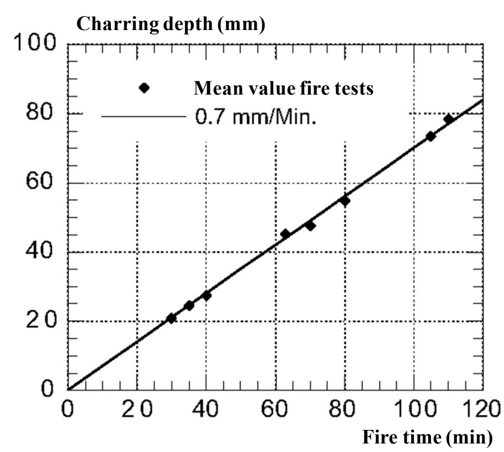
$$\beta = \frac{d_{char}}{t}$$

$$\beta = \frac{d_{char}}{t} = \frac{50mm}{63min} = 0.8\,mm/min$$



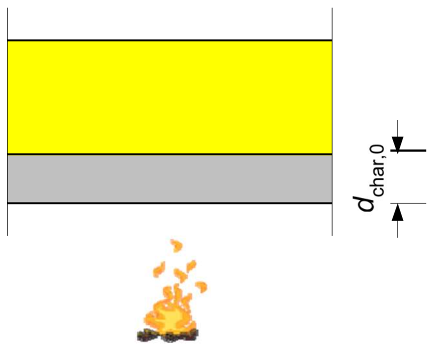
Charring rate

- Depends on fire exposure
  - Constant value for ISO-fire exposure
- Depends on wood species
  - Spruce: β ≈ 0.7 mm/Min.
- Small influence of moisture content and density of wood



A. Frangi, M. Fontana: "Charring rates and temperature profiles of wood sections", *Fire and Materials* 2003; 27: 91–102, DOI: 10.1002/fam.819.

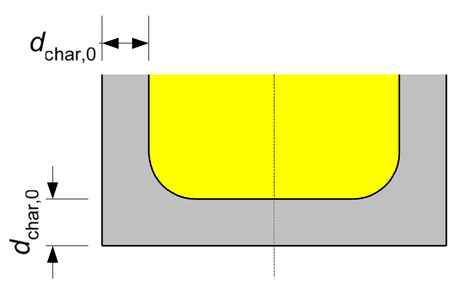
Charring



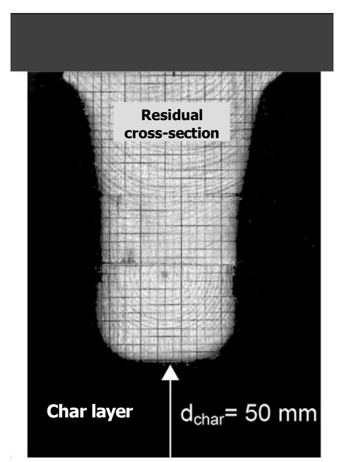
$$d_{char,0} = \beta_0 \cdot t$$

One-dimensional charring: charring rate β_0

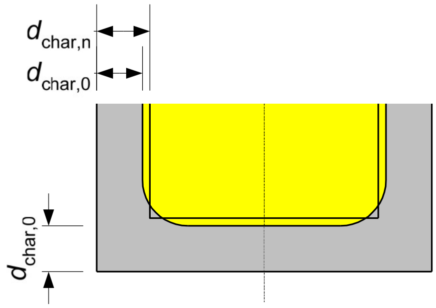
Charring



glued laminated beam



Charring



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

Notional charring: notional charring rate β_n

Equivalent residual cross-section

Charring rates according to EN 1995-1-2:2004

	β_0 mm/min	β_n mm/min
a) Softwood and beech		
Glued laminated timber with a characteristic density of ≥ 290 kg/m^3	0,65	0,7
Solid timber with a characteristic density of ≥ 290 kg/m^3	0,65	0,8
b) Hardwood		
Solid or glued laminated hardwood with a characteristic density of 290 kg/m^3	0,65	0,7
Solid or glued laminated hardwood with a characteristic density of ≥ 450 kg/m^3	0,50	0,55
c) LVL		
with a characteristic density of ≥ 480 kg/m^3	0,65	0,7
d) Panels		
Wood panelling	0,9[a]	–
Plywood	1,0[a]	–
Wood-based panels other than plywood	0,9[a]	–

[a] The values apply to a characteristic density of 450 kg/m^3 and a panel thickness of 20 mm; see 3.4.2(9) for other thicknesses and densities.

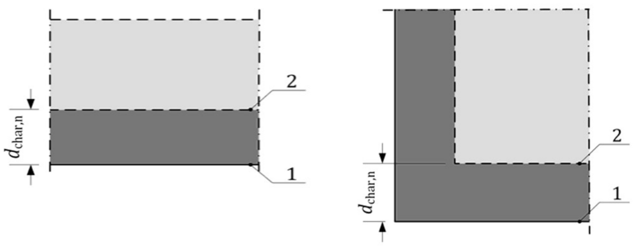
News from prEN 1995-1-2:2021

European charring model

(1) The European charring model should be applied to **standard fire exposure.**

(2) If the timber member undergoes charring in different charring phases the European charring model shall be individually applied for the **individual charring phases** and combined in series.

Notional charring depth



a) One-dimensional charring

b) Two-dimensional charring.

Key: 1 Fire exposed side
2 Residual cross-section

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

$d_{char,n}$ notional charring depth in mm;

β_n notional design charring rate in mm/min;

t time for the charring phase considered, in min.

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Notional design charring rate

$$\beta_n = \prod k_i \cdot \beta_0$$

Modification factor	Designation	Reference
k_{gd}	grain direction factor	5.4.2.2 (4)
k_g	gap factor	5.4.2.2 (6)
k_h	thickness factor	5.4.2.2 (8)
k_n	conversion factor	5.4.2.2 (5), 7.2.2 (2)
$k_{s,n,1}$	combined section and conversion factor for the fire exposed side	5.4.2.2 (7); 7.2.4 (12)
$k_{s,n,2}$	combined section and conversion factor for the lateral side	5.4.2.2 (7); 7.2.4 (12)
k_ρ	density factor	5.4.2.2 (9)
k_2	protection factor for Phase 2	5.4.2.2 (10)-(12)
k_3	post-protection factor for Phase 3	5.4.2.2 (13)
$k_{3,1}$	post-protection factor for the fire exposed side for Phase 3	7.2.4 Table 7.6
$k_{3,2}$	post-protection factor for lateral side for Phase 3	7.2.4 Table 7.6
k_4	consolidation factor for Phase 4	5.4.2.2 (14)

News from prEN 1995-1-2:2021

Basic design charring rates

$$\beta_n = \prod_i k_i \cdot \beta_0$$

	β_0 [mm/min]
a) Timber member made of softwood(1) (3) (4)	0,65
b) Timber member made of hardwood(1)	
Beech(5)	0.70
Beech(5) LVL	0,65
Ash(6)	0,60
Oak(7)	0,50
c) Panel(2)	
Solid wood panelling and cladding, solid wood panel with only one layer	0,65
LVL panel(3), particleboard, fibreboard	0,65
OSB, solid wood panel with multiple layers	0,9
Plywood	1,0

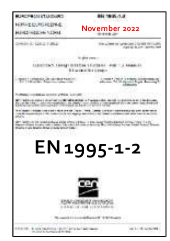
(1) Timber members according to 7.1.1(5), subgroup timber members
(2) Panels according to 7.1.1(5), subgroup panels.
(3) LVL and GLVL with a characteristic density of ≥ 480 kg/m³
(4) Table B.2 in EN 14081-1
(5) FASY in EN 14081-1
(6) FXEX in EN 14081-1
(7) QCXA, QCXE, QCXR in EN 14081-1

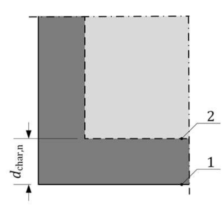
T. Engel, et. al., "TIMpuls Grundlagenforschung zum Brandschutz im Holzbau - Abbrandraten, Schutzzeiten von Bekleidungen und Nachbrandverhalten von Holz", Bautechnik 97 (2020), Sonderheft Holzbau, Ausgabe, DOI:10.1002/bate.202000043.

News from prEN 1995-1-2:2021

Initially unprotected sides of timber members

$$\beta_n = \beta_0 \cdot k_{gd} \cdot k_g \cdot k_h \cdot k_n \cdot k_\rho$$





b) Two-dimensional charring.

Key: 1 Fire exposed side
2 Residual cross-section

Linear members

$$\beta_n = \beta_0 \cdot k_n$$

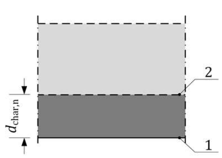
Solid timber $\beta_n = 0,65 \cdot 1,23 = 0,8$ mm/min

Glulam $\beta_n = 0,65 \cdot 1,08 = 0,7$ mm/min

Plane members (solid timber, glulam, LVL, CLT)

$$\beta_n = \beta_0 \cdot k_g$$

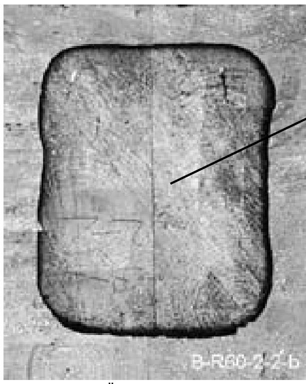
- Gaps ≤ 2 mm $\beta_n = 0,65 \cdot 1 = 0,65$ mm/min
- Gaps 2..5 mm $\beta_n = 0,65 \cdot 1,2 = 0,78$ mm/min



a) One-dimensional charring

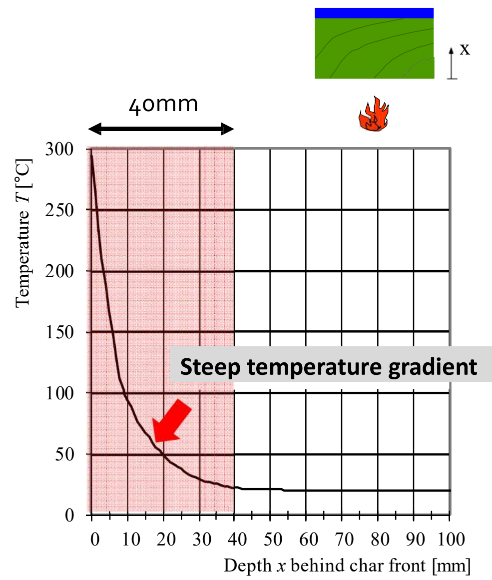
Timber behaviour in fire

Char layer protects the residual cross-section from high temperatures



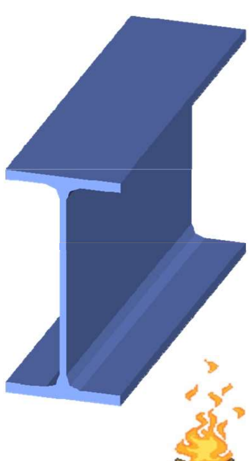
Quelle: proHolz, Österreich

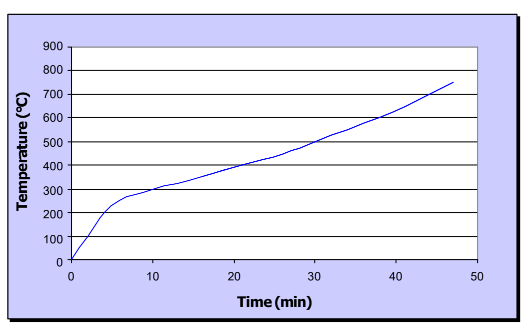
Residual cross-section
- "cold"
- load-bearing



Intumescent coating systems on steel members

- Mode of action: intumescent systems expand at a temperature of about 200°C by a factor of 30 to 60 and form a compact insulating layer.





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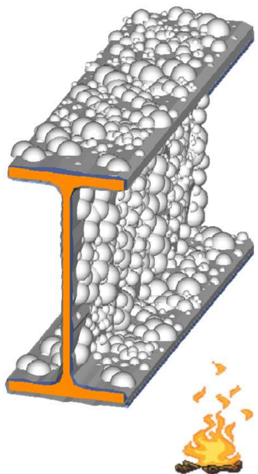

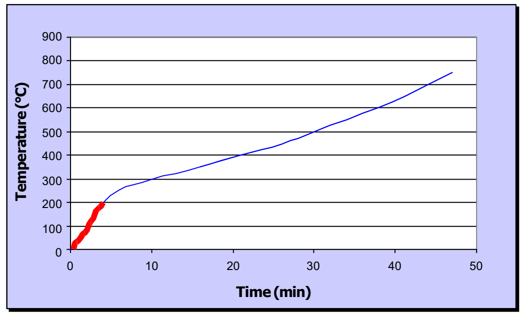

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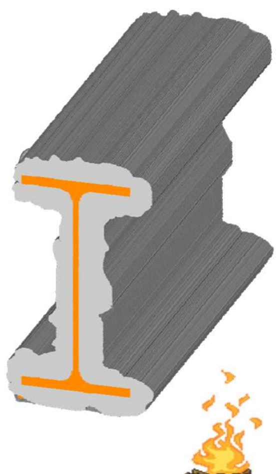
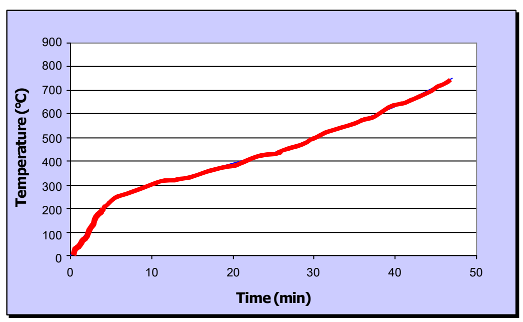
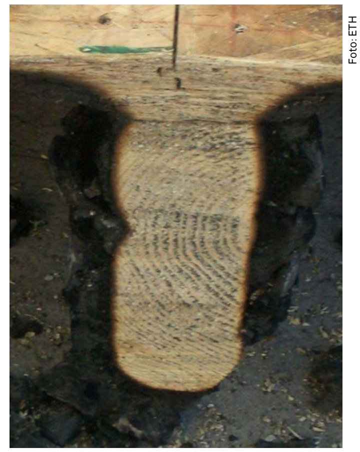




Intumescent coating systems

"Modern manmade intumescent materials applied to steel structural elements are in essence an attempt to replicate what timber does naturally."

"Overview of design issues for tall timber buildings", I. Smith, A. Frangi, Structural Engineering International 2008; 18: 141–147, DOI: 10.2749/101686608784218833.



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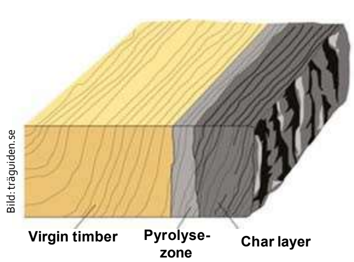
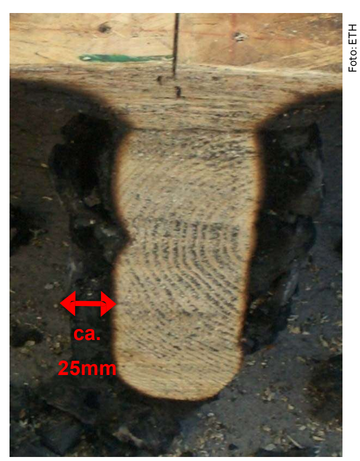
Fire resistance of timber elements

Increase of fire resistance

- Use of massive cross-sections
- Increase of dimensions
- Cladding with gypsum or timber panel





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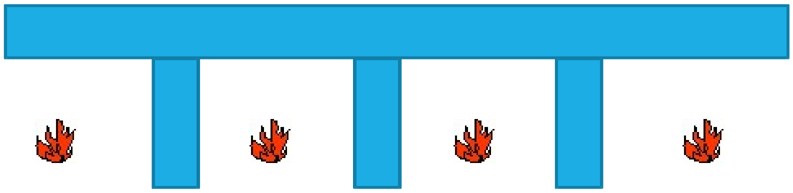
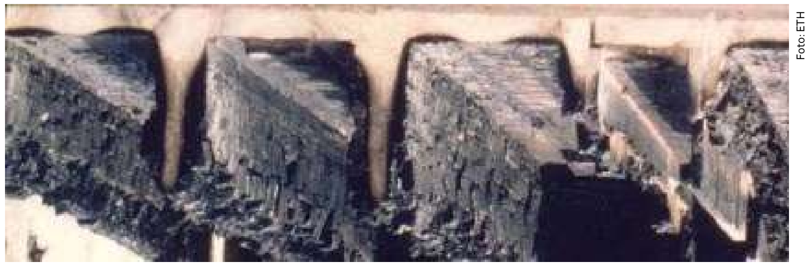
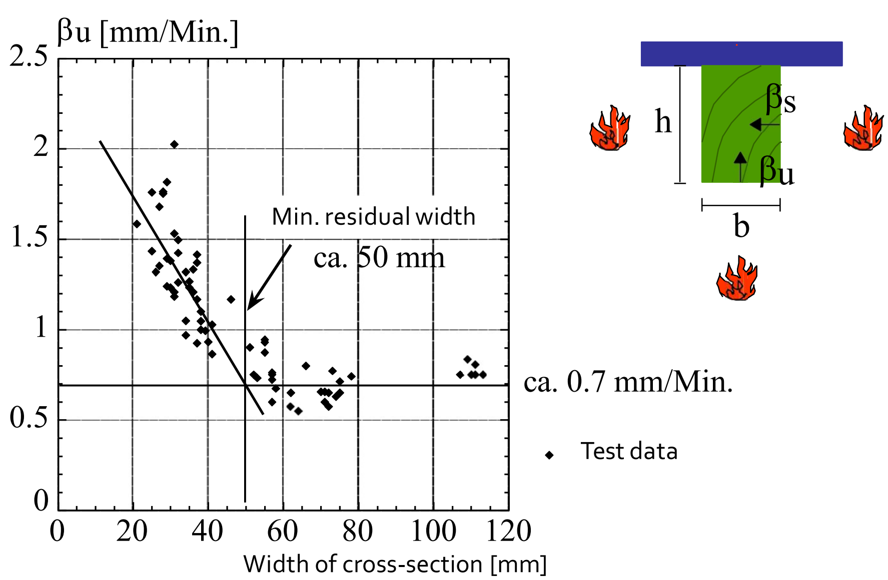
Fire behaviour of small sections





Residual cross-section of timber slabs made of hollow core elements after 30 min ISO-fire exposure

Charring rate



Fire behaviour of timber slabs made of hollow core elements

- Observations
  - If thin vertical timber members are exposed to fire on 3 sides, very irregular residual cross-sections with charring depths much greater than for heavy timber structures

- Conclusion
  - From a fire design point of view it is therefore desirable that the vertical timber members are not exposed to fire on 3 sides

Fire behaviour of timber slabs made of hollow core elements

- Fire exposed timber layer is so designed that a fire penetration into the cavities is prevented

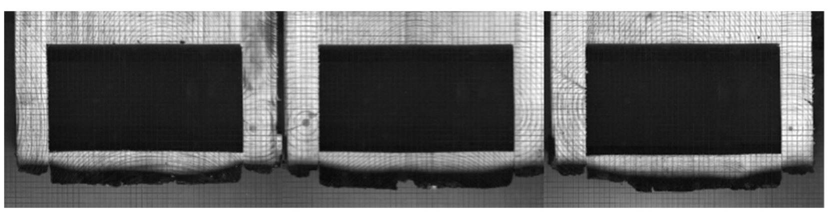


Foto: ETH

- The cavities are filled with insulation material

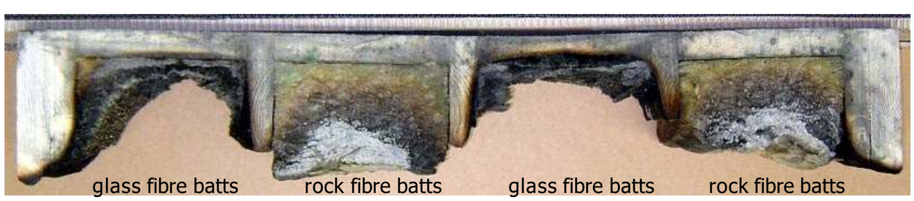
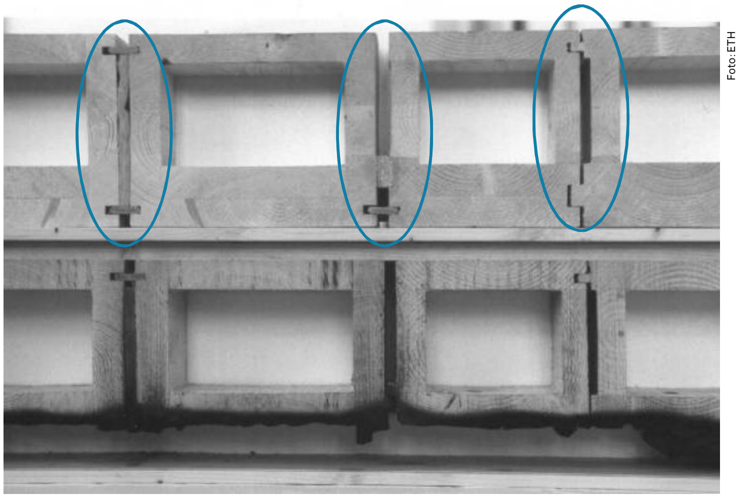


Foto: ETH

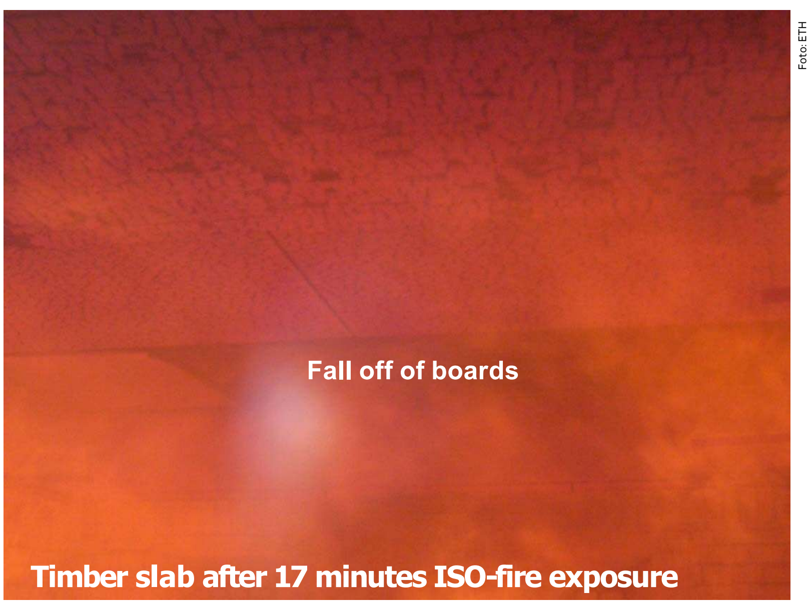
A. Frangi, M. Knobloch, M. Fontana: "Fire design of timber slabs made of hollow core elements", *Engineering Structures* 2009; 31: 150–157, DOI: 10.1016/j.engstruct.2008.08.002.

