THE UNIVERSITY OF QUEENSLAND AUSTRALIA | CREATE CHANGE

19th June 2019
Sydney, Australia

Designing Safe Timber Buildings

Fire Research for Modern Construction

Dr Juan P. Hidalgo
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School of Civil Engineering

FUTURE TIMBERHUB

Engineered-Wood Products Potential

Source: www.arup.com

Aesthetics

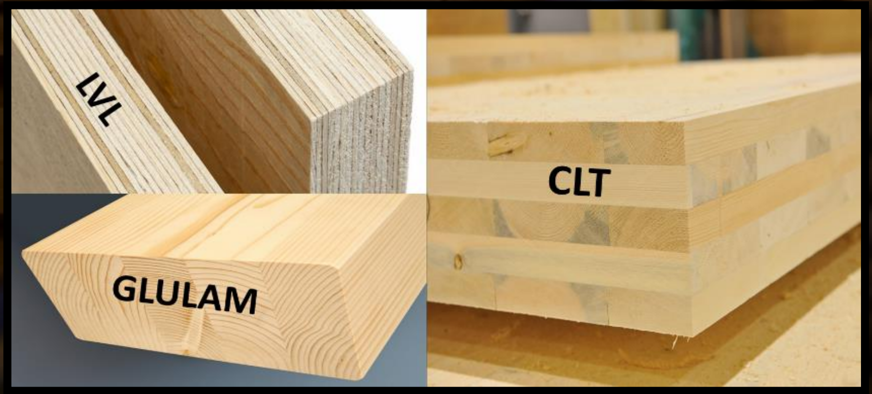
Sustainability

Cost effective

Great strength-weight ratio

Ease of construction

Structural Timber Renaissance



Source: D. Soreguer, PhD confirmation report, UQ, 2015

Premium market value…

Push for tall timber construction

Barangaroo (6)
Australia

Limnologen (8)
Sweden

Murray Grove (9)
UK

Forté (9)
Melbourne

25 King Street (9)
Brisbane

Dalston Lane (10)
London

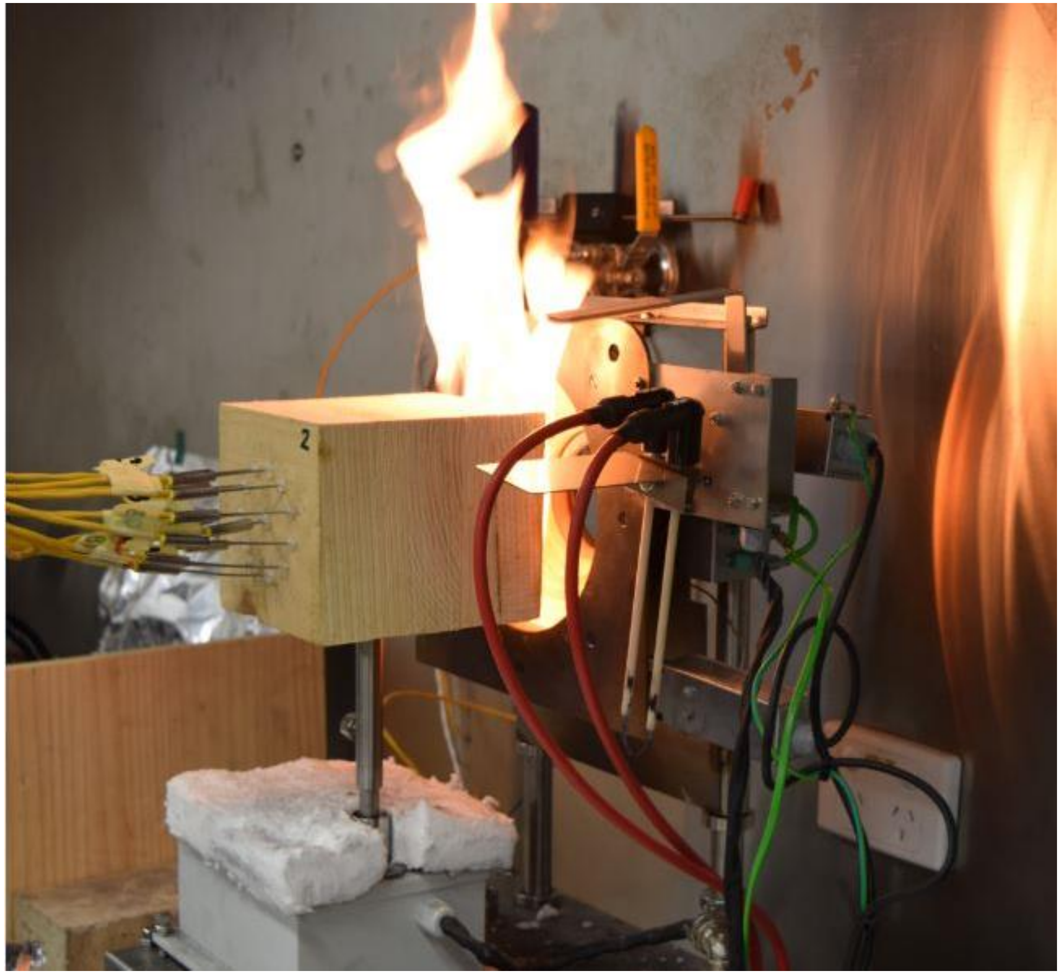
Trehus Bergen (14)
Norway

Brock Commons (17)
Canada

How tall can we go?

Oakwood Tower (+80), London

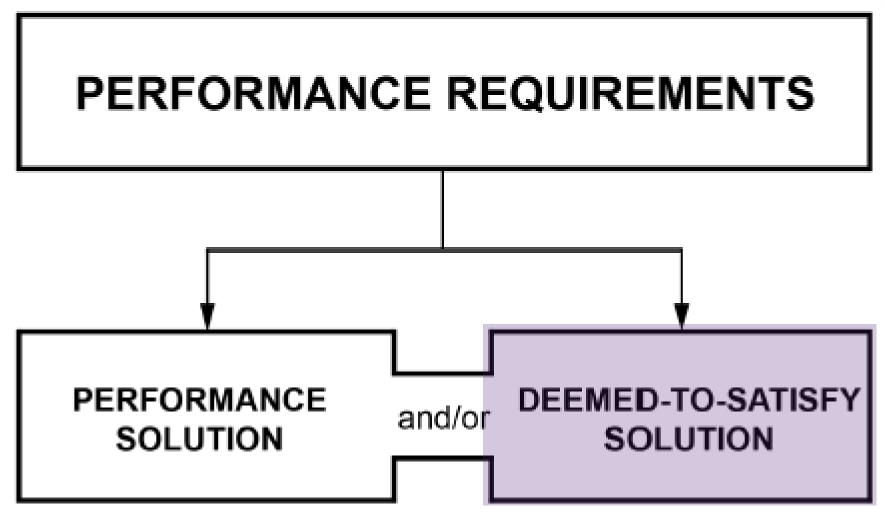
The challenge…Structural timber is combustible!



Designing for Fire Safety and Others… (not only in Australia!)

Figure A0.2

NCC COMPLIANCE STRUCTURE



Note:

1. The term *Performance Solution* was formerly known as *Alternative Solution*.
2. The terms *Performance Solution* and *Deemed-to-Satisfy Solution* were formerly used under the term *Building Solution*.

Timber Construction in Australia

Prior to NCC 2016

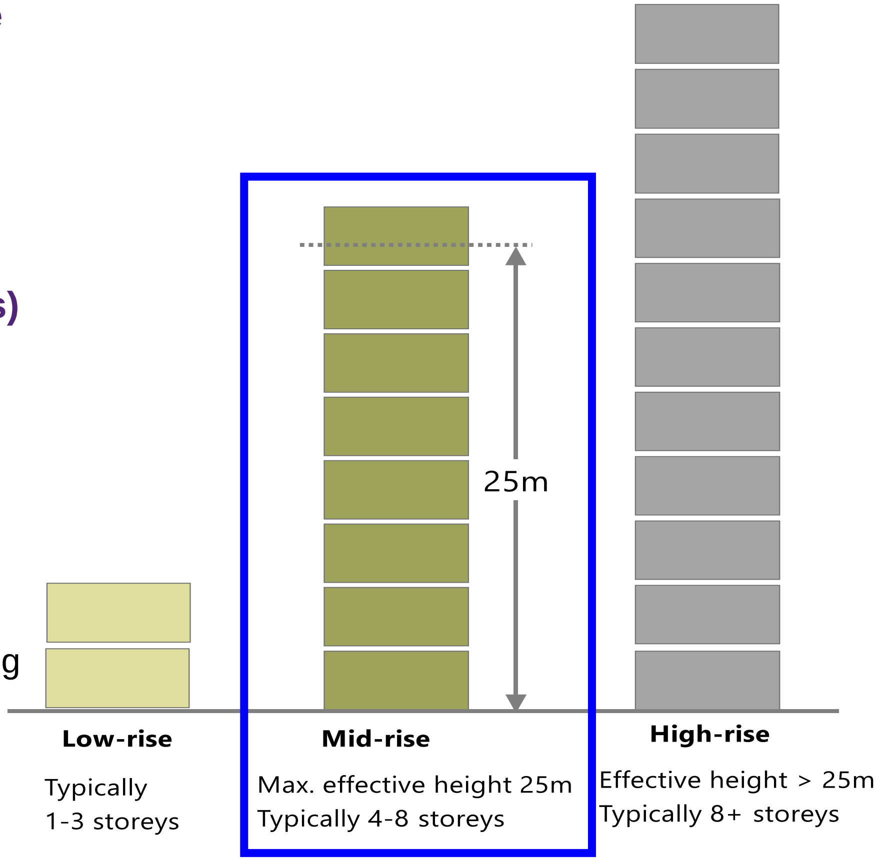
- timber construction systems in Australia have been **restricted to 3 storeys under the Deemed-to-Satisfy (DTS)** provisions with higher buildings requiring an 'Alternative (Performance) Solution' pathway for compliance purposes.

2016 NCC

- timber construction allowed **up to up to 25 metres in effective height under the Deemed-to-Satisfy (DTS) with fire-protected timber (encapsulation and sprinklers)** in:
  - Class 2 (apartments),
  - Class 3 (e.g. hotels) and
  - Class 5 (offices) buildings

Update 2019 NCC

- concessions extended to include **all Classes of buildings**, enabling the use of timber building systems in aged accommodation, schools, retail and hospitals.
- all Class 2 and 3 buildings four stories or above in height, to be sprinkler protected
- new concessions include some reductions in fire resistance levels and extended travel distances



Why encapsulation?

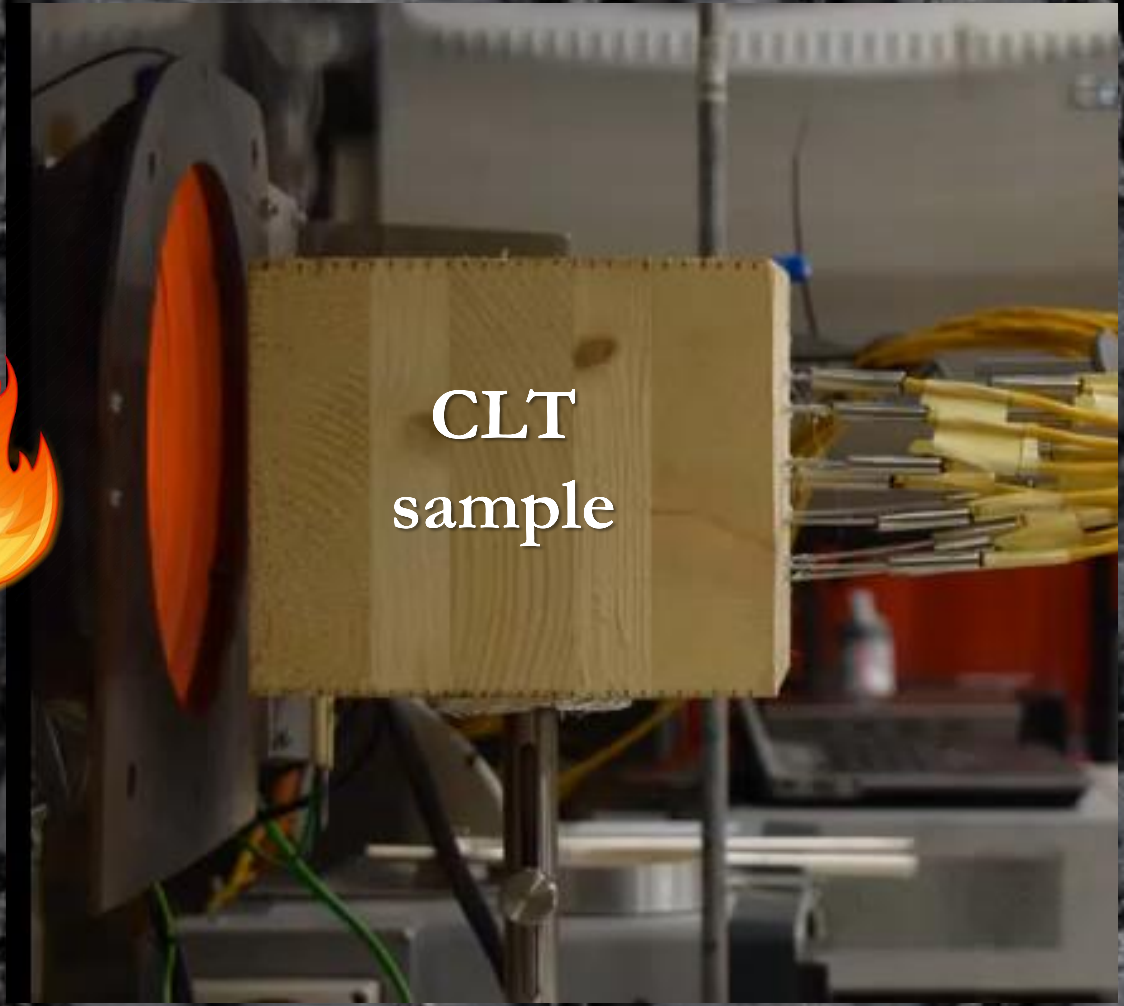
Why a height restriction for timber buildings?

Why a height restriction for timber buildings?

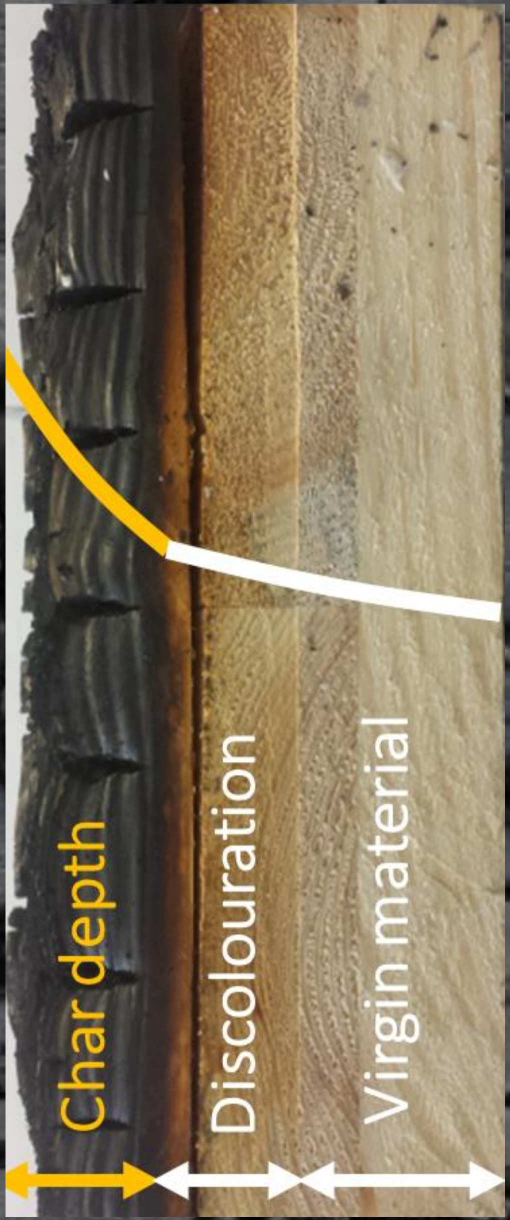
- **Evacuation**
  - Detection
  - Alarm
  - Displacement away from the fire
  - Crowd management
- **Compartmentation**
  - Constrains fire growth
  - Minimises smoke spread
- **Response**
  - Automatic (fire suppression)
  - External
  - Internal
- **Structural Stability**

How does timber burn?

