Compartment fire design
in Eurocode and advanced modeling

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Contents

1. Evolution of Eurocode – Fire Design

→Eurocode 1 - Actions on Structures: Part 1-2: Fire loads

2002-version lacks guidance about the *fire load by "structural timber"*

→Eurocode 5 - Timber structures: Part 1-2: Fire Design

2004-version lacks guidance about the *fire load by "structural timber"*

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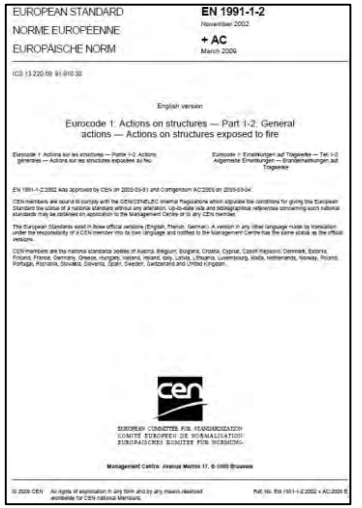

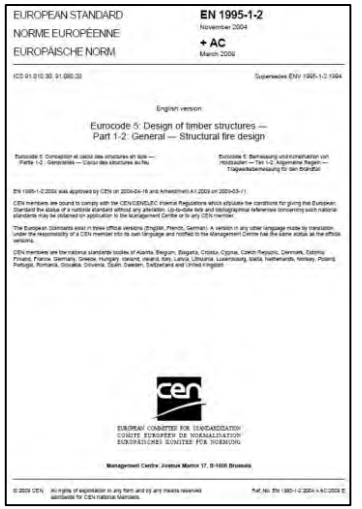

1. Evolution of Eurocode – Fire Design of Timber Structures

[c Thinkwood]

[c AJC carpentry]

[c khanecheen.ir]

[c N. Clark/INDEPENDENT]

[c строй-россия.рф]

[c L. Wang/IHNABITAT]

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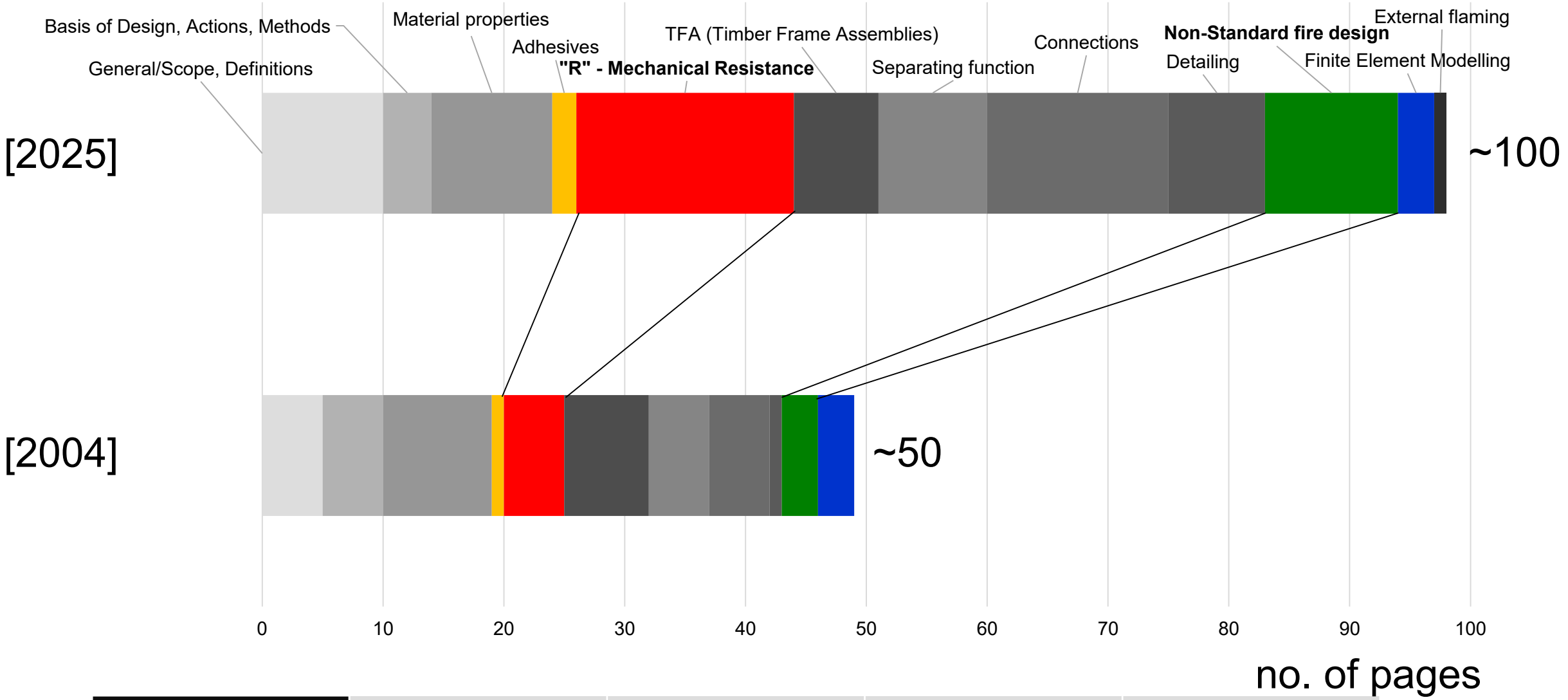
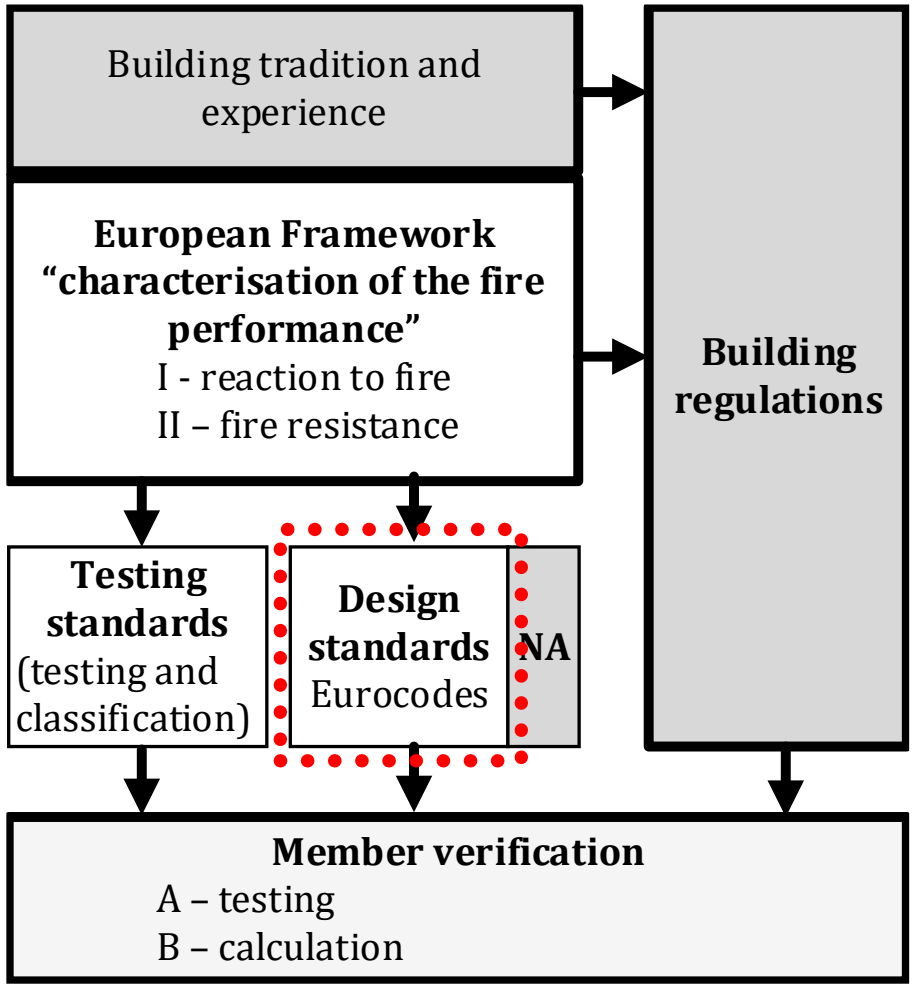