Influence of joint between timber hollow core elements



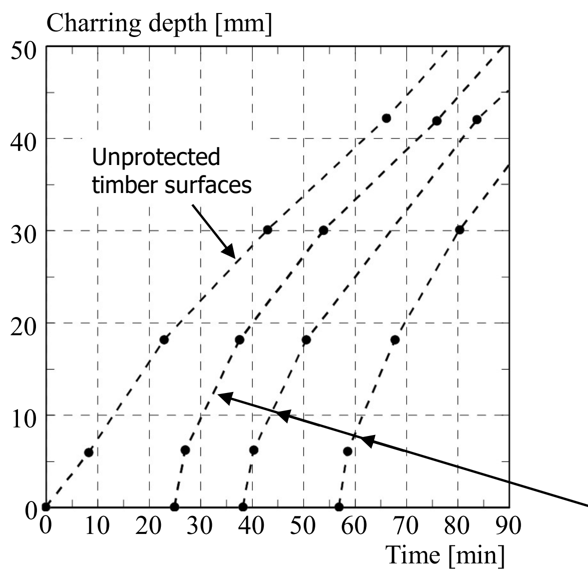
Residual cross-section after 60 minutes ISO-fire exposure

Fall off of protection system

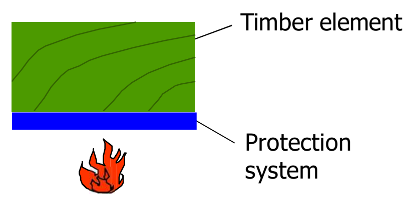


Fire behaviour of initially protected surfaces

Influence of fall off of protection system



- Charring rate not constant
- Increased charring rate after failure of protection system



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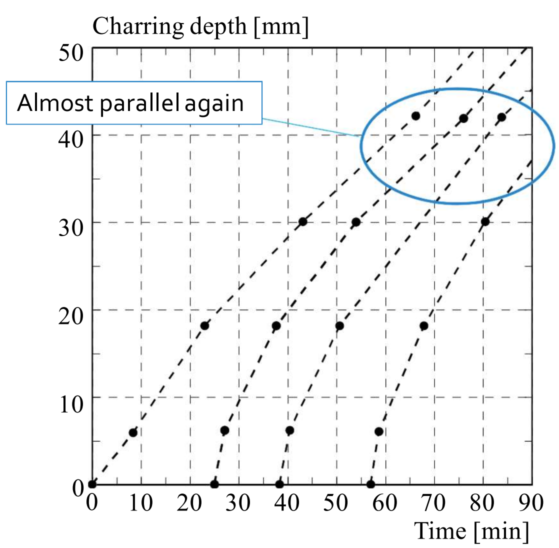
Fire behaviour of initially protected surfaces

Influence of fall off of protection system



Increased charring rate observed after failure of the protection system is due to temperature **high level** while no protective **char-layer** exists to reduce the effect of the temperature. Influence of **preheating** not relevant!

A. Frangi, C. Erchinger, M. Fontana: "Charring model for timber frame floor assemblies with void cavities", *Fire Safety Journal* 2008; 43: 551–564, DOI: 10.1016/j.firesaf.2007.12.009.

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Charring model for initially protected surfaces

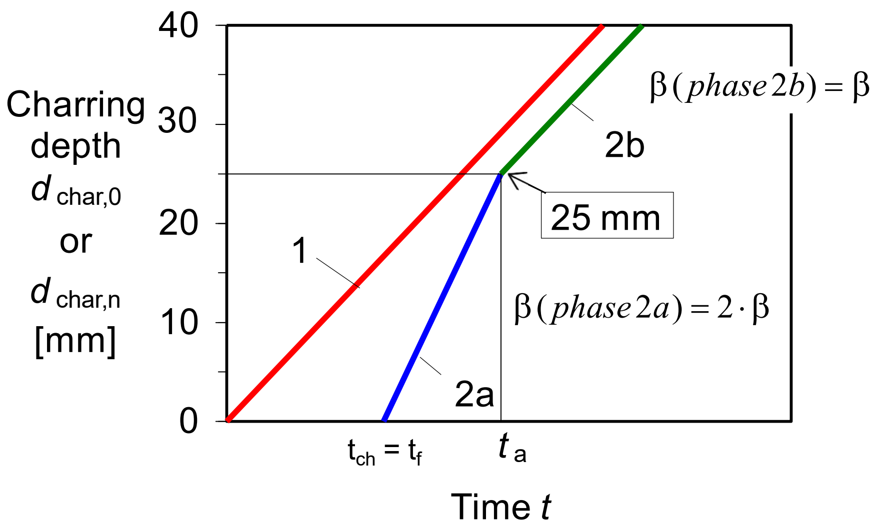
Different charring phases

- t_{ch} = time of start of charring
- t_f = failure time of protection system (fall off)

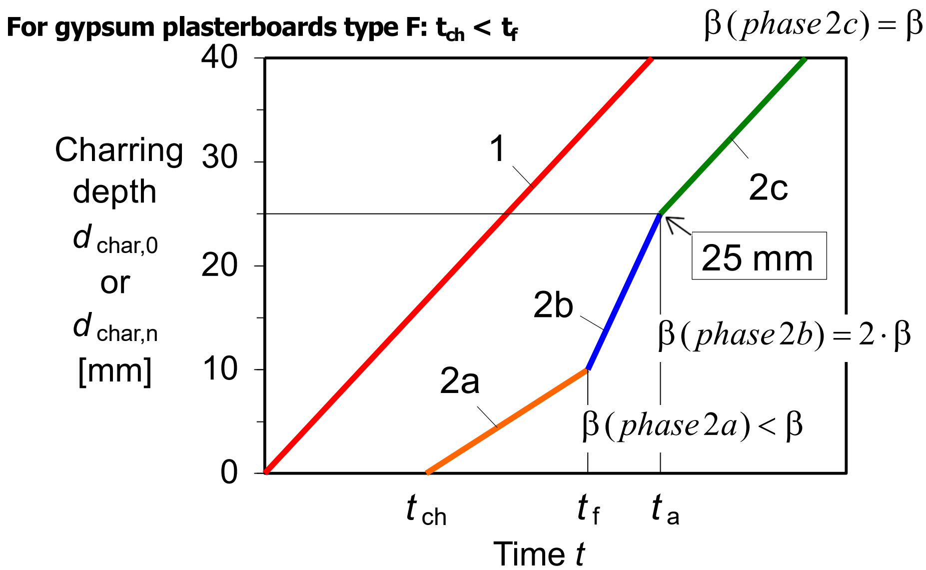
- For wood-based panels and gypsum plasterboards type A or H: $t_{ch} = t_f$
- For gypsum plasterboards type F: $t_{ch} < t_f$

Charring of initially protected timber structures

For wood-based panels and gypsum plasterboards type A or H: $t_{ch} = t_f$



Charring of initially protected timber structures



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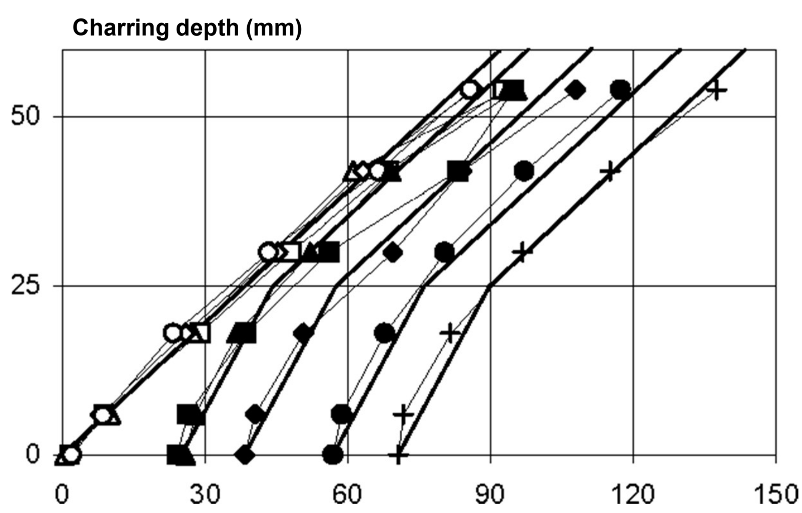
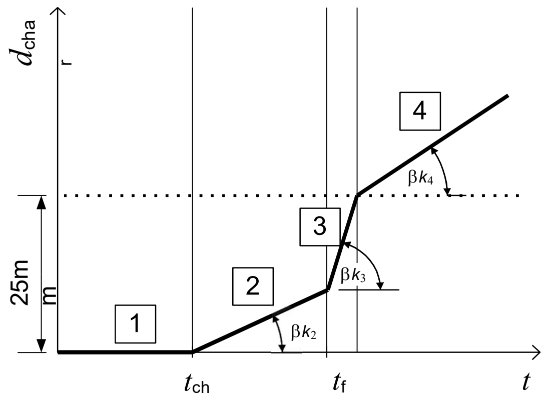
Fire behaviour of initially protected surfaces

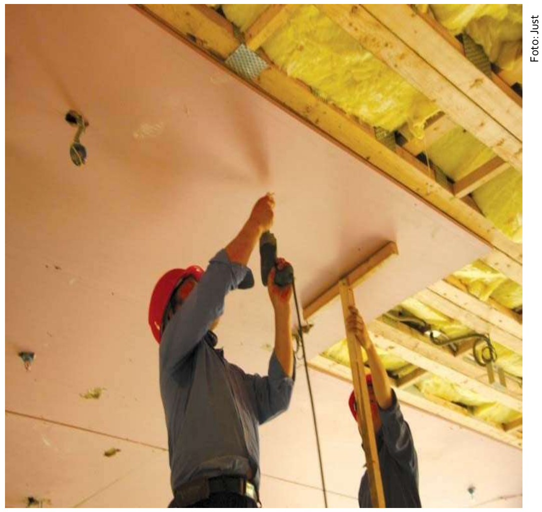


J. König, "Structural fire design according to Eurocode 5 - design rules and their background", Fire Mater. 2005; 29:147–163. DOI: 10.1002/fam.873

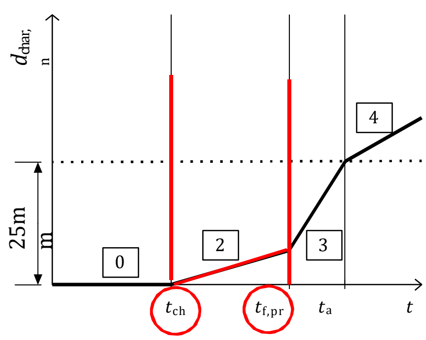
EM iepirkums „Apmācību semināru cikls "Moderno koka konstrukciju projektēšana un ugunsaizsardzība" ID Nr. EM 2021/42

Charring of initially protected timber structures





Charring of initially protected timber structures



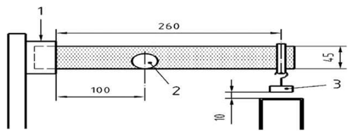
$t_{ch} < t < t_{f,pr}$

$t > t_{f,pr}$

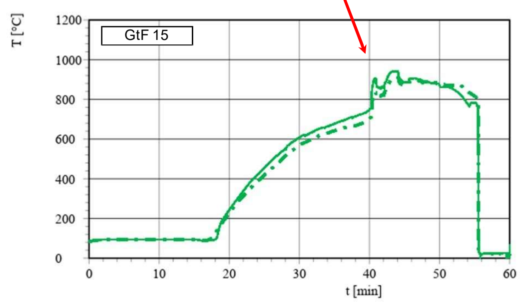
t_{ch} : start time of charring behind protection
$t_{f,pr}$: failure time (of protection system)

Charring of initially protected timber structures

- EN 520



Ca 40 min



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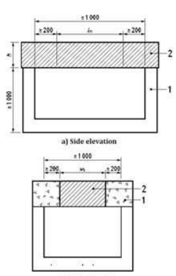
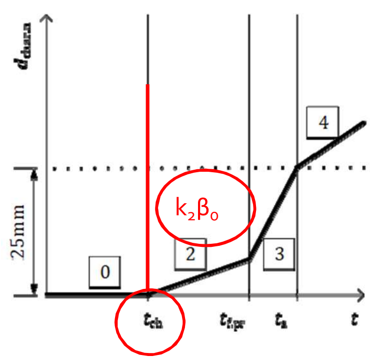
Charring of initially protected timber structures

- Tested values for specific products
  - EN 13381-7





Start time of charring (t_{ch}) and charring rate (k_2)

  - K-classes (EN 13501-2, defined times only!)

EM iepirkums „Apmācību semināru cikls "Moderno koka konstrukciju projektēšana un ugunsaizsardzība" ID Nr. EM 2021/42

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Charring of initially protected timber structures

- Generic values
  - COST ACTION FP 1404 document:

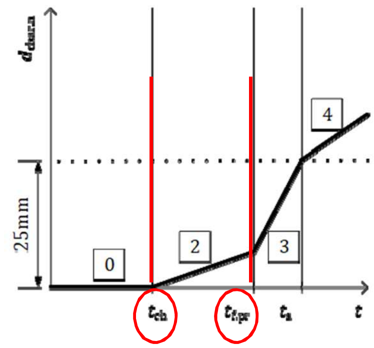
    Just et al. (2018), Improved fire design models for Timber Frame Assemblies - Guidance document N 217-07
    https://costfp1404.ethz.ch/publications.html

  - Fire Safety in Timber Buildings handbook:

    Östman et al. (2010) Fire Safety in Timber Buildings. Technical guideline for Europe.

  - EN 1995-1-2:2025 (coming soon)

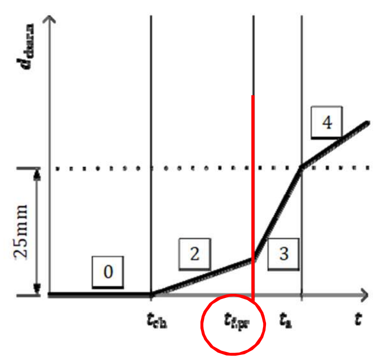
    → t_{ch} and $t_{f,pr}$ as tabulated data



Charring of initially protected timber structures

Failure of the cladding

Mechanical degradation **Pull-out of fasteners**



Charring of initially protected timber structures

Table 6.1 – Start time of charring t_{ch} and the failure time of the fire protection systems $t_{f,pr}$ vertically oriented (e.g. walls)

Panels	Thickness of the fire protection system h_p [mm] [a] layer 1 h_1	layer 2 h_2	Layers backed by [b]	Start of charring t_{ch} [min]	Failure time $t_{f,pr}$ [min]
Gypsum plaster board type A	12,5	-	Insulation	17	20
	12,5	-	Panel	22	22
	12,5	12,5	Insulation	26	41
	12,5	12,5	Panel	36	45
Gypsum plaster board type F	12,5	-	Insulation	17	32
	12,5	-	Panel	24	35
	15	-	Insulation	22	44
	15	-	Panel	30	48
	18	-	Insulation	29	58
	18	-	Panel	37	63
	12,5	12,5	Insulation	39	60
	12,5	12,5	Panel	49	66
	15	15	Insulation	50	82
	15	15	Panel	60	90
	18	18	Insulation	63	108
	18	18	Panel	75	119
Gypsum plaster board type F+A (type F is layer 1)	12,5	12,5	Insulation	39	60
	12,5	12,5	Panel	49	66
	15	12,5	Insulation	45	71
	15	12,5	Panel	55	78
Gypsum fibre board	12,5	-	Insulation	17	26
	12,5	-	Panel	24	29
	12,5	12,5	Insulation	39	50
	12,5	12,5	Panel	49	55
Particle board, $\rho_k \geq 500$ kg/m³	18	-	Insulation	19	19
	18	-	Panel	27	27
OSB, $\rho_k \geq 550$ kg/m³	18	-	Insulation	16	16
	18	-	Panel	21	21
Softwood plywood, $\rho_k \geq 400$ kg/m³	18	-	Insulation	12	12
	18	-	Panel	16	16
Solid wood panels, $\rho_k \geq 290$ kg/m³	18	-	Insulation	17	17
	18	-	Panel	26	26
LVL, $\rho_k \geq 480$ kg/m³	27	-	Insulation	29	29
	27	-	Panel	41	41

where:
ρ_k is the characteristic density, in kg/m³
[a] Layer 1 is at the fire exposed side
[b] The unexposed side for layers may be backed by panel or plane timber member.

Table 6.2 – Start time of charring t_{ch} and the failure time of the fire protection systems $t_{f,pr}$ horizontally orientation (e.g. floors)

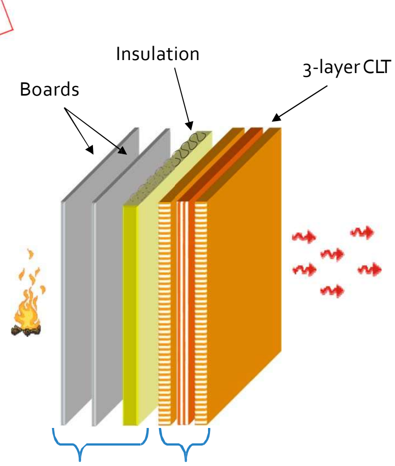
Panels	Thickness of the fire protection system h_p [mm] [a] layer 1 h_1	layer 2 h_2	Layers backed by [b]	Start of charring t_{ch} [min]	Failure time $t_{f,pr}$ [min]
Gypsum plaster board type A	12,5	-	Insulation	17	17
	12,5	-	Panel	19	19
	12,5	12,5	Insulation	26	29
	12,5	12,5	Panel	32	32
Gypsum plaster board type F	12,5	-	Insulation	17	25
	12,5	-	Panel	24	28
	15	-	Insulation	22	28
	15	-	Panel	30	31
	18	-	Insulation	28	32
	18	-	Panel	35	35
	12,5	12,5	Insulation	39	52
	12,5	12,5	Panel	49	57
	15	15	Insulation	50	60
	15	15	Panel	60	66
	18	18	Insulation	63	69
	18	18	Panel	75	76
Gypsum plaster board type F+A (type F is layer 1)	12,5	12,5	Insulation	39	52
	12,5	12,5	Panel	49	58
	15	12,5	Insulation	45	56
	15	12,5	Panel	55	62
Gypsum fibre board	12,5	-	Insulation	17	23
	12,5	-	Panel	24	25
	12,5	12,5	Insulation	39	46
	12,5	12,5	Panel	49	51
Particle board, $\rho_k \geq 500$ kg/m³	18	-	Insulation	19	19
	18	-	Panel	27	27
OSB, $\rho_k \geq 550$ kg/m³	18	-	Insulation	16	16
	18	-	Panel	21	21
Softwood plywood, $\rho_k \geq 400$ kg/m³	18	-	Insulation	12	12
	18	-	Panel	16	16
Solid wood panels, $\rho_k \geq 290$ kg/m³	18	-	Insulation	17	17
	18	-	Panel	26	26
LVL, $\rho_k \geq 480$ kg/m³	27	-	Insulation	29	29
	27	-	Panel	41	41

where:
ρ_k is the characteristic density, in kg/m³
[a] Layer 1 is at the fire exposed side
[b] The unexposed side for layers may be backed by panel or plane timber member.

Calculation example

$$t_{ch} = \Sigma\, t_{prot,\ cladding}$$

Separating Function Method



T_{prot} = 270°C T_{ch} = 300°C

$$t_{prot,i} = \left(t_{prot,0,i} \cdot k_{pos,exp,i} \cdot k_{pos,unexp,i} + \Delta t_i\right) \cdot k_{j,i}$$

No	Material	Protection time $t_{prot,i}$	Sum of protection times
		min	min
1	Gypsum plaster-board type F (GtF)	30	30
2	Gypsum plaster-board type F (GtF)	11,3	41,3
3	Stone wool (SW)	28,7	**69,9**
4	CLT		

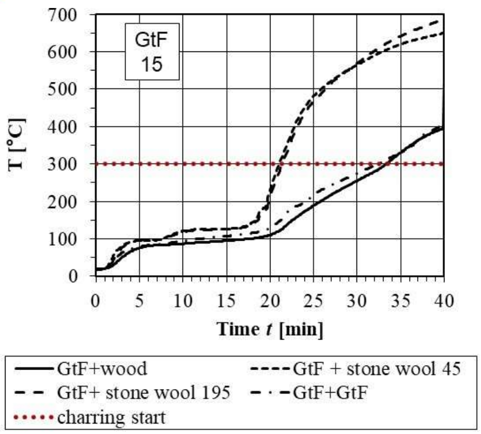
$$t_{ch} = \min\begin{cases} \sum t_{prot} \\ t_f \end{cases}$$

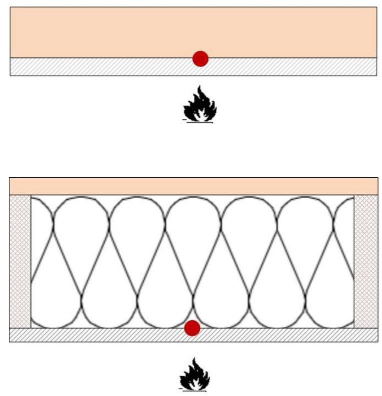
Calculation example

Start time of charring
Mineral wool vs wood substrate

$t_{prot}=t_{prot,o}*k_{pos,unexp}$

Separating Function Method

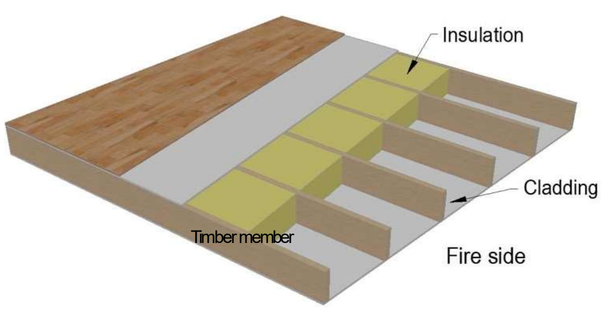


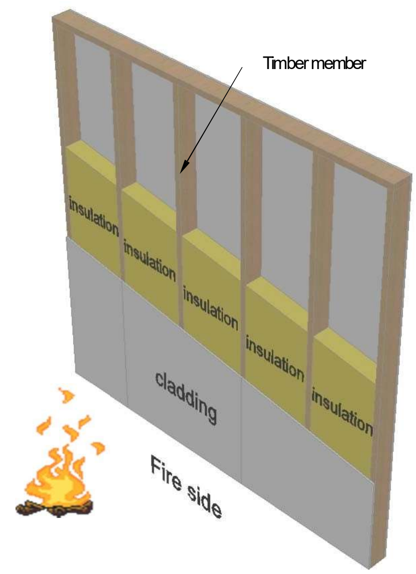


$k_{pos,unexp} = 1$

$k_{pos,unexp} < 1$

Design of Timber Frame Assemblies





V. Schleifer, „Zum Verhalten von raumabschliessenden mehrschichtigen Holzbauteilen im Brandfall“, Diss. ETH Zürich, 2009.

A. Frangi, V. Schleifer, M. Fontana: “Design model for the verification of the separating function of light timber frame assemblies”, Engineering Structures 2010; 32: 1184–1195, DOI: 10.1016/j.engstruct.2009.12.044.

A. Just, J. Schmid (eds) (2018), Improved fire design models for Timber Frame Assemblies – Guidance document, COST Action FP1404, Zürich, Switzerland.