How does timber burn?



Source: R. Emberley, PhD thesis, UQ, 2015



Source: A. Bartlett, PhD thesis, 2017

How do fires behave in real compartments?

The Malveira Fire Test, Portugal, 2014

https://doi.org/10.1016/j.firesaf.2019.102827

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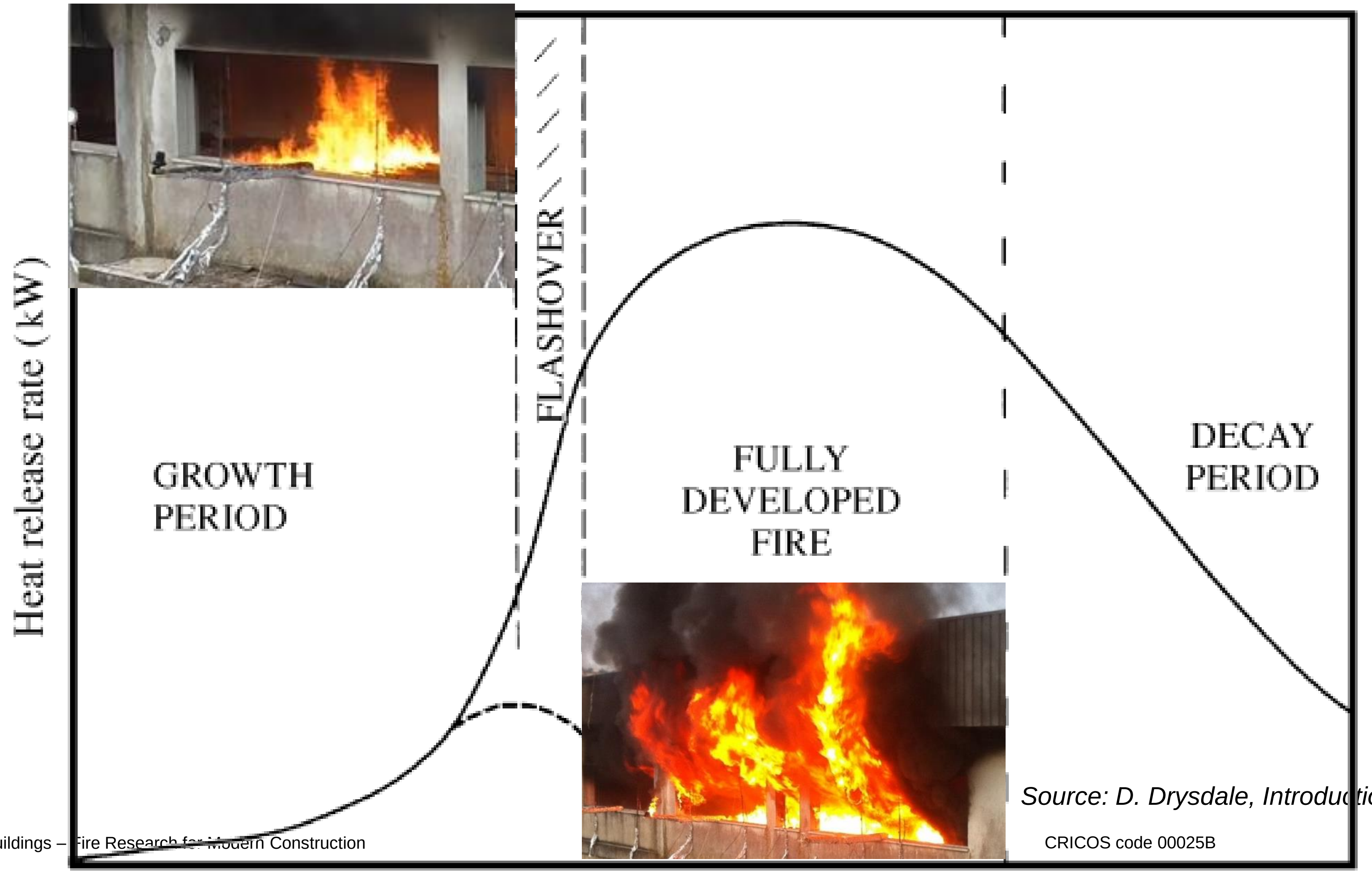
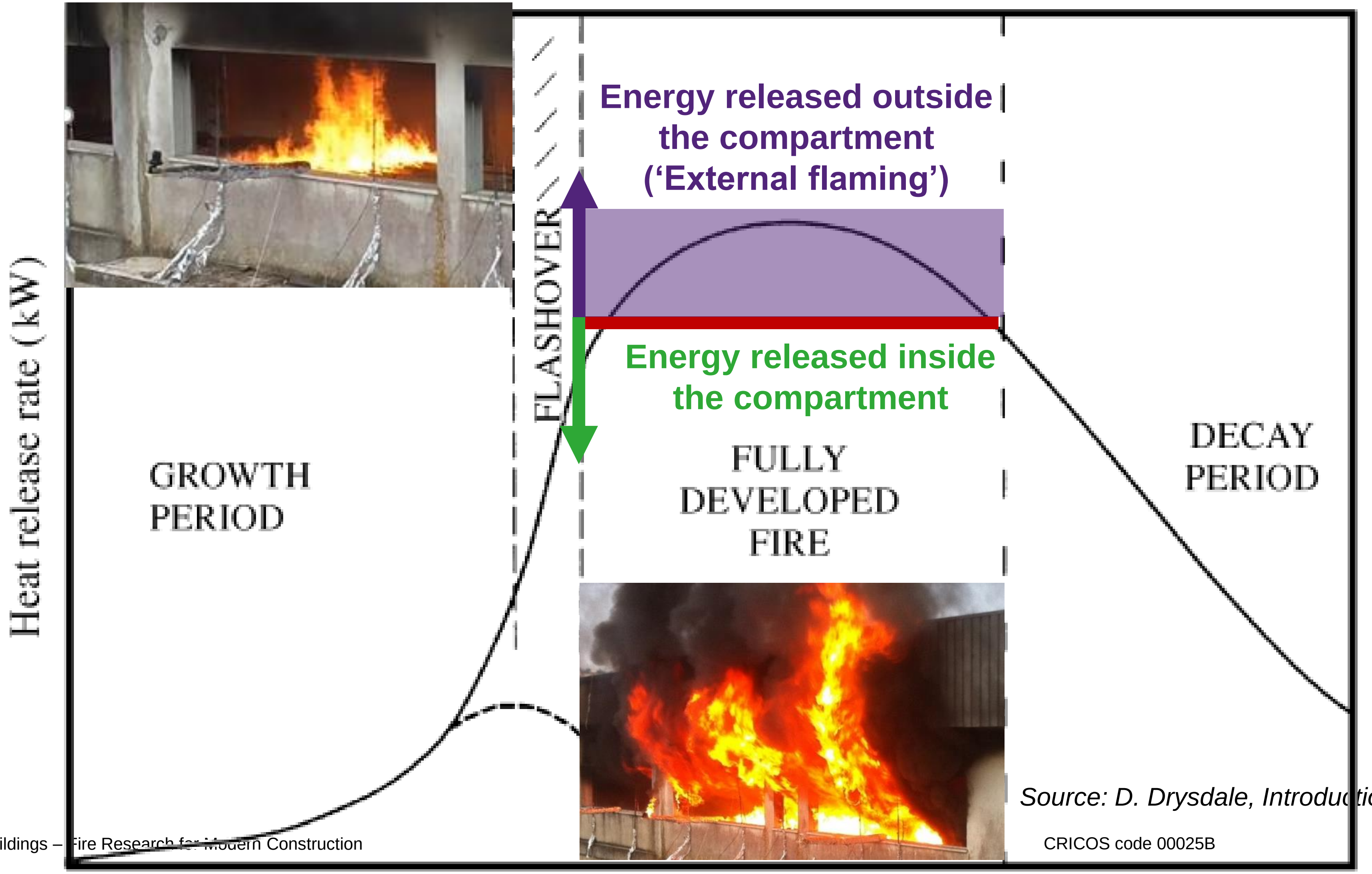
Classical fire behaviour in compartments



Source: D. Drysdale, Introduction to Fire Dynamics, Wiley, 201

Classical fire behaviour in compartments



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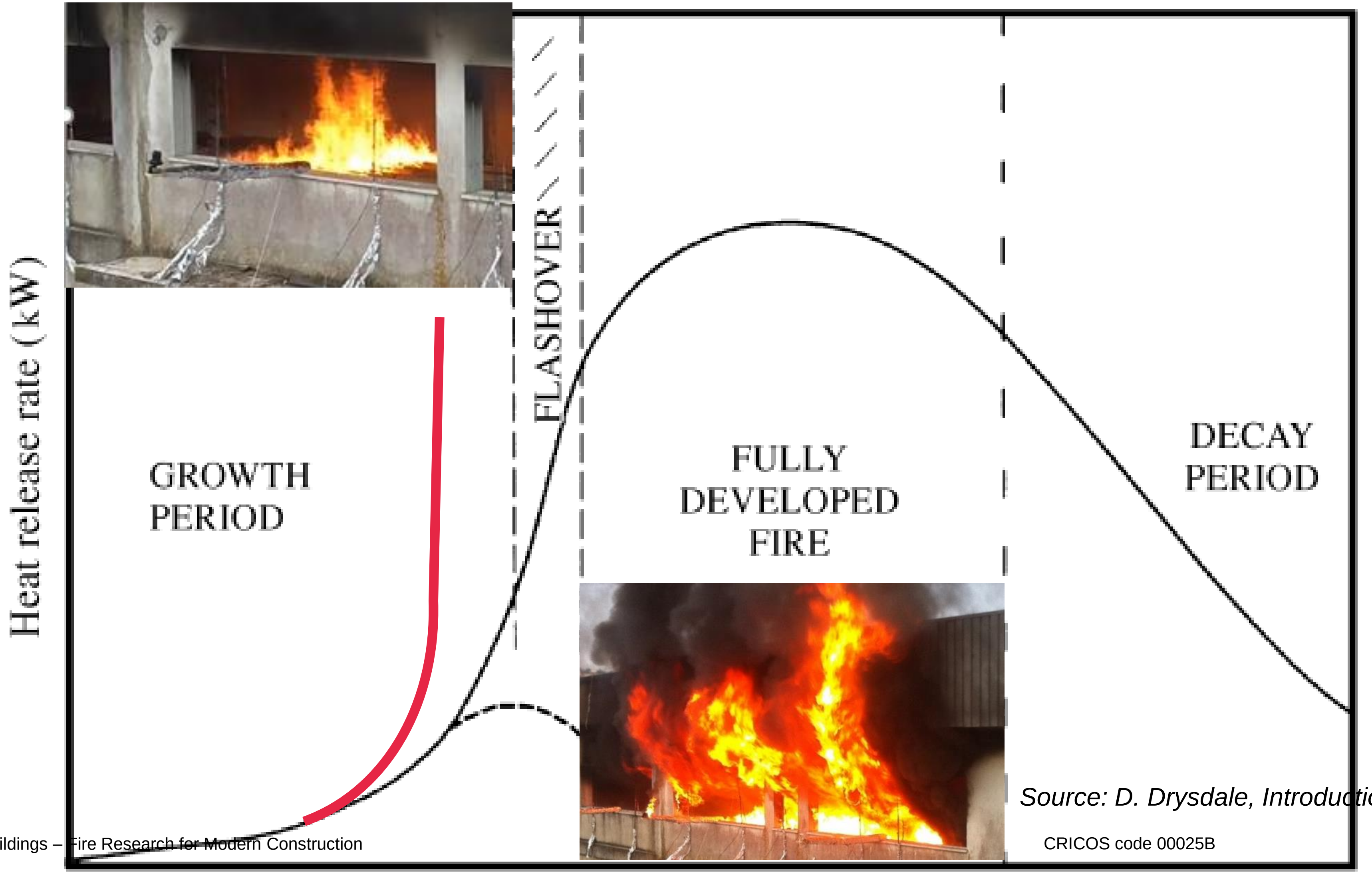
Engineering analysis with exposed timber…



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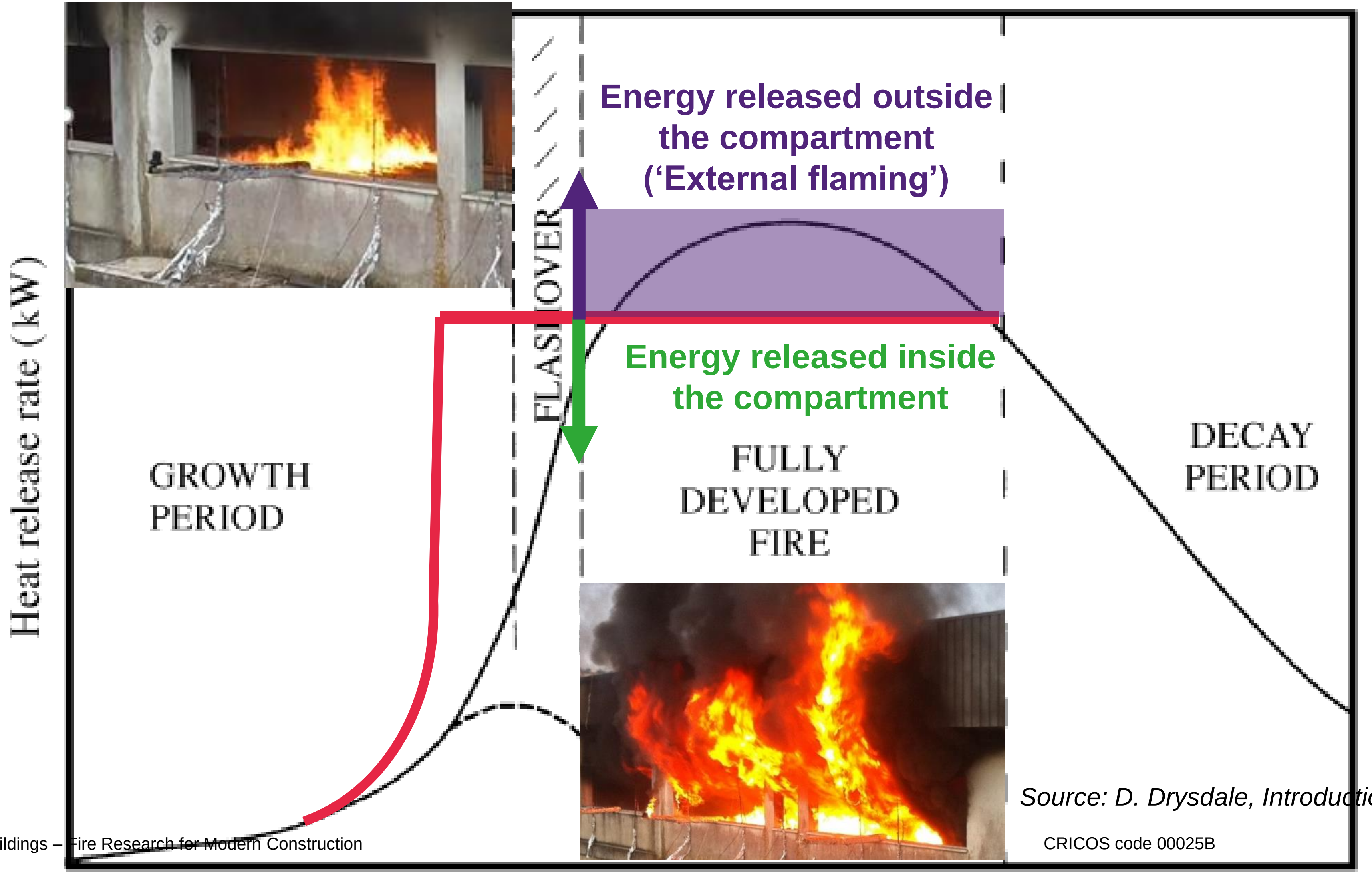