1. Evolution of Eurocode – Fire Design



[Schmid et al. 2019]

1. Evolution of Eurocode – Fire Design of Timber Structures

[c Schmid]

1. Evolution of Eurocode – Fire Design of Timber Structures

Effective cross-section model (ECSM)

0 Step 0:

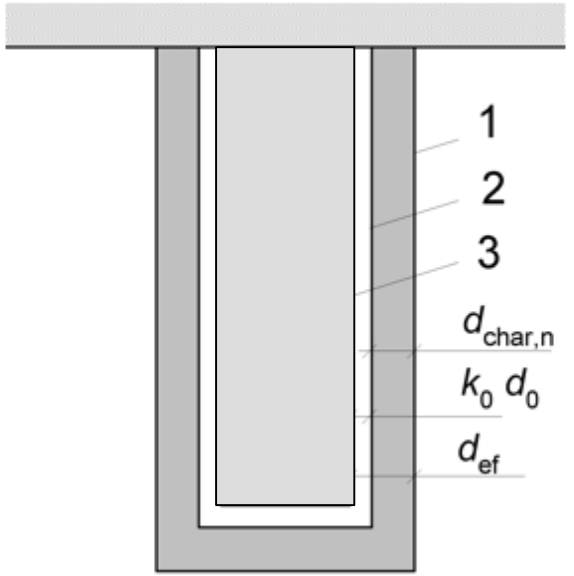
Definition of the design fire

1 Step 1:

Reduction of the initial cross-section
→ residual cross-section

2 Step 2:

Reduction of the residual cross-section
→ effective cross-section

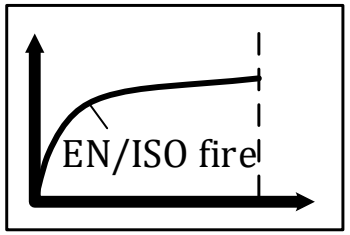


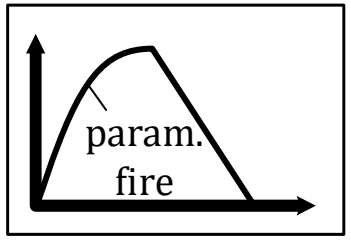
Key:

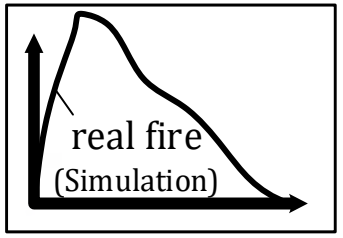
1...	original CS
2...	residual CS
3...	effective CS
d_0	zero-strength layer (ZSL)
$d_{char,n}$	char depth
d_{ef}	effective char depth

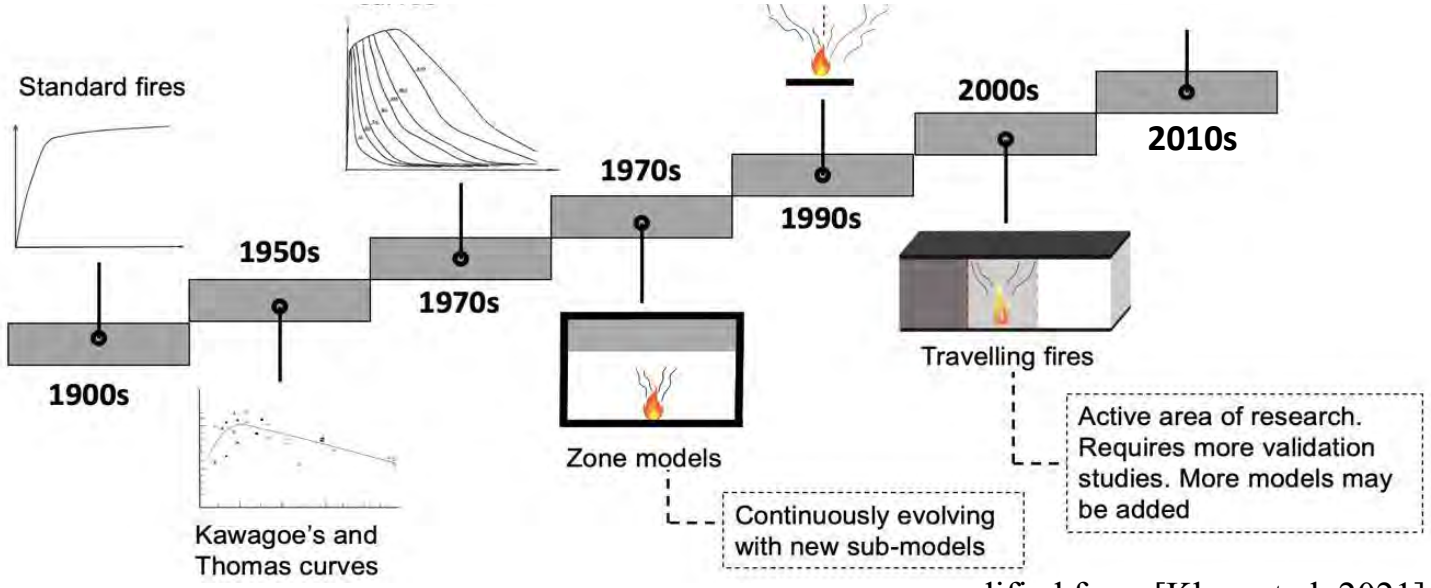
2. Overview of design models

… from “a temperature” to fluid dynamics models in fire



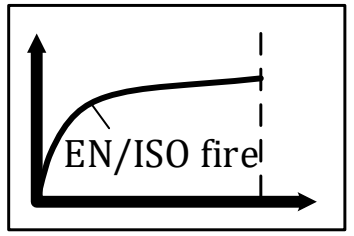






modified from [Khan et al. 2021]