Design of Timber Frame Assemblies

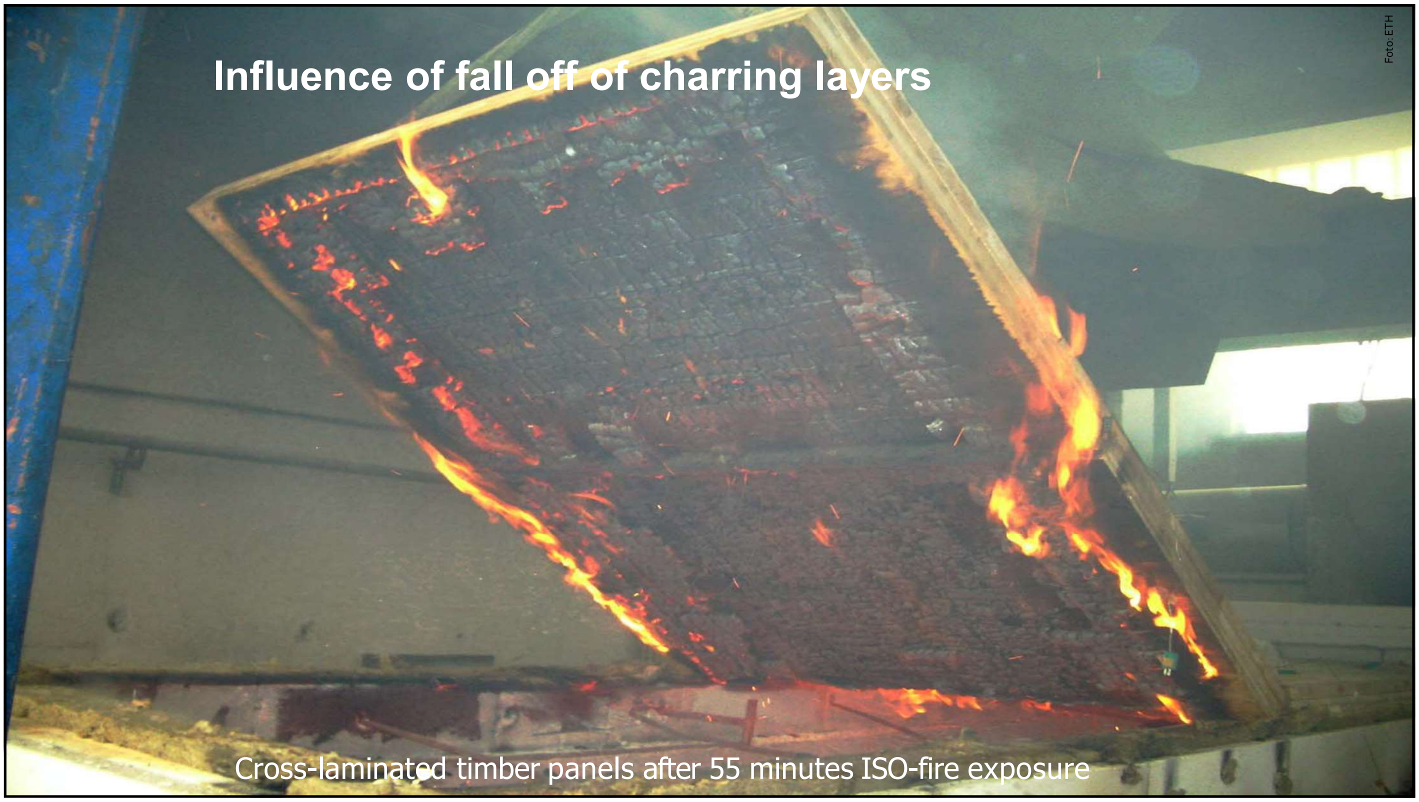
Separating function method // performance of insulation

Protection level PL	Insulation material	Density
PL 1	Stone wool	≥ 26 kg/m³
PL 2	Glass wool	≥ 14 kg/m³
	Wood fibre	≥ 50 kg/m³
	Cellulose fibre	≥ 50 kg/m³
PL 3	XPS	-
	EPS	-
	PUR	-
	PIR	-
	Not assessed insulation materials	-

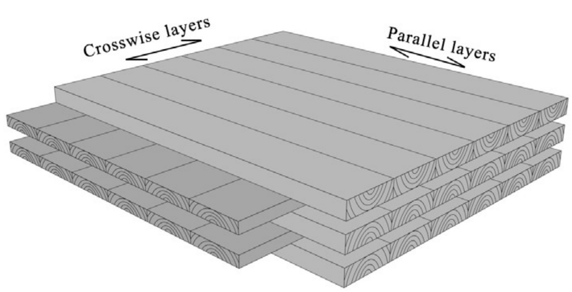
Protection level PL can be assessed according to Annex D of prEN 1995-1-2:2004.

General summary for initially protected structures

- Different charring phases for initially protected structures depending on properties of protection system.
- Substrate and fastening can influence start time of charring and failure time significantly.
- Start time of charring and failure time can be determined by EN 13381-7
- Generic values on start time of charring calculated according to Separating Function Method
- Generic values of failure times for gypsum boards in EN 1995-1-2:2025.



Cross-laminated timber (CLT) panels



- CLT is produced from timber boards, which are usually stacked crosswise and glued together over their entire surface
- CLT with 3, 5, 7 or more board layers
- Width of single boards between 80 and 240mm
  Thickness of single boards between 10 and 35mm

→ Differences from solid timber

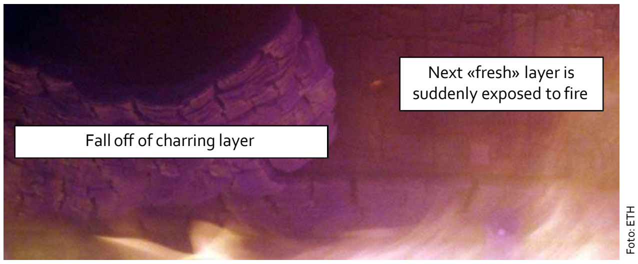
- Layered cross-section
- Joints

Video on char layer fall-off

Fall-off of charring layers

Fall off of charring layers depends on different parameters, e.g.:

- Adhesive
- Layup
- Thickness of lamellas
- Quality of glueing
- …



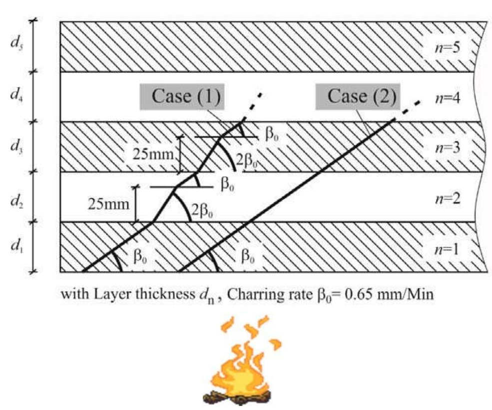
The behaviour (with or without) fall off of charring layers must be considered in the design of CLT exposed to fire

Fire resistance of CLT

1 Calculation of char depth → 2 Calculation of effective cross-section

Simplified charring model (step model) in analogy to EN 1995-1-2

Design of fire resistance:



CASE 1

- 1st layer: one-dimensional charring rate
  β_0**=0.65 mm/min**
- If falling off of 1st layer:
  2· β_0=1.3 mm/min
  until 25mm of char layer has been formed

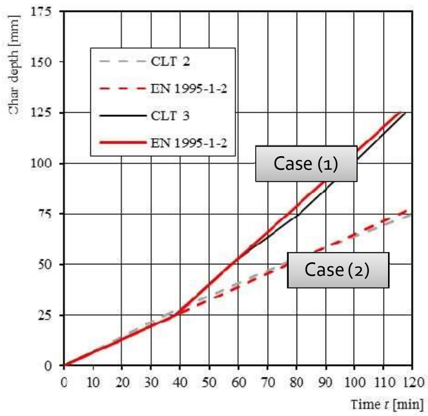
CASE 2

- If no falling off of 1st layer:
  β_0**=0.65 mm/min**

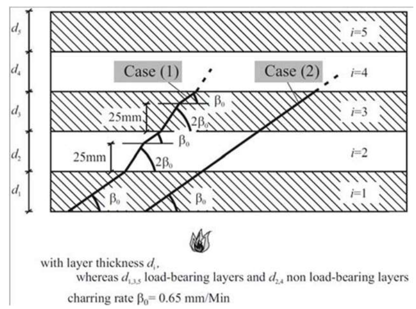
A. Frangi, M. Fontana, E. Hugi, R. Jöbstl: "Experimental analysis of cross-laminated timber panels in fire", *Fire Safety Journal* 2009; 44: 1078–1087, DOI: 10.1016/j.firesaf.2009.07.007.

Comparison of CLT fire tests and EN 1995-1-2 model

Design of fire resistance:



Note:
Case (1): PUR 1
Case (2): PUR 2 (shows charring as solid timber)

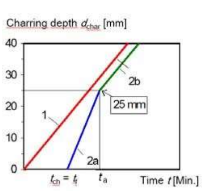


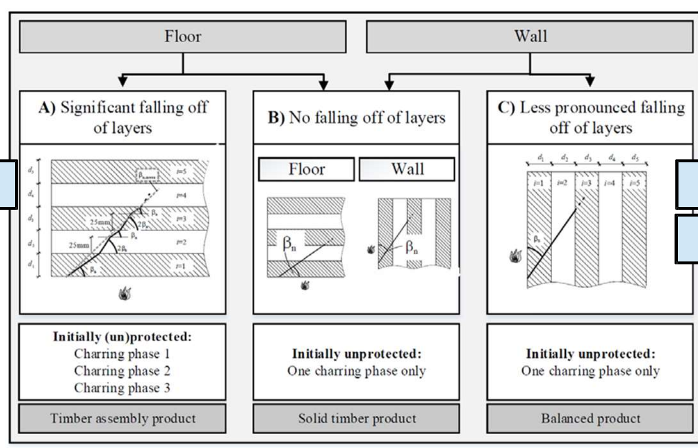
Very good agreement between tests and model of EN 1995-1-2

European charring model applied for CLT

1 Calcualtion of charring

«stepped model»





β_n= 0.78 mm/min

β_n= 0.65 mm/min

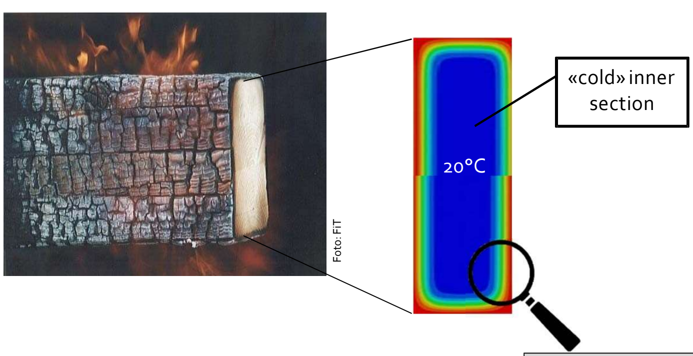
β_n= 0.65 mm/min

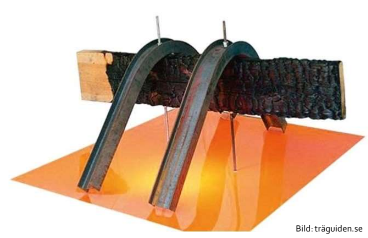
Fire resistance of CLT

1 Calculation of char depth → 2 Calculation of effective cross-section

Effective cross-section method

2 Calculation of effective cross-section



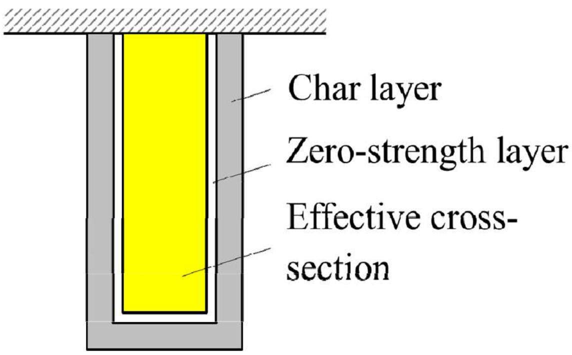


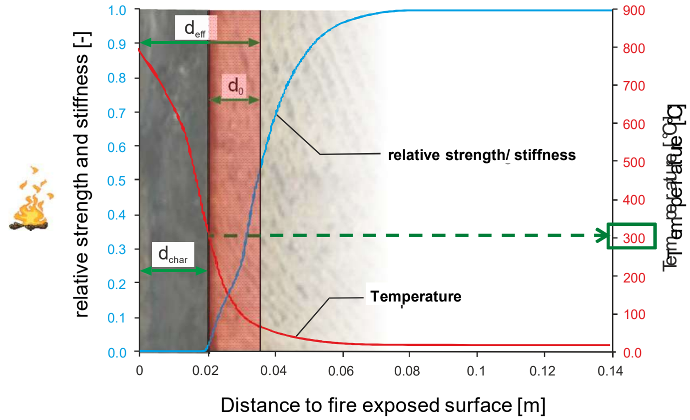
Consider heated zone behind the char layer with an additional reduction of the uncharred cross-section.
This value is called «zero-strength-layer» (ZSL) d_0.

Effective cross-section method

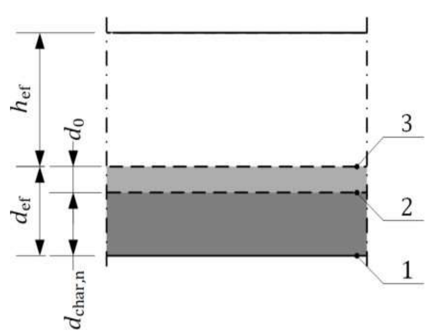
2 Calculation of effective cross-section

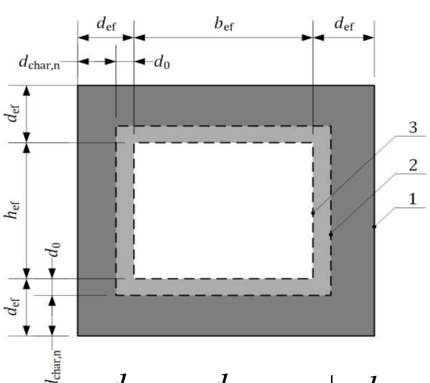
d_0 compensates stiffness and strength reduction of uncharred but heated timber





Effective cross-section method: prEN 1995-1-2:2021





1 Fire exposed side
2 Residual cross-section
3 Effective cross-section

d_0 is the zero-strength layer depth
$d_{char,n}$ is the notional charring depth
d_{ef} is the effective charring depth
k_{side} is the number of respective sides exposed to fire

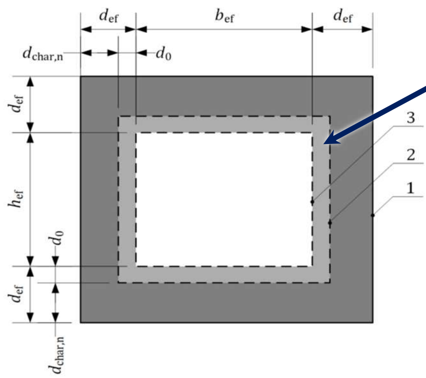
$$d_{ef} = d_{char,n} + d_0$$

$$b_{ef} = b - k_{side} \cdot d_{ef}$$

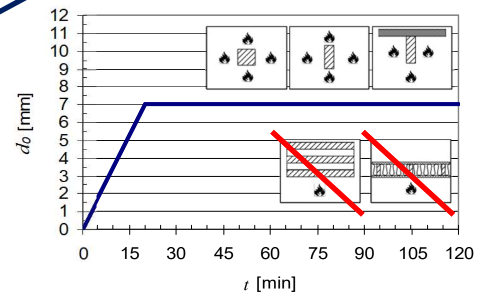
$$h_{ef} = h - k_{side} \cdot d_{ef}$$

Effective cross-section method: prEN 1995-1-2:2021

Zero strength layer depth according to EN 1995-1-2:2004

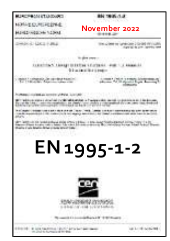


zero-strength layer d_0

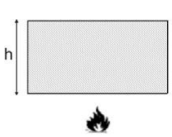


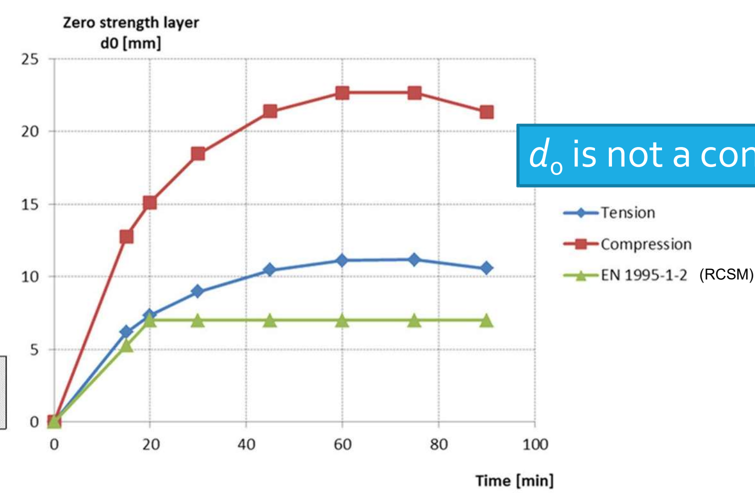
$$h_{ef} = h - 2d_{char,n} - 2d_0$$

Effective cross-section method: prEN 1995-1-2:2021

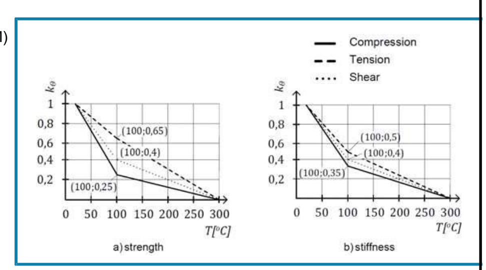


Zero strength layer depth based on simulations



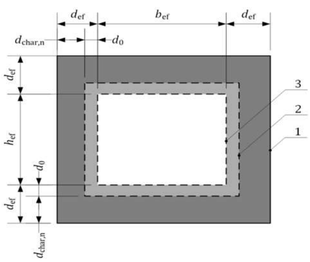


d_o is not a constant value!



Effective cross-section method: prEN 1995-1-2:2021

Zero strength layer depth for linear members (e.g. glulam beams)

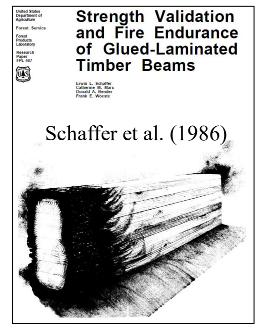


(7) <RCM> Unless rules are given in this standard, the value of zero-strength layer depth d_0 for the design of linear timber members should be assumed as follows:

$$d_0 = 14\ mm$$

(8) <PER> For linear timber members subjected predominantly to tension or bending the value of zero-strength layer depth d_0 for the design of linear timber members may be assumed as follows:

$$d_0 = 10\ mm$$



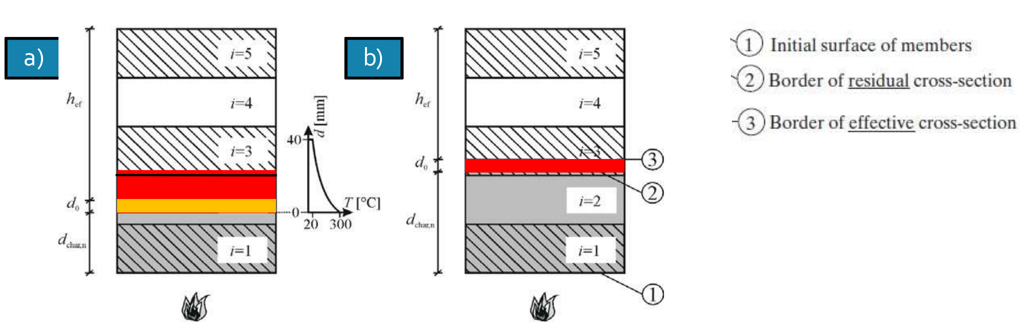
Background information:
J. Schmid, J. König, A. Just, "The Reduced Cross-Section Method for the design of timber structures exposed to fire - Background, limitations and new developments", Structural Engineering International, 2012, Vol. 22. - pp. 514-522,
DOI: 10.2749/101686612X13363929517578

Effective cross-section method: prEN 1995-1-2:2021

Different «zero-strength layer (ZSL)» for CLT:

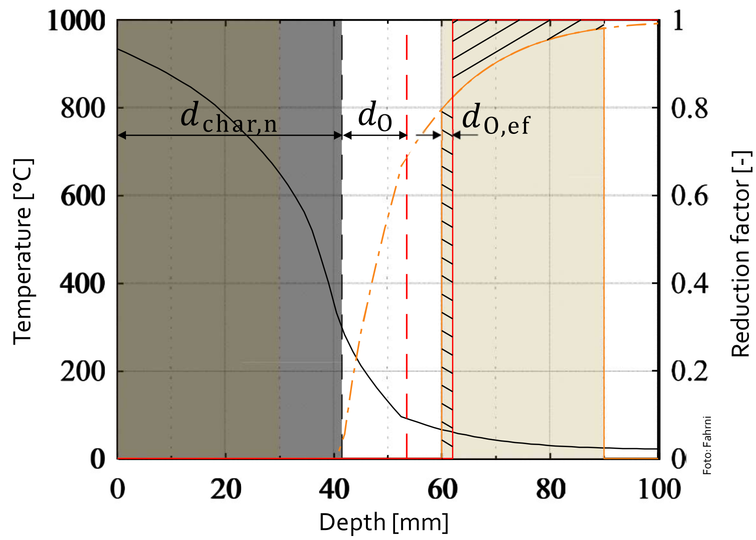
a) ZSL is in cross-layer and thus not effective («reduction of nothing»)

b) ZSL is in longitudinal layer reduces load-bearing capacity



Effective cross-section method: prEN 1995-1-2:2021

Different «zero-strength layer (ZSL)» for CLT:



Effective cross-section method: prEN 1995-1-2:2021

2 Calculation of effective cross-section

Option 1: Design using tabulated data

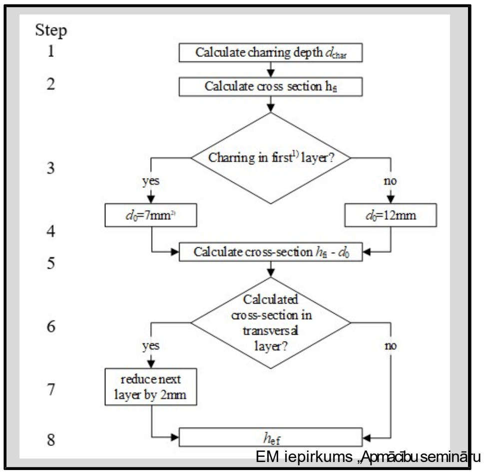
Zero strength layer d_0 for specific CLT layups (unprotected)

CLT-layup	d_{char}= 20 mm (R 30 min)	d_{char}= 39 mm (R 60 min)	d_{char}= 59 mm (R 90 min)
20+20+20	2.0	7.0	n.a.
40+40+40	8.0	4.0	n.a
20+20+20+20+20	3.0	9.5	5.0
40+20+20+20+40	6.0	5.0	8.0
40+20+40+20+40	5.0	6.0	9.0
40+30-40-30-40	5.0	5.0	3.0
40+40+40+40+40	5.0	5.0	2.0

Effective cross-section method: prEN 1995-1-2:2021

2 Calculation of effective cross-section

Option 2: Design using general **model «12 and 2»**



«12 und 2» Modell

- Model can be used for floor elements
- Flexible application for all layups
- Easy to use
- High accuracy
- Safe and economic approach
- Also for initially protected CLT

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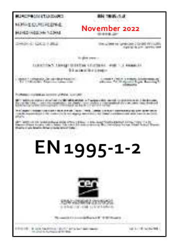
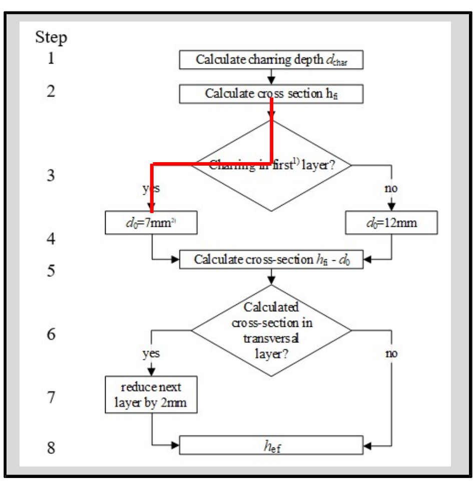
Effective cross-section method: prEN 1995-1-2:2021

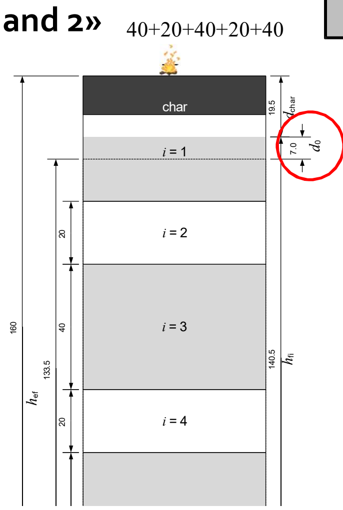


2 Calculation of effective cross-section

Option 2: Design using general **model «12 and 2»**

R30



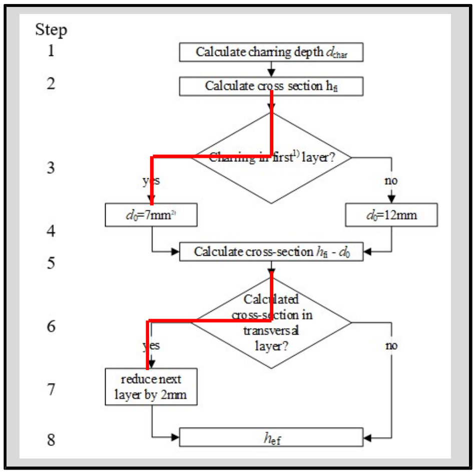


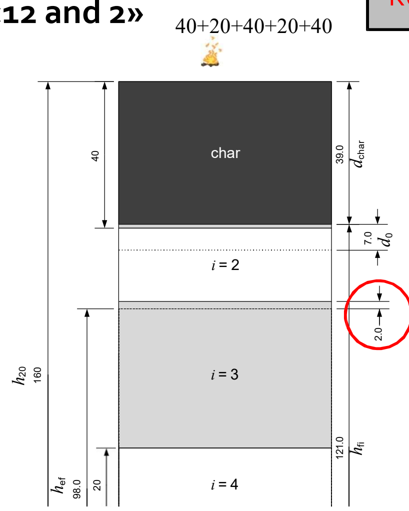
Effective cross-section method: prEN 1995-1-2:2021

2 Calculation of effective cross-section

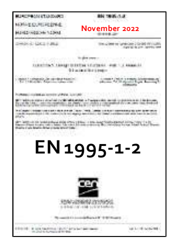
Option 2: Design using general **model «12 and 2»**

R60





Effective cross-section method: prEN 1995-1-2:2021



CLT floor elements:
Zero-strength layer depth d_0

Fire exposure on	Floors	
	Initially unprotected	Initially protected
Tension side for first layer	7[a]	12[a]
Tension side for other layers	12[a b]	
Compression side for first layer	10[c]	16[c]
Compression side for other layers	16[c d]	

[a] When d_{ef} is within a layer with grain perpendicular to the span direction, d_{ef} should be increased in order to reduce the following layer with grain parallel to the span direction at least by 2 mm.