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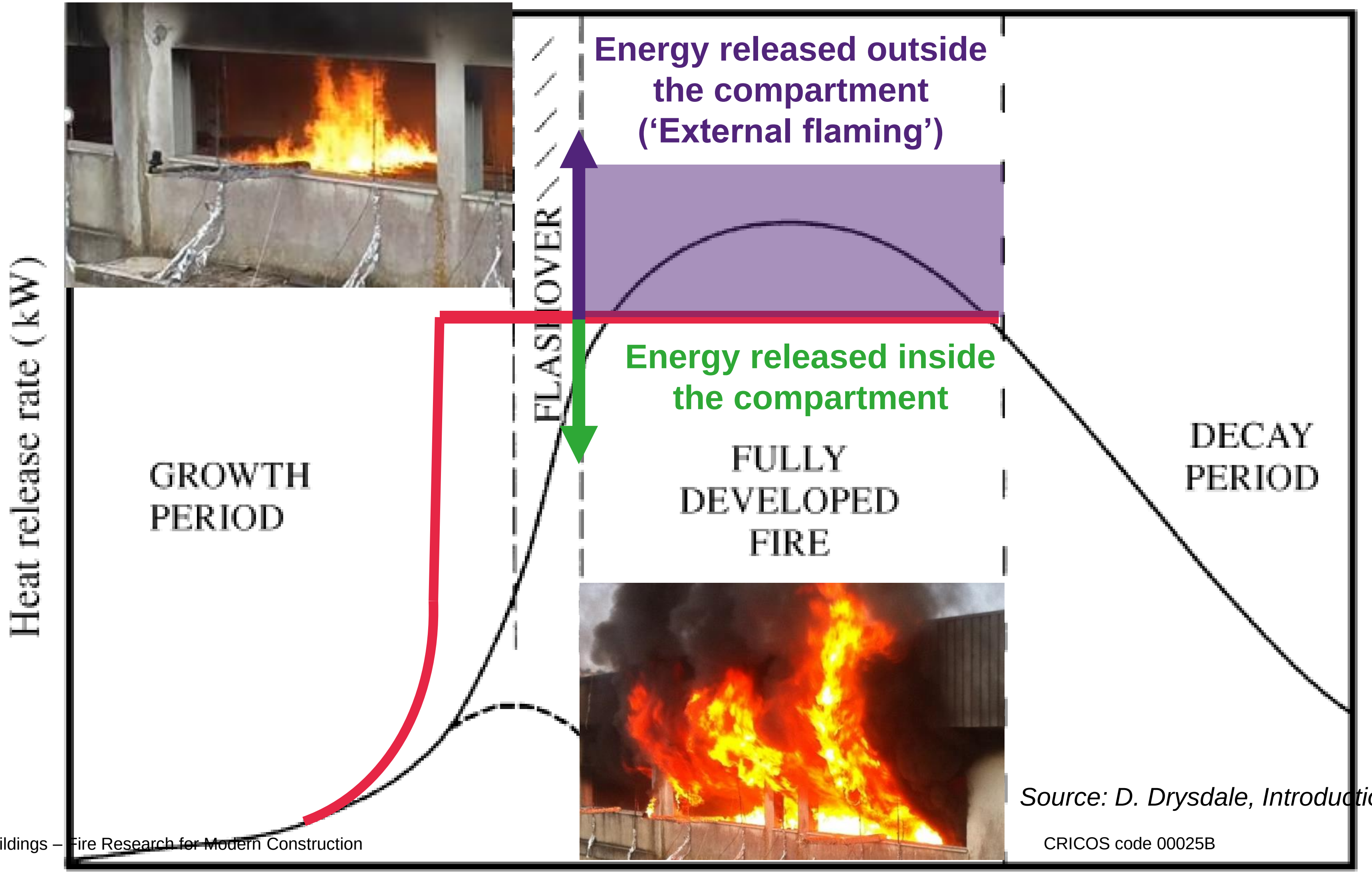

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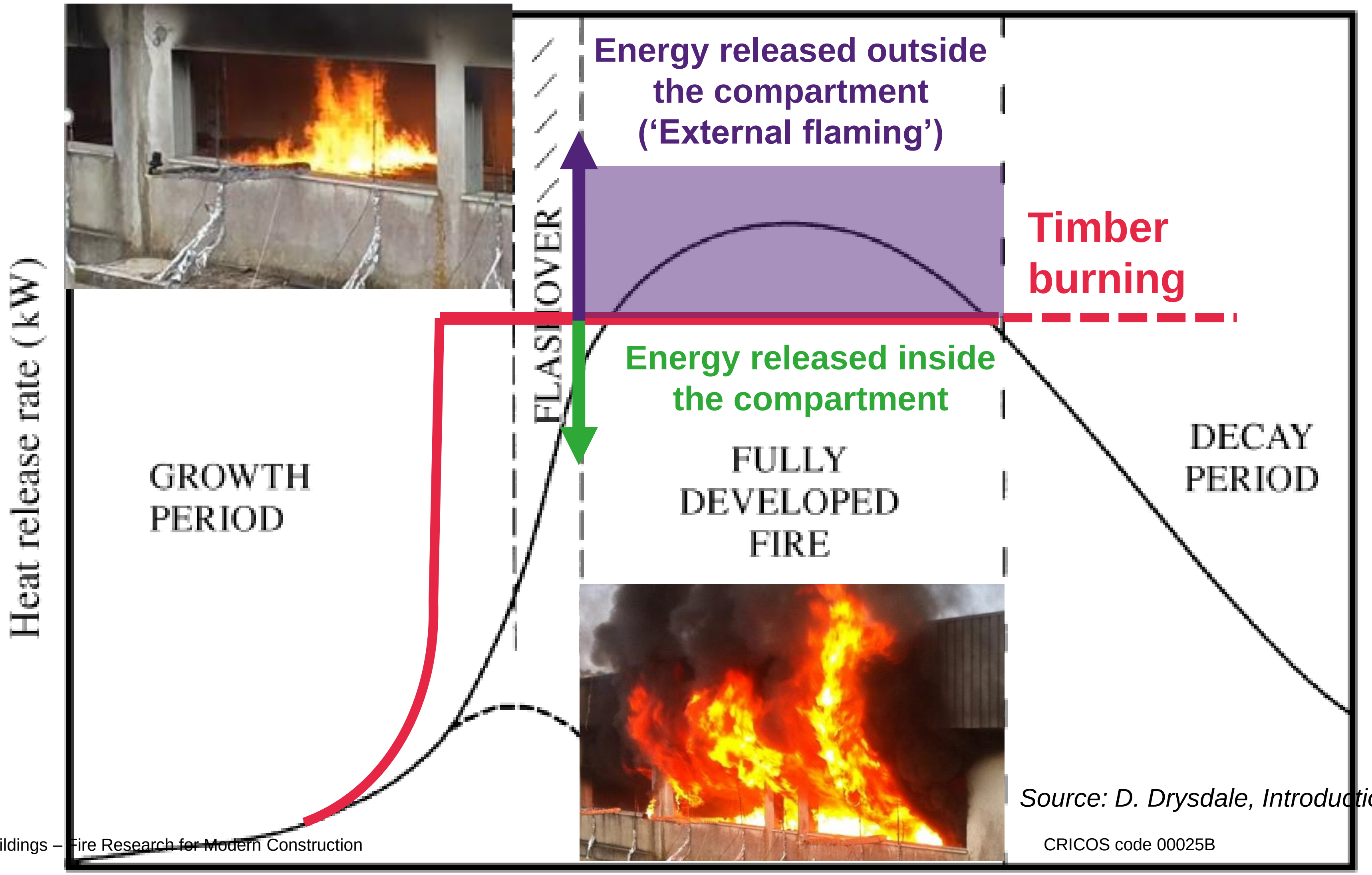

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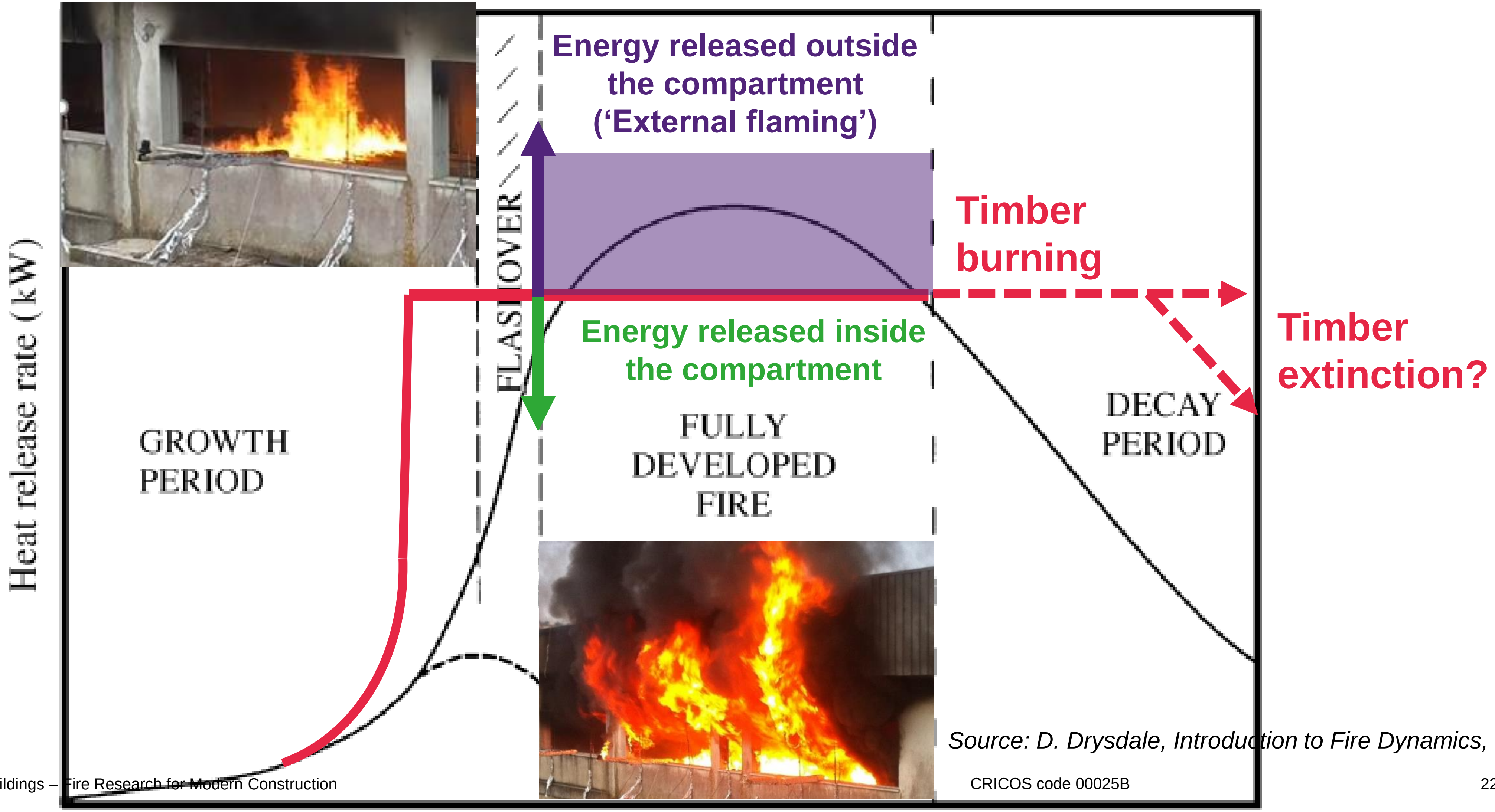
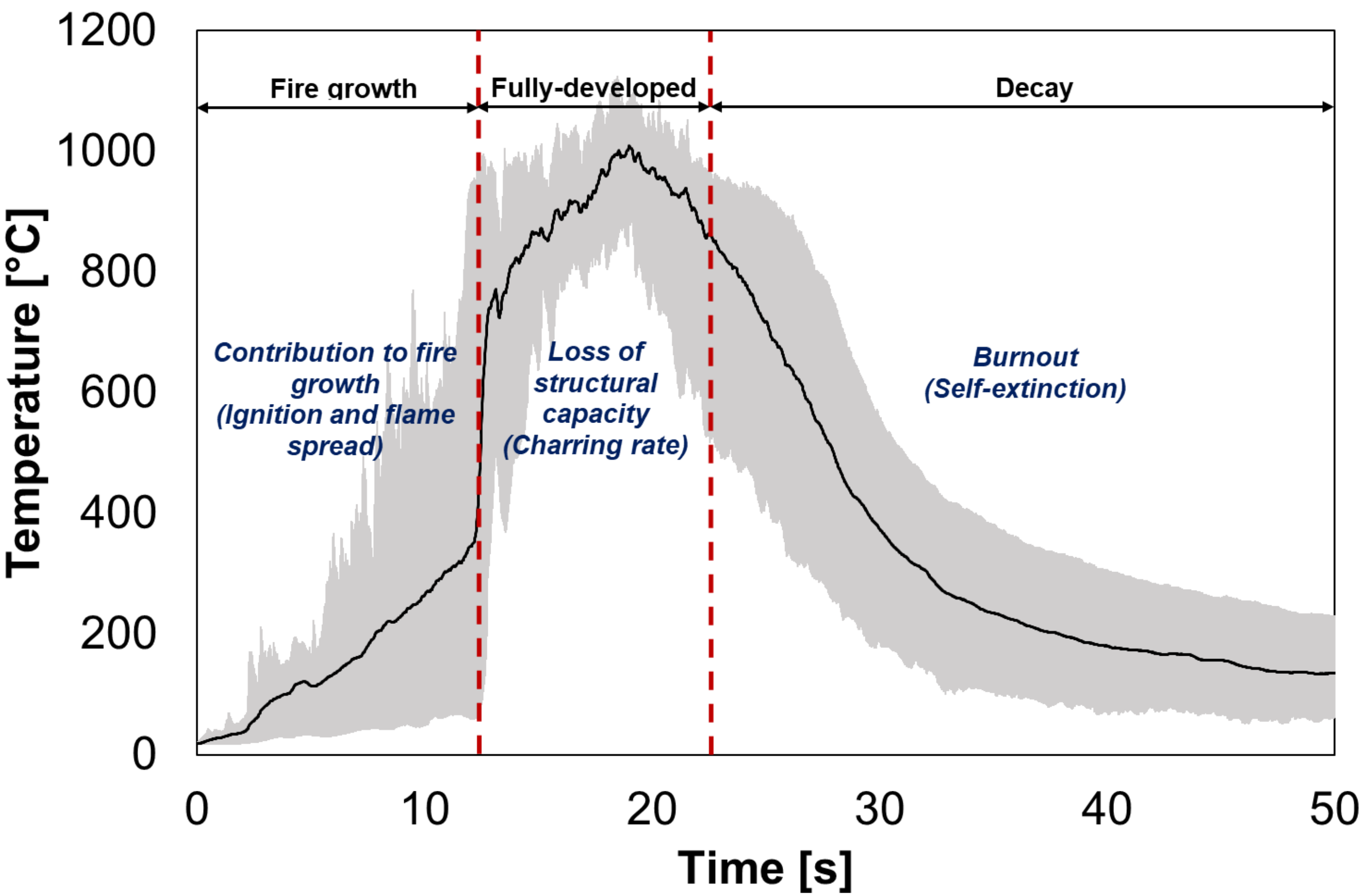


Source: D. Drysdale, Introduction to Fire Dynamics, Wiley, 201

‘Fire performance’ of mass timber structures

- How shall ‘**fire performance**’ be defined?
- ‘Fire performance’ of materials is **specific to each stage of the fire**.
- Each stage requires addressing a **different fire performance criteria**.



