Eurocode 5 Revision – Fire Design of Timber Structures

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Eurocode 5 Revision – Fire design of timber structures

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1 Introduction

The European Commission has a strong interest on the development of the Eurocodes to achieve a further harmonisation of design rules in Europe and the revision process of all Eurocodes has started 2015. The second generation of the Eurocodes is expected to be published starting from 2025. The main objectives of the revision are the improvement of the Ease-of-Use of the Eurocodes for practical users, the reduction of National Determined Parameters and the further harmonisation and inclusion of state-of-the-art. After an intensive discussion within CEN/TC 250 it was defined that the Eurocodes are addressed to competent civil, structural and geotechnical engineers, typically qualified professionals able to work independently in relevant fields [1].

This paper provides an overview to the CEN Enquiry draft of the European design standard EN 1995-1-2 entitled Eurocode 5: Design of timber structures — Part 1-2: Structural fire design [2]. The revision work of the Eurocode 5, fire part (EN 1995-1-2 [3]) was performed by a Project Team (PT), which consisted of Andrea Frangi (chair, ETH), Alar Just (TalTech), Norman Werther (TU Munich), Jouni Hakkarainen (Eurofins), Joachim Schmid (ETH), and additional members from 2021 – Harald Krenn (KLH), Renaud Blondeau (Stora Enso) and Gordian Stapf (Henkel).

Basis for the drafting work are extensive documents, reports and publications with the update state-of-the-art with regard to the structural fire behaviour and fire design of timber structures, e.g. the European Technical Guideline “Fire safety in timber buildings” [4] or the reports prepared in the frame of the concluded COST Action FP1404 [5-7]. The PT started its work in June 2018 and reported regularly to the Working Group WG4 of CEN/TC250/SC5, which is responsible for the revision of EN 1995-1-2. During the last years, the PT prepared three drafts, which were reviewed by the WG4 and commented by the national standardisation bodies. The first draft (May 2019, 75 pages) received 265 comments, the second draft (Mai 2020, 134 pages) 624 comments and the third draft (November 2020, 138 pages) 364 comments. The final draft of EN 1995-1-2 was submitted at the end of August 2021 and received 396 comments. The CEN Enquiry of the document will start in September 2023, the publication will be at the end of 2025.

2 Structure of prEN 1995-1-2

The structure of prEN 1995-1-2 follows the harmonised logic of all fire parts of the second generation of Eurocodes. The structure and also the first four chapters for all fire parts of the Eurocodes are written by TC250 "Horizontal Group Fire". This has resulted in a harmonised structure, which increases the ease-of-use. Table 1 provides an overview of the structure of prEN 1995-1-2 [2] and a comparison with the current EN 1995-1-2 [3]. The principle of a three-stage possibility of verification levels with different levels of complexity and accuracy, which is already known from other Eurocodes, is now also fully established for timber construction. Thus, in the future there are

- tabulated design data (Chapter 6),
- simplified design methods (Chapter 7) and
- advanced design methods (Chapter 8)

In addition to the principles for simplified design models already known in the current EN 1995-1-2 and the basics for numerical simulation models, Chapter 6 in prEN 1995-1-2 lists for the first time fire-tested construction and predefined characteristic values (such as the protection time (t_{prot}) of panels or the effective height of the cross-section for cross-laminated timber with typical lay-ups defined by the industry). In this way, the user is given a very simple and efficient way for the verification of the fire resistance. Despite the increased scope of regulations and the expansion of the scope of application, the structure adapted in this way should enable a simple application.