[b] When d_{ef} is within a layer with grain parallel to the span direction, d_{ef} should at least as large to reduce this layer by 2 mm.

[c] When d_{ef} is within a layer with grain perpendicular to the span direction, d_{ef} should be increased in order to reduce the following layer with grain parallel to the span direction at least by 4 mm.

[d] When d_{ef} is within a layer with grain parallel to the span direction, d_{ef} should at least as large to reduce this layer by 4 mm.

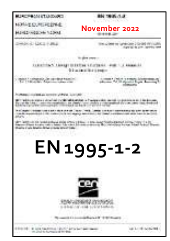
Fire resistance of CLT

Some notes on the adhesive performance:

- Separation into adhesive families (PUR, MUF, etc.) not possible

  → PUR 1 can show a fully different behaviour than PUR 2!
- Behaviour of adhesive should be known for the design of the CLT panel in fire
- If you do not know the performance of «your adhesive», you can ask us!
- **prEN 1995-1-2 (2021): Contains a new method (glueline integrity in fire, GLIF) to classify adhesives for the use in mass timber, such as CLT**

General information on prEN 1995-1-2:2021


November 2022

EN 1995-1-2

Revision of Eurocode

$$X_{d,fi} = k_{\Theta} \cdot k_{fi} \cdot X_k / \gamma_{M,fi}$$

$X_{d,fi}$ is the design value of a strength or stiffness property (generally f_k or E_k) for fire temperature design;

X_k is the characteristic value of a strength or stiffness property (generally f_k or E_k) for normal temperature design according to EN 1995-1-1;

k_{Θ} is the temperature-dependent reduction factor for a strength or stiffness property, see 5.3.2;

k_{fi} is the modification factor for a strength or stiffness property for the fire situation according to Table 4.1;

$\gamma_{M,fi}$ is the partial factor for the relevant mechanical material property for the fire situation.

$\gamma_{M,fi} = 1$

General information on prEN 1995-1-2:2021

Revision of Eurocode

20 % Fractile of "cold" strength

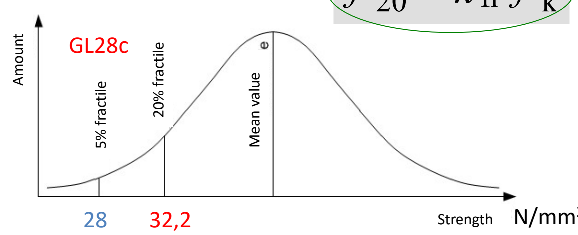
$$X_{d,fi} = k_{\Theta} \cdot k_{fi} \cdot X_k / \gamma_{M,fi}$$

$$f_{d,fi} = k_{mod,fi} \frac{f_{20}}{\gamma_{M,fi}}$$

$$f_{20} = k_{fi} f_k$$

k_{fi}

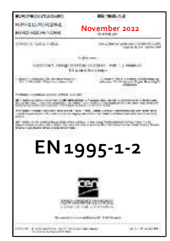
Solid timber	1,25
Glued-laminated timber, cross-laminated timber	1,15
Wood-based panels	1,15
LVL	1,10
Connections with laterally loaded fasteners with side members of wood and wood-based panels	1,15
Connections with laterally loaded fasteners with side members of steel	1,05
Connections with axially loaded fasteners	1,05



Characteristic strength
ambient
fire

General information on prEN 1995-1-2:2021

Revision of Eurocode



Main objectives
- Improvement of the **Ease-of-Use** of the Eurocodes for practical users
- Reduction of National Determined Parameters (NDP)
- Further harmonisation and inclusion of **state-of-the-ar**t

Target
- After an intensive discussion within CEN/TC 250 it was defined that the Eurocodes are addressed to **competent civil, structural and geotechnical engineers**.

General information on prEN 1995-1-2:2021

Revision of Eurocode

1. Scope
2. Normative references
3. Terms, definitions and symbols
4. Basis of design
5. Material properties
6. Tabulated design data
7. Simplified design methods
8. Advanced design methods
9. Detailing
10. Connections
11. Timber structures exposed to physically based design fires

Annexes

Common part for all EN 199x-1-2 (sections 1–4)

Start of charring, failure time of protection, Charring rate (section 5)

Specific rules Zero-strength layer (section 7)

Requirements for detailing (section 9)

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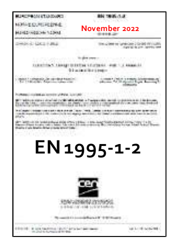
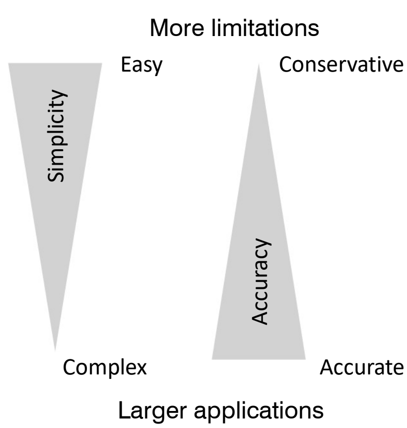
General information on prEN 1995-1-2:2021



Revision of Eurocode

- 6 Tabulated design data
  - 6.1 xx
  - 6.2 xx
  - .....
- 7 Simplified design methods
  - 7.1 xx
  - 7.2 xx
  - ....
- 8 Advanced design methods
  - 8.1 xx
  - 8.2 xx
  - ....



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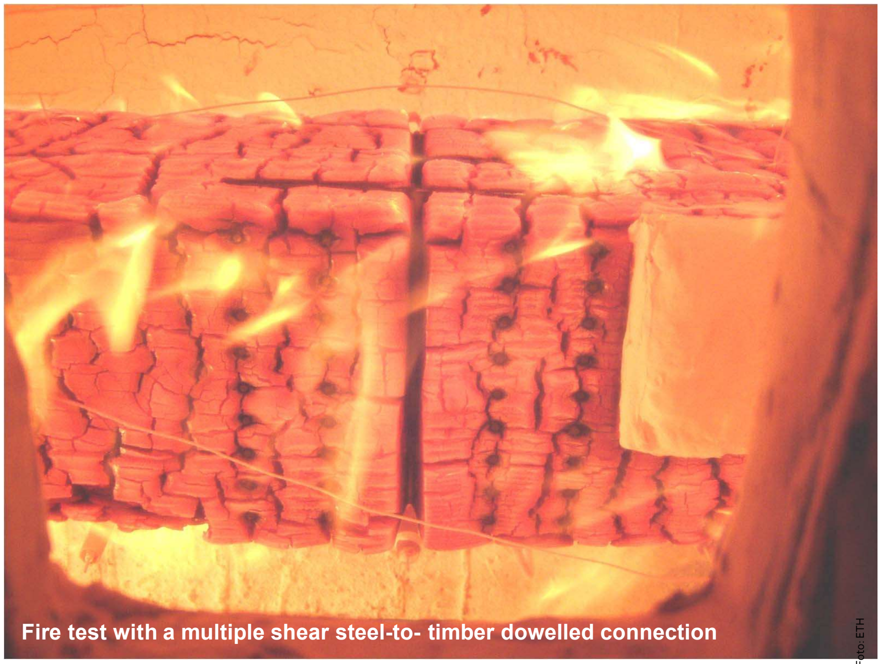
Coffee break / 11:30 - 12:00

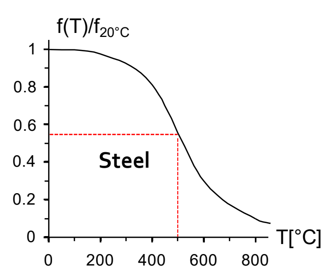
Agenda / 12:00 - 13:30

- Fire resistance of connections in timber structures
- Insight in advanced calculations methods of fire resistance of timber structures
- Case studies of timber building fire design

Connections with steel elements in fire



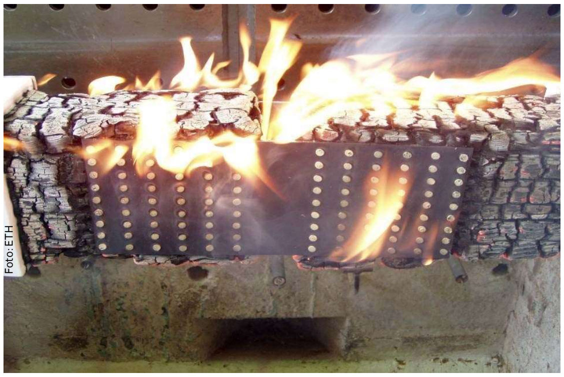
Steel behaviour in fire



- Steel heats up quickly
- Temperature dependent reduction of strength and stiffness
- Protection of the steel plates against fire by timber members!

Connections with steel elements in fire

Connections with **side** steel plates



Connection with side steel plates and annular ringed shank nails

Connections with **slotted-in** steel plates

Multiple shear steel-to-timber dowelled connection

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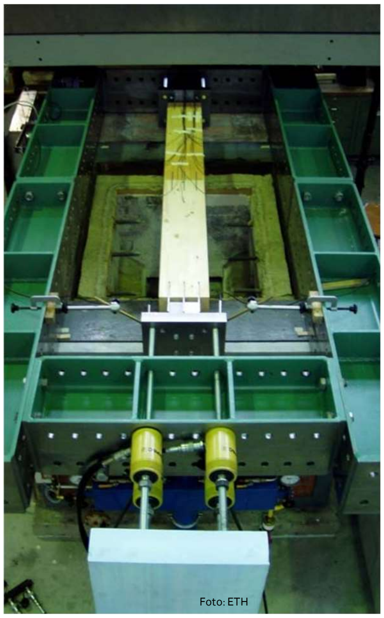
Connections with steel elements in fire

Basic strategies

- Connections with slotted-in steel plates much better than connections with side steel plates
- Increase of the overall thickness of the timber members as well as the end distance of the dowels
- Fire protection of connections by boards (timber boards or gypsum plasterboards)



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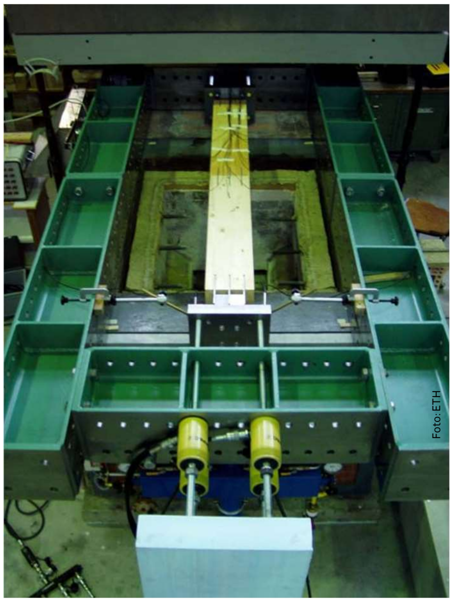
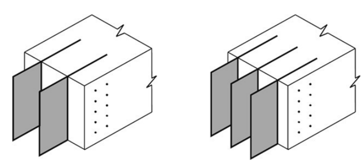
Fire tests with connections



Fire tests with connections



Fire tests with connections

Test specimens

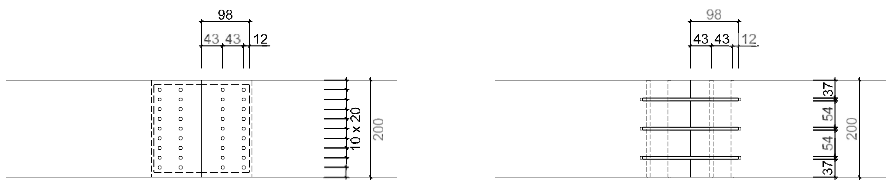
- Material properties:
  - glued laminated timber (spruce) grade GL 24h according to EN 1194
  - mean value of moisture: 10 %z
  - mean value of density: 445 kg/m^3
- Test parameters:
  - load level during the fire tests ($0.3{\cdot}F_u$, $0.15{\cdot}F_u$ and $0.075{\cdot}F_u$ with F_u = load-carrying capacity at room temperature)
  - number and configuration of the steel dowels (9x2, 9x3, 3x3 and 4x2 steel dowels)
  - diameter of the steel dowels (6.3 mm and 12 mm)
  - connections with improved fire performance

A. Frangi, C. Erchinger, M. Fontana: “Experimental fire analysis of steel-to-timber connections using dowels and nails”, *Fire and Materials* 2010; 34: 1–19, DOI: 10.1002/fam.994.

Fire tests with connections

Multiple shear steel-to-timber connections with dowels

connection type	number of tests	test type	load level	remarks
D 01.1	5	room temp.	until failure	9x2 steel dowels diameter dowels: d = 6.3 mm cross-section: 200/200 mm
	2	fire test	$0.3{*}F_{u,D\,01.1}$	
	2	fire test	$0.15{*}F_{u,D\,01.1}$	
	2	fire test	$0.075{*}F_{u,D\,01.1}$	

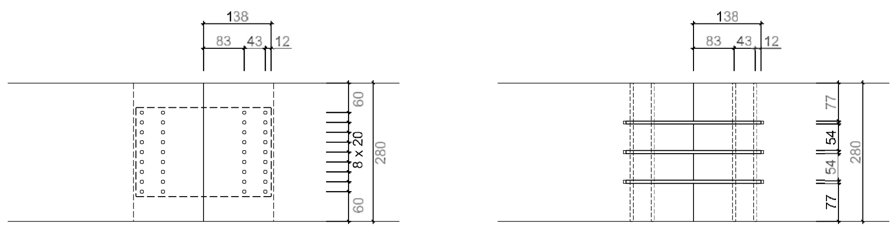


Test specimens

Fire tests with connections

A) Connection with increased timber covers

connection type	number of tests	test type	load level	remarks
D 01.2	5	room temp.	until failure	9x2 steel dowels diameter dowels: d = 6.3 mm cross-section: 280/280 mm
	2	fire test	$0.3{*}F_{u,D\ 01.2}$	

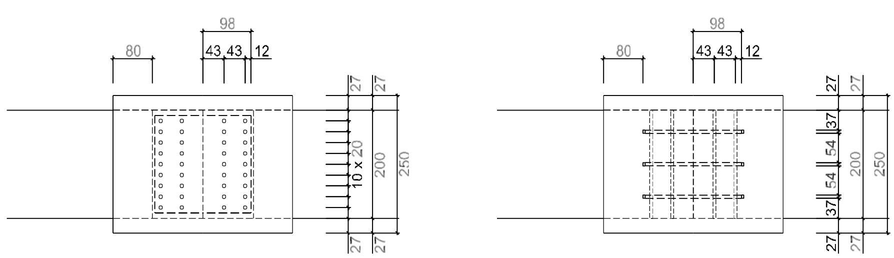


Test specimens

Fire tests with connections

B) Connection protected by timber boards

connection type	number of tests	test type	load level	remarks
D 01.3	2	fire test	$0.3{*}F_{u,D\ 01.1}$	same as D 01.1, connection protected by 27 mm thick timber boards

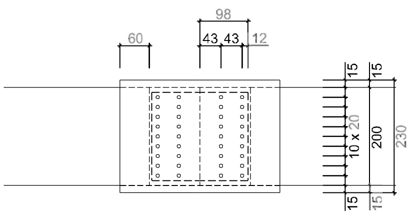


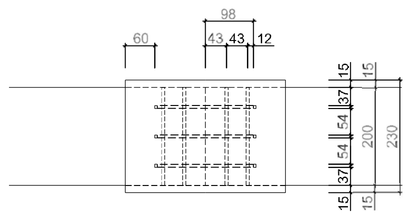
Test specimens

Fire tests with connections

C) Connection protected by gypsum plasterboards

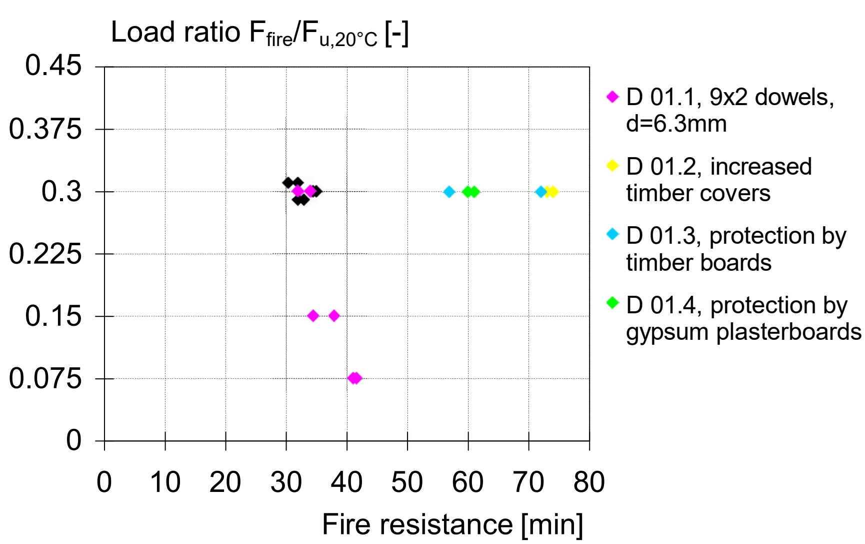
connection type	number of tests	test type	load level	remarks
D 01.4	2	fire test	$0.3*F_{u,D\ 01.1}$	same as D 01.1, connection protected by 15 mm thick gypsum plasterboards



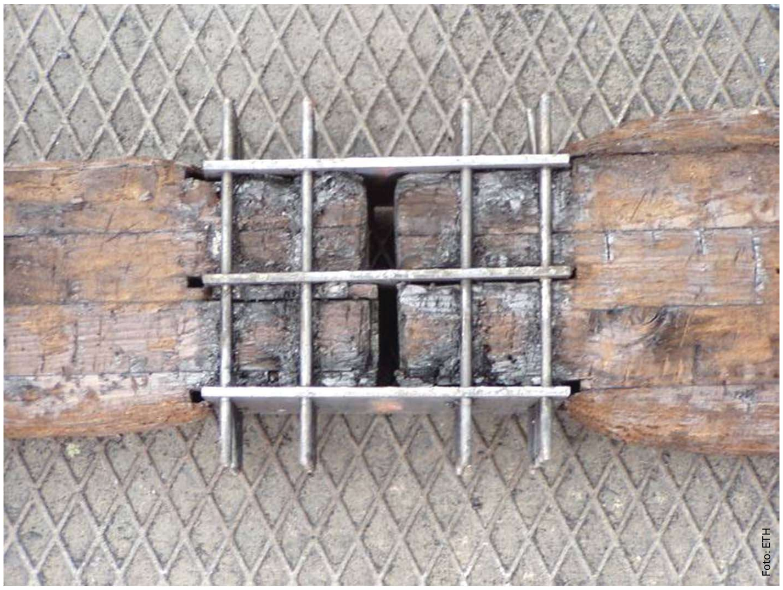


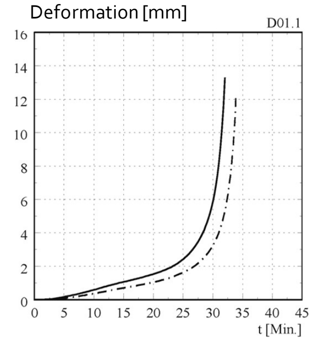
Test specimens

Results of fire tests



Results of fire tests





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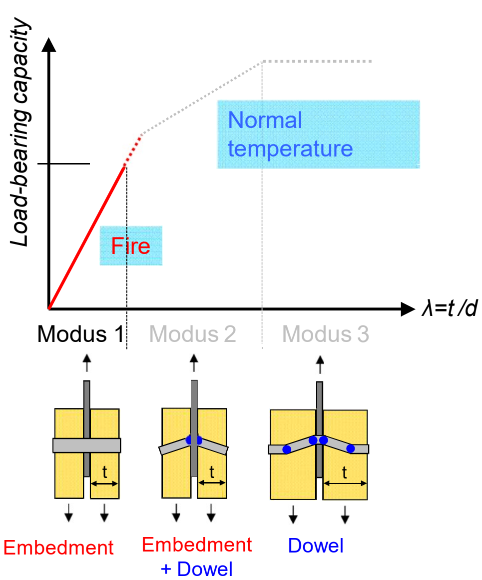
Results of fire tests



Connections failed by embedment failure, i.e. failure mode I according to the Johansen yield model

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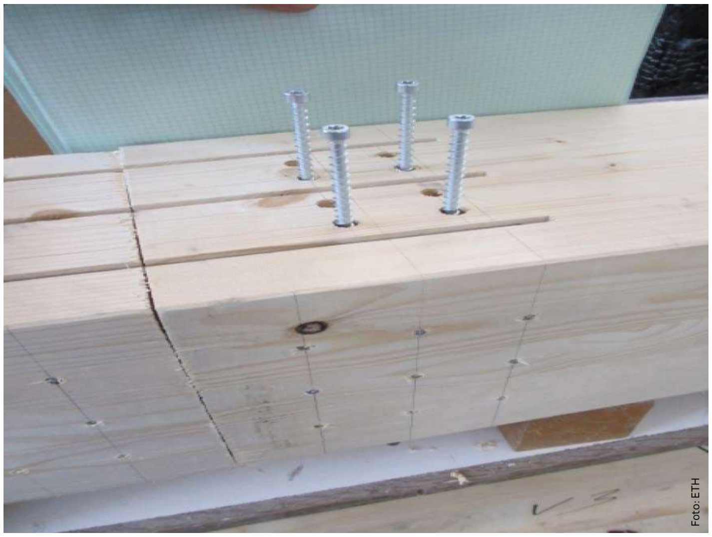
Increase of fire resistance of connections?



- Insert fully threated screws as reinforcement

Source of the following slides:
Palma, P. (2016). *Fire behaviour of timber connections* (Doctoral dissertation, ETH Zurich).

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Increase of fire resistance of connections?