Adapted from Emberley at al. (2017) Description of small and large-scale cross laminated timber tests, Fire Safety Journal, 91:327-335.

Defining 'fire performance' of mass timber structures

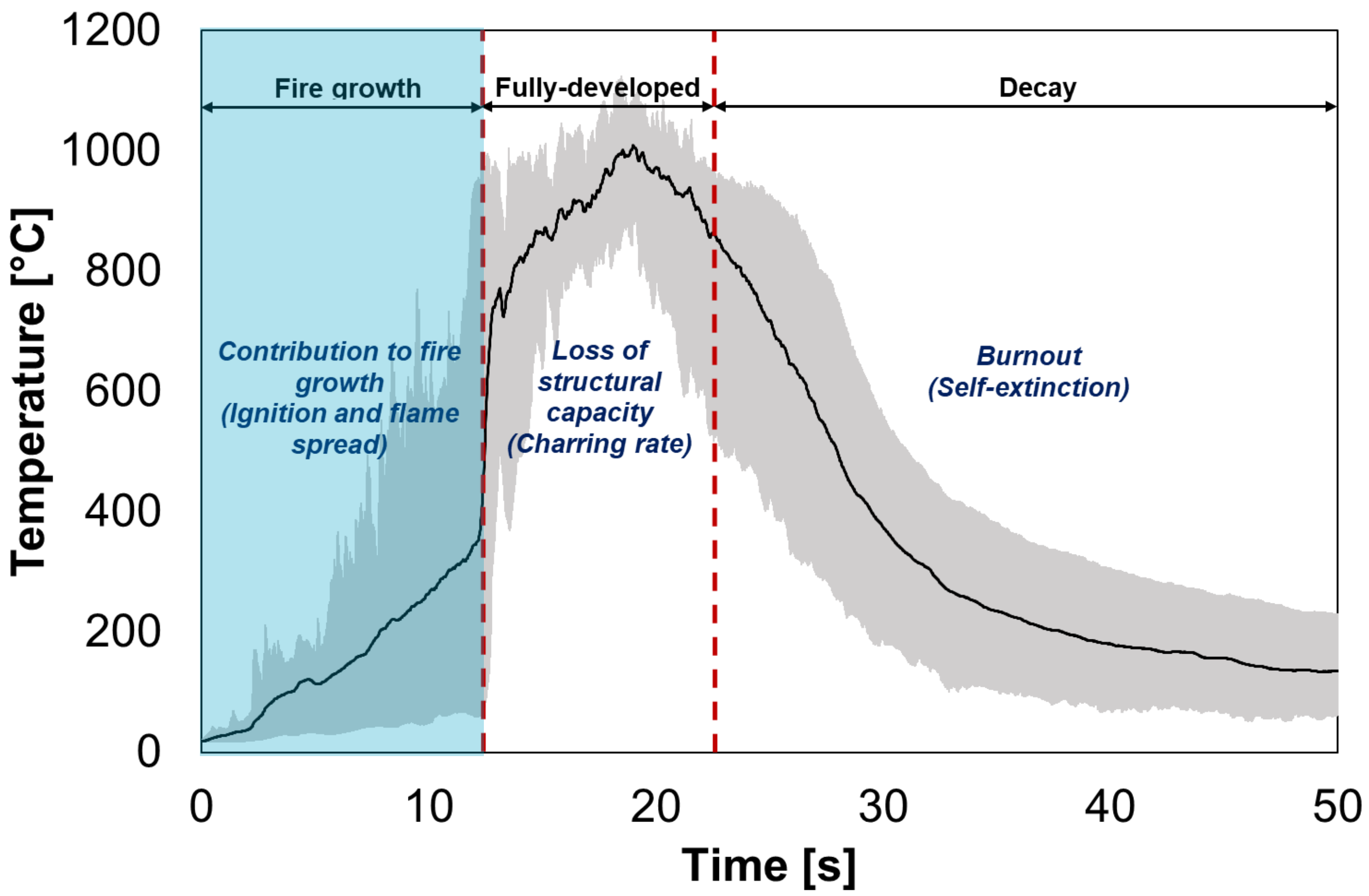
Fire growth stage

- **Aim**

Limit fire growth to allow safe evacuation of occupants before untenable conditions.

- **Performance criteria**

  Flammability parameters:
  - Ignition
  - Flame spread
  - Fire growth



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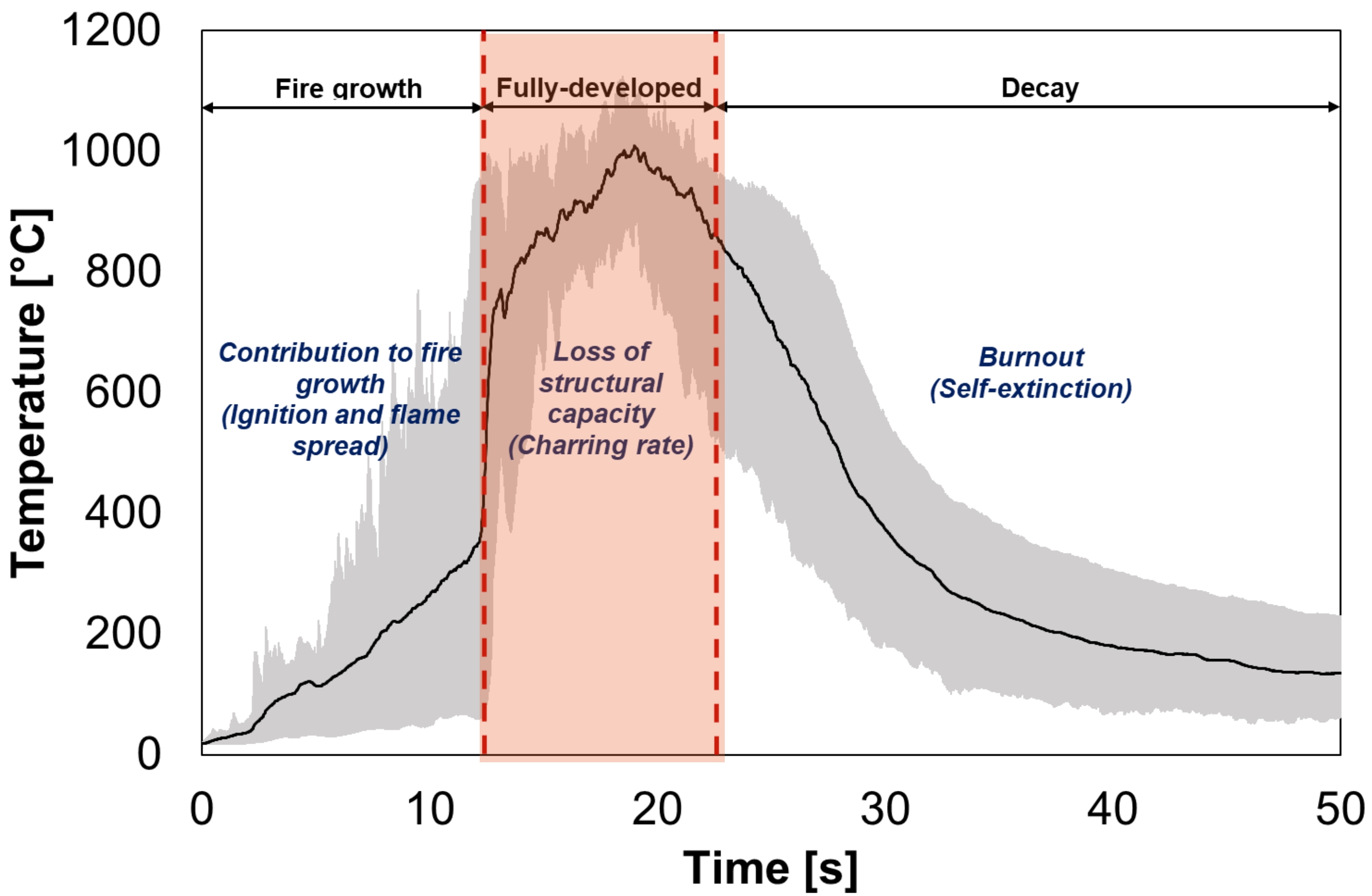
Defining 'fire performance' of mass timber structures

Fully-developed stage

- **Aim**

Preserving structural integrity.

- **Performance criteria**
  - Charring rate
  - Loss of structural capacity



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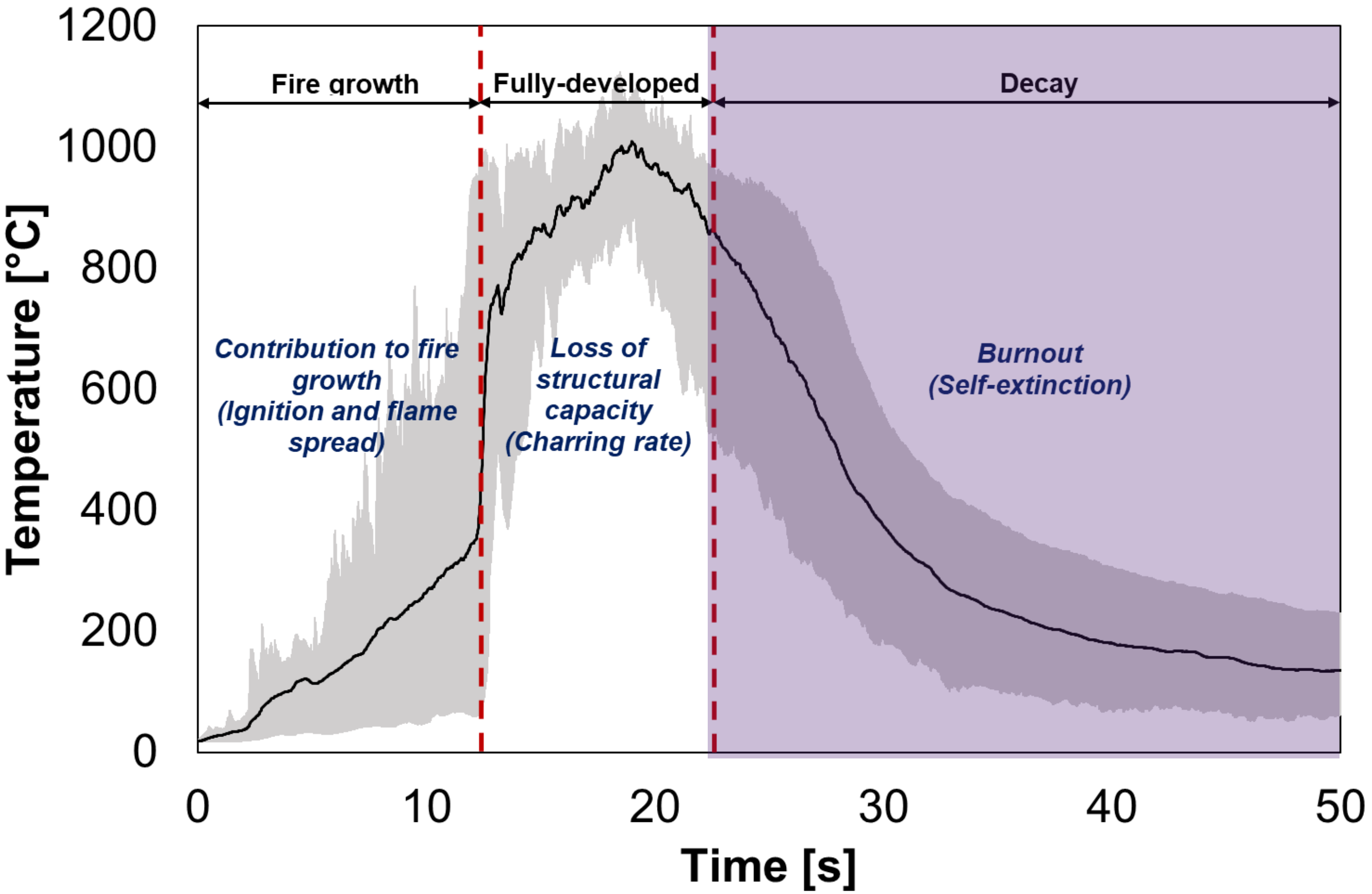
Defining 'fire performance' of mass timber structures

Decay stage

- **Aim**

Ensure fire burns out and compartmentation is not breached.

- **Performance criteria**
  - Self-extinction



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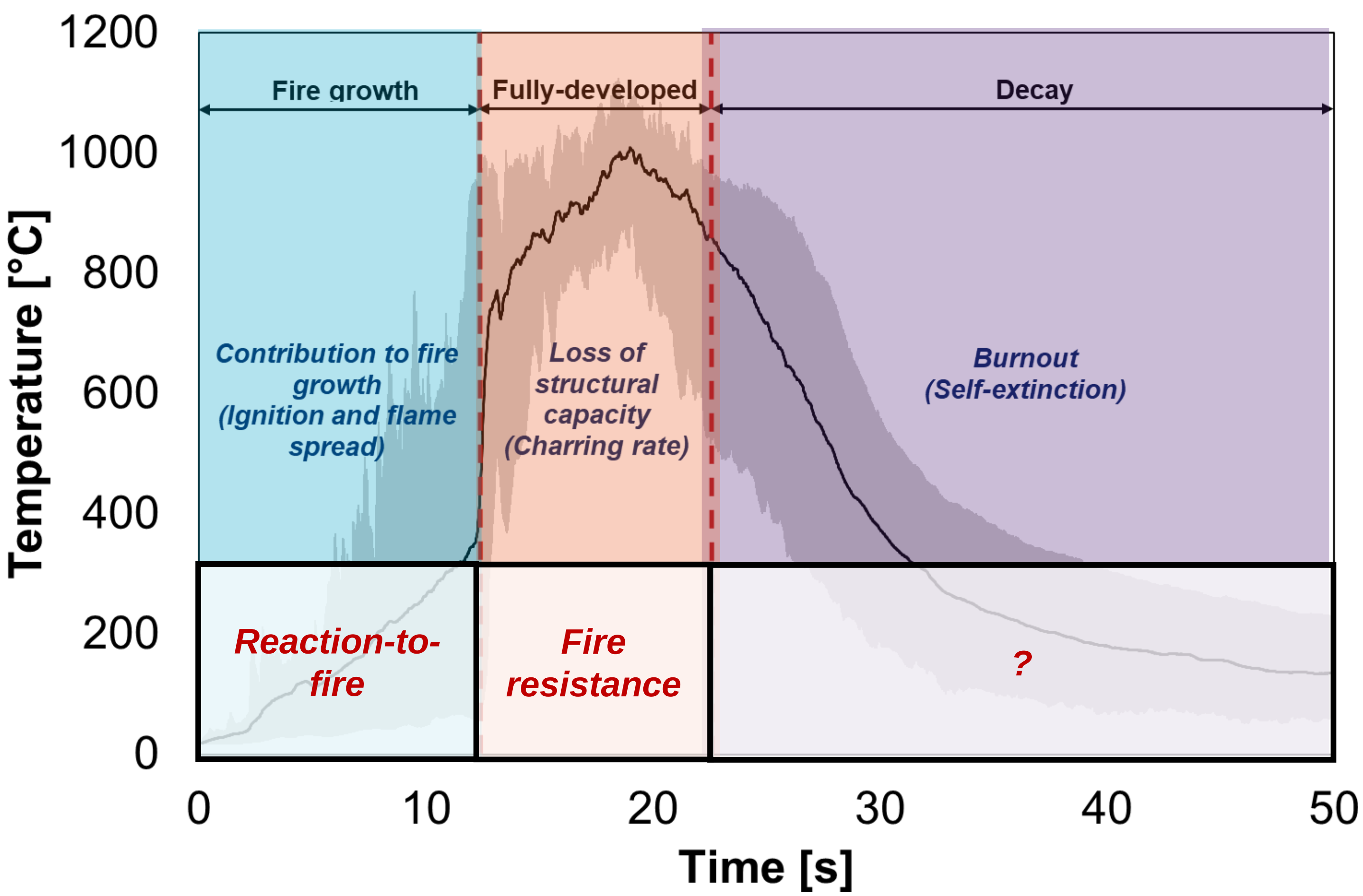
Existing frameworks to address fire-safe design of timber