3. Consideration of Structural Timber



Applicability of “standard-fire furnace testing” for timber products

- Is it **acceptable** to test timber components in furnaces?
  - → Limitation of results to fully developed phase;
  - → no decay/burnout assessment can be done
- Do timber members receive a different **thermal exposure** in furnaces?
  - →No difference for combustible and non-combustible products
  - →reduced burner fuel by lower thermal inertia AND topped up by “structural fuel” (50 to 100kW/m^2)

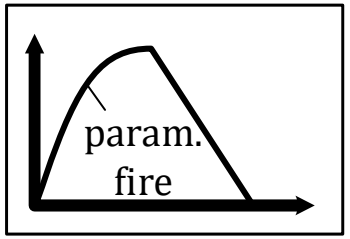

Image: Kordina et al.


Image: Katerra


Image: BTF

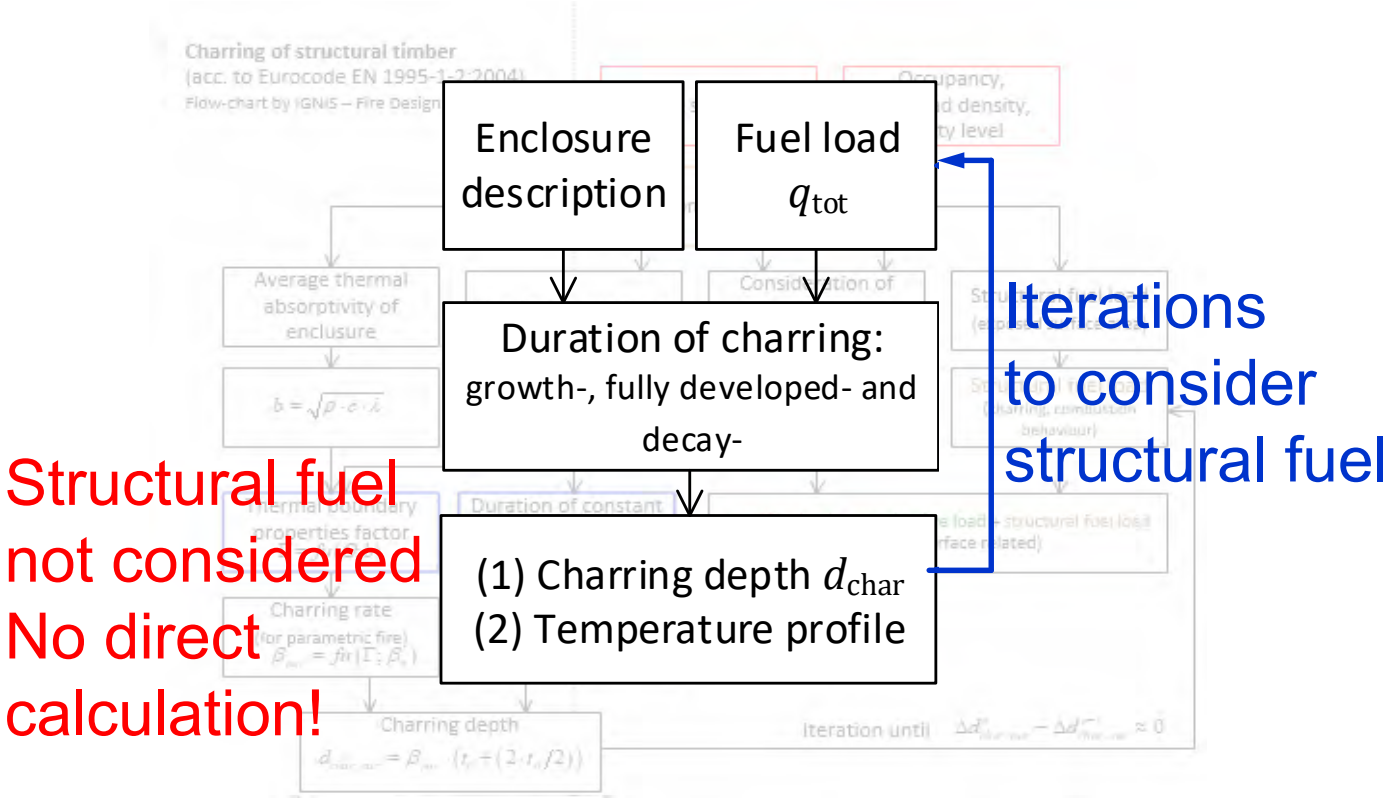

Image: USDA

3. Consideration of Structural Timber

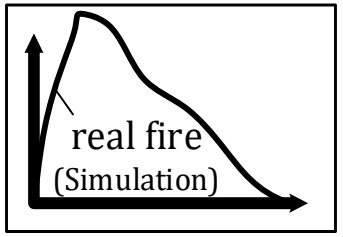


Applicability of “parametric fire design” for timber products

- Is it **Annex B (2002)** applicable for exposed timber surfaces (e.g. by CLT panels)?



3. Consideration of Structural Timber

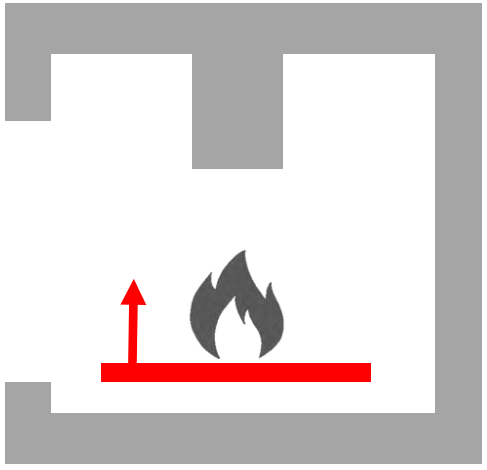


Behaviour of timber members in “natural fires”

- How much of a timber member will **contribute** to the fire dynamics in a compartment fire?
- Will **burnout** occur?