- Insert fully threated screws as reinforcement

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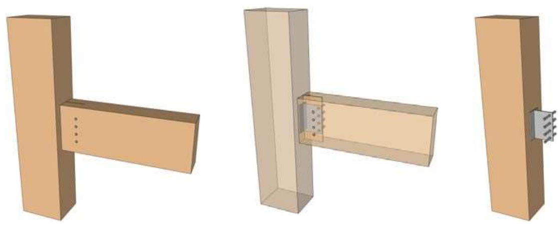
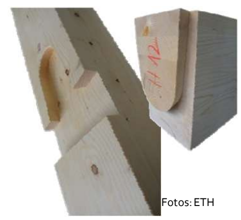
Beam-to-column shear connections

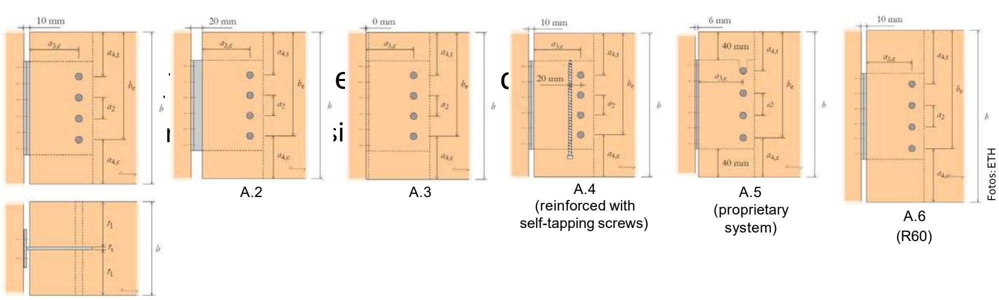
- Tested connection typologies
  - Steel-to-timber dowelled connections
  - Custom and proprietary connection systems
  - Dovetail timber connections





Beam-to-column shear connections

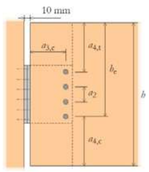
- Steel-to-timber dowelled connections
  - R30 and R60 fire resistances

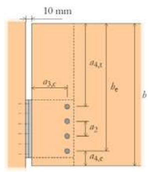


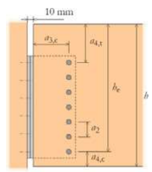
A.1 (splitting failure)
A.2
A.3
A.4 (reinforced with self-tapping screws)
A.5 (proprietary system)
A.6 (R60)

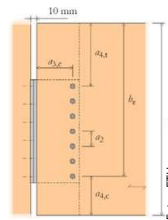
Beam-to-column shear connections

- Steel-to-timber dowelled connections
  - R30 and R60 fire resistances
  - Embedment/dowel, splitting and shear failure modes


B.1
(splitting failure)


B.2
(dowel failure)


C.1
(shear failure)


C.2
(R60)

Fotos: ETH

Beam-to-column shear connections

- Experimental campaigns
  - Tests at normal temperature

Fotos: ETH

Beam-to-column shear connections

- Experimental campaigns
  - Tests at normal temperature

Connection typology	Number of tests	Load-carrying capacity $R_{m,20°C}$ [kN]	Coefficient of variation [%]
A.1	3	**52**	7
A.4	3	**65**	3
A.6	3	**59**	11
B.1	5	**32**	10
B.2	5	**47**	7
C.1	3	**69**	8
C.2	3	**89**	4

Beam-to-column shear connections

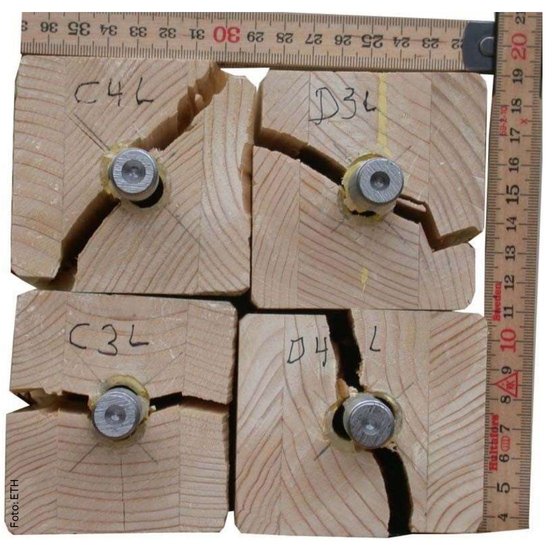
- Experimental campaigns
  - Fire tests

Beam-to-column shear connections

- Experimental campaigns
  - Fire tests

	Connection typology	Number of tests	Fire resistance t_{fi} [kN]	Failure
	A.1	1	44	Beam-side
	A.2	2	33 ; 34	Column-side
	A.3	2	48 ; 47	Beam-side
	A.4	1	39	Beam/column
	A.5	1	39	Column-side
R60	**A.6**	2	76 ; 83	Beam/column
	B.1	2	49 ; 43	Beam-side
	B.2	2	43 ; 45	Beam-side
	C.1	2	44 ; 42	Beam/column
R60	**C.2**	2	78 ; 89	Beam-side

Connections with glued-in rods

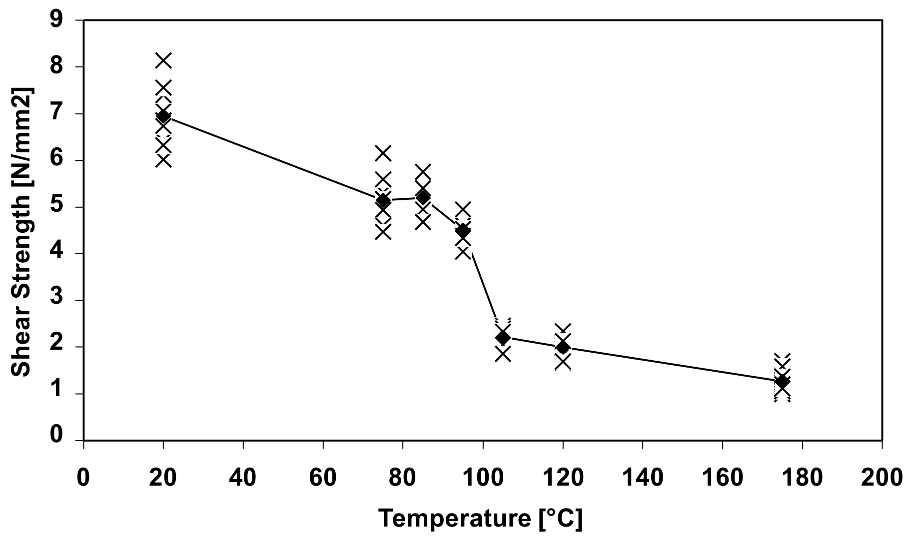


Failure modes

- Steel failure
- Adhesive failure
- Timber failure

Connections with glued-in rods

Test results: pull-out strength



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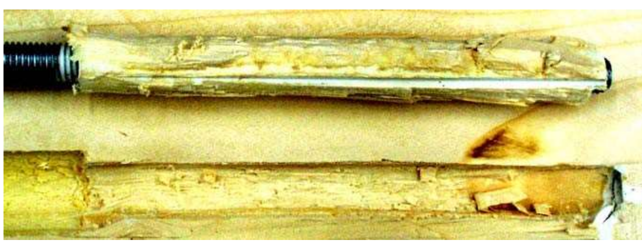
Connections with glued-in rods

Failure modes



75°C

85-95°C

105-175°C

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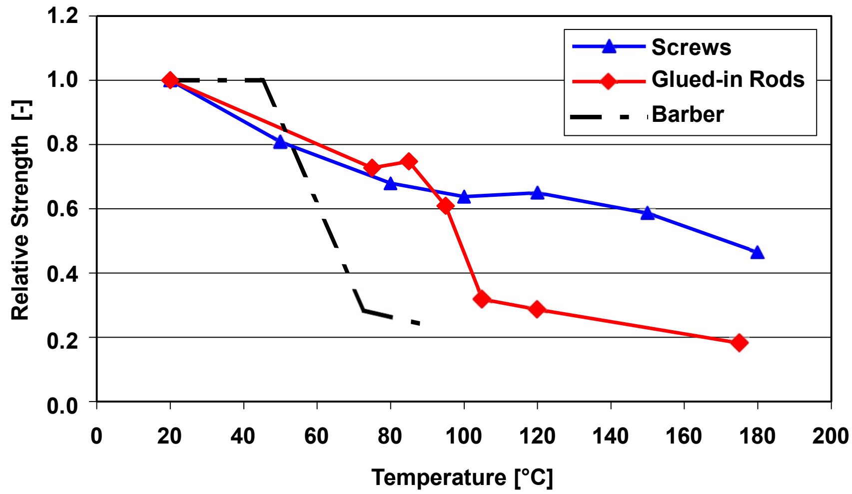
Connections with glued-in rods

Test results: pull-out strength



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Fire tests on truss systems with glued in rods connections

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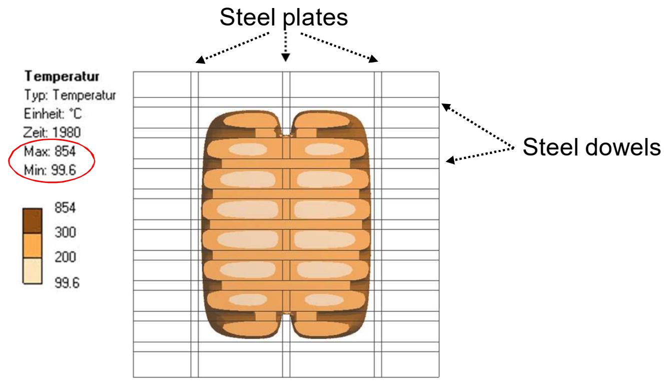
102

FE thermal analysis

→ Comparison between FE-thermal analysis and fire test

Connection D01.1 (33 min)

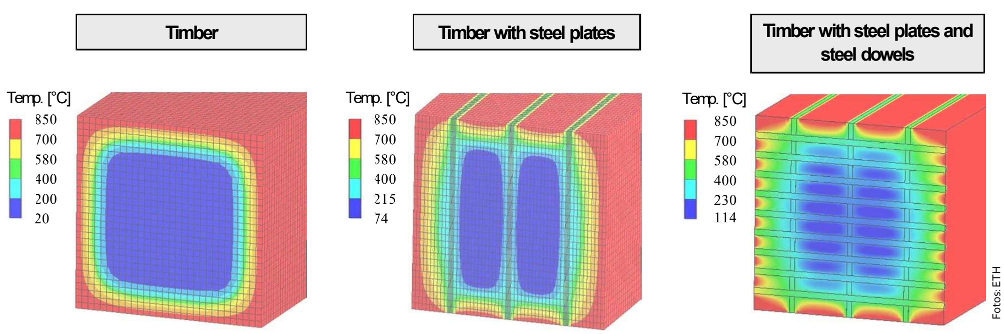


FEM (33 min)

FE thermal analysis

Charring behaviour

→ Influence of steel plates and steel dowels on charring



C. Erchinger, A. Frangi, M. Fontana: "Fire design of steel-to-timber dowelled connections", *Engineering Structures* 2010; 32: 580–589, DOI: 10.1016/j.engstruct.2009.11.004.

Fire design of connections: prEN 1995-1-2:2021

Geometric requirements for a specific fire resistance up to 120 min

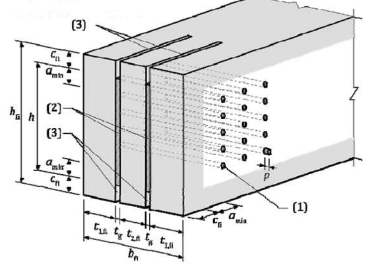
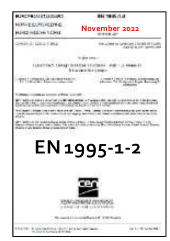


Table 10.4 – Geometric requirements for a specific fire resistance time of steel-to-timber connections with dowels[a] and two slotted-in steel plates, in mm

Fire resistance time, t_{fi}	$t_{1,fi}$			a_{fi}
	$\eta_{fi} \leq 0{,}1$	$\eta_{fi} \leq 0{,}2$	$\eta_{fi} \leq 0{,}3$	
30 min	≥ 30	≥ 45	≥ 50	≥ 15
60 min	≥ 60	≥ 75	≥ 80	≥ 50
90 min	≥ 90	≥ 100	≥ 110	≥ 90
120 min	≥ 120	≥ 135	≥ 140	≥ 130
[a] The table may be used even if 2 dowels are replaced by 2 bolts (or screws)				

Fire design of connections: prEN 1995-1-2:2021



Nails and screws

$$R_{k,fi} = R_k \cdot e^{-k \cdot t_{req}}$$

Dowels and dowels

$$R_{k,fi} = R_k \cdot e^{\left(-c_1 \cdot t_{req} + c_2 \cdot t_{1,fi} + c_3\right)}$$

- $R_{k,fi}$ characteristic load-carrying capacity at the required fire resistance time
- R_k characteristic load-carrying capacity at normal temperature
- c_i, k coefficients depending on type of fastener and connection
- t_{req} required fire resistance time

Fire design of connections: prEN 1995-1-2:2021

Methods extended to fire resistance **up to 120 min**.

Connections with timber side members

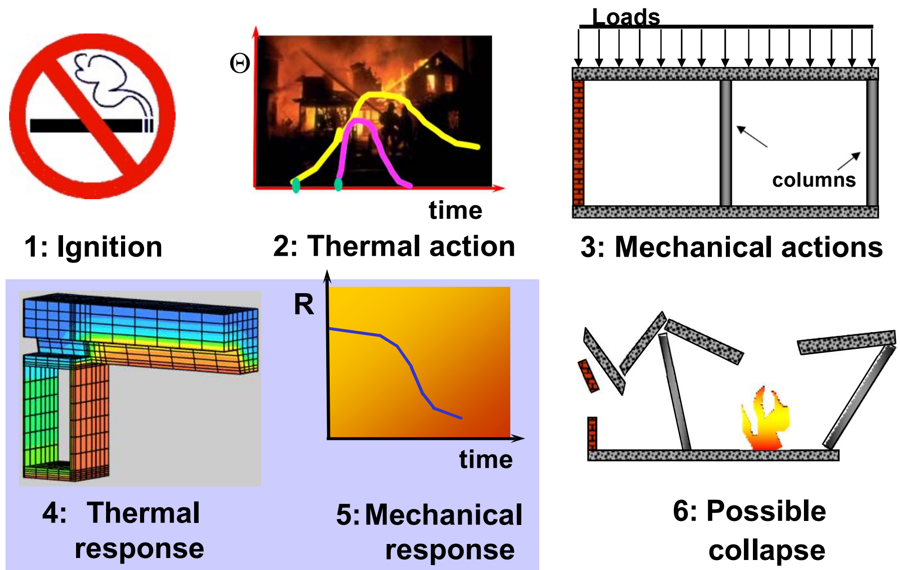
- minimum fire resistance of initially unprotected timber-to-timber and steel-to-timber connections
- geometric requirements for a specific fire resistance up to 120 min
- **exponential reduction method**

Agenda / 12:00 - 13:30

- Fire resistance of connections in timber structures
- Insight in advanced calculations methods of fire resistance of timber structures
- Case studies of timber building fire design

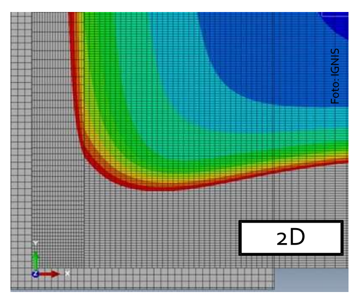
Advanced design methods

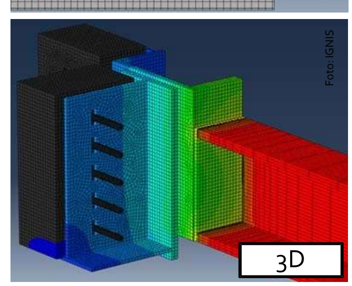
Advanced design methods



Advanced design methods: thermal analysis

- FE-program (Abaqus, Ansys, Safir, etc.)
- ε_{res} = 0.8; $\alpha_{c,exp}$ = 25W/m²K; $\alpha_{c,unexp}$ = 4W/m²K
- ISO-fire exposure (or parametric fire exposure)
- Density, specific heat and thermal conductivity of different materials as a function of the temperature based on own tests, literature review and calibration to fire tests
- Mass transfer of moisture into or out of timber or gypsum board as well as cracking and ablation indirectly considered using "effective" value of thermal conductivity calibrated to results of fire tests





Advanced design methods: thermal analysis

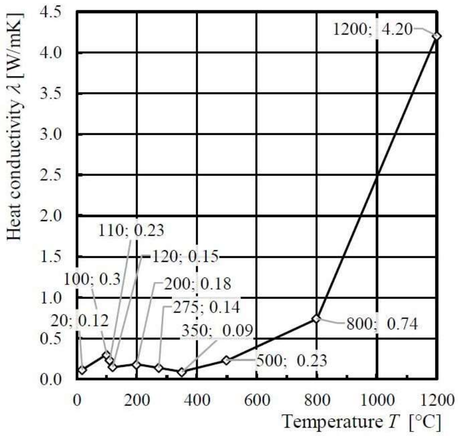


Figure 8.3 – Heat conductivity as function of temperature for timber members and wood-based panels except OSB and plywood.

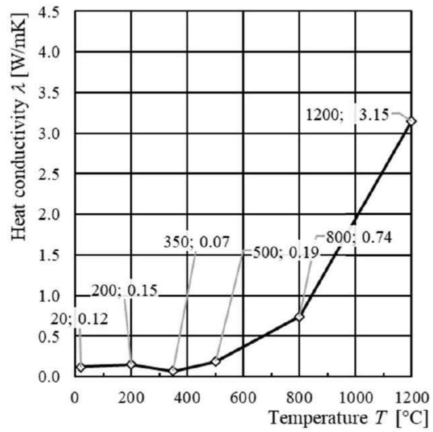


Figure 8.4 – Heat conductivity as function of temperature for OSB and plywood.

Advanced design methods: thermal analysis

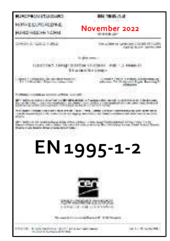


Table 8.2 - Temperature-dependent thermal properties of gypsum plasterboards and gypsum fibreboards

	Gypsum plasterboard			Gypsum fibreboard		
T [°C]	λ [W/mK]	c [kJ/kgK]	ρ/ρ_{20} [-]	λ [W/mK]	c [kJ/kgK]	ρ/ρ_{20} [-]
20	0,40	0,96	1,0	0,40	0,96	1,00
70	0,40	0,96	1,0	0,40	0,96	1,00
100	0,27	0,96	1,0	0,27	0,96	1,00
130	0,13	14,9	0,926	0,13	9,17	0,926
140	0,13	25,2	0,902	0,13	17,55	0,902
150	0,13	21,7	0,877	0,13	16,66	0,877
170	0,13	0,96	0,828	0,13	0,96	0,828
600	0,13	0,96	0,827	0,13	0,96	0,827
720	0,33	4,36	0,826	0,39	4,359	0,826
750	0,38	0,96	0,776	0,46	0,96	0,776
1000	0,80	0,96	0,776	1,00	0,96	0,776
1200	2,37	0,96	0,776	2,37	0,96	0,776

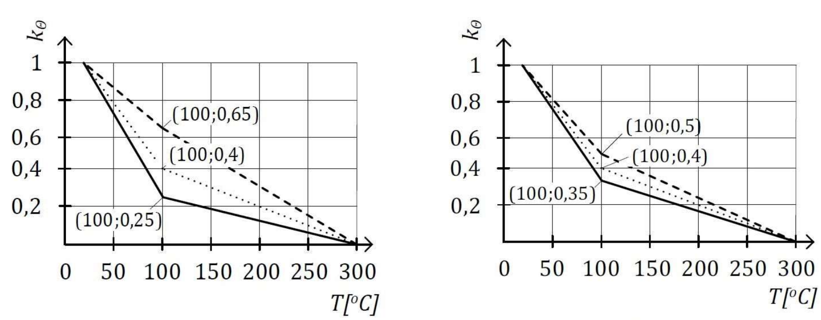
Advanced design methods: thermal analysis

Table 8.3 – Temperature-dependent thermal properties of batt- or matt-type mineral wool insulation with protection level 1 (PL1) and density more than 26 kg/m³

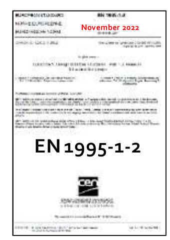
T [°C]	λ_ρ [W/mK]	c [kJ/kgK]	ρ / ρ_{20} [–]
20	0,036	0,880	1,00
100	0,047	1,040	1,00
200	*	1,160	0,980
400	$0,09 \cdot (11 \cdot e^{-0,05 \cdot \rho_{20}} + 1,9)$	1,280	0,977
600	$0,15 \cdot (11 \cdot e^{-0,05 \cdot \rho_{20}} + 1,9)$	1,355	0,973
800	$0,23 \cdot (11 \cdot e^{-0,05 \cdot \rho_{20}} + 1,9)$	1,430	0,970
925	$0,30 \cdot (11 \cdot e^{-0,05 \cdot \rho_{20}} + 1,9)$	1,477	0,960
1200	$0,45 \cdot (11 \cdot e^{-0,05 \cdot \rho_{20}} + 1,9)$	1,580	0,887

With λ_ρ density dependent conductivity
*linear interpolation may apply

Advanced design methods: mechanical analysis



a) strength b) stiffness



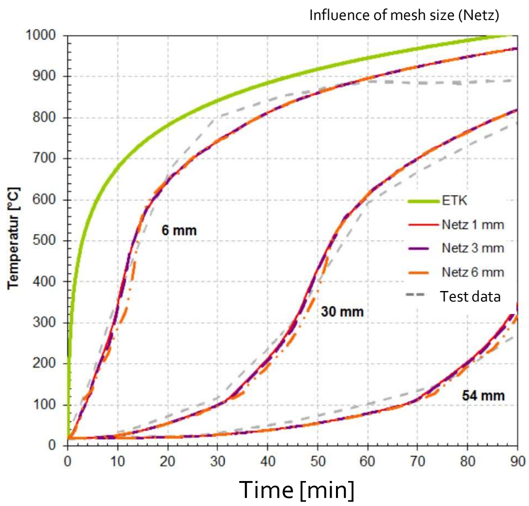
Key:

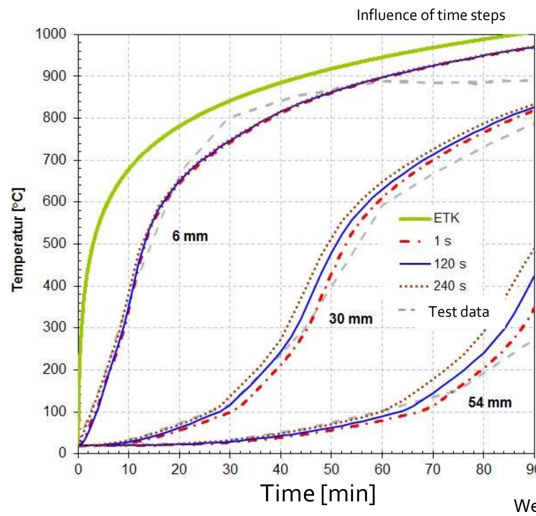
- —— Compression
- – – Tension
- ···· Shear
- T Temperature, in °C
- k_θ temperature-dependent reduction factor

Figure 8.5 – Temperature-dependent reduction factor k_θ for strength and stiffness parallel to grain

Those values cannot be used for constant elevated temperature design!

Implicit analysis - influence of element sizes and time steps

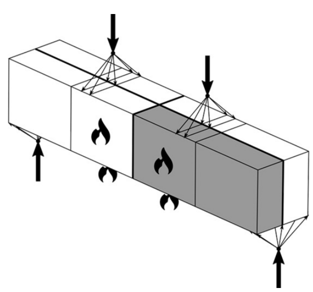




Werther 2016

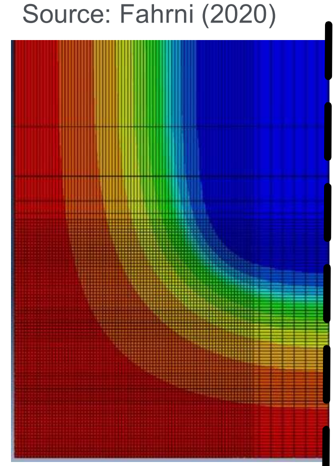
The necessary mesh size also depends on the selected elements!

Modellierung



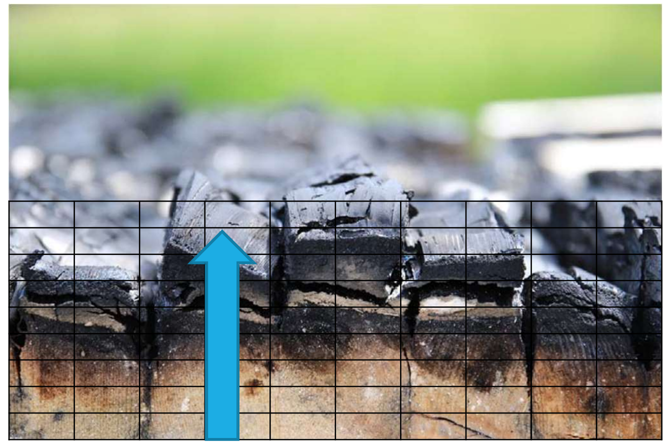
- Use of symmetrie (if possible)
  - Half or a quarter of the member to be modeled
  - Symmetrie line = adiabatic surface
- Element size
  - Small mesh size in case of steep temperature gradients
  - Rather big mesh size otherwise

Source: Fahrni (2020)



The **Adiabatic Surface** Temperature is defined as the temperature of a surface which cannot absorb or lose heat to the environment

Effective material properties for timber

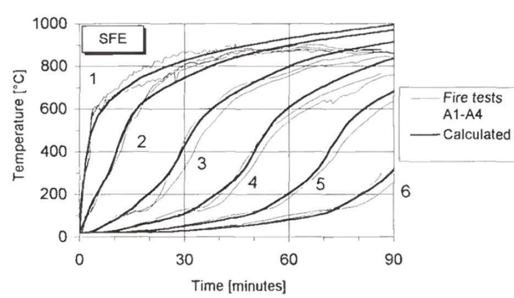


Uniform material properties?