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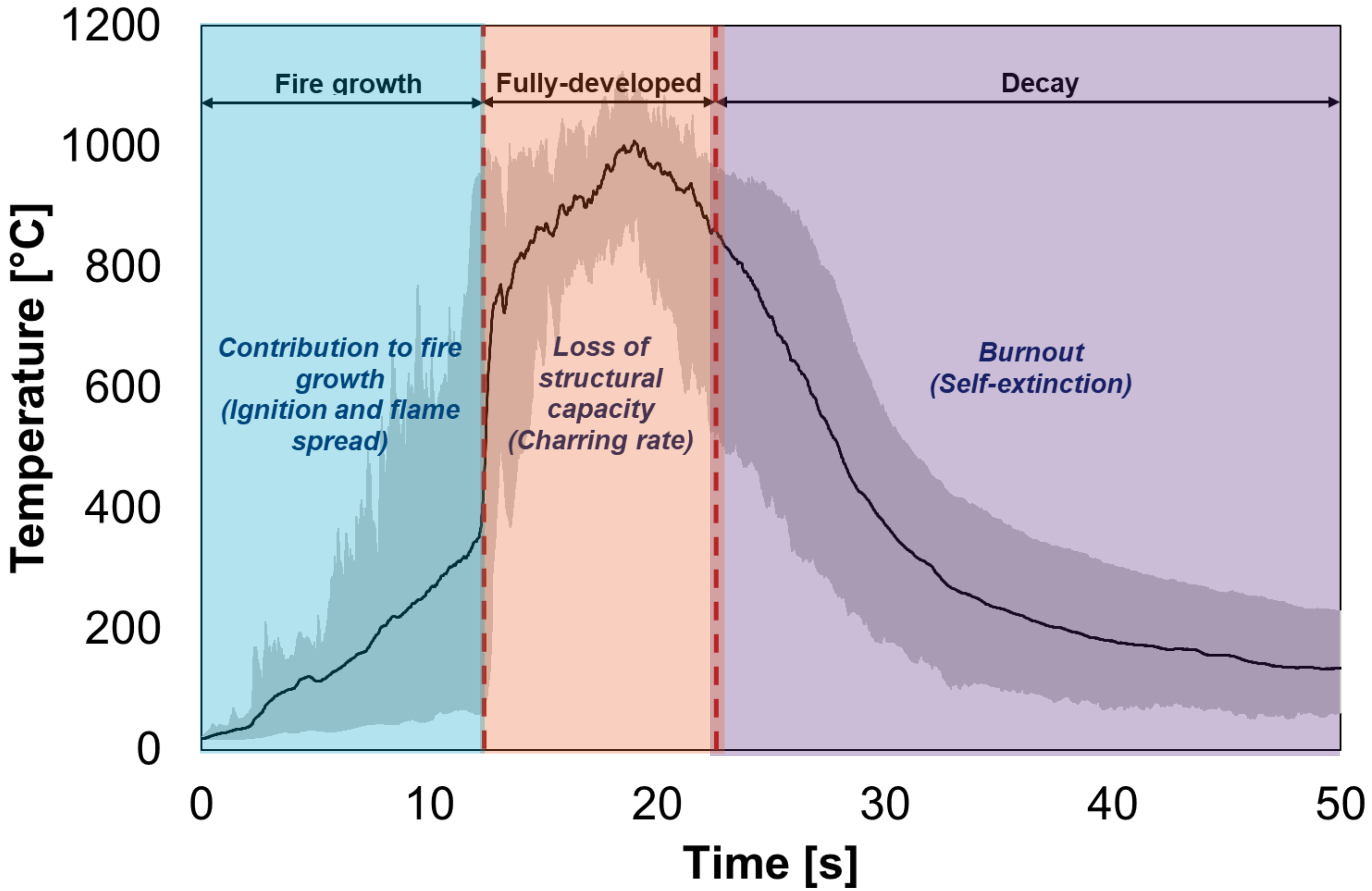
Research to help the design and safe use of timber structures?

Improving the performance of existing timber products.

(slow fire spread, degradation, avoid delamination/debonding, improve extinction…)

Enabling engineering tools for the the analysis of timber behaviour under fire conditions

(contribution, loss of structural capacity, and self-extinction)



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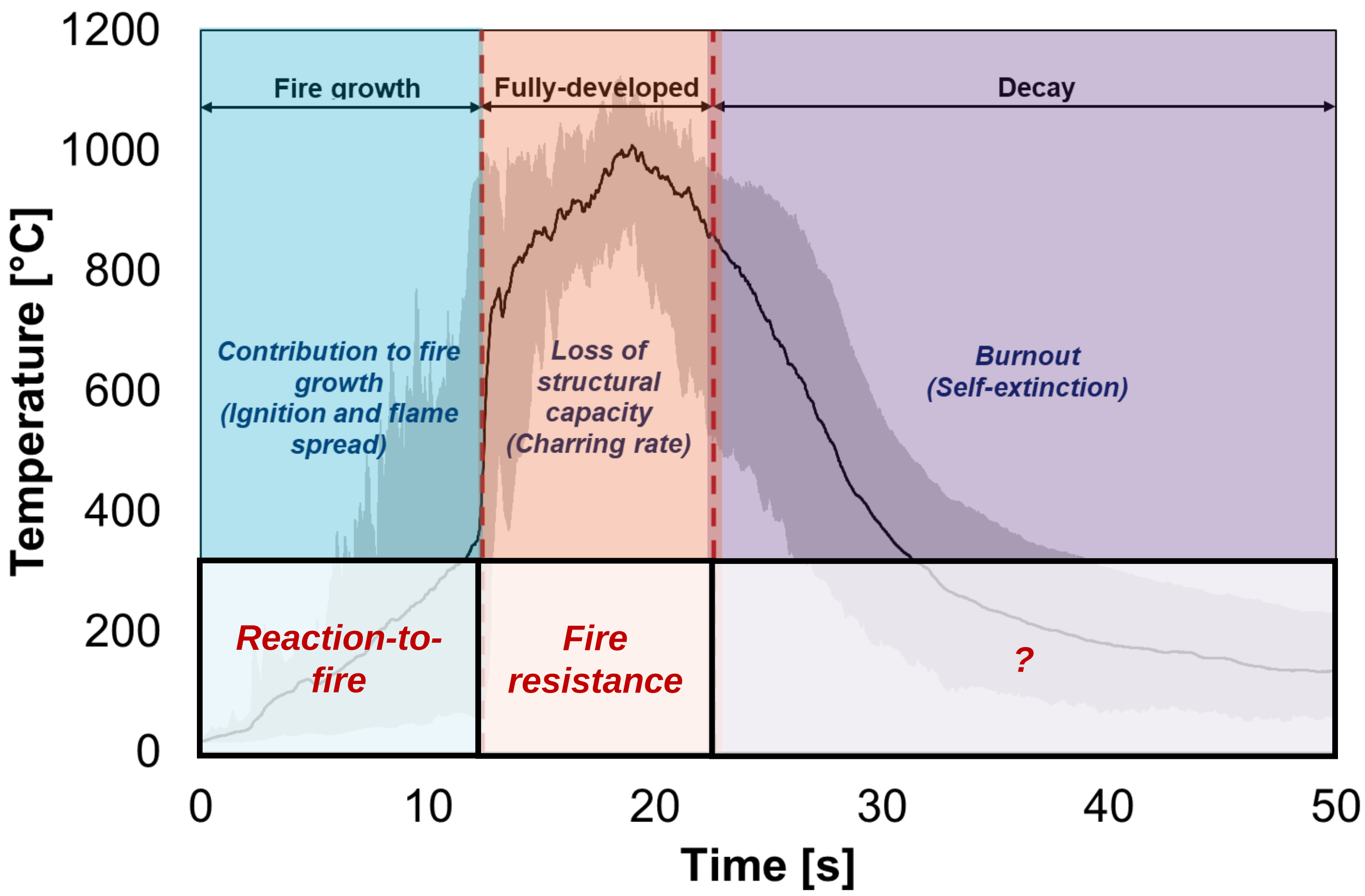

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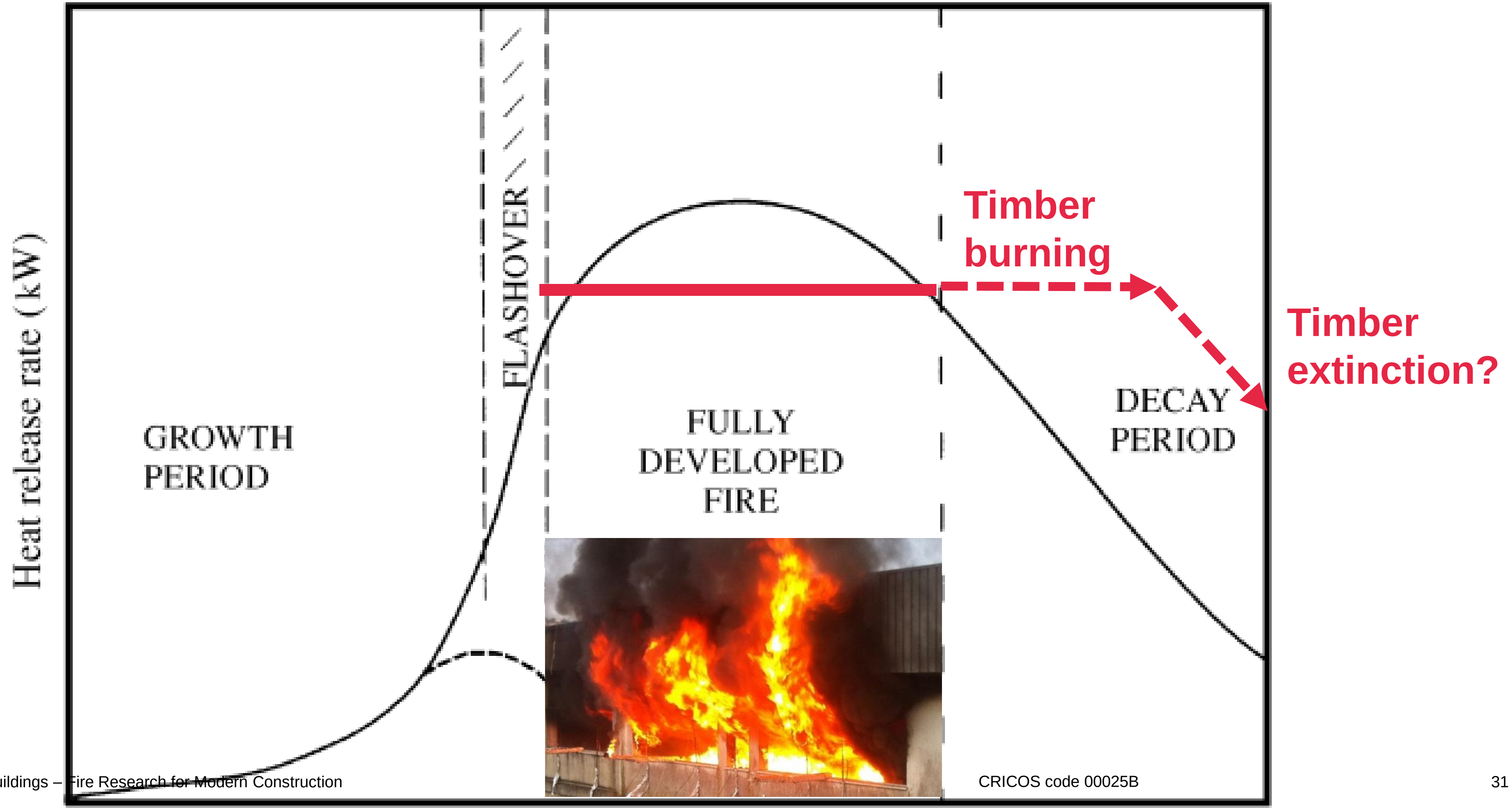
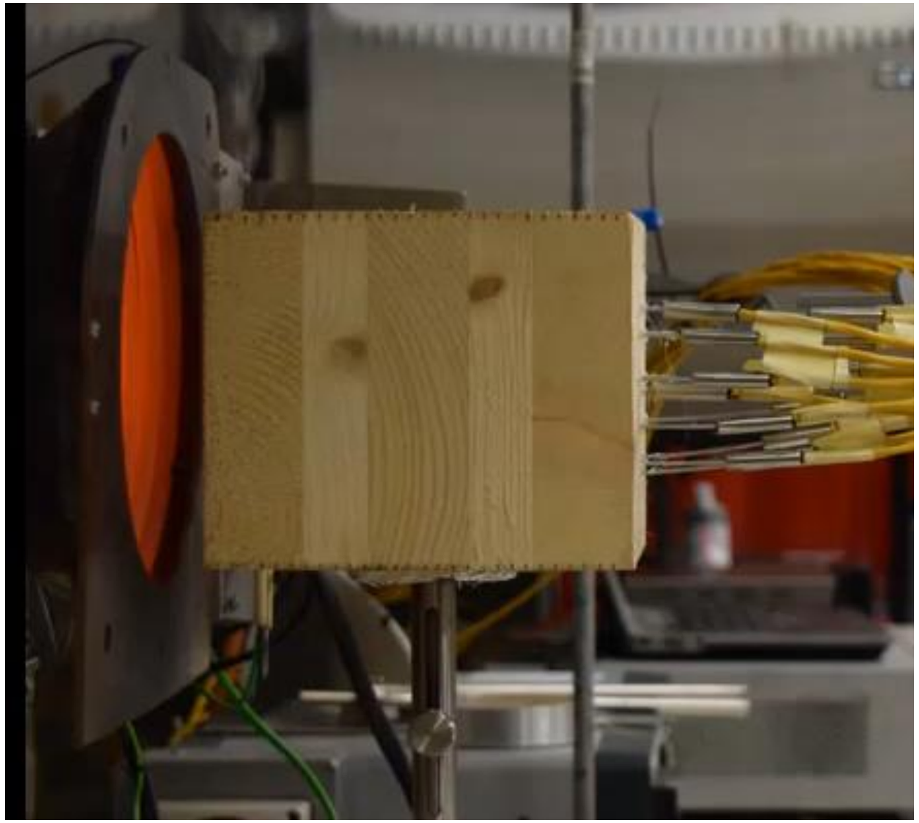
Self-
Extinction