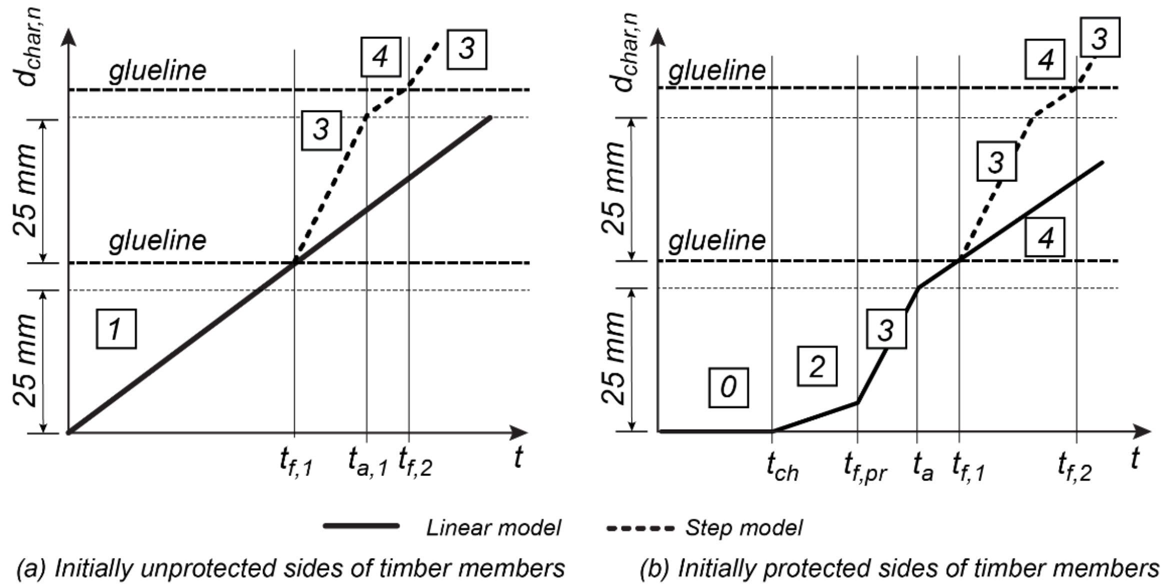
Table 1 Comparison of the content and structure between prEN 1995-1-2 and EN 1995-1-2

EN 1995-1-2:2004		prEN 1995-1-2:2023	
1	General	1	Scope
	-	2	Normative references
	-	3	Terms, definitions and symbols
2	Basis of design	4	Basis of design
3	Material properties	5	Material properties
4	Design procedures for mechanical resistance	6	Tabulated design data
5	Design procedures for wall and floor assemblies	7	Simplified design methods
	-	8	Advanced design methods
6	Connections	9	Connections
7	Detailing	10	Detailing
Annex A: Parametric fire exposure		Annex A: Design of timber structures exposed to physically based design fires	
Annex B: Advanced calculation methods		Annex B: Assessment of the bond line integrity in fire	
Annex C: Load-bearing floor joists and wall studs in assemblies whose cavities are completely filled with insulation		Annex C: Determination of the basic charring rate	
Annex D: Charring of members in wall and floor assemblies with void cavities		Annex D: Assessment of Protection Level (PL) of the cavity insulation	
Annex E: Analysis of the separating function of wall and floor assemblies		Annex E: Assessment of external flaming	
Annex F: Guidance for users of this Eurocode Part		Annex F: Assessment of the failure time of fire protection systems	
-		Annex G: Implementation rules for the Separating Function Method	
-		Annex I: Design model for timber frame assemblies with I-shaped linear timber members	
-		Annex M: Material and product properties for the design with EN 1995-1-2	
-		Annex T: Determination of temperature in timber members	

3 Improvements of prEN 1995-1-2

3.1 European Charring Model

Charring has extensively been dealt with and the current model (in the future renamed as the European Charring Model) has been generalised considering the different phases of protection and the different modification factors for charring in a more systematic way. Furthermore, the charring model clearly distinguishes two cases (bond line integrity maintained or not maintained during the fire exposure), see Figure 1. Supplementary guidance for the assessment of the bond line integrity in fire is given in Annex B.



Key:

0	Encapsulated phase (Phase 0)
1	Normal charring phase (Phase 1)
2	Protected charring phase (Phase 2)
3	Post-protected charring phase (Phase 3)
4	Consolidated charring phase (Phase 4)

$d_{char,n}$ - notional charring depth

t - time

t_{ch} - start time of charring

$t_{f,pr}$ - failure time of the fire protection system

t_a - consolidation time

Figure 1: Phases for timber members according to the European charring model

Time limits between phases for initially protected timber members are defined by the start time of charring t_{ch}, the failure time (or fall-off time) of the fire protection system $t_{f,pr}$ and the consolidation time t_a. For structures with bond line integrity not maintained, the fall-off time of charred layers $t_{f,i}$ is considered.