Effective material properties for timber - determination

- Measured temperatures at different depths during standard fire exposure (EN/ISO).
- Specific heat capacity and thermal conductivity calibrated as a function of temperature so that the simulated temperatures corresponded to the measured ones

Effective material properties to consider:
- Mass transport (moisture, gases, fly ash, ...)
- Cracks in the char layer
- Charring of timber AND char
- Heat generation (exothermic reactions)



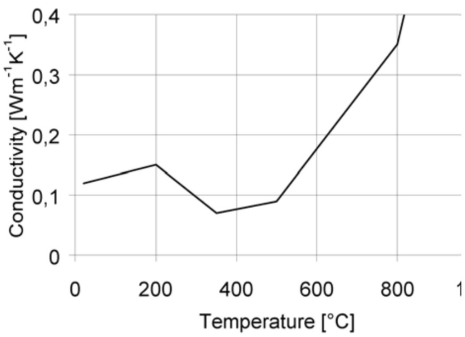
König & Walleij 1999

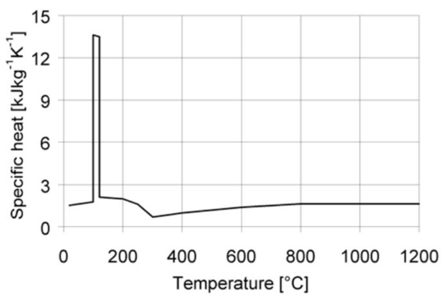
Figure 3.3: Temperature-time relationships of tests A1-A4: Comparison of fire tests and calculations

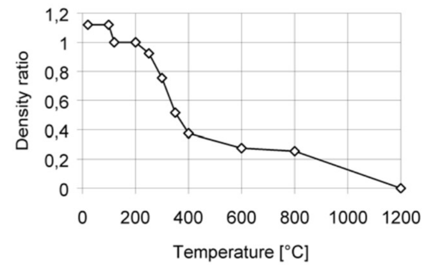
Literature:
- König & Walleij 1999
- König + Källsner 2000
- König 2005

Effective material properties for timber

EN 1995-1-2, Annex B

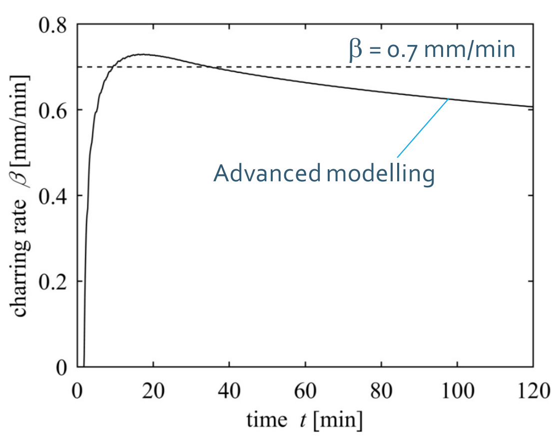


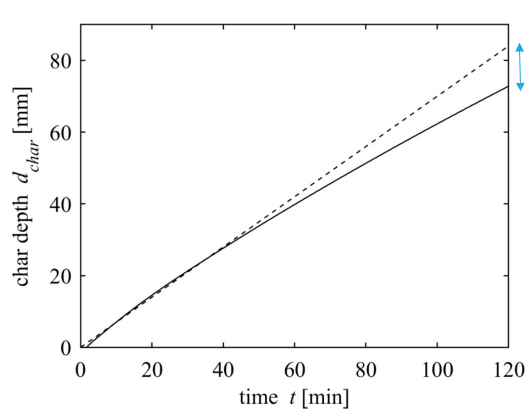




Effective material properties for timber

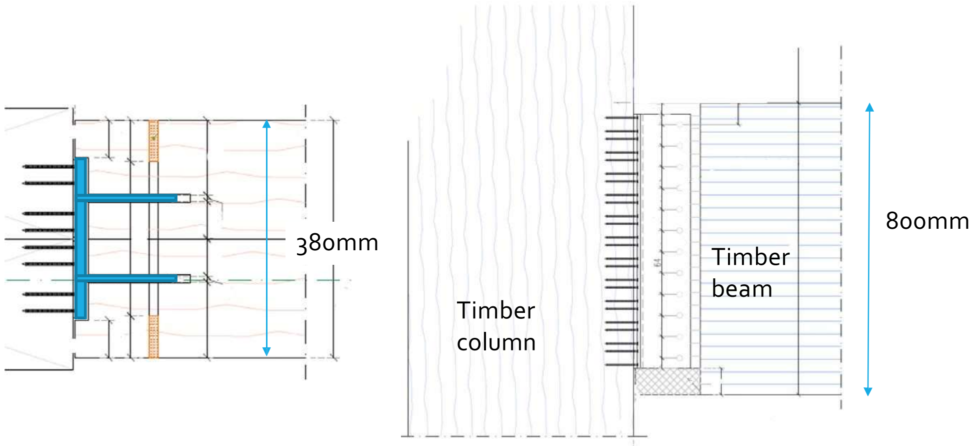
Comparison between standard value and advanced modelling:





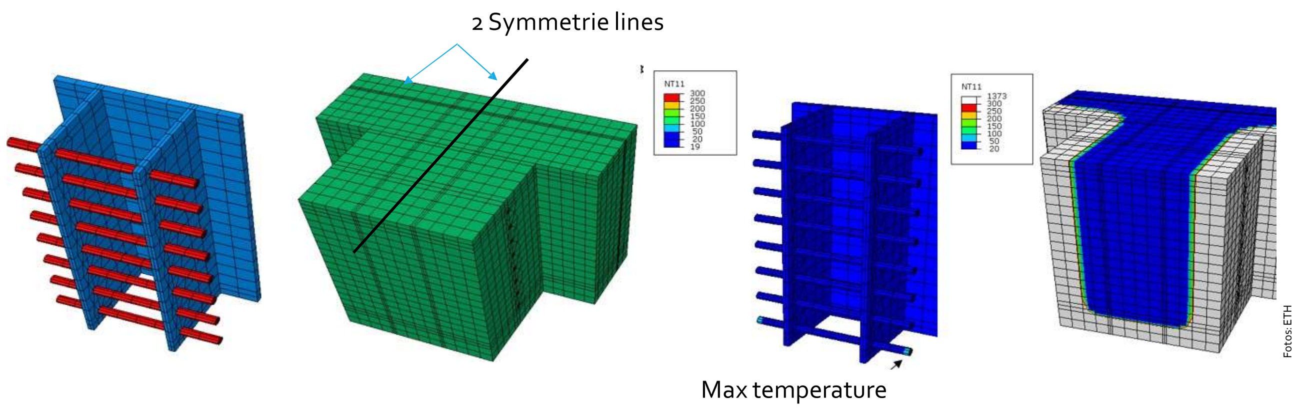
Example: Application of advanced modelling, R

Thermal simulation of connection, R90?



Example: Application of advanced modelling, R

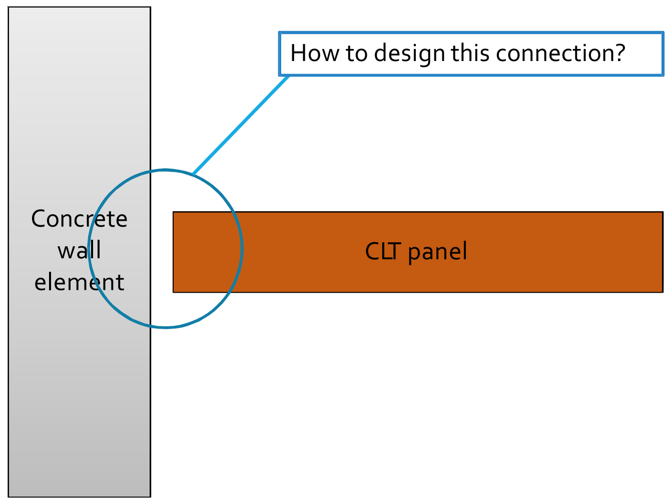
Thermal simulation of connection, R90?



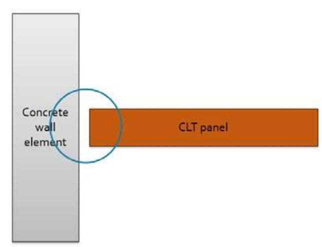
After 90min EN/ISO exposure: Metal parts stay mostly at 20°C in this example

Please note that such an analysis must be done by an expirienced engineer with a clear record.

Example: Design of support, EI and R



Example: Design of support, EI and R



1. What is the fire resistance requirement?

→ Design for EI 60 and R 60 (for fire exposure from both sides!)
(Comment: This depends from country to country; sometimes only design for fire from

2. What does EI 60 mean?

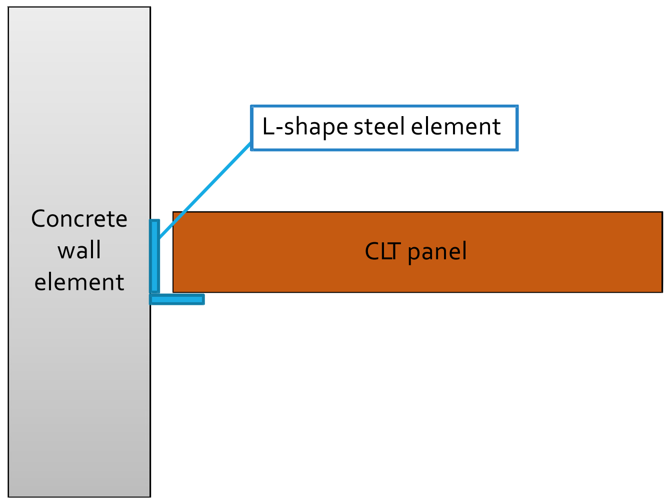
→ Temperature at fire unexposed surface 160°C

3. Which general requirements should be checked?

→ Air-tightness, both sides! Chimney effect must be avoided!
Fire does not know a direction! Radiation in all direction!

→ Voids should be filled with non-combutible material (e.g. rockwool)

Example: Design of support, EI and R



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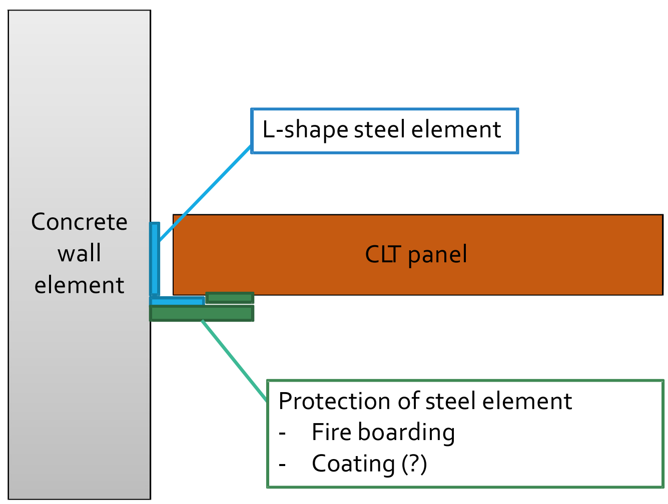
Example: Design of support, EI and R



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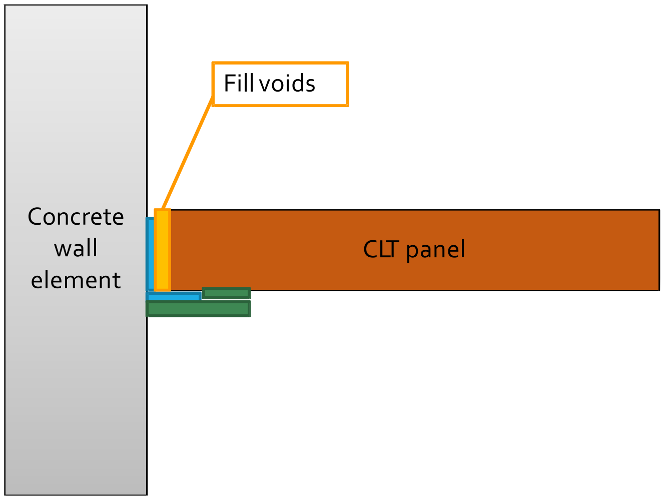
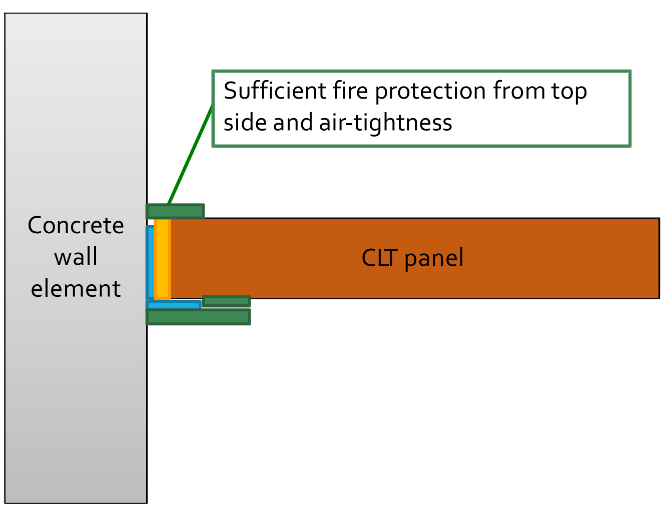
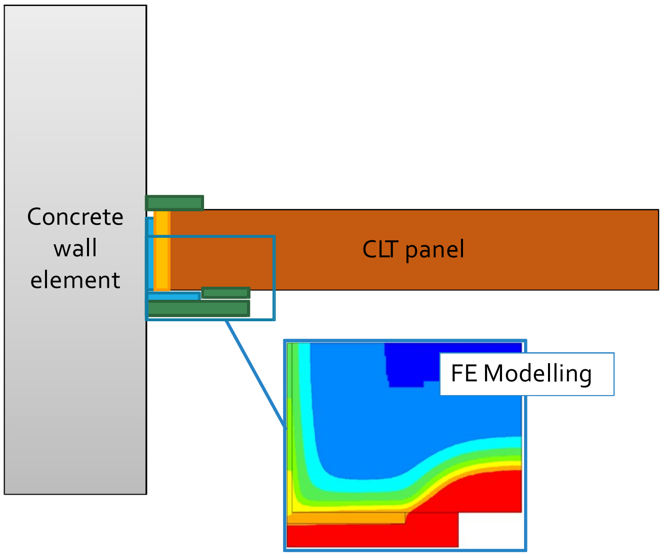
Example: Design of support, EI and R



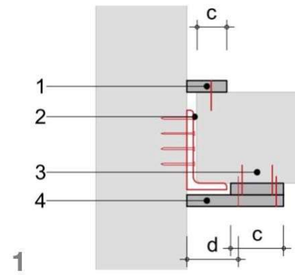
Example: Design of support, EI and R



Example: Design of support, EI and R



Design according to Lignum documents



1 Beplankung beidseitig überlappt oder einseitig oben
- Feuerwiderstandsdauer ≥ Feuerwiderstandsdauer Bauteil
  - Bauteil R 30: BSP 30
  - Bauteil R 60: BSP 60
  Ist die Beplankung mehrlagig, so ist jede Lage unabhängig ins tragende Bauteil zu befestigen.
- Mindestauflager auf Holz:
  - Bauteil R 30: c ≥ 40 mm
  - Bauteil R 60: c ≥ 60 mm
  - Bauteil R 90: c ≥ 80 mm

2 Hohlraum zwischen Stahlträger und Decke darf nicht über Brandabschnitte führen

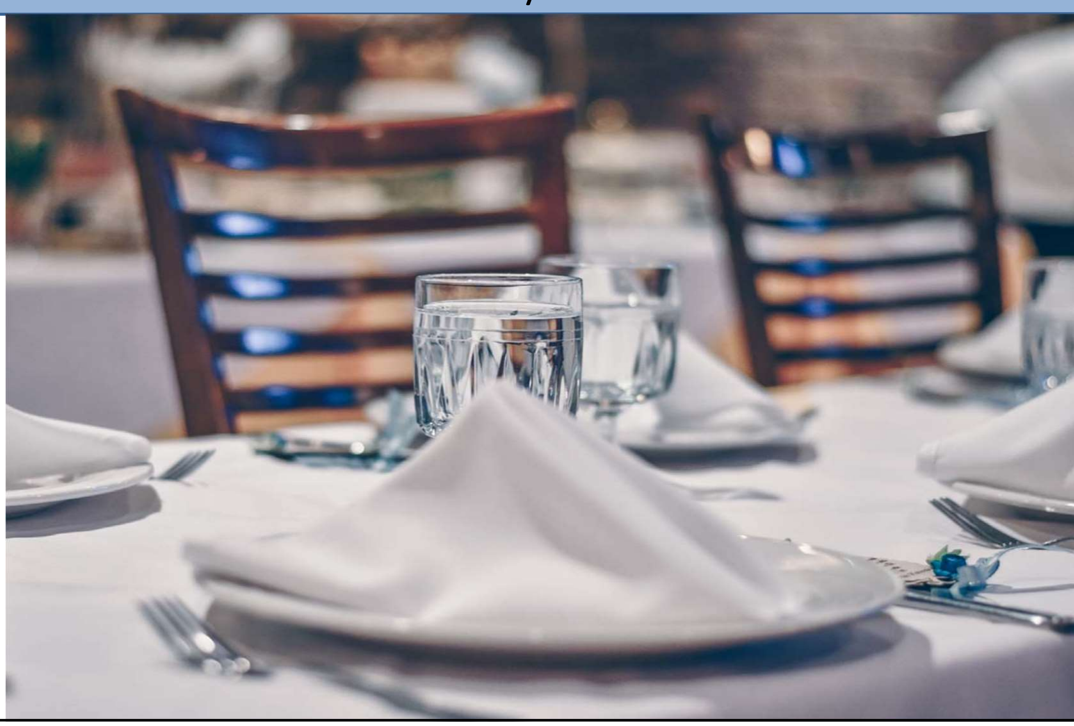
3 Längsfugen in Bauteilebene:
- Längsfugenbreite ≤ 5 mm im Abstand von min. 200 mm sowie Brettstapelfugen: keine Massnahmen erforderlich
- Längsfugenbreite > 5 mm: Fugenausbildung gemäss Kap. 4.2.7

4 Beplankung einseitig unten
- Feuerwiderstandsdauer ≥ Feuerwiderstandsdauer Bauteil
  - Bauteil R 30: BSP 30
  - Bauteil R 60: BSP 60
  Ist die Beplankung mehrlagig, so ist jede Lage unabhängig ins tragende Bauteil zu befestigen.
- Mindestauflager auf Holz:
  - Bauteil R 30: c ≥ 100 mm
  - Bauteil R 60: c ≥ 120 mm
  - Bauteil R 90: c ≥ 140 mm

5 Bemessung Stahlauflager für den Lastfall Brand gemäss Norm SIA 263, Stahlbau [16] bzw. Steeldoc, Brandschutz im Stahlbau [20]

d Maximale Distanz: d ≤ 150 mm: einseitig befestigt
d ≤ 500 mm: beidseitig befestigt
Grössere Distanzen unter Berücksichtigung der Ausführungsbestimmungen der Beplankungen

Lunch break / 13:30 - 14:00

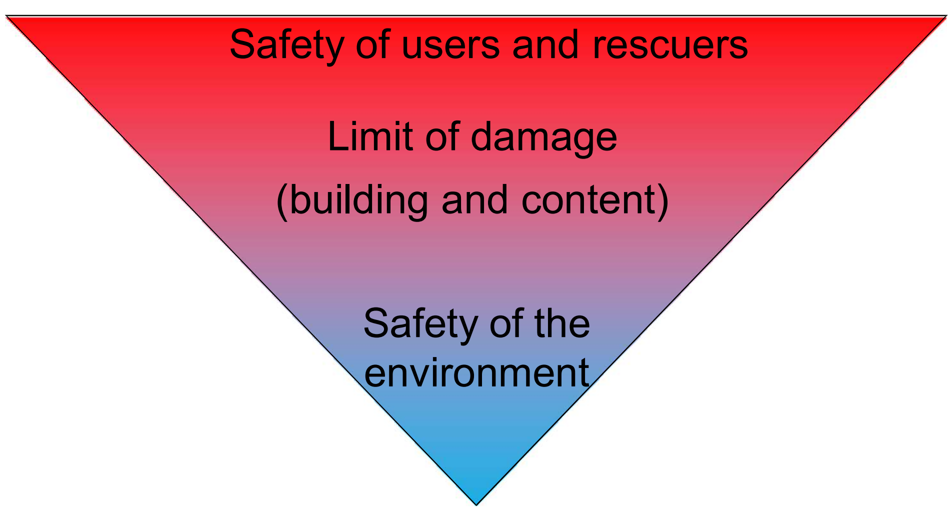


Agenda 14:00-15:30

- Fire protection strategies in mid-rise and high-rise timber buildings – required fire resistances and combustibility, timber structures additional fire protection, additional measures, etc.
- Fire protection solutions for mid-rise and high-rise timber buildings, examples
- Questions and answers

Fire protection objectives

Smoke is the main cause of fire casualties (>80% of casualties).
Casualties due to building collapse are very rare.

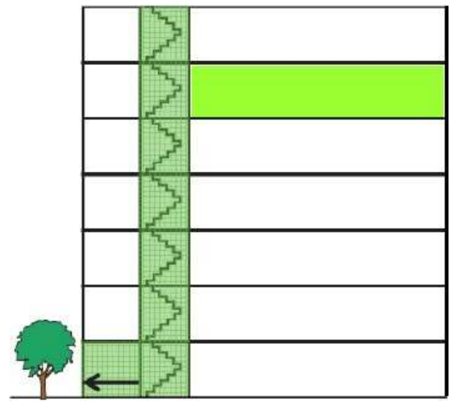


Escape routes

Escape routes

Main criteria

- Use and position of building
- Building geometry
- Occupancy (number of people)



- Vertical escape route (stairwell): without visible timber
- Horizontal escape route: Limited visible timber possible?