Framework to design for self-extinction



Self-extinction demonstrated at material scale…

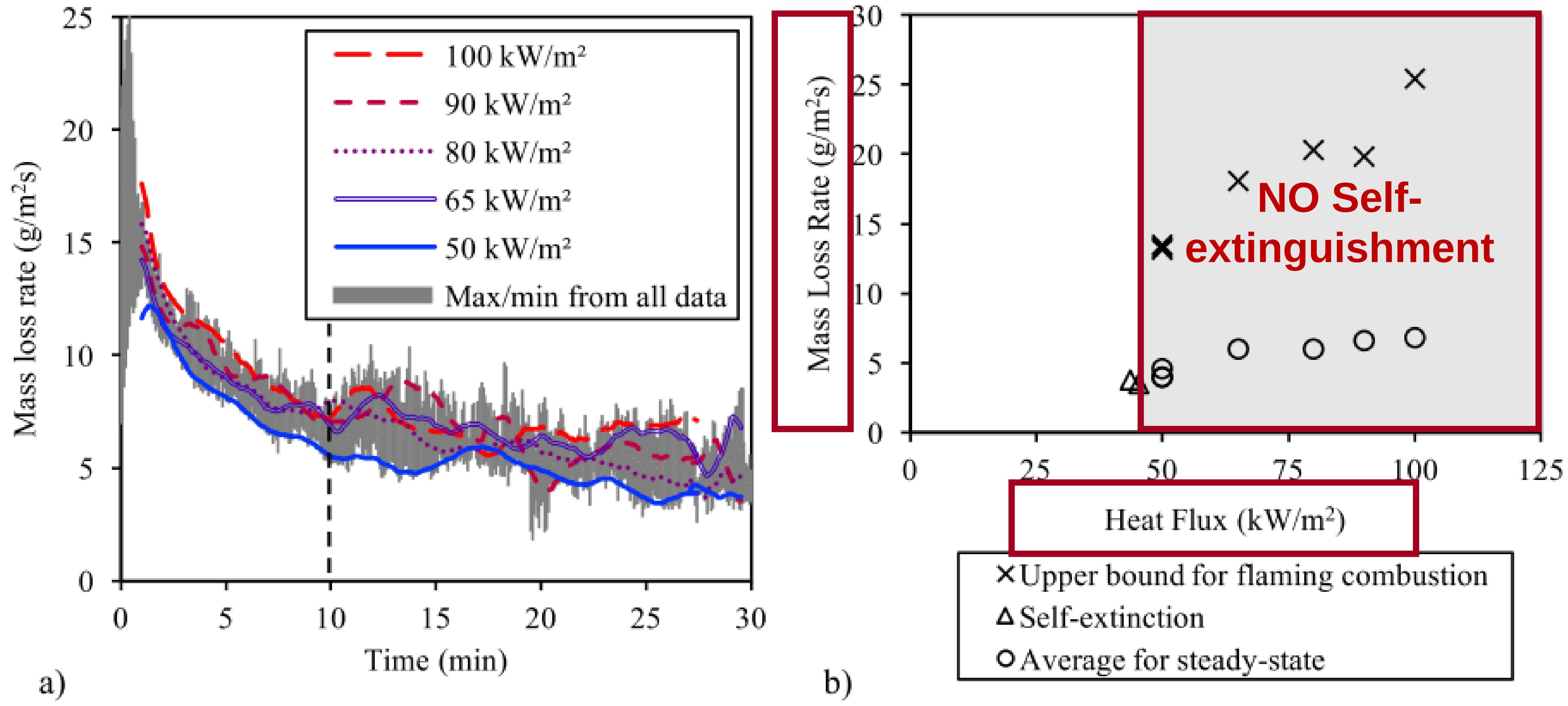
- **Timber can self-extinguish…**



Source: Emberley et al., 2017

Self-extinction demonstrated at material scale…

- **Timber can self-extinguish… if the right conditions are met.**

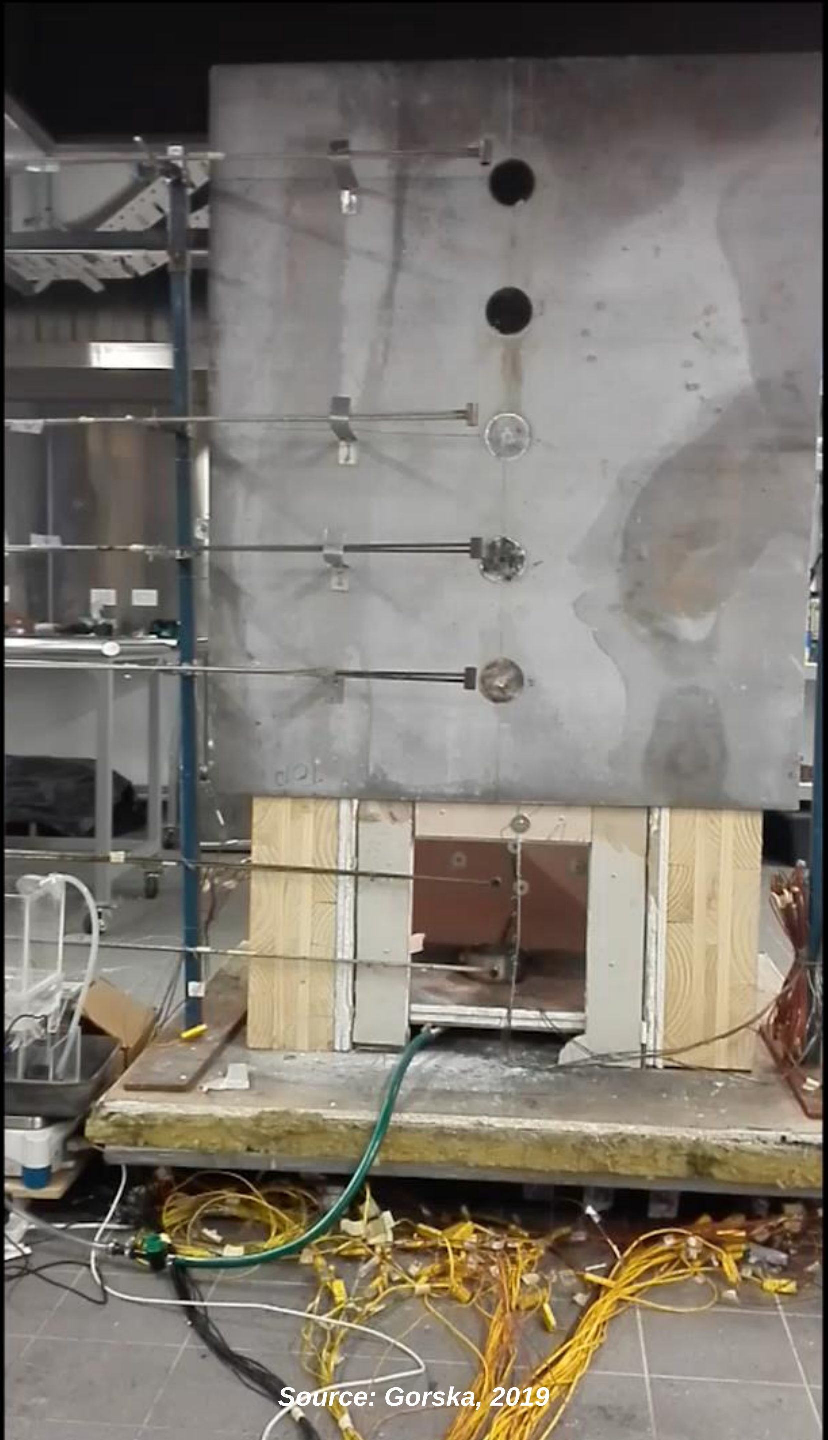


Source: Emberley et al., 2017

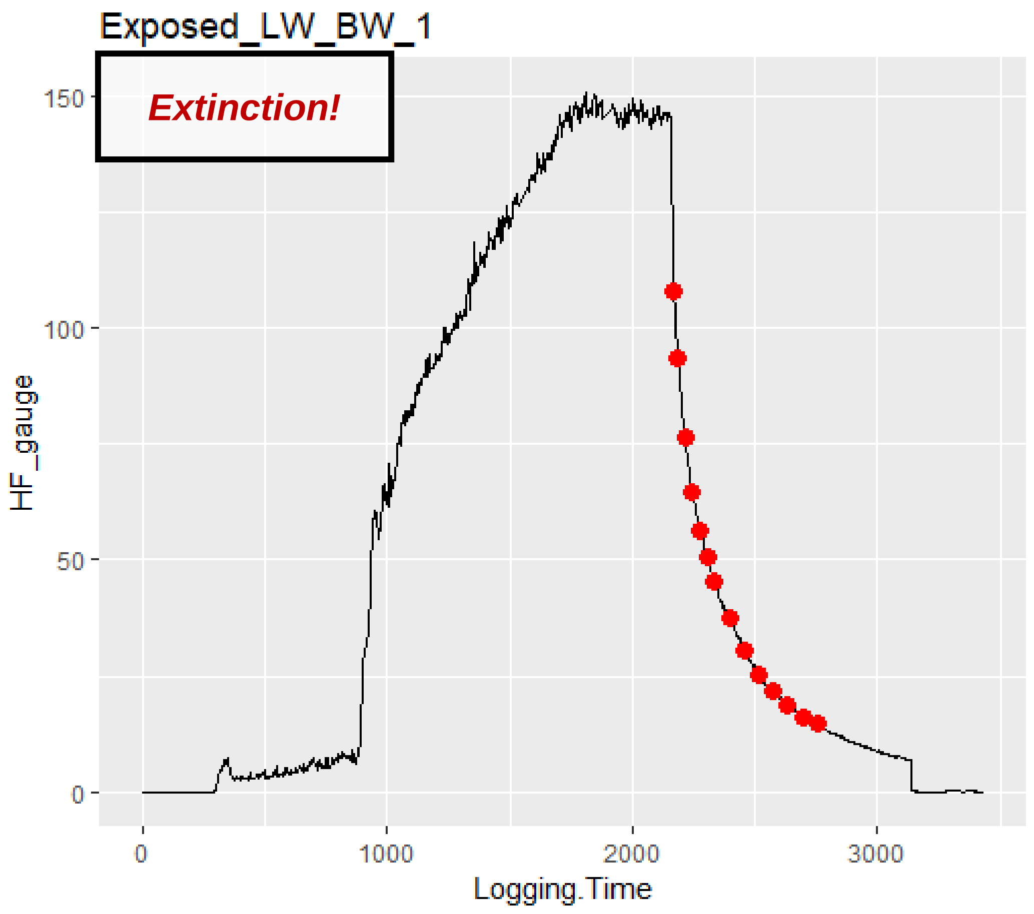
…demonstrated at system (intermediate) scale…

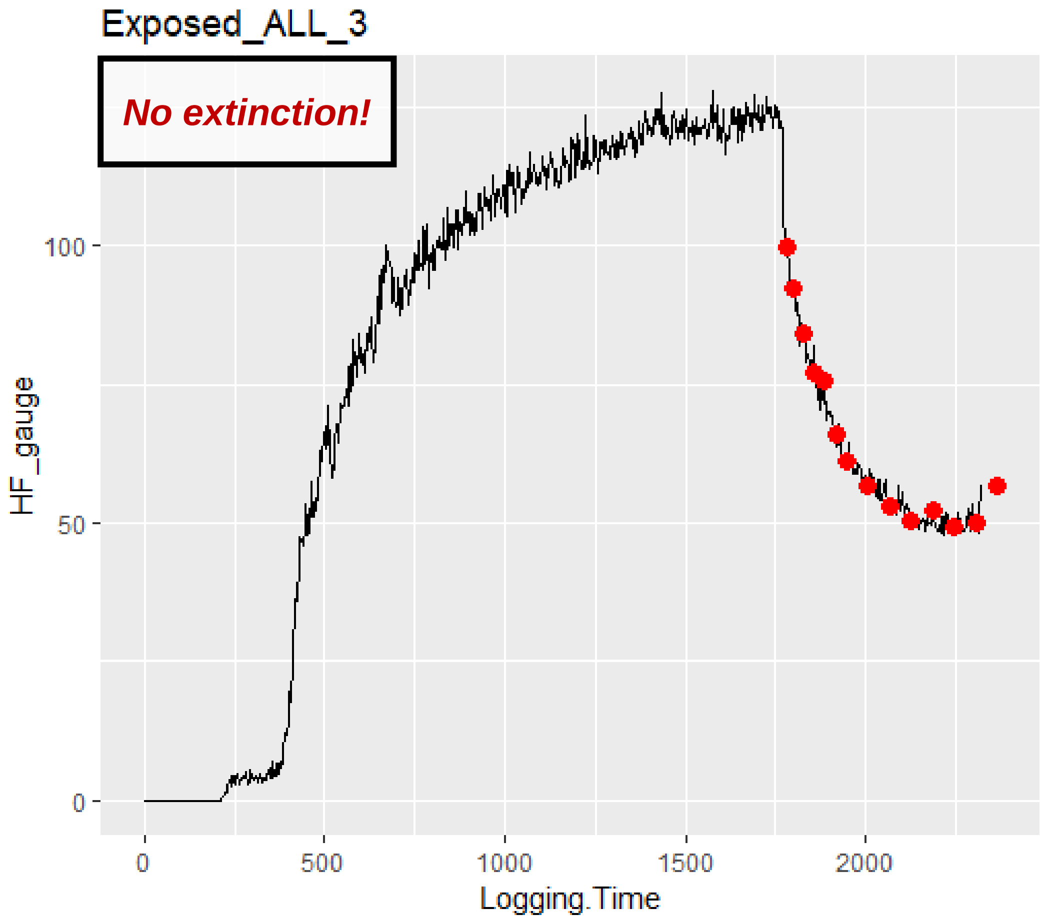



Source: Gorska, 2019


Source: Gorska, 2019

Extinction depends on the area of exposed timber…





Source: Gorska, 2019

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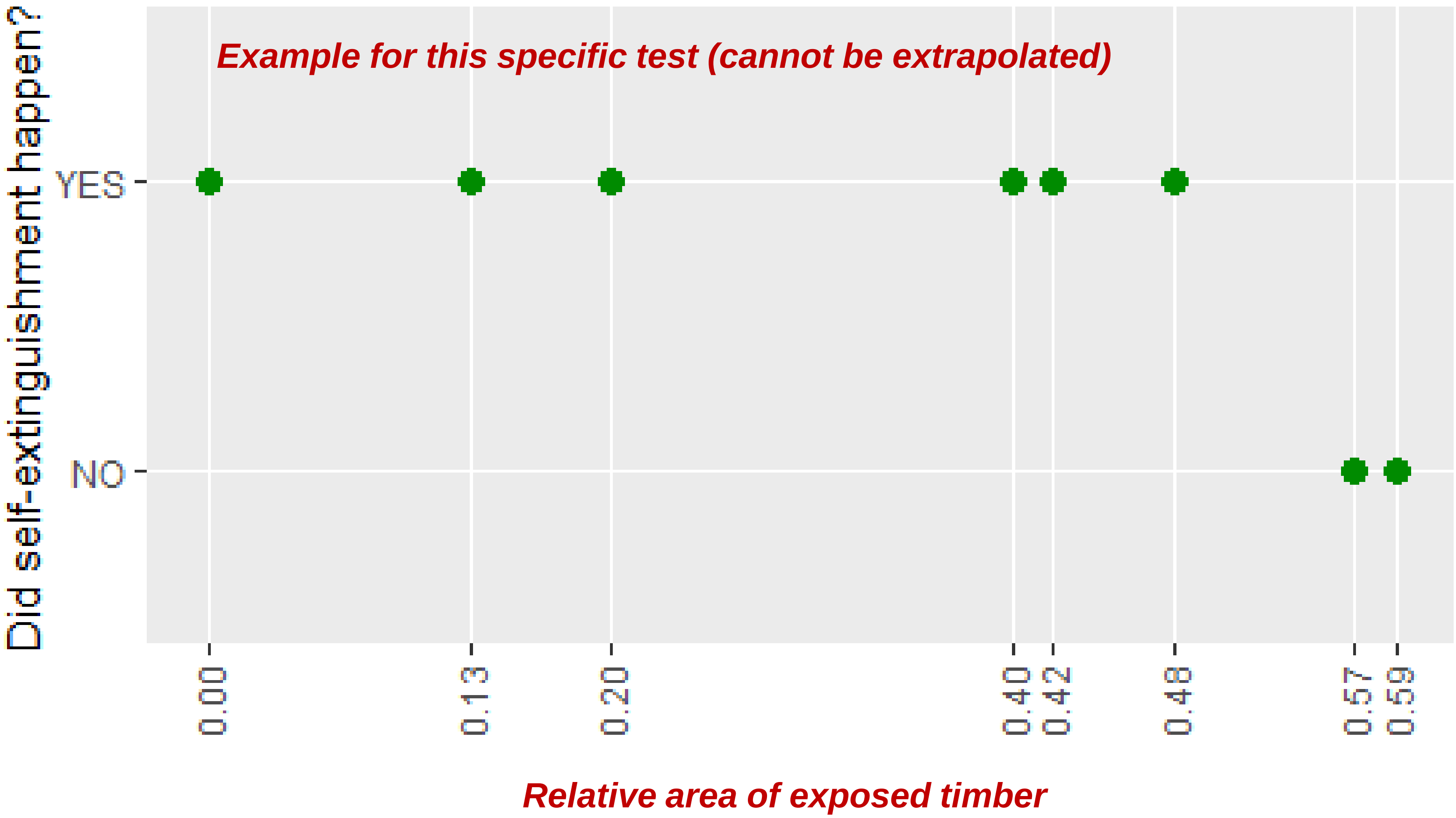