The start time of charring t_{ch} will be designed according to the Separating Function Method. The fall-off time $t_{f,pr}$ is one of the most important parameters influencing the fire resistance of initially protected timber structures, especially concerning timber members with small cross-section. In the new Eurocode, the failure times (defined as fall-off times) of different panels, including gypsum plasterboard Type A and F and gypsum fibreboards, are given with simplified equations based on a large data base of fire tests [8, 9], see Table 2. Moreover, for the fire design it is possible to use failure times based on full-scale fire tests performed according to EN 13381-7 [10].

Table 2 Failure time t_f of panels initially exposed to fire

Panels		Vertical		Horizontal	
		t_f [min]	h_p [mm]	t_f [min]	h_p [mm]
Gypsum plasterboards	Type F, one layer	$t_f = 4{,}6 \cdot h_p - 25$	$9 \leq h_p \leq 18$	$t_f = 1{,}3 \cdot h_p + 9$	$9 \leq h_p \leq 18$
	Type F, two layers or Type F[a] + A	$t_f = 4{,}4 \cdot h_p - 50$	$25 \leq h_p \leq 36$	$t_f = 1{,}5 \cdot h_p + 15$	$25 \leq h_p \leq 36$
	Type A, one layer	$t_f = 2{,}1 \cdot h_p - 6$	$9 \leq h_p \leq 18$	$t_f = 2{,}1 \cdot h_p - 9$	$9 \leq h_p \leq 18$
	Type A, two layers	$t_f = 1{,}8 \cdot h_p - 4$	$25 \leq h_p \leq 36$	$t_f = 1{,}7 \cdot h_p - 13$	$25 \leq h_p \leq 36$
Gypsum fibreboards, one layer		$t_f = 3{,}8 \cdot h_p - 21$	$9 \leq h_p \leq 18$	$t_f = 1{,}3 \cdot h_p + 7$	$9 \leq h_p \leq 18$
Gypsum fibreboards, two layers		$t_f = 3{,}7 \cdot h_p - 42$	$25 \leq h_p \leq 36$	$t_f = 1{,}3 \cdot h_p + 14$	$25 \leq h_p \leq 36$

where

h_p is the thickness of the single panel or the total thickness of multiple panels, in mm.

[a] Type F directly exposed to fire.

The temperature increase behind gypsum plasterboards backed by insulation occurs faster and the fall-off of the board occurs earlier. Hence, the fall-off from a timber surface like CLT may be delayed due to decreased heat transfer and distance between fasteners. Thus, when the fire protection system is applied to plane timber members, for timber frame assemblies with void cavities and for linear timber members (e.g. beams and columns), the values according to Table 2 are conservative and may be increased.

The protective properties of clay and lime plaster have been investigated experimentally and numerically. The fall-off of time of clay plaster depends on the fixation as well as the adhesion between clay and the fastening system. Fixation of clay plaster onto

CLT can be excellent and, therefore, clay plaster offers good protection to the timber structure [11].

Notional design charring rates in different phases and for different types of members will be calculated using applicable modification factors:

$$\beta_n = \prod k_i \cdot \beta_0 \tag{1}$$

where

β_n	is the notional design charring rate within one charring phase, in mm/min
β_0	is the basic design charring rate, in mm/min
$\prod k_i$	is the product of applicable modification factors for charring