Escape routes

Escape routes – vertical routes:

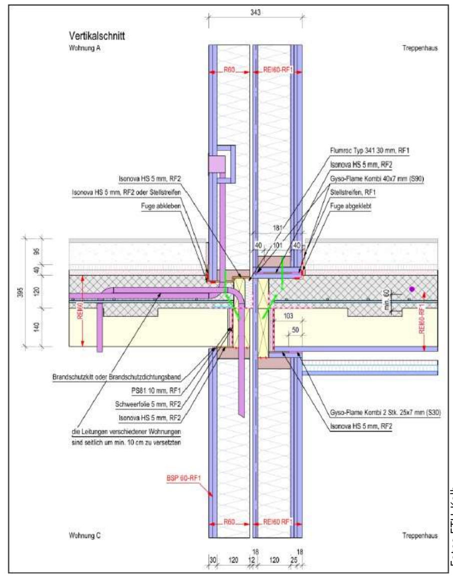
Usually in concrete! In Switzerland also possible with timber but encapsulated with (minimum) K_230 (EN 14135)

Source: Josef Kolb AG

Escape routes

Escape routes – vertical routes:

Source: Josef Kolb AG



Fotos: ETH, Kolb

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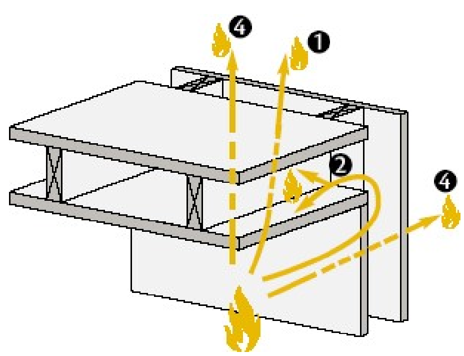
Quality of construction

- Fire safety plan with all fire safety measures
- Careful planning and detailing
- Professionally implementation of fire safety measures during the execution
- Periodic controls and maintenance
- The intensity of maintenance and controls must be set depending of the type of structures and the type and importance of the building



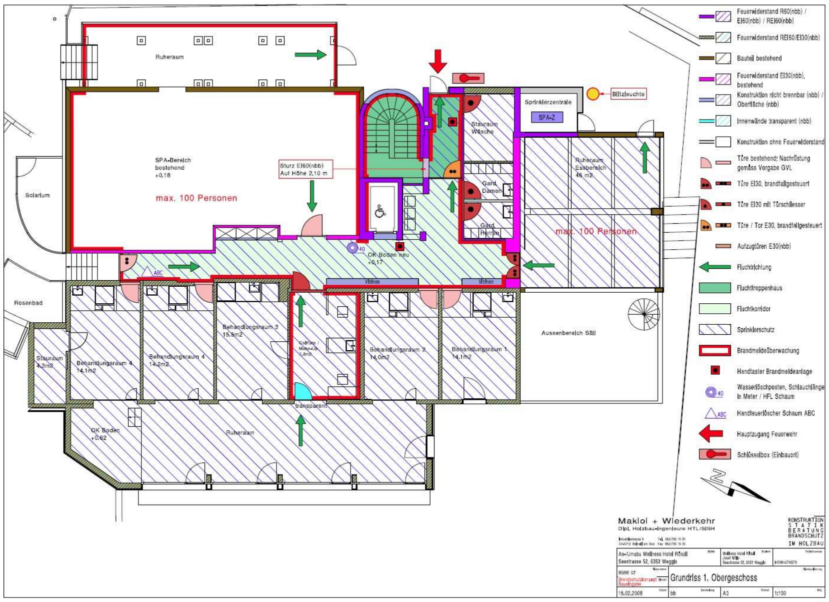
Quality of construction

Fire safety plan

Information about:

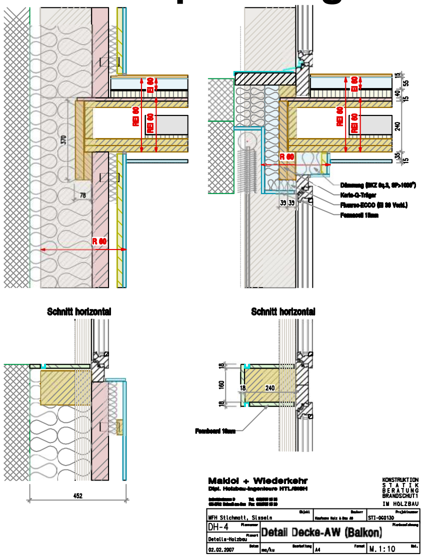
- Compartmentation
- Egress route
- Fire resistance
- Technical fire safety measures
- Etc.

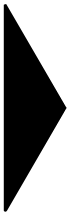
Note: In Switzerland, pictograms and colours are all standardised, which makes it easy to read and understand

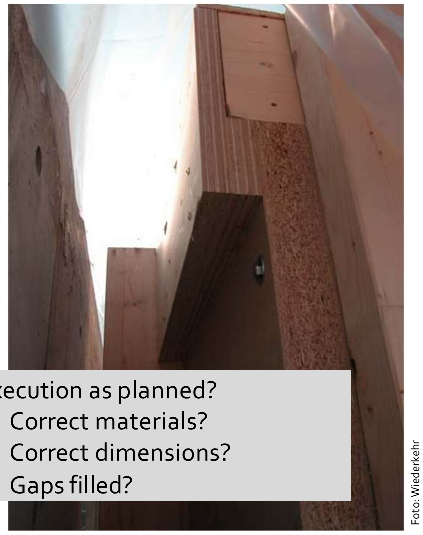


Quality of construction

Careful planning and detailing







Execution as planned?

- Correct materials?
- Correct dimensions?
- Gaps filled?

Quality of construction

Careful execution and period controls

(in factory and at construction site)

Fotos: Wiederkehr

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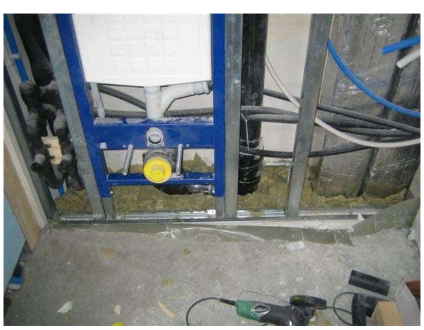
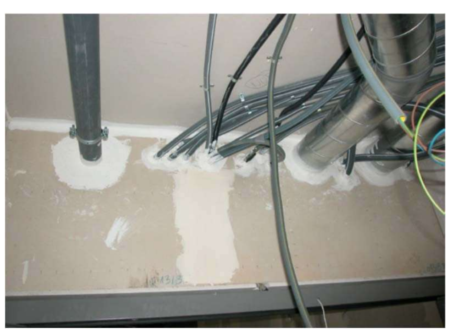
Quality of construction

Careful execution and period controls

(in factory and at construction site)





Fotos: Wiederkehr

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148

Quality of construction

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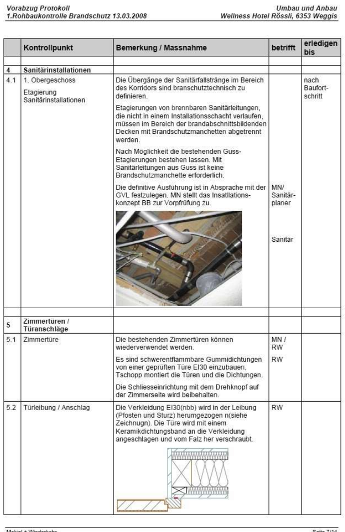

Vorabzug Protokoll
1.Rohbaukontrolle Brandschutz 13.03.2008

Umbau und Anbau
Wellness Hotel Rössli, 6353 Weggis

	Kontrollpunkt	Bemerkung / Massnahme	betrifft	erledigen bis
4	**Sanitärinstallationen**			
4.1	1. Obergeschoss Etagierung Sanitärinstallationen	Die Übergänge der Sanitärfallstränge im Bereich des Korridors sind branschutztechnisch zu definieren. Etagierungen von brennbaren Sanitärleitungen, die nicht in einem Installationsschacht verlaufen, müssen im Bereich der brandabschnittsbildenden Decken mit Brandschutzmanchetten abgetrennt werden. Nach Möglichkeit die bestehenden Guss-Etagierungen bestehen lassen. Mit Sanitärleitungen aus Guss ist keine Brandschutzmanchette erforderlich. Die definitive Ausführung ist in Absprache mit der GVL festzulegen. MN stellt das Insatllations-konzept BB zur Vorpfrüfung zu.	MN/ Sanitär-planer Sanitär	nach Baufort-schritt
5	**Zimmertüren / Türanschläge**			
5.1	Zimmertüre	Die bestehenden Zimmertüren können wiederverwendet werden. Es sind schwerentflammbare Gummidichtungen von einer geprüften Türe EI30 einzubauen. Tschopp montiert die Türen und die Dichtungen. Die Schliesseinrichtung mit dem Drehknopf auf der Zimmerseite wird beibehalten.	MN / RW RW	
5.2	Türleibung / Anschlag	Die Verkleidung EI30(nbb) wird in der Leibung (Pfosten und Sturz) herumgezogen n(siehe Zeichnugn). Die Türe wird mit einem Keramikdichtungsband an die Verkleidung angeschlagen und vom Falz her verschraubt.	RW	

Makiol + Wiederkehr
Seite 7/14

Protokoll
4. Rohbaukontrolle Brandschutz 29.04.2008

Umbau und Anbau
Wellness Hotel Rössli, 6353 Weggis

	Kontrollpunkt	Bemerkung / Massnahme	betrifft	erledigen bis
2.7	Geberitrohr 4. OG im Korridor. Geberitrohr EI60(nbb) abisolieren analog Lüftungskanal oder Verkleidungskasten aus Gipsfaserplatten EI60(nbb) erstellen und Hohlraum mit Steinwolle ausdämmen		MN / MO / RW	nach Bauverlauf
2.8	Durchdringungen von Leitungen in brandab-schnittsbildenden Bauteilen. Ausspachteln oder mit Brandschutzsilikon ausfugen.	Vor der Montage der heruntergehängten Decken müssen alle Leitungen und Kanäle welche Beplankungen durchdringen sauber ausgespachtelt oder mit Brandschutzsilikon abgedichtet werden. MN beauftragt Gipser oder Spezialist.		

Makiol + Wiederkehr
Seite 4/7

Relevant information:

- Description and documentation of detail
- Decription of what is wrong
- Responsible person
- Date until it must be improved

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The three key pillars: Education & Experience & Guidance documents

Fire safe timber buildings

Education

- Courses at universities for students
- Advanced studies programs for engineers in practise
- Local conferences
- Etc.

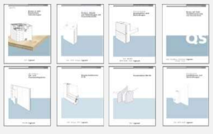
Experience

- Case study buildings and demonstrators
- Experienced engineers and craftsman
- Learn from experts from abroad that might have more experience

Learn from each other

Guidance documents

- Standarisation and standardised details
- Guidance documents for engineers for the design
- Establish common understanding within main stakeholder groups



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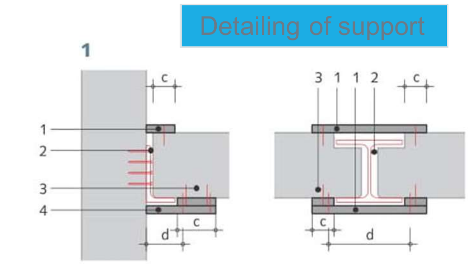
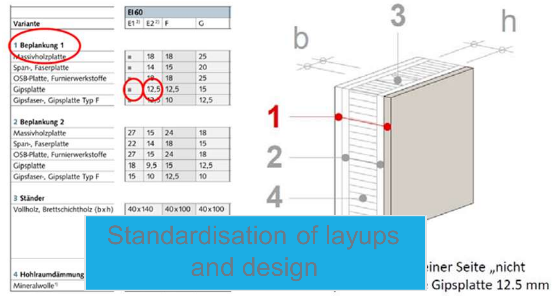
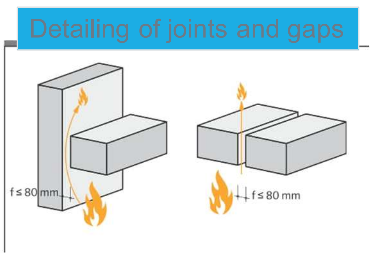
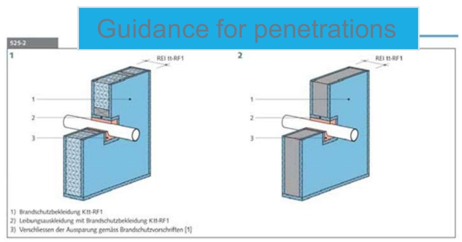
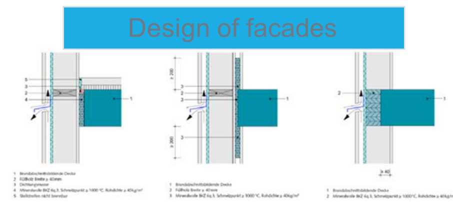
Guidance documents: Lignum documentation



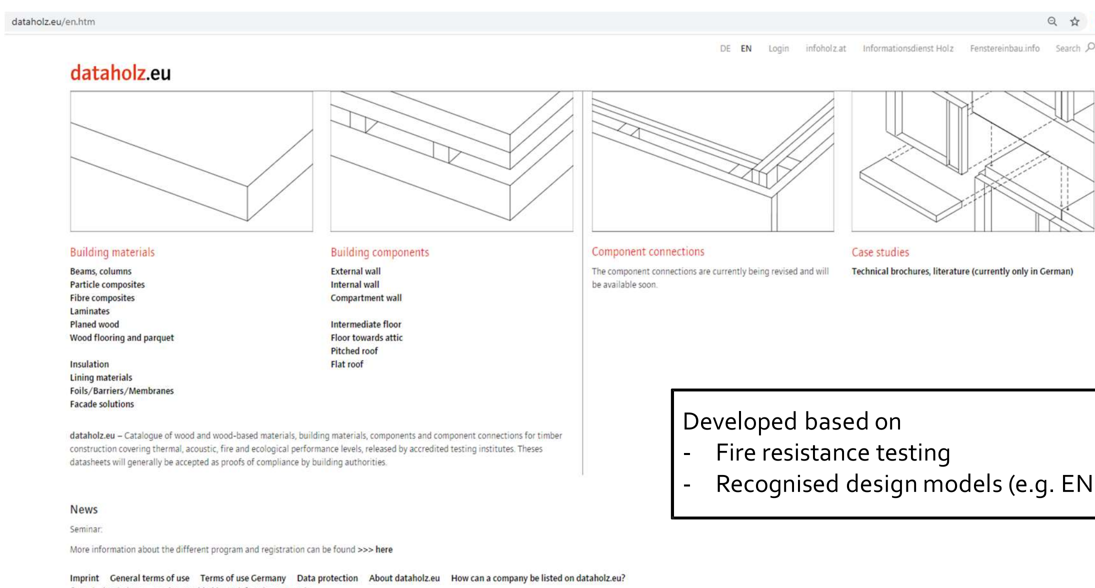






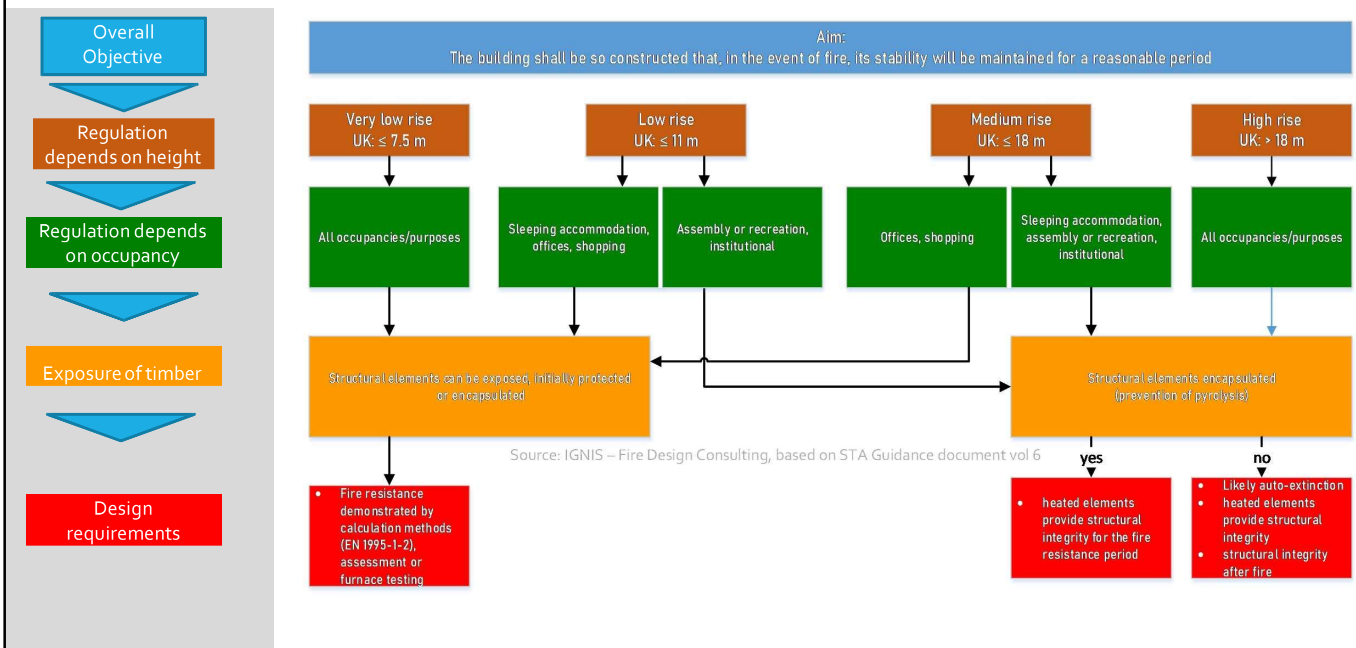


Guidance documents: dataholz.eu



Developed based on
- Fire resistance testing
- Recognised design models (e.g. EN 1995-1-2)

Clear guidance for designers



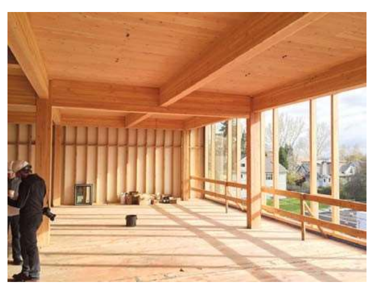
Some examples of mid-rise buildings in Switzerland

Regulations in Switzerland

Current tendencies

...to build tall timber buildings & ... more visible (exposed) timber

https://www.pinterest.at/pin/740279876118396151/



https://continuingeducation.bnpmedia.com/

The design challenge

- The Architect wants slender wood elements, all exposed
- The Fire Engineer wants massive wood elements, mostly hidden

What is the solution?

→ It depends on the building height and use

→ Critical elements need special protection

→ How do we codify this?

Selection of timber high-rise timber buildings / overview

Selection of timber high-rise timber buildings / overview


Holz 8, Bad Aibling, [5]


Carbon 12, Portland, [1]


Forté, Melbourne, [4]

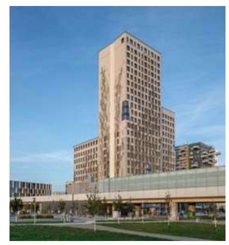

Skaio, Heilbronn, [8]


Suurstoffi S22, Rotkreuz, [3]


Origine, Québec City, [10]

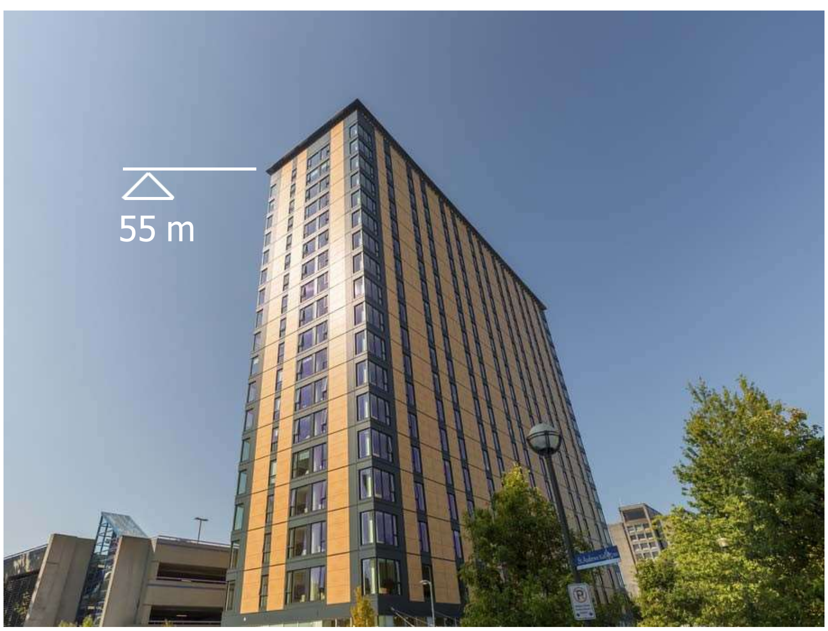

Treet, Bergen, [9]


Brock Commons, Vancouver, [7]


HoHo, Wien, [2]


Mjøstårnet, Brumunddal, [6]

UBC Brock Commons, Vancouver (Canada)



Suurstoffi BF1, Risch Rotkreuz (Switzerland)

Statical system: single span beams

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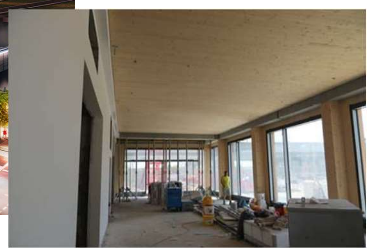
HoHo Vienna, Austria



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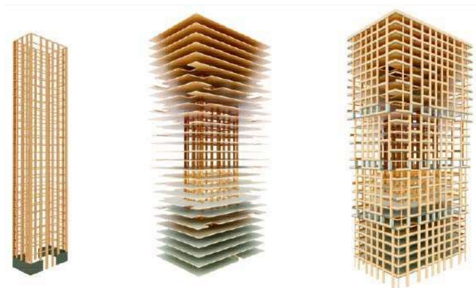
Haut, Amsterdam, The Netherlands

Source: http://www.skyscrapercenter.com/building/haut/26753

Ascent, Milwaukee, USA

Source: http://www.skyscrapercenter.com/building/ascent/34292

Project Pi, Zug, Switzerland



https://techclusterzug.ch/technologiecluster-zug/projektpi

Tall timber buildings

- Severity of design fires
- Contribution of timber to the fire load
- Charring rate of wood as a function of fire exposure
- Self-extinguishment of charred wood
- Fire performance of encapsulated timber
- Dangers of combustible facade claddings
- Effect of different combinations of passive and active fire protection
- Quantitative risk assessment, to include all these items
- ……

River Beech Tower (228m), Chicago, USA
http://www.skyscrapercenter.com/building/river-beech-tower/27372

Mjøstårnet, Norway

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Mjøstårnet, Norway

- **General information**
  - Height: 85.4 m (18 stories)
  - Mixed use (office, residential, restaurant,…)
- **Fire safety design**
  - Structural system: stiff frames and truss system
  - Primary structure: R120, secondary structure: R90
  - Sprinklers and fire alarm
  - Three elevators, one of them is dedicated for fire
  - Two staircases, one is for emergencies only, with gypsum cladding
  - Wood is visible throughout the building (also at the façade), but surfaces are fire painted in emergency routes and common areas
- **Robustness elements considered in the design**

Source: Agnese Bifulco

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Mjøstårnet, Norway

The design team of this building give the following information about robustness:

Robustness:

Structures should be designed to have an adequate level of robustness. This is a recommendation and not a requirement.

In Mjøstårnet, they have made provisions to make the building more robust:

1. **The structure is designed to sustain the loss of the horizontal stiffness of one timber floor.**
2. **It can also carry the impact load of a timber deck falling down on the floor below.**
3. **You can remove a random diagonal without getting collapse**
4. **A fire cell can burn out without total collapse**
5. **Glulam columns are very big. Probability of column failure smaller**

The topic robustness

… in context of more and more complex and tall buildings

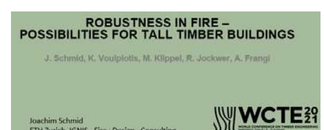


Image: Matt Hughes

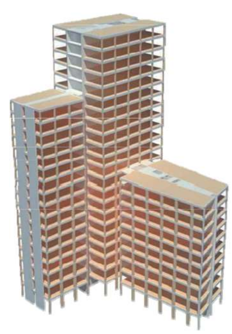


Image: Woschitz Group

Image: PLP

Failure in fire → limited damage should be verified / investigated

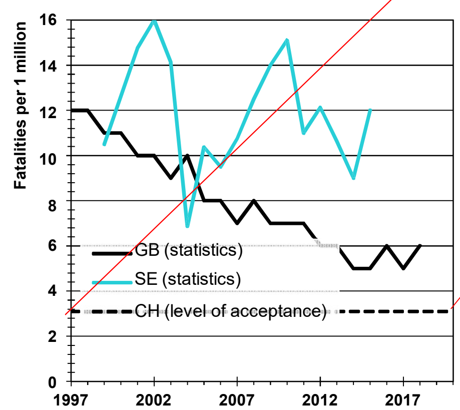
Slides about Robustness, see Schmid et al. paper at WCTE 2021

The topic robustness

Safety management:

Safety is the state of being "safe", the condition of being protected from harm or other non-desirable outcomes.

Safety refers to the control of recognized hazards to achieve an acceptable level of risk.