[c ETH Zürich]

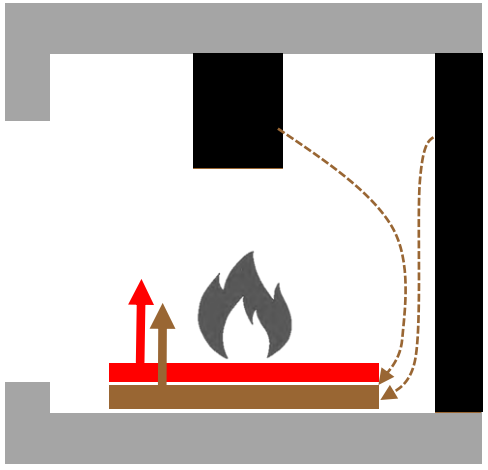
Non-combustible surfaces
(NC)



Fire load = movable fire load (interior)

[c ETH Zürich]

Combustible surfaces
(C)

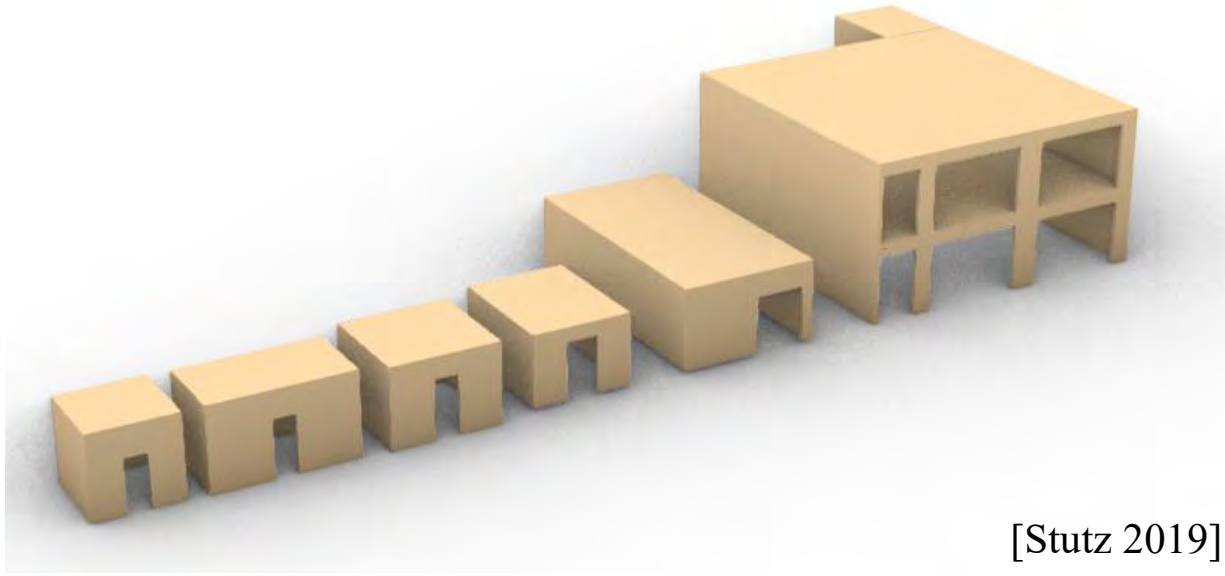


Fire load = movable fire load
“+” structural fire load

3. Consideration of Structural Timber

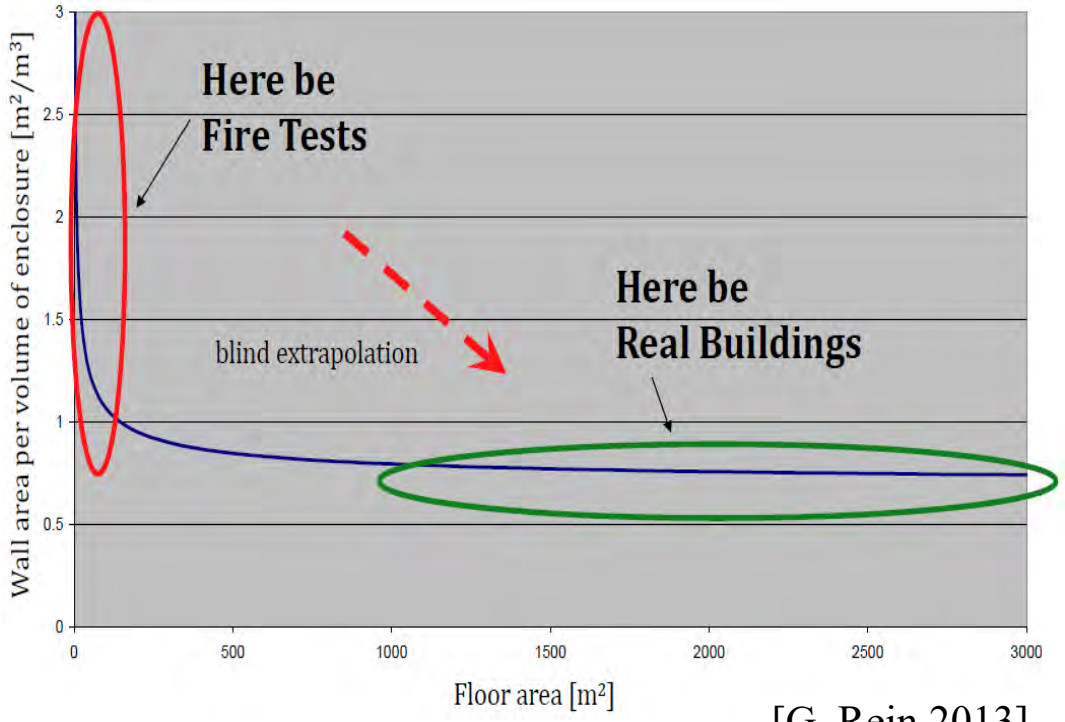
Behaviour of timber members in “natural fires”

- Experiments are costly (time, money) and difficult to control.
- The design need is 20x larger…



[Stutz 2019]

7.5m² … 85 m²



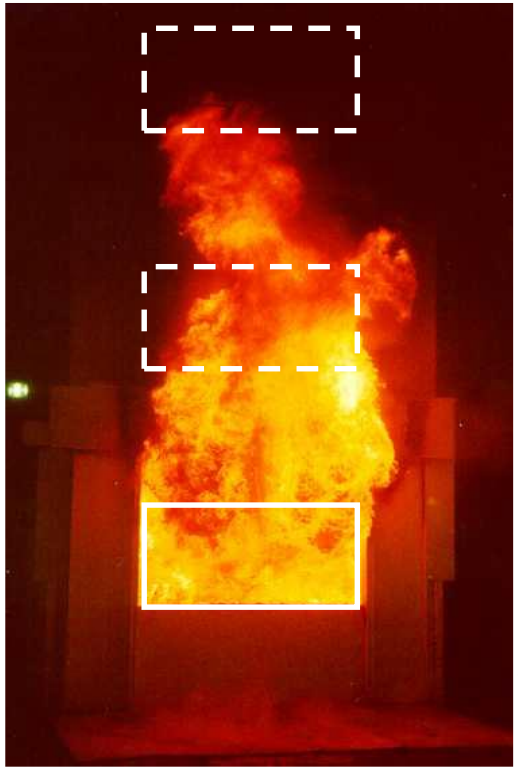
[G. Rein 2013]