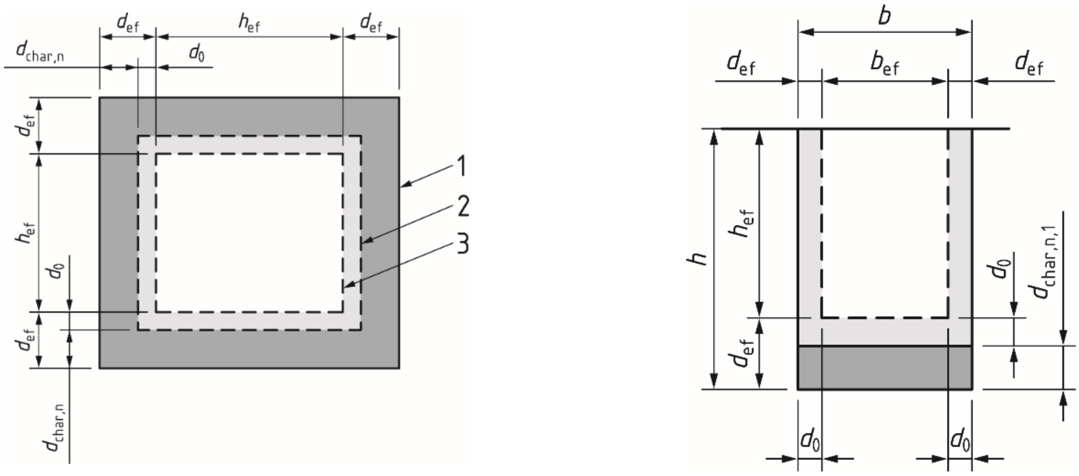
3.2 Effective Cross-Section Method

As simplified design method only the current Reduced Cross-section Method (in the future renamed as Effective Cross-section Method) is given. The current Reduced Properties Method was deleted. The Effective Cross-section Method was revised extensively and its use extended to all common structural timber members, including cross-laminated timber panel (CLT), timber frame assemblies and timber-concrete-composite elements (TCC) [12-16].

According to the effective cross-section method, the initial cross-section of a timber member is decreased by a notional charring depth and by a zero-strength layer depth from the respective sides (see Figure 2). The strength (and stiffness) properties of the effective cross-section will not be decreased for the fire situation. The heating effect is taken into account by a zero-strength layer depth, which has extensively been studied and revised [17-19]. For cross-laminated timber, the calculation of the effective cross-section takes into account the load-bearing and non-load bearing layers.

Fahrni [36-37] conducted an extensive reliability-based code calibration for initially unprotected timber members in fire. From this study, it is concluded that a partial factor should be introduced on the charring rate, which is by far the most important parameter for the fire design of timber members. However, to keep the same format as the current standard, the partial (modification) factor k_{fi} for a strength or stiffness property for the fire situation can be used leading to the same result as the introduction of an additional, new partial factor on the charring rate. Further, Fahrni showed that the current description of the load-bearing resistance is not conservative particularly for short fire resistances (e.g. 30min) in comparison to advanced thermal and mechanical simulations of timber members subjected to bending which were validated with fire resistance tests. The increase of the zero-strength layer depth from 7 to 10mm allows a good calibration of the code for bending timber members in standard fire. As simplification, a constant value for the zero-strength layer over the time (for fire resistances up to R120) represents an adequate accuracy. For timber members subjected to compression (including buckling) a value of 14mm for the zero-strength layer depth seems to be enough accurate considering material properties and support conditions. As simplification, it is recommended to use the value of 14mm for the zero-strength layer depth as default value for linear timber members. However, for linear timber members (beams and columns) subjected predominantly to tension or bending the value of zero-strength layer depth may be assumed as 10mm.

The current informative Annexes C (timber frame assemblies with filled cavities) and D (timber frame assemblies with void cavities) have extensively been improved and moved to the main part of prEN 1995-1-2. Further, the revised content is normative. The design model for timber frame assemblies with filled cavities is based on the Effective Cross-section Method and allows considering the performance of different types of insulation (mineral wool, cellulose, wood fibre, etc.). The performance of the insulation can be evaluated with small-scale fire tests and assessed in 3 different protection level according to the new Annex D.



a) Linear member exposed from 4 sides

b) Member of a timber frame assembly exposed from 1 side

Key

1 fire exposed side(s) or fire exposed perimeter

2 border-line of the residual cross-section

3 border-line of the effective cross-section

$\boldsymbol{d_{ef}}$ - effective charring depth

$\boldsymbol{d_{char,n}}$ - notional charring depth

$\boldsymbol{d_0}$ - zero-strength layer depth

$\boldsymbol{b_{ef}}$ - width of the effective cross-section

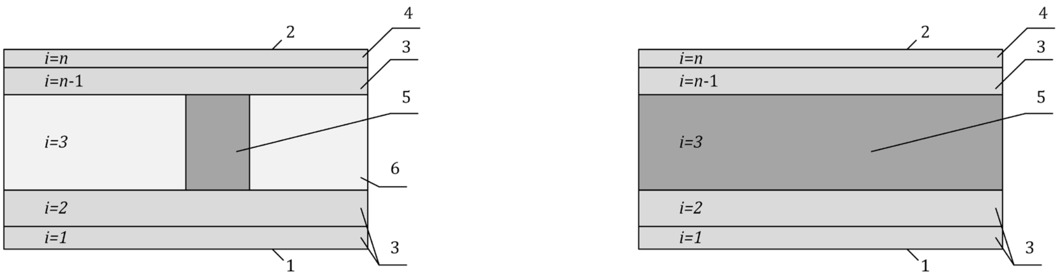
$\boldsymbol{h_{ef}}$ - depth of the effective cross-section