Source: Gorska, 2019

Self-extinction demonstrated at full-scale…

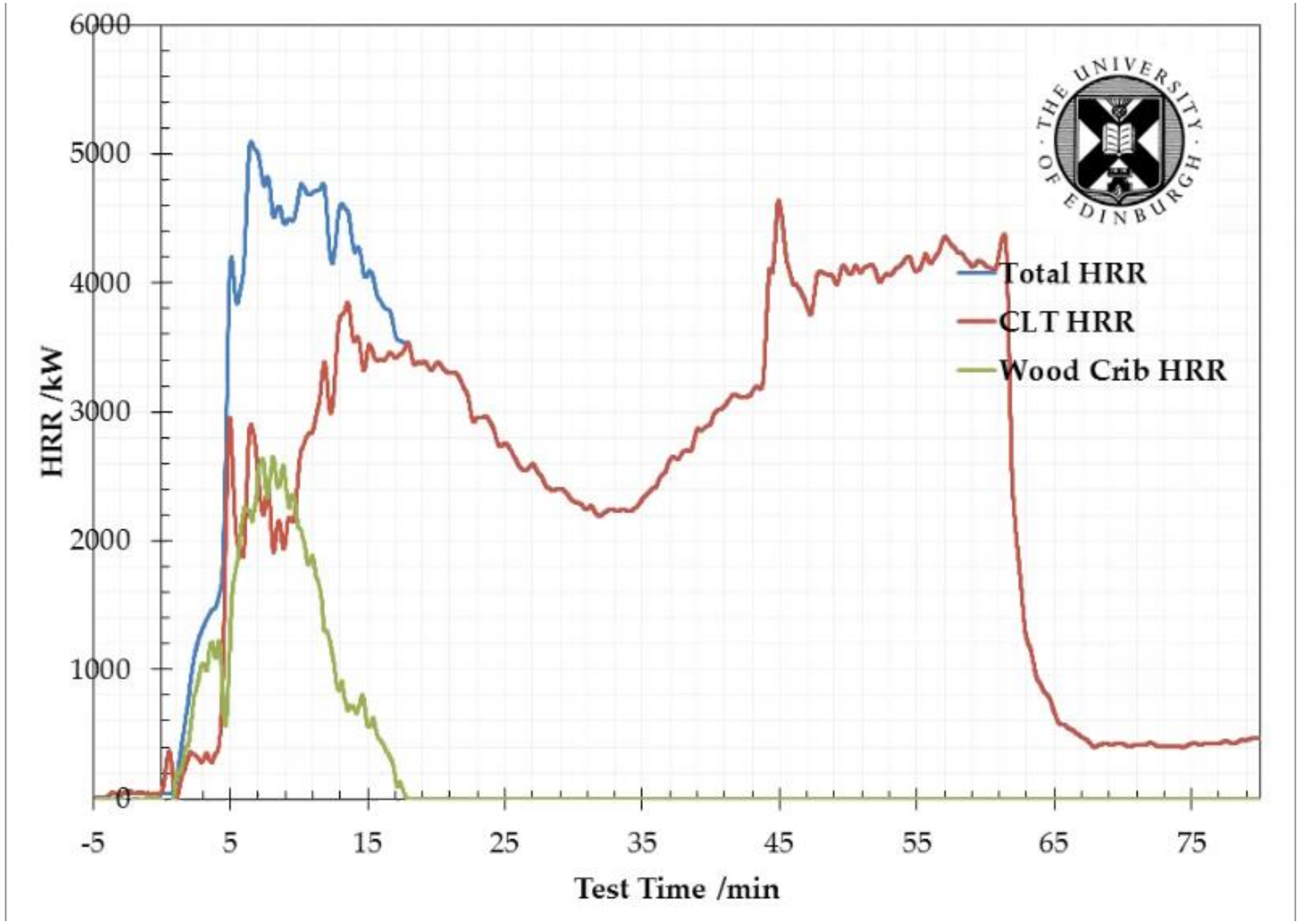
Source: Emberley et al., 2017

Extinction can be achieved…

subject to a limited number of exposed surfaces!

Source: Emberley et al., 2017 ; Gorska, 2019

Encapsulation and char fall-off needs to be considered!

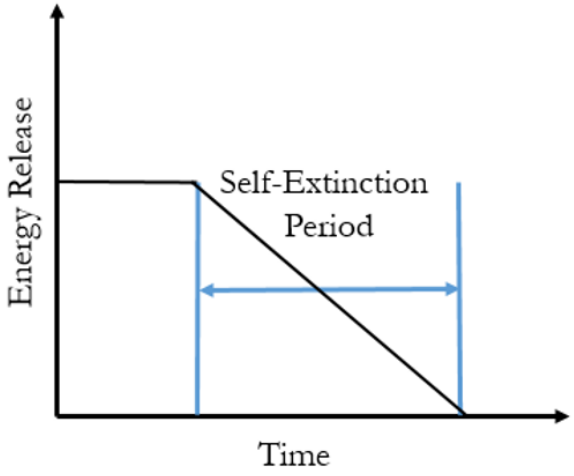


Hadden et al., 2017

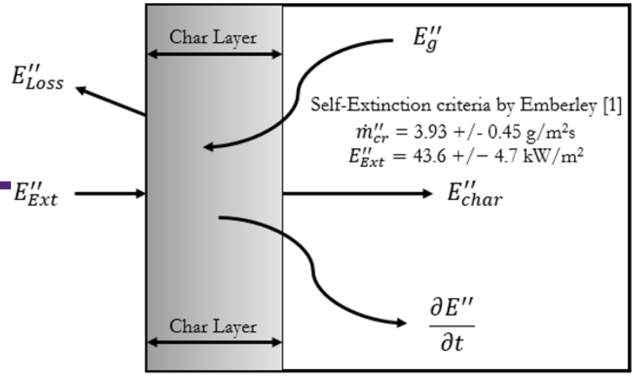
Framework to design for self-extinction of mass timber products (CLT)

Self-extinguishment design framework proposal

- **Conditions during the decay phase are critical for self-extinction.**
- Thermal feedback on boundaries must be less that the conditions required for self-extinction.



$$\dot{q}''_{decay} < \dot{q}''_{critical}$$



The heat flux at the decay-phase depends on:

- Number of exposed surfaces.
- Ventilation conditions (heat losses).
- Fuel nature and fuel load density.

Self-extinguishment design framework proposal

Fuel Load | **Encapsulation failure** | **Lamellae fall-off failure**

Design criteria: Definition of Characteristic Times

Fully-developed fire duration

Duration till:
a) Protection collapse
b) Onset pyrolysis of protected timber

Duration till failure of the char integrity or adhesive degradation

$$t_{c_{fire}} < t_{c_{encapsulation}} , t_{c_{fall-off}}$$

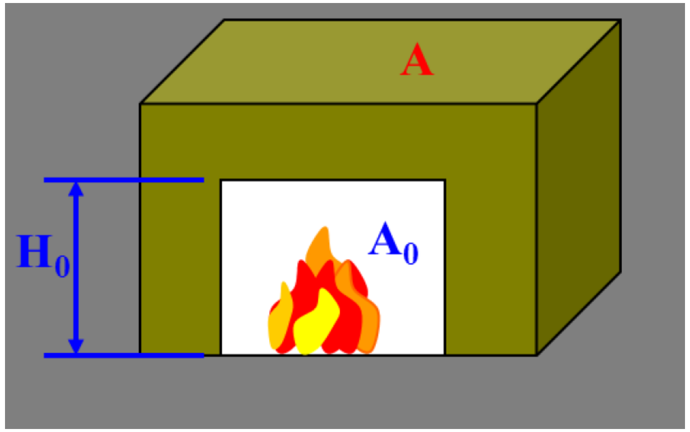
($t_{c_{fire}}$) Characterisation of the fire duration

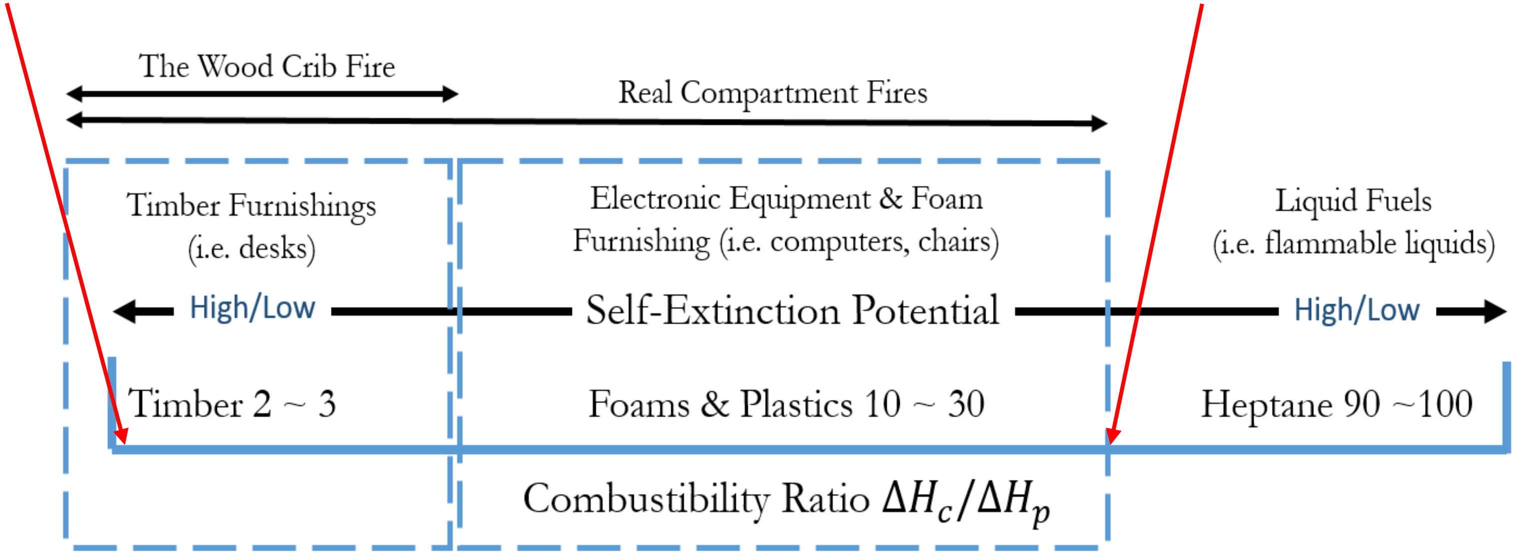
Duration of the fire is calculated as $t_{c_{fire}} = mass\ of\ fuel/burning\ rate$

- Burning rate (kg/s) = Constant x Ventilation factor ($A_0H_0^{1/2}$)
- Mass of fuel (kg) = Design fuel load (MJ/m^2) x Area of the compartment (m^2) / Heat of Combustion (MJ/kg)

Wooden Cribs $\frac{\Delta H_c}{\Delta H_p} = 3$

Polyethylene (granular) $\frac{\Delta H_c}{\Delta H_p} = 25$





Source: Browning, 2018

$(t_{c_{fire}})$ Standard fuel loads vs real fuel loads?

Source: Browning, 2018

$(t_{c_{fire}})$ Standard fuel loads vs real fuel loads?

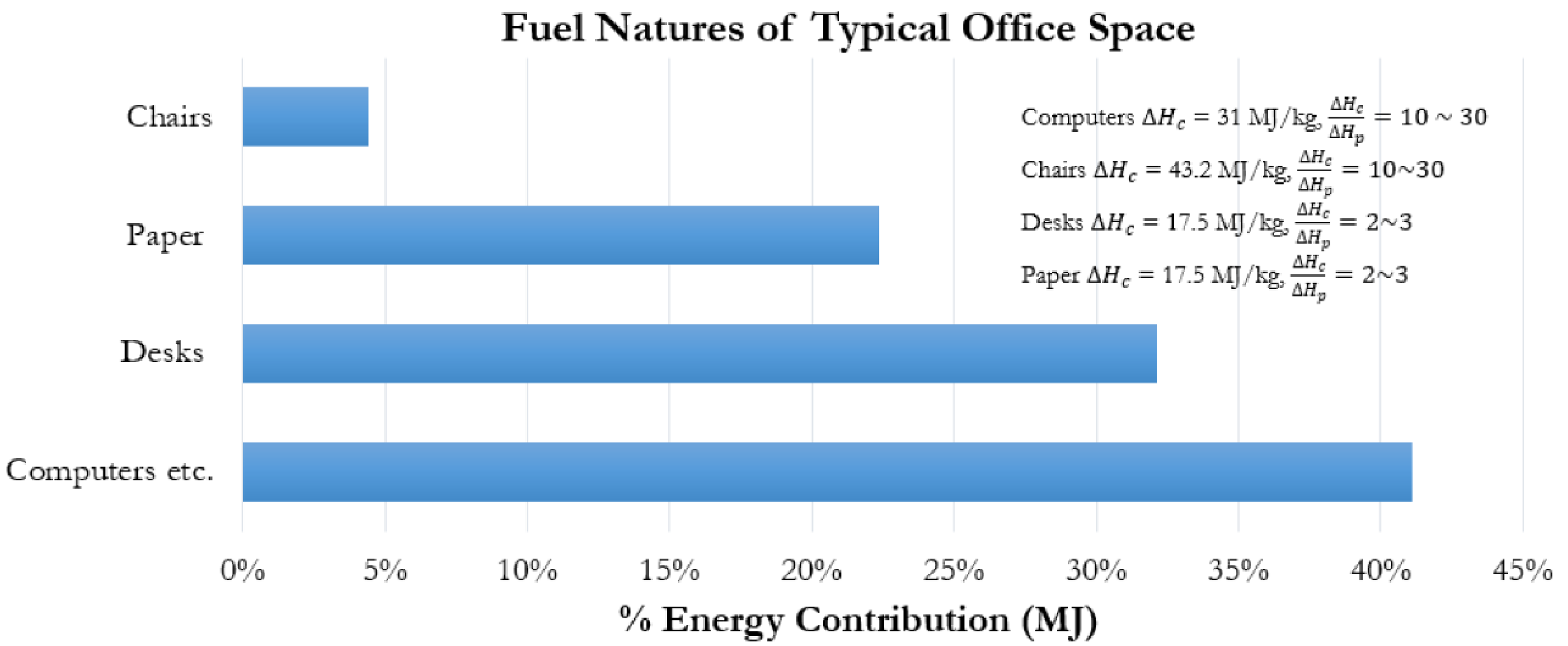
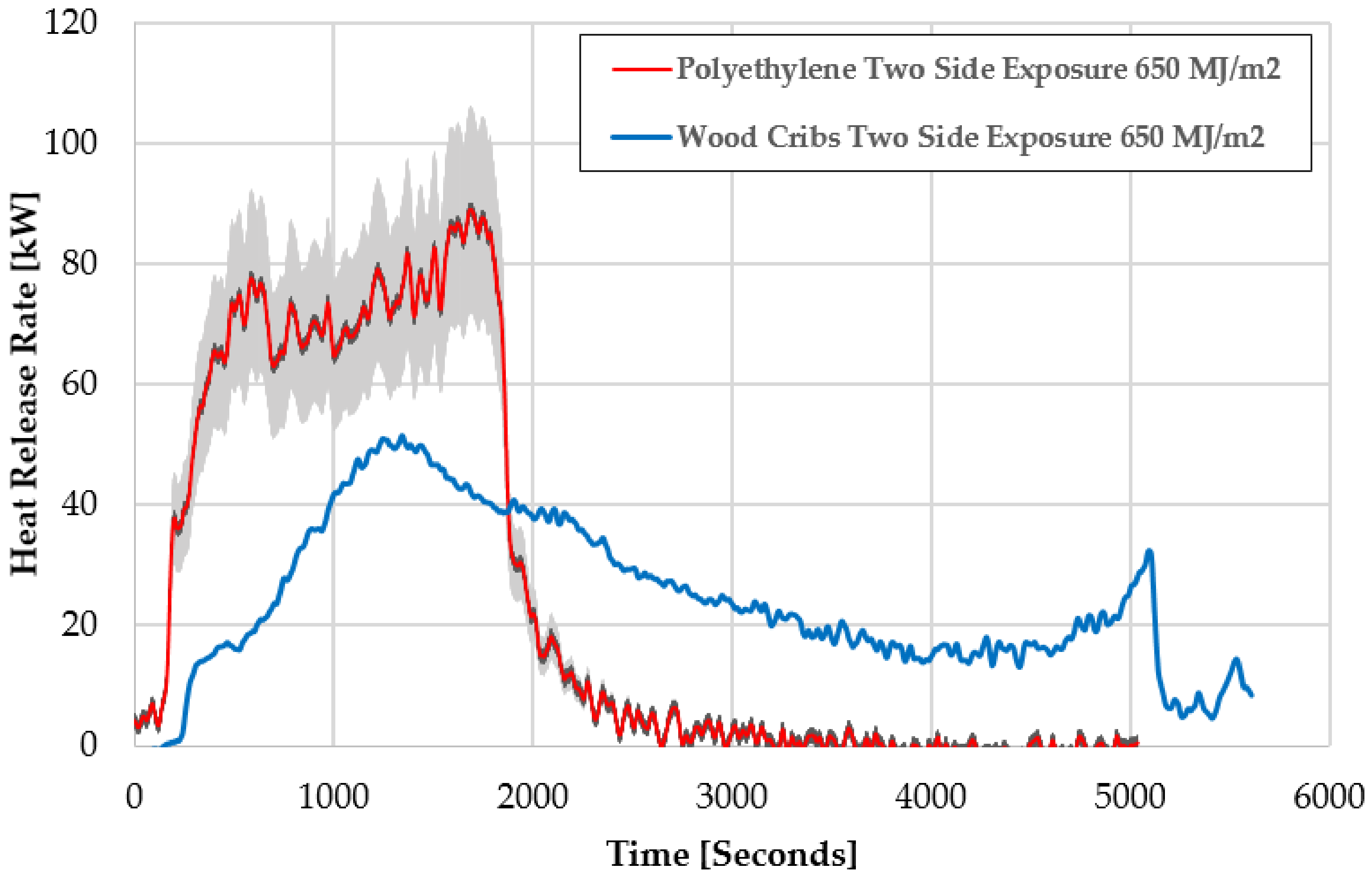