3. Consideration of Structural Timber

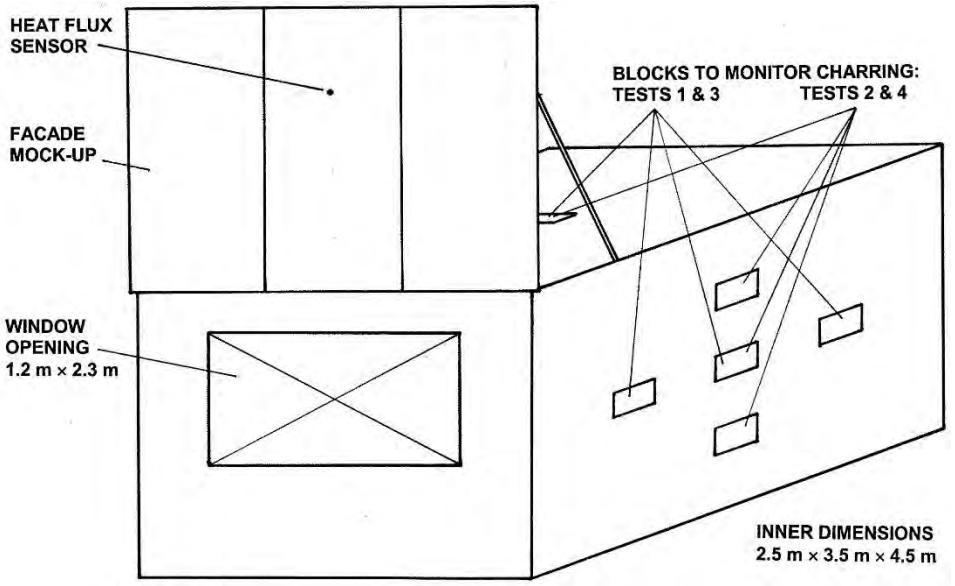
Behaviour of timber members in “natural fires”

- How much of a timber member will **contribute** to the fire dynamics in a compartment fire?
- First quantification of “combustion behaviour” of structural timber by Hakkarainen [2000]:

Hakkarainen observed that the measured, *total HRR* is only ~50% of the expected level estimated by charring.



[c Trätek]



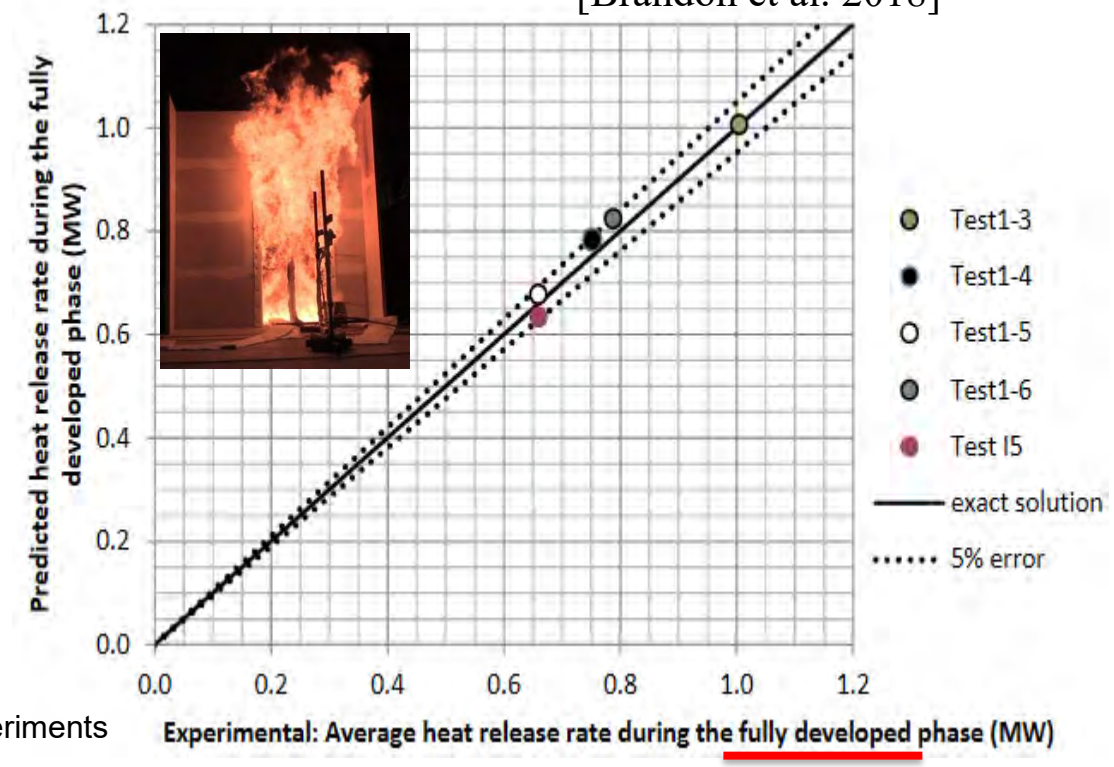
[Hakkarainen 2001]

3. Consideration of Structural Timber

Behaviour of timber members in “natural fires”

- How much of a timber member will **contribute** to the fire dynamics in a compartment fire?
- Comprehensive experimental series by NIST and RISE:

[Brandon et al. 2018]



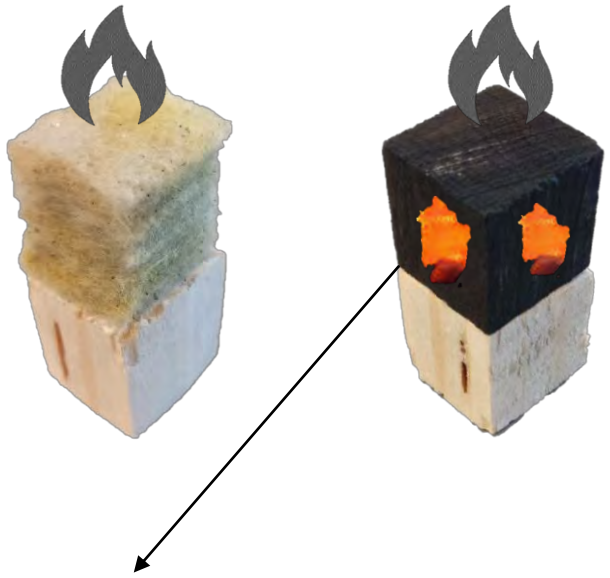
Brandon could calculate a “fitting factor” to align the measured, *total HRR* with the predicted value by a charring rate:

Energy release from cone-calorimetry — Charring rate

$$q_{st} = \alpha_1 \cdot \alpha_2 \cdot \beta_{st}$$

Structural timber — Fitting factor from compartment experiments

3. Consideration of Structural Timber – combustion behaviour



Mass loss:
- Measure of material conversion
- Measure of the combustion of the char layer

$$q_{st} = \alpha_1 \cdot \alpha_2 \cdot \beta_{st}$$

$$q_i = H_{\mathrm{i}} \cdot \dot{\mathrm{m}}_{\mathrm{i}}$$

$$q_{st} = q_{pyrolysis} + q_{oxidation}$$

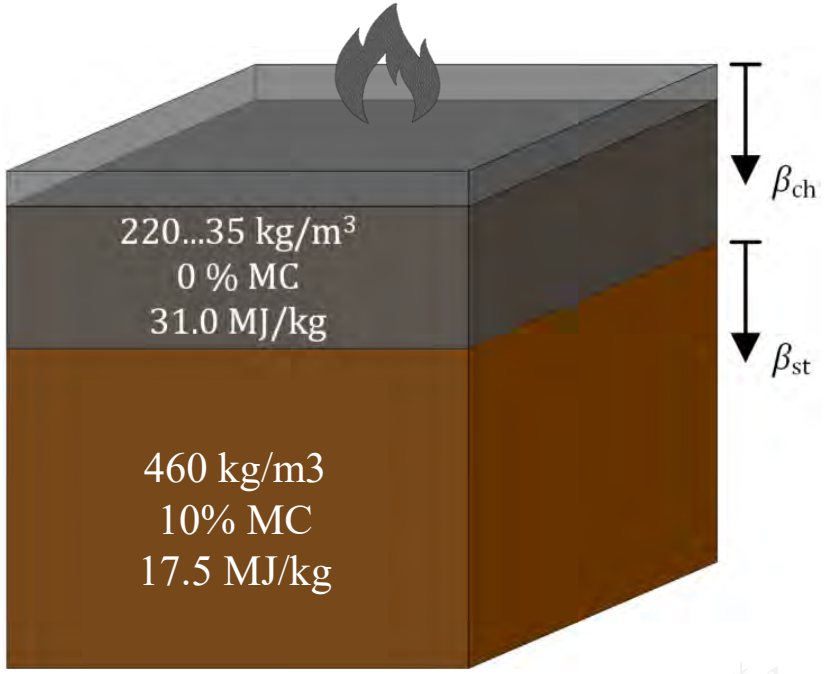
$$q_{st} = \left(H_{\mathrm{ww}} \cdot \dot{\mathrm{m}}_{\mathrm{ww}} - H_{\mathrm{ch}} \cdot \dot{\mathrm{m}}_{\mathrm{ch,tm}}\right) + \left(H_{\mathrm{ch}} \cdot \dot{\mathrm{m}}_{\mathrm{ch,ox}}\right)$$

Glowing and smouldering combustion: Decay of the char layer

$$q_{st} = 120 \cdot \alpha_{st} \cdot \beta_{st} \quad [\mathrm{kW}]$$

Variable energy storage and release factor

3. Consideration of Structural Timber



HRR_{st}

Material 2: char layer = energy storage

α_2	[Brandon 2018]
α_{st}	[EN 1995-1-2, draft for revision]

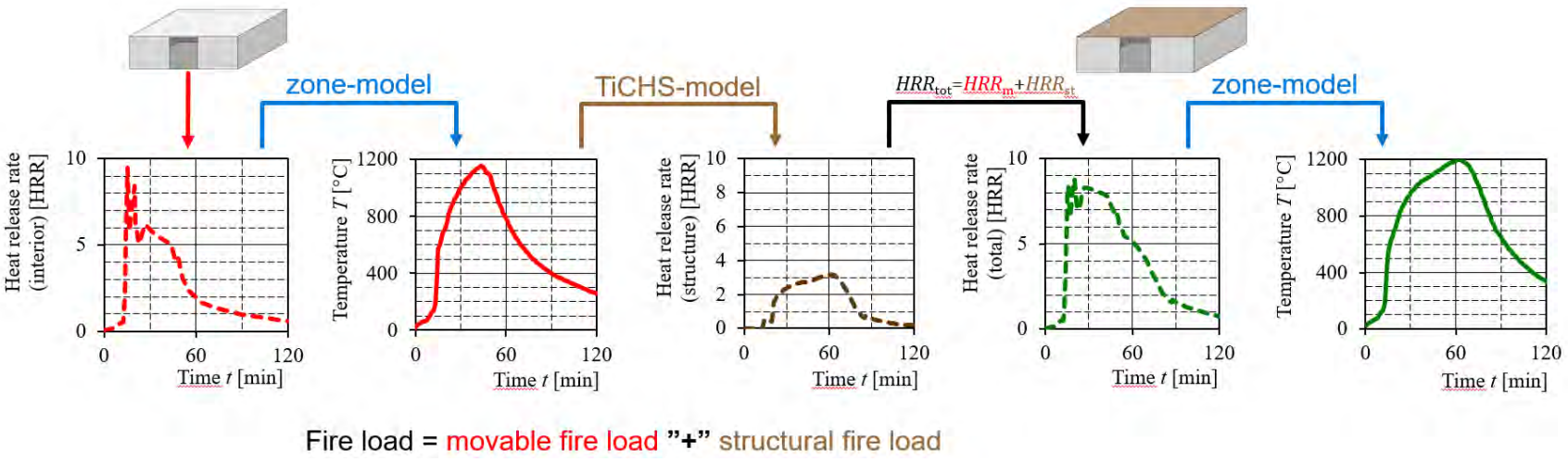
Material 1: structural timber = energy source

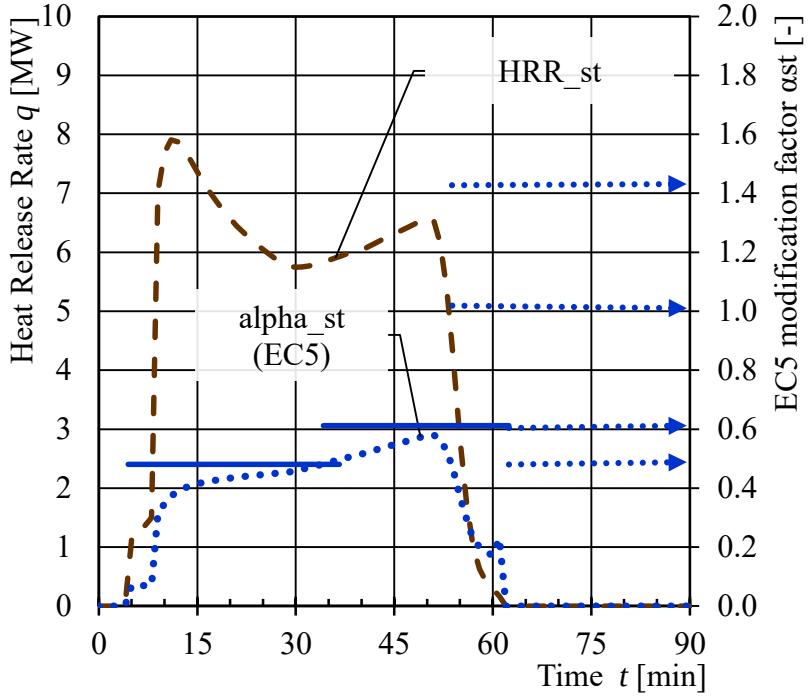
3. Consideration of Structural Timber

Framework: Timber Charring and Heat Storage (TiCHS) – Model [Further reading: Open Engineering]