Figure 2 Examples of the effective cross-sections

3.3 Separating Function Method

The current informative Annex E (Component additive method) for the verification of the separating function has extensively been improved and moved to the main part of the EN 1995-1-2. The revised content is normative and the design method for separating function has been extended to 120 minutes fire resistance [20-23].

The heat path through the timber members or other materials as panels and insulations maybe calculated by taking the contribution of each layer into account starting from the fire exposed side (see Figure 3). Total insulation time of an assembly is the sum of contributions of all layers. Generic values for protection times are given for wood-based products, gypsum boards, clay and lime plasters, mineral wool and cellulose based insulation materials and as well as cement-based screed. The method is open to include new materials or products using the procedure in the new Annex G.



Key:

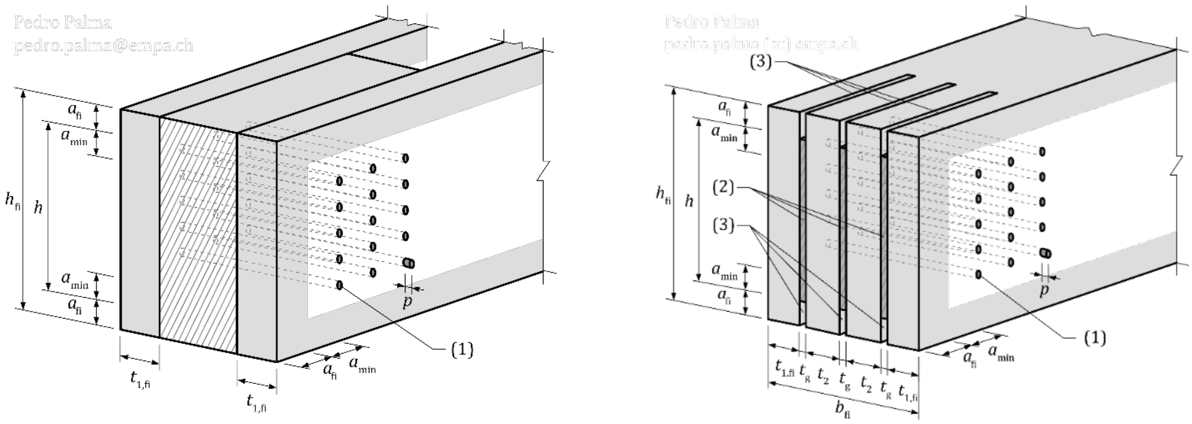
1	Fire exposed side
2	Unexposed side
3	Panels as protective layers
4	Panel as insulating layer (last layer n)
5	Timber member as protective layer
6	Cavity (insulation or void) as protective layer

Figure 3: Definition of layers for the Separating Function Method

The coefficients of the design method (basic values, correction time as well as position coefficients) were calculated by extensive finite element thermal simulations based on physical models for the heat transfer through separating multiple layered construction. The material properties used for the finite element thermal simulations were calibrated and validated by fire tests performed on unloaded specimens at Empa (Swiss Laboratories for Materials Testing and Research) in Dübendorf using ISO fire exposure. The design method was verified with full scale fire tests showing that the improved model is able to predict the fire resistance of timber assembly safely. All details with regard to the development and validation of the design method can be found in [38]. The developed design method significantly improves the current design method according to EN 1995-1-2 and permits the verification of the separating function of a large number of common timber assemblies.