The topic robustness

Mathematical formulation of robustness [Starossek et al. 2010]

$$P(C) = P(E) \times P(D|E) \times P(C|D)$$

P(C): Probability of Disproportionate Collapse

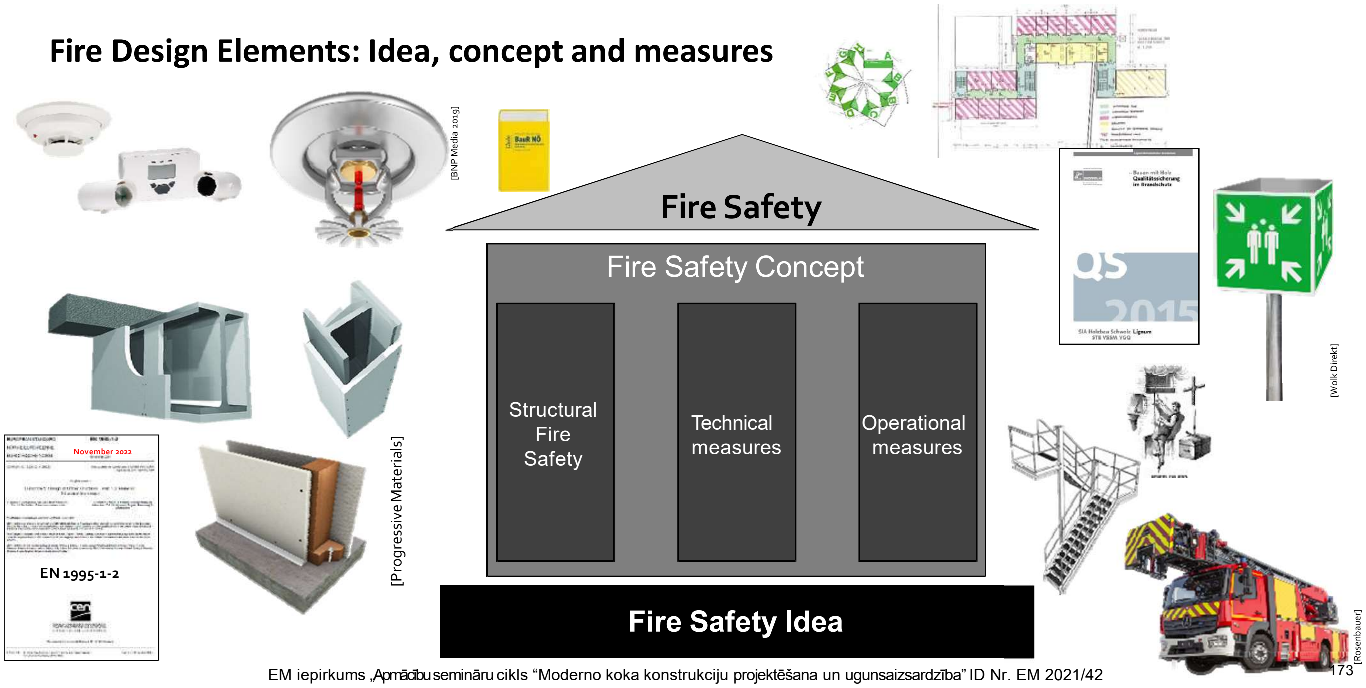
P(E): Exposure

P(D|E): Vulnerability

P(C|D): (Complement of) Robustness

The topic robustness

Fire Design Elements: Idea, concept and measures

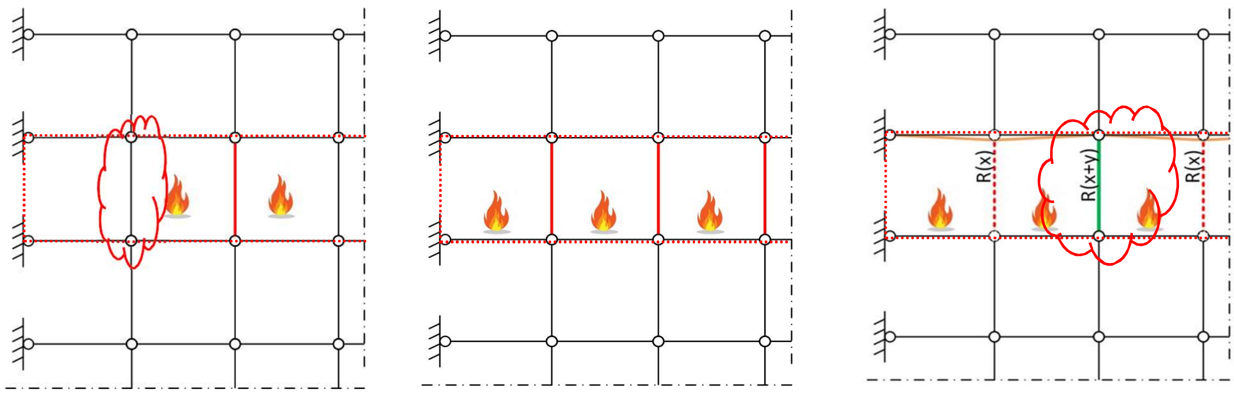


The topic robustness

1) by avoiding critical events;
   Reduce risk of flashover → sprinkler systems,
2) by dimensioning of individual components;
   Over-dimensioning of fire boarding or additional depth
3) by enabling alternative load paths;
   as at normal temperature. But: correlated failure modes!
4) by the reduction of the consequences.
   Enhanced evacuation; compartmentation.

The topic robustness

Example – structural elements:



correlated failure expected!

The topic robustness

Example – fire design:

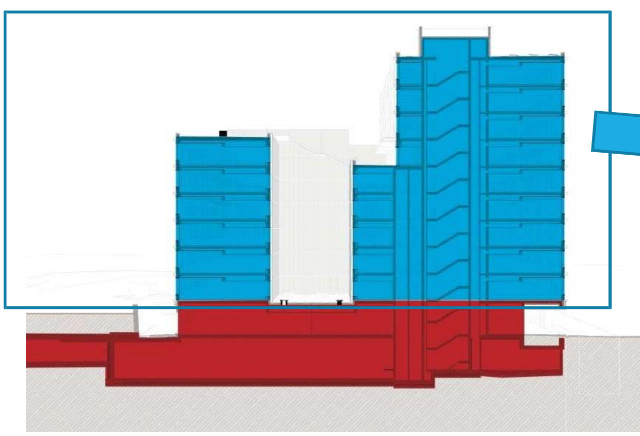
1. What if smoke detector doesn't work? → multi-channel, several circuits
2. What if sprinkler pipe is blocked? → reductant feeding, zones
3. What if FB is not able to reach the fire? → further scenarios
4. What if the exit is blocked? → several exit scenarios

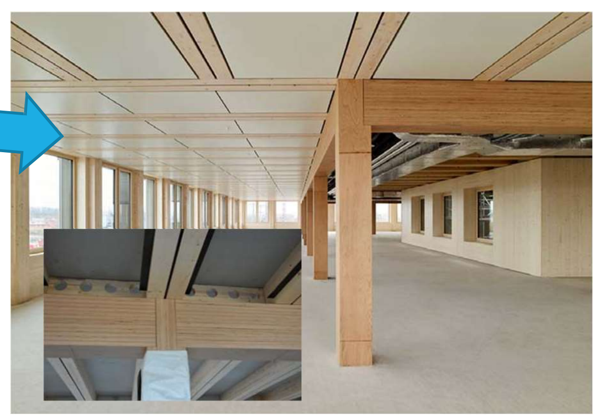
5. What if the encapsulation/lining fails? → parameter study, robustness
6. What if the sprinklers don't work at all? → design for R+, burnout
7. What if the fire spreads faster on ceilings? → compartmentation

Suurstoffi S22, Switzerland

Slides about Suurstoffi S22 from COST ACTION FP 1404 final conference event by R. Wiederkehr, adopted for this presentation

Suurstoffi S22, Switzerland



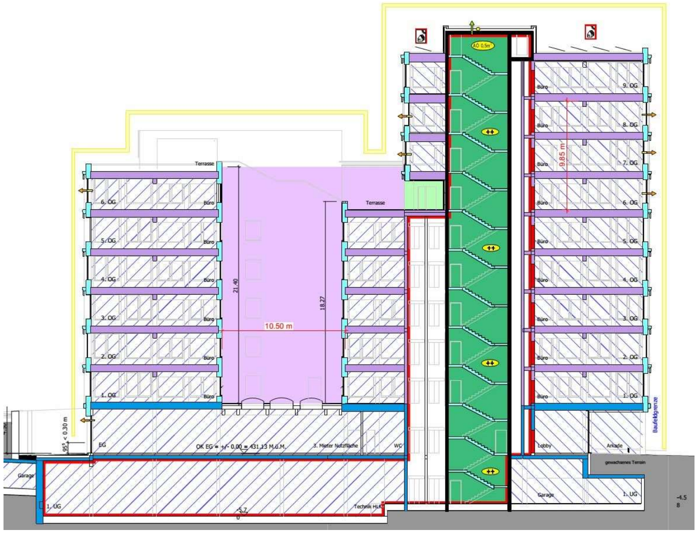


- Basement and lift shafts in concrete,
- Timber as load bearing structure

- Floor elements: Concrete-timber composite
- Timber columns and beams (hard- and softwood)

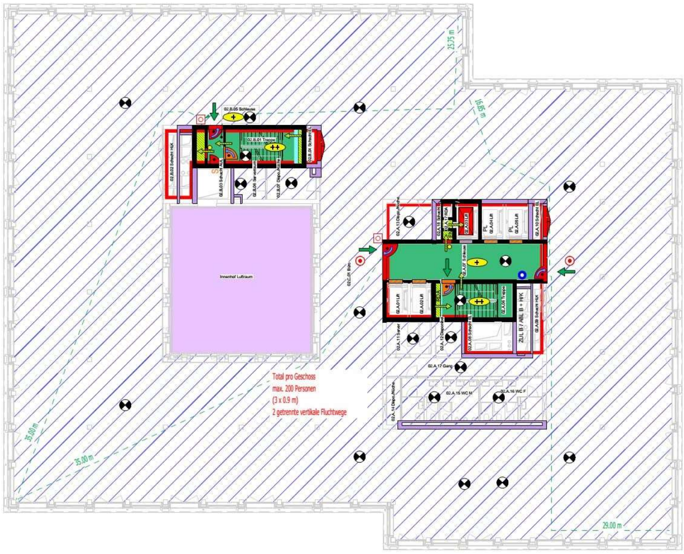
Suurstoffi S22, Switzerland

- Building is equipped with sprinkler (Technical - Standard concept)
- Core basement to 9th floor
  REI 90 (non-combustible)
- Basement and 1st floor
  R 60 (non-combustible)
  REI 60 (non-combustible)
- 1. – 9. floor R 60
  REI 60
  Timber construction
- Outer wall: non-combustible



Suurstoffi S22, Switzerland

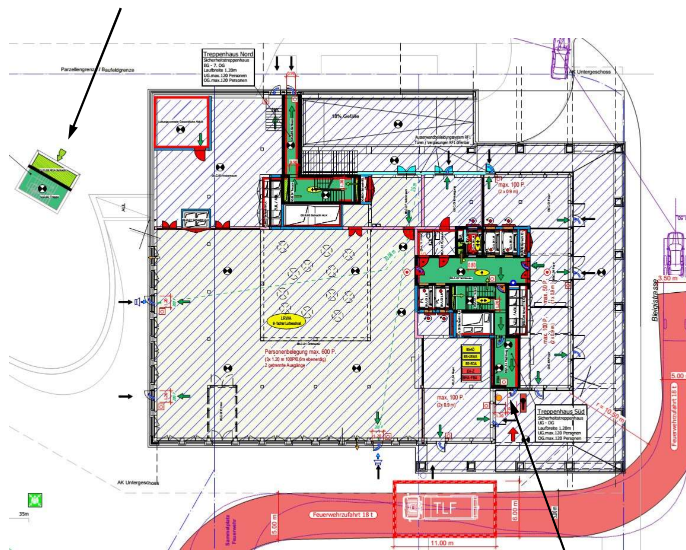
- Overall building implemented as a high-rise building
- Sprinkler system as full protection
- Fire alarm system as partial monitoring | Single smoke detector in front of lock
- Safety staircases with smoke protection pressure system | Outflow via shafts
- Floor area 1'500m²



Suurstoffi S22, Switzerland

- Main access fire brigade Staircase South
- Use of 1st floor not yet defined | LRWA would be provided
- Outboard vertical escape route from parking | Intake point smoke protection pressure system

Suction - Smoke protection pressure system

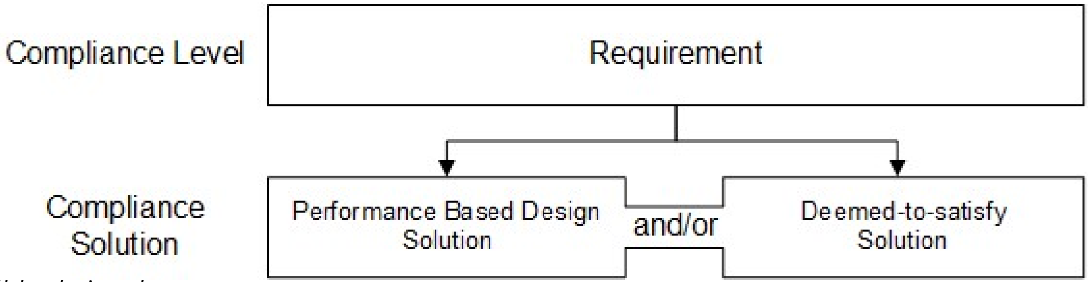


Main access fire brigade

Some key questions to audience

- What is needed to build high-rise timber buildings?
- How much timber can be left visible/exposed in high-rise timber buildings?
- In which parts of the buldings can timber left visible/exposed?
- Which aspects are important for the design of the facade to consider?

Performance based design vs. Prescriptive design



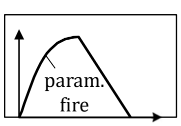
"Exit shall be designed to allow for evacuation of all people in good time"

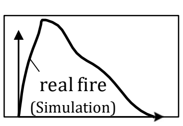
"Exit shall be 120cm wide"

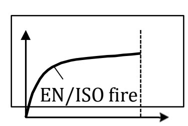
Sometimes difficult to understand the background

Performance based design vs. Prescriptive design

In terms of fire resistance:







Fire Safety Engineering	**Fire resistance design**
Eurocode 1 and 5	Eurocode 5 (EN 1995-1-2)
Include structural timber into fire dynamics	

Performance based design vs. Prescriptive design

→ Clear difference between combustible surfaces and non-combustible surfaces in fire room

Both pictures were taken after 7 minutes of testing:

Combustible surface in fire room

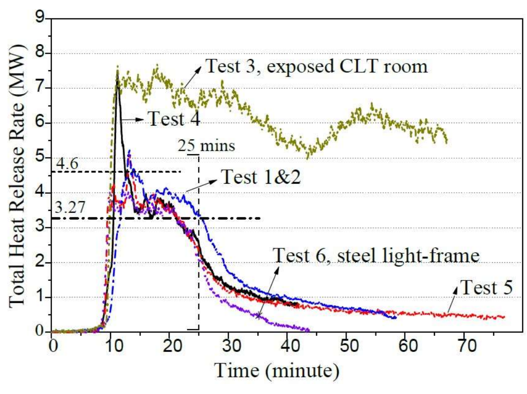
Non combustible surface in fire room

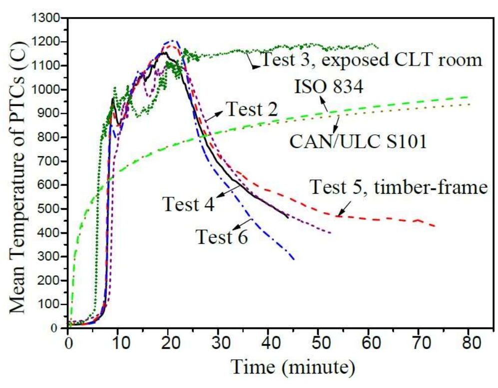
For complex/high buildings: Fire Safety Engineering and design for burnout essential!

Influence of combustible surfaces

Recently many compartment fire tests

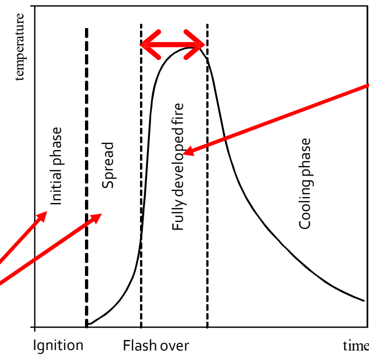
- CLT Compartment Fire Tests 2012, Carleton University, Ottawa, Canada
- CLT Compartment Fire Tests 2016, Arup and University of Edinburgh, UK
- CLT Compartment Fire Tests 2017, NFPA Fire Protection Research Foundation
- CLT two-story, full-scale fire tests 2017, Forest Products Laboratory (FPL), American Wood Council (AWC), U.S. Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF)
- ……





CLT Compartment Fire Tests 2012, Carleton University, Ottawa, Canada

Performance based design vs. Prescriptive design



Fire resistance

Reaction to fire

Fotos: WarringtoFireGent

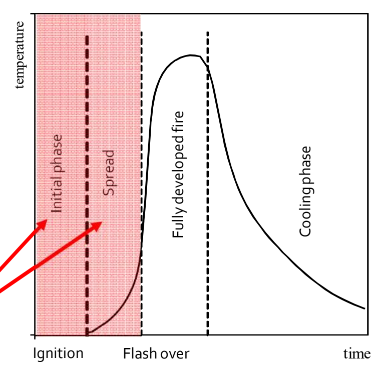
Performance based design vs. Prescriptive design

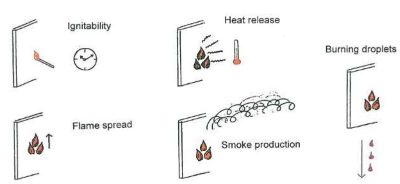
Reaction to fire

To consider:

- Testing of end product
- Not a material property only
- In general wood is class D
- Wood based products are never non-combustible
- Today no reliable possibility exists to simulate reaction to fire (R2F)

Reaction to fire

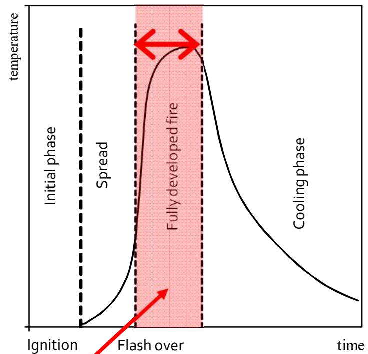




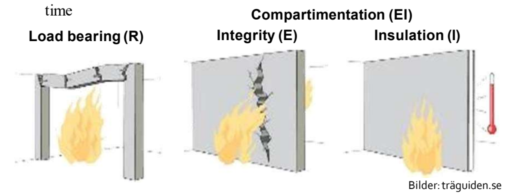
Performance based design vs. Prescriptive design

To consider:

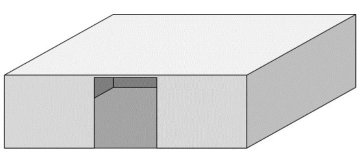
- All elements in contact with the compartment are exposed to the same *fire exposure*.
- Temperature development is depending of the thermal inertia of the enclosure and the oxygen access.
- Temperature are not depending of the reaction to fire classification.
- Fire duration is depending of the available *fire load* (the higher the load the earlier the failure).



Fire resistance

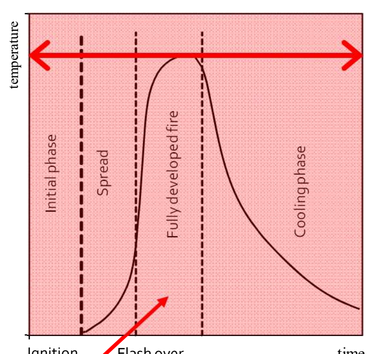


Performance based design vs. Prescriptive design



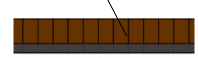
Compartment NC

- 10m x 10m x 3m
- 500 MJ/m² movable fuel
- 100% total fuel

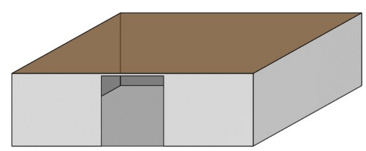


Fire Safety Engineering

No gaps



$\beta_n = 0.65\, mm/min$



Compartment with exposed timber ceiling

- 10m x 10m x 3m
- 500 MJ/m² movable fuel
- **Ceiling: Solid timber panel (STP)**

Q: x % total fuel assuming 1h (standard) fire?

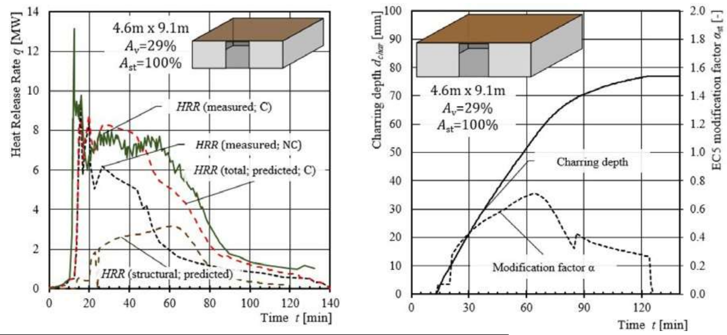
Performance based design vs. Prescriptive design

Fire dynamics considering structural exposed timber

Structural Timber In Compartment Fires – The Timber Charring and Heat Storage Model
Joachim Schmid and Andrea Frangi
From the journal Open Engineering
https://doi.org/10.1515/eng-2021-0043

Generally, fire scenarios are influenced by:

- Geometry
- Ventilation conditions
- Type and distribution of fuel load
- Material(s), combustibility...
- Robustness of models



For complex/high-rise buildings:

- perform a *performance based design* for individual structures with exposed timber *[Design for Burnout]*
- apply natural fire design concepts
- determine the consequences to structural design, façade and other fire safety measures

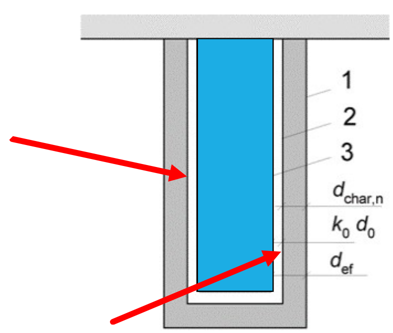
Eurocode 1 and Eurocode 5

In consequence: Include a "STEP 0" into the verification of the fire resistance of your structural member
Effective cross-section model (ECSM)

0 Step 0:
Definition of the design fire

1 Step 1:
Reduction of the initial cross-section
→ <u>residual</u> cross-section

2 Step 2:
Reduction of the residual cross-section
→ <u>effective</u> cross-section



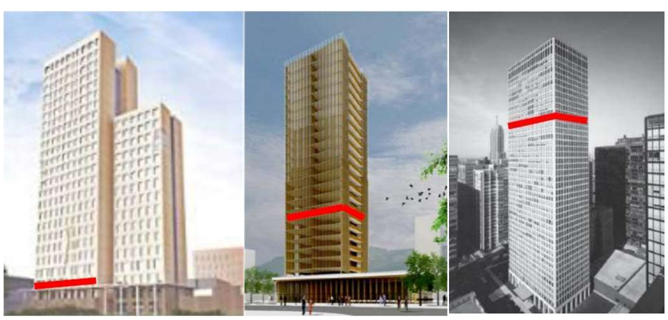
Key:

1... original CS
2... residual CS
3... effective CS
d_0 zero-strength layer (ZSL)
$d_{char,n}$ char depth
d_{ef} effective char depth

Some general conclusions for the design

- Fire protection strategies depend on local boundary conditions and cannot be copied from one country to another!
- Combustible surfaces: Restrictions on wood surfaces areas are needed (prescriptive or definition via a performance based (burnout) design
- If the strategy bases on a sprinkler concept: Sprinklers are not 100% reliable; develop a maintenance strategy
- Contain the fire: interior and exterior fire spread!
- Allow people movement: Occupants out and fire fighers in
- For high-rise: Consider robustness also in the fire strategy, include a design for burnout strategy and thus prevent a collapse

Further elements and questions to consider // tall timber buildings



- Does it matter where the fire is?
- Fire figther access, egress?
- Can the fire spread?
- What happens after the fire goes out?

Source: A. Buchanan

Some general conclusions for the design (of tall timber buildings)

Design strategy (following Buchanan 2019):

1. Prevent ignition
2. Prevent rapid flame spread
3. Ensure sprinkler activation
4. Design for full room involvement (visible structural timber, fuel load contribution)
5. Prevent vertical fire spread
6. Ensure Fire Service access
7. Prevent collapse – charring calculations // result of burnout verification
8. Design for complete burnout (no sprinkler, no fire brigade)

General remark

Fire safety is not primarily a question of building material but of **concept** (education, quality assurance, careful design and execution, maintenance)

Announcement

FSUW Fire Safety Use of Wood network currently prepares an
International Guideline for the design of timber buildings

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www.fsuw.com

Publication expected in mid 2022

Agenda 15:30 -16:00

Question and answer session

Ministry of Economics
Republic of Latvia

Thank you for attention!

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Current regulations in Switzerland