Process:

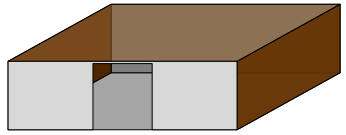
- Calculation of the energy balance *structure-compartment-exterior* → zone-model + TiCHS-model
- Novelty: Calculation of the "sum" of the movable fire load and the structural fire load
- Calculation of the energy release α_{st}



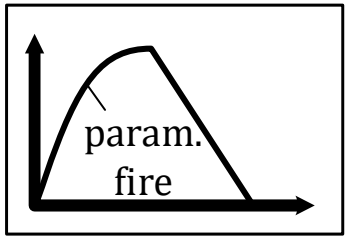


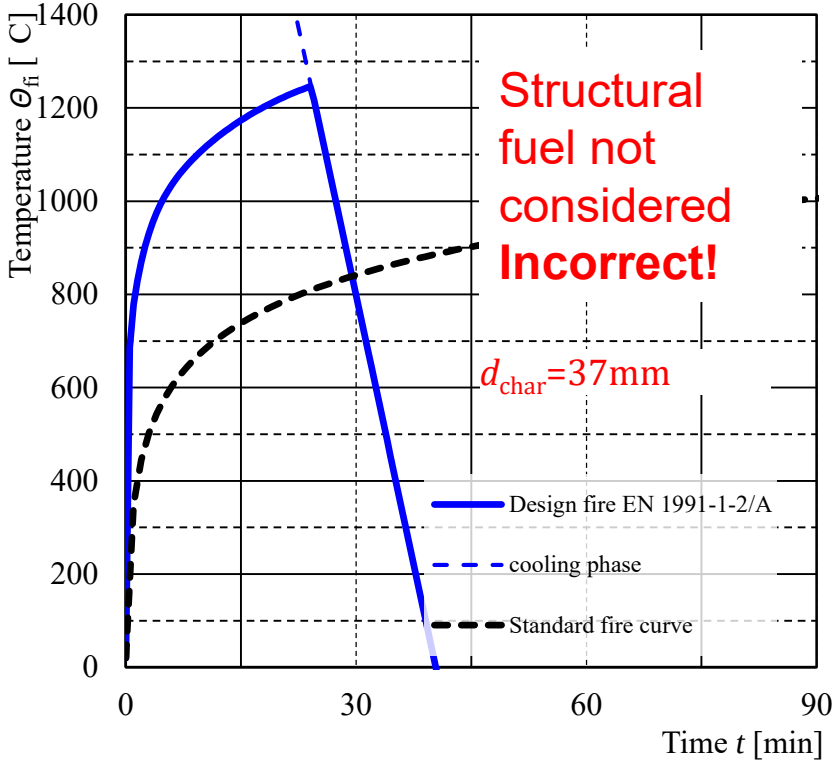
4. Application

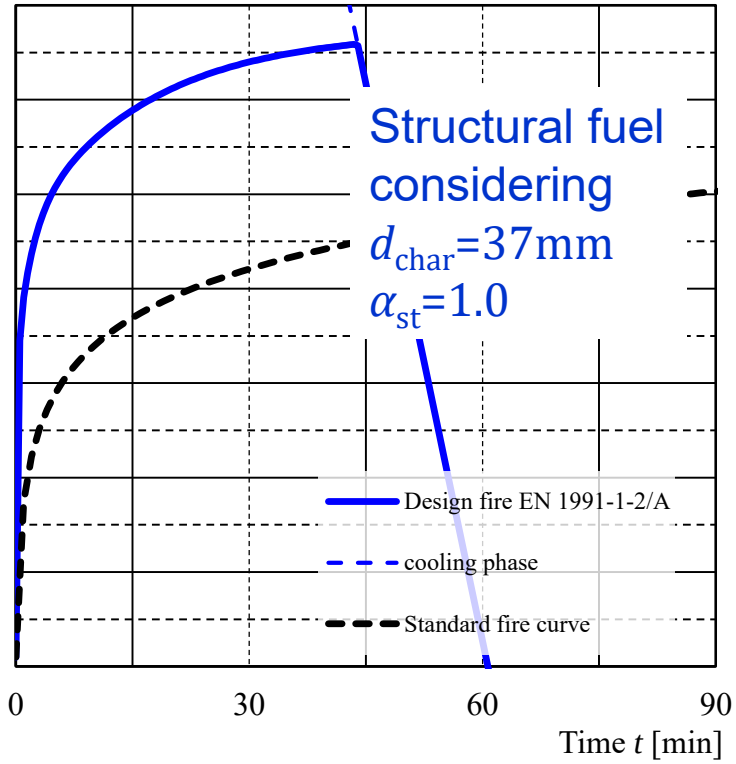
Comparison of Models: Parametric fire:2004

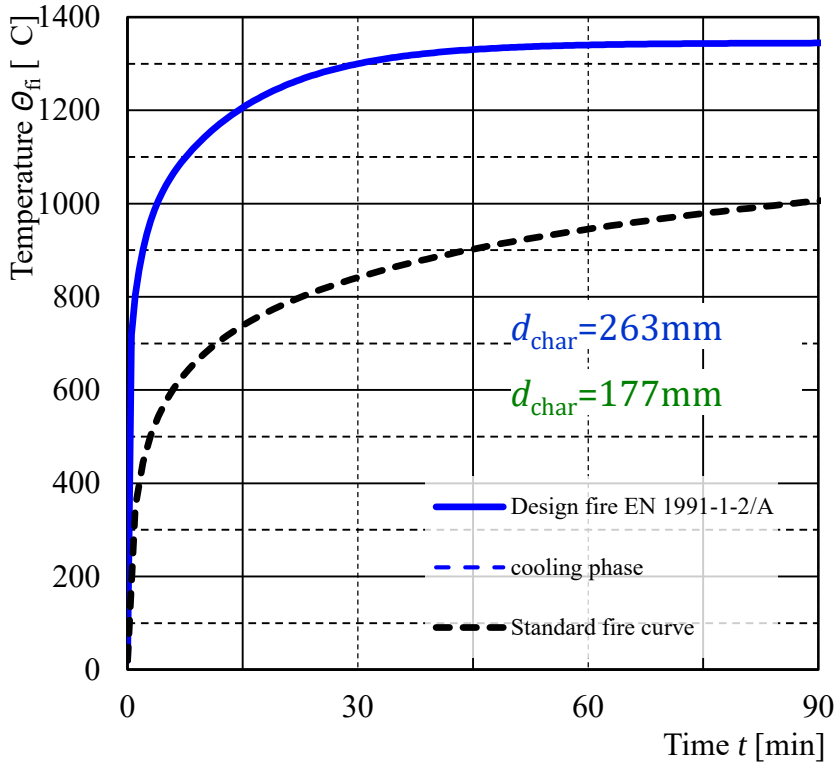


7m x 7m
A_v=42%
A_{st}=195%



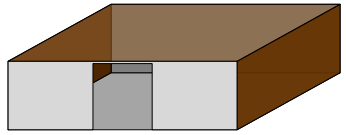






4. Application

Comparison of Models: TiCHS and experiments



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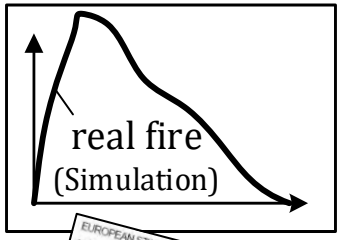