3.4 Connections

The calculation method for connections was extended and enhanced. Improved rules for the fire design of connections up to 120 minutes fire resistance are given based on extensive experimental and numerical analysis. The rules given in prEN 1995-1-2 are applied to laterally loaded symmetrical connections (timber-to-timber and steel-to-timber connections) with nails, screws, dowels or bolts, designed for normal temperature in accordance with prEN 1995-1-1 (see Figure 4). Laterally loaded connections include typical tensile connections and shear connections (e.g. beam-column connections). Furthermore, tabulated design data is included allowing a simple fire design of connections [24-28] (see Table 3 and Figure 5).



a) Timber-to-timber connection

b) Steel-to-timber connection

Figure 4: Examples of connections

Table 3 Geometric requirements for steel-to-timber connections with dowels[a] and two slotted-in steel plates

Fire resistance time, t_{fi}	**$t_{1,fi}$ [mm]**			**a_{fi} [mm]**
	$\eta_{fi} \leq 0,1$	**$\eta_{fi} \leq 0,2$**	**$\eta_{fi} \leq 0,3$**	
30 min	≥ 30	≥ 45	≥ 50	≥ 15
60 min	≥ 60	≥ 75	≥ 80	≥ 50
90 min	≥ 90	≥ 100	≥ 110	≥ 90
120 min	≥ 120	≥ 135	≥ 140	≥ 130

where

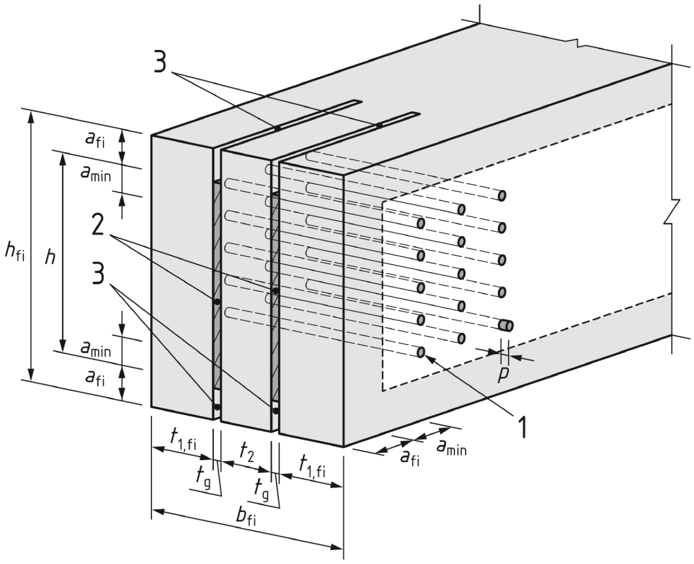
t_{fi} is the fire resistance time, in min;

$t_{1,fi}$ is the thickness of the timber side member required for the fire situation, in mm;

a_{fi} is the increase of end or edge distance required for the fire situation, in mm;

η_{fi} is the ratio between the design effect of actions for the fire situation and the characteristic loadbearing capacity of the connection at normal temperature.

[a] The table may be used even if 2 dowels are replaced by 2 bolts (or screws)



Key

1	steel dowel	h	depth of the initial cross-section of the timber member
2	slotted-in steel plate	h_{fi}	depth of the cross-section of the timber member required for the fire situation
3	slot for the steel plate	p	projection of steel dowels above the timber surface ($p \leq 5mm$)
a_{min}	minimum end or edge distance according to prEN 1995-1-1	$t_{1,fi}$	thickness of the timber side member required for the fire situation
a_{fi}	increase of end or edge distance required for the fire situation	t_2	thickness of the timber internal member according to prEN 1995-1-1
b_{fi}	width of the cross-section of the timber member required for the fire situation	t_g	thickness of the slot

Figure 5: Example of geometric requirements for steel-to-timber connections with dowels and two slotted-in steel plates (example for 3x5 dowels)

3.5 Detailing

The rules for detailing were extended and enhanced. In addition to rules for panels and insulation (dimensions, spacings, fixation, etc.), rules for joints in and between elements and to other adjacent components as well as rules for penetrations and openings are given. E.g. Table 4 gives the maximum spacings between fasteners.

Table 4 Perimeter spacing between fasteners for the fire exposed layer of wood-based panels, wood panelling, gypsum plasterboards and gypsum fibreboards[a]

Staples		Nails		Screws	
Wall	Ceiling	Wall	Ceiling	Wall	Ceiling
Maximum spacing of fasteners for wood-based panels and wood panelling					
150	150	150	150	250	250
Maximum spacing of fasteners for gypsum plasterboards					
80	80	120	120	250	170
Maximum spacing of fasteners for gypsum fibreboards					
200	150	200	150	250	200

[a] Internal spacing may be increased to twice the values given in the table, but not more than 300 mm.