Figure 1: Contribution of specific materials to fuel loads with a typical office space with fuel load density of 220 MJ/m^2

Source: Browning, 2018

($t_{c_{fire}}$) Effect of fuel load on self-extinction!



For same fuel load (MJ/m^2) density:

- Test with plastic fuel achieves self-extinction
- Test with cellulosic fuel delaminates and fails to achieve self-extinction

Source: Browning, 2018

How to establish ($t_{c_{encapsulation}}$, $t_{c_{fall-off}}$)?

- Phenomena strongly linked to the **transient heat transfer** in the solid. Extremely complex phenomena:
  - **Plasterboard – dehydration and loss of mechanical properties**
  - **Char fall-off – integrity loss in char and loss of bond due to thermal degradation of adhesive**

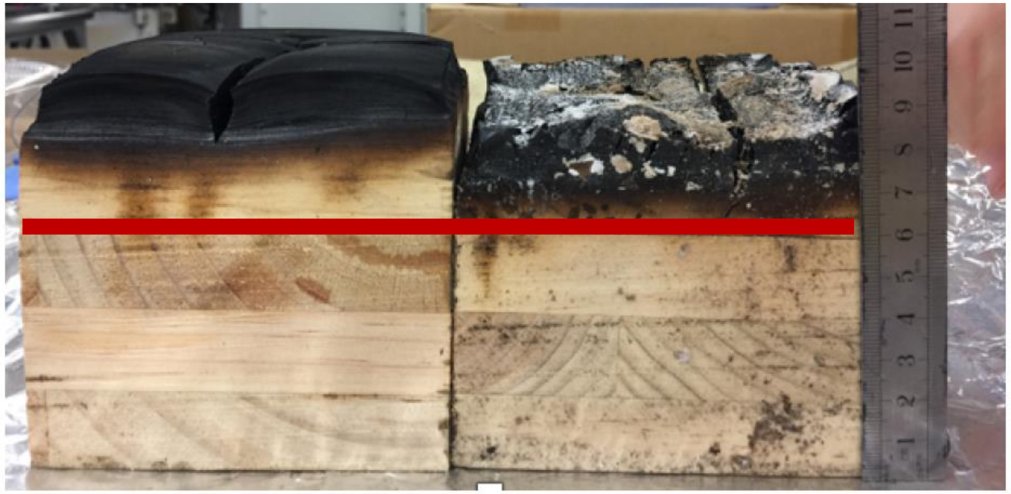
- Need for simplified failure criteria!

$$t_{c_{solid}} = constant \cdot \frac{L^2}{\alpha}$$

- Critical selection of:

  Thickness (L)

  Thermal properties (k/ρc)



Source: Xu et al., ongoing

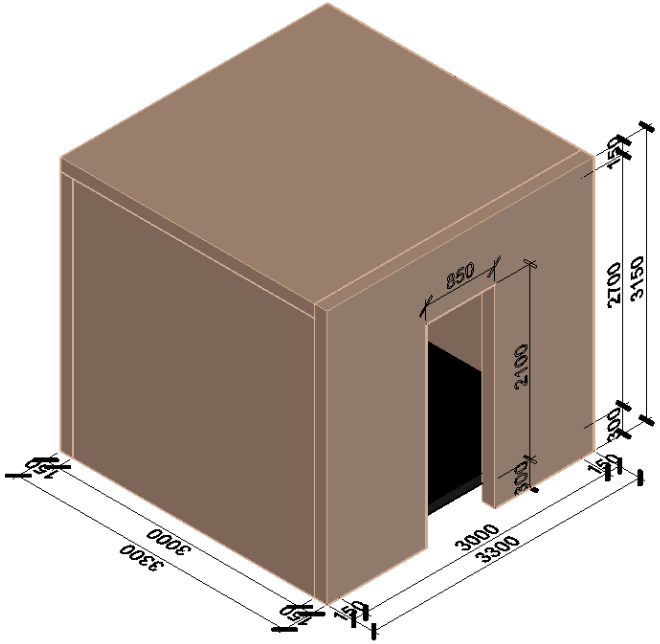
Large-scale tests to validate proposed methodology

Large-scale CLT Project

- Stage 0: Baseline Test
- Stage 1: Char Fall-Off Study
- Stage 2: Encapsulation Failure Study
- Stage 3: Safe Configuration Study

- **Isolation of failure modes:**
  - **Char fall-off**
  - **Encapsulation failure**
  - **Number of exposed surface**

- Project designed in 4 different stages to reduce complexity!



Source: Xu et al., ongoing




Source: Xu et al., ongoing

Stage 0: Baseline Test

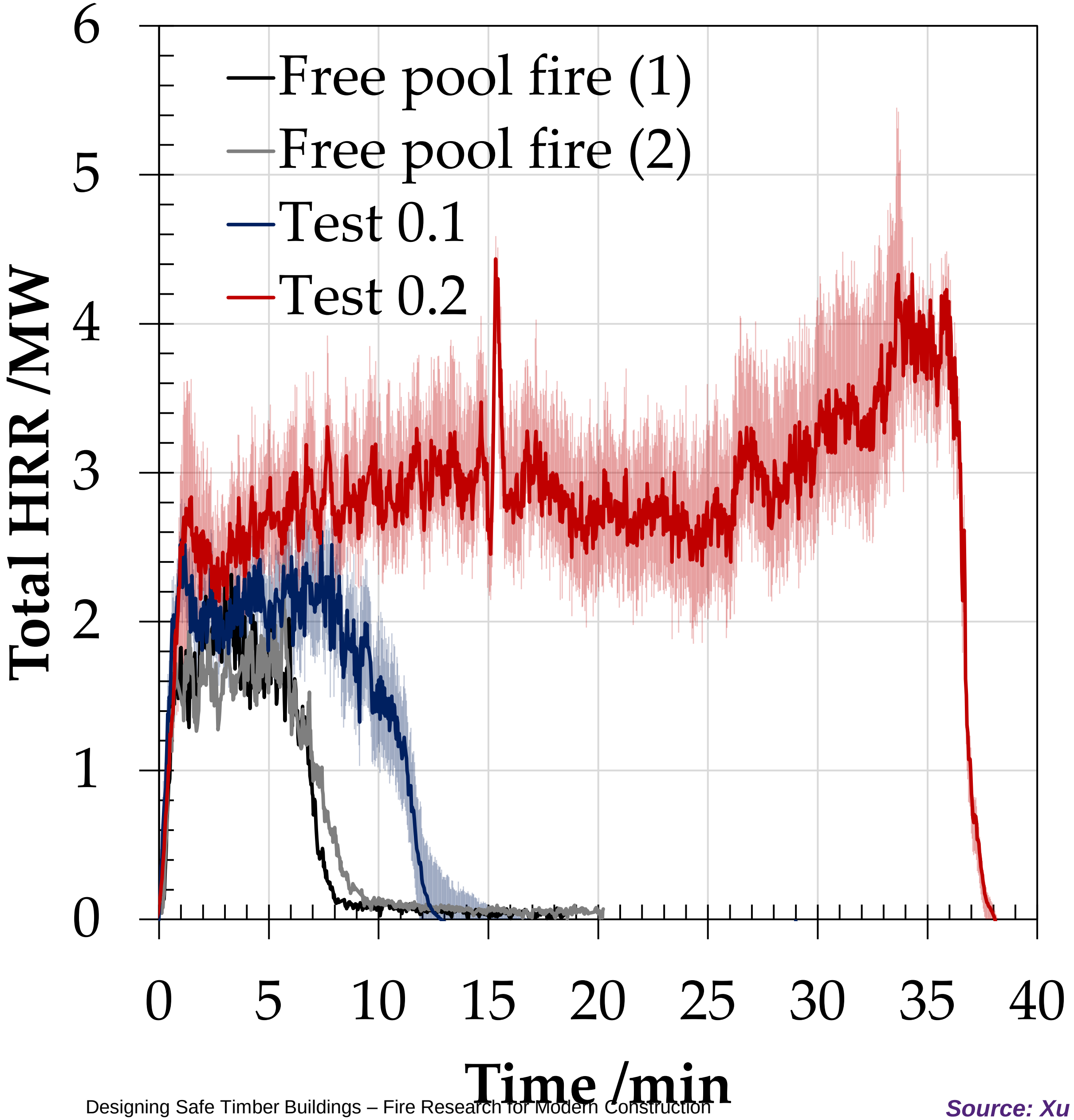
Test 0.1

Test 0.2

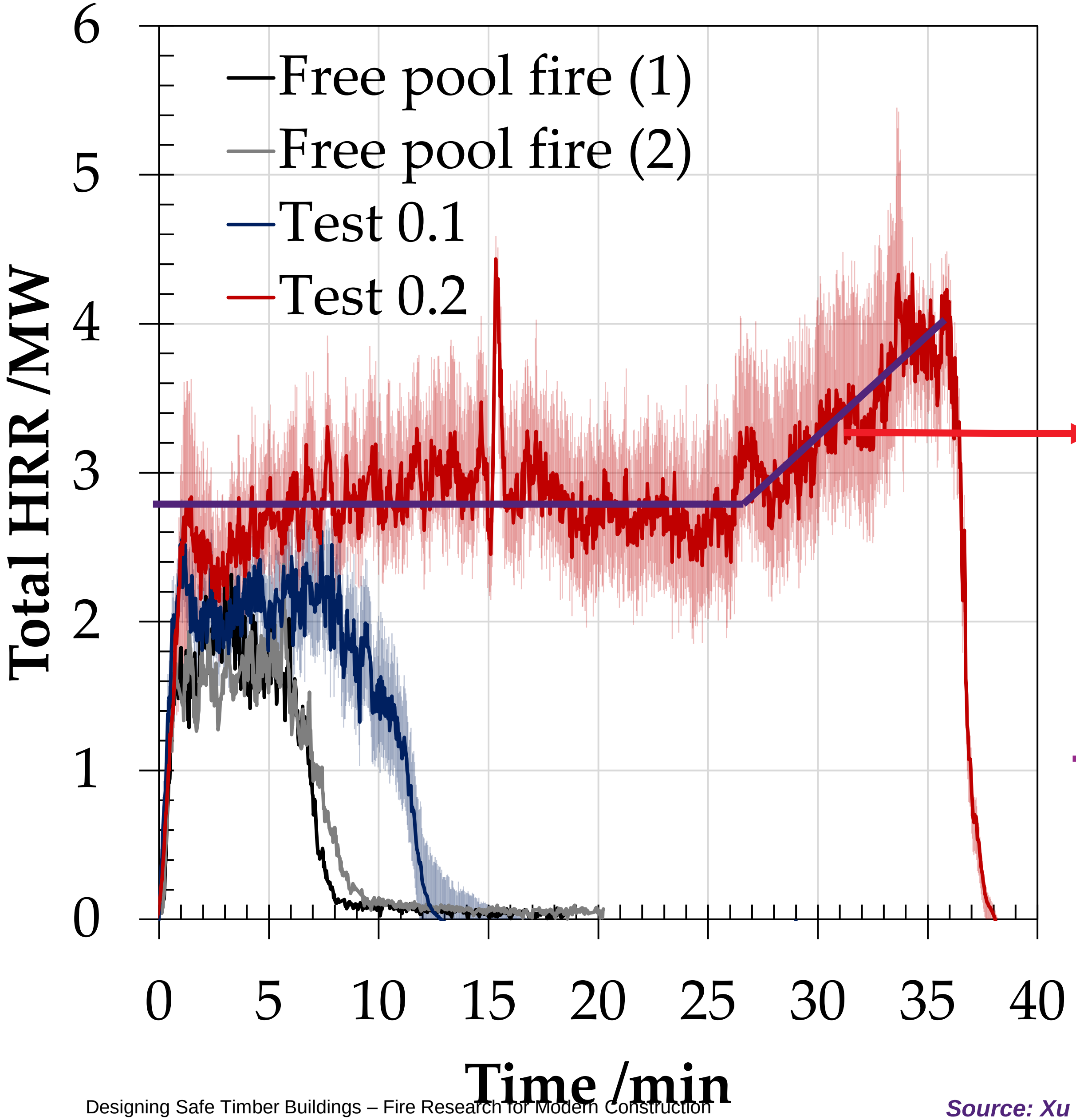
short fire = low fuel load

long fire = high fuel load

Source: Xu et al., ongoing



Source: Xu et al., ongoing