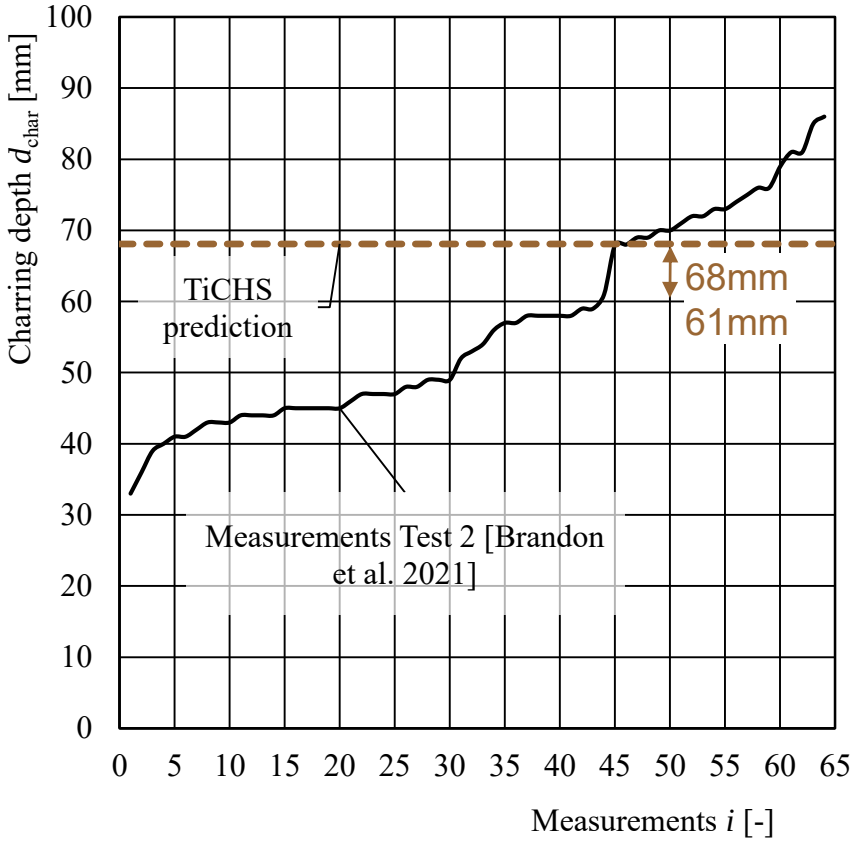

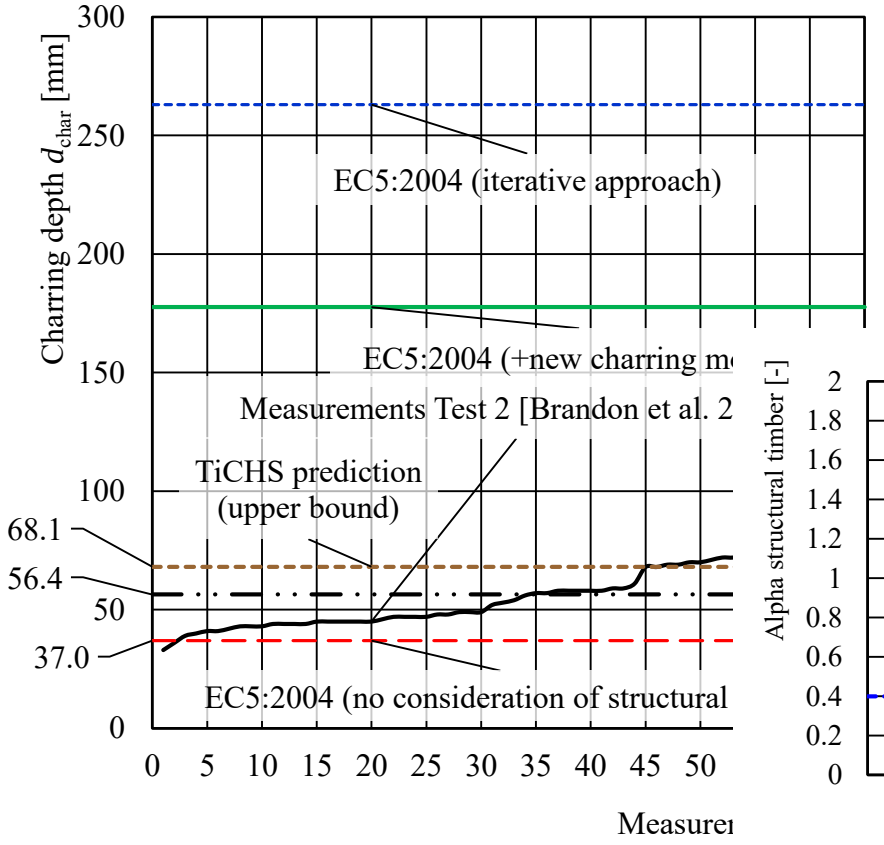

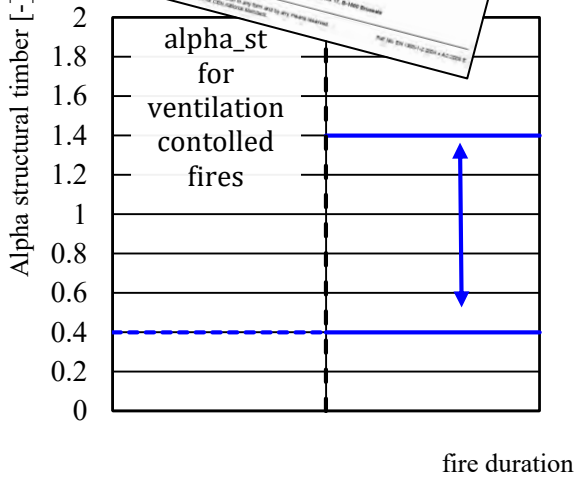

5. Conclusions

- **Eurocode 5-1-2:2004** models **DO NOT** consider a fire load by structural timber; no burnout can estimated;
- **Fire dynamics** in structural timber compartments is a complex area; difficult to cover in standardisation in detail → area for specialists
- **Sub-models** to be checked for “conservativeness” for structural timber;
- **Data Acquisition** and documentation;
- **Eurocode 5-1-2** development will proceed until 2025;

- More details about **Fire Dynamics, Data Acquisition** and **Robustness** in fire will be presented at **WCTE**.

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Acknowledgements

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