3.6 Annex A: Design for physically based fires

Physically based fires are of more general nature than standardised time-temperature fire exposure developed as comparative measure, typically used for the fire resistance testing and classification of components, respectively. When (structural) timber surfaces are fire exposed in a compartment fire, they contribute to the fire dynamics. Consequently, structural timber elements may influence the growth, the duration, the maximum temperature and the cooling phase including the likelihood of burnout (understood as auto-extinguishment). Thus, depending on the amount of exposed structural timber, the heat release of the structure should be considered.

For the design of timber structures exposed to physically based design fires, improved rules and design methods have been developed and are given in Annex A [29, 30]. Design methods for any temperature-time curve including the parametric fires are given. According to prEN 1995-1-2 Annex A, timber structures can be analysed for burnout considering the contribution of the structural fire load to the total fire load. This creates new possibilities for design of fire resistance of large and tall timber buildings for a large range of design fire scenarios.

3.7 Annex B: Assessment of the bond line integrity in fire

To evaluate the performance characteristic of the bonding in case of fire, two test methods were introduced in Annex B. Consequently, examination is possible of the surface bonding of timber layers and the finger-jointing in the flanges of web beams [31].

For surface bonding, it is known that the falling off of charring layers leads to an increased charring rate, cf. figure 2. This phenomenon can be investigated experimentally by measuring the temperature rise between the layers. However, experience with temperature measurements has shown that the evaluation of the surface bonding via temperature is only feasible with correctly installed temperature sensors (highly conductive thermocouples in low conductive substrate), whereby the correct installation of the thermocouple is often difficult [32]. In addition, misinterpretations have frequently occurred in the past when evaluating temperature measurements. For this reason, the mass loss of the timber specimens as a result of the fire exposure was considered as a simple and alternative way to describe the behaviour of the surface bonding in case of fire [33]. This method was further investigated and tested in the research project GLIF (Glue Line Integrity in Fire). Due to the observed large scatter of the results in the different fire labs, it was decided to choose the measured charring rate as a criterion.

Further, it is proposed to test the test specimen with a reference specimen made of glulam with vertically oriented lamellae. Thus, a direct comparison is possible and the influence of the furnace is reduced. The assessment of the bond line integrity in fire is performed using the mean charring rate of the test specimen $\beta_{mean,specimen}$ and the reference specimen $\beta_{mean,reference}$ in accordance with Table 5.

Table 5 Assessment of the bond line integrity in fire based on the mean charring rate of the test specimen $\beta_{mean,specimen}$ and the reference specimen $\beta_{mean,reference}$

Bond line integrity maintained	$\beta_{mean,specimen} \leq 1{,}05 \cdot \beta_{mean,reference}$
Bond line integrity not maintained	$\beta_{mean,specimen} > 1{,}05 \cdot \beta_{mean,reference}$

On the other hand, for the assessment of finger-joints in the flanges of web beams in case of fire, a test method was introduced in Annex B with small test specimens that are exposed to constant high temperature. The test method was developed as part of the FIRENWOOD research project and calibrated with fire tests. Based on the test results, the finger joints are divided into three performance classes, which are taken into account in the design for the fire case [34, 35].

4 Conclusion and outlook

Even if the completion of the work on prEN 1995-1-2 with the years 2025 still seems far away and the associated national annexes and additional supporting documents will probably not be available until 2027, the essential changes are already known. It is obvious that the second generation of EN 1995-1-2 closes the gaps of the current EN 1995-1-2 and, above all, enables new areas of application and will, thus, enable a safe and economical design of timber structures in case of fire.

It is also clear that the scope of the standard has been growing due to the necessary consideration of new products, the demand for more accurate design and the increase of available design approaches. Despite this, a central focus is on maintaining and even increasing the ease-of use through restructuring, homogenisation and simplified methods. Nevertheless, similar to the change over to the first generation of EN 1995-1-2, an additional learning and training process will be necessary, which should start before the final publication.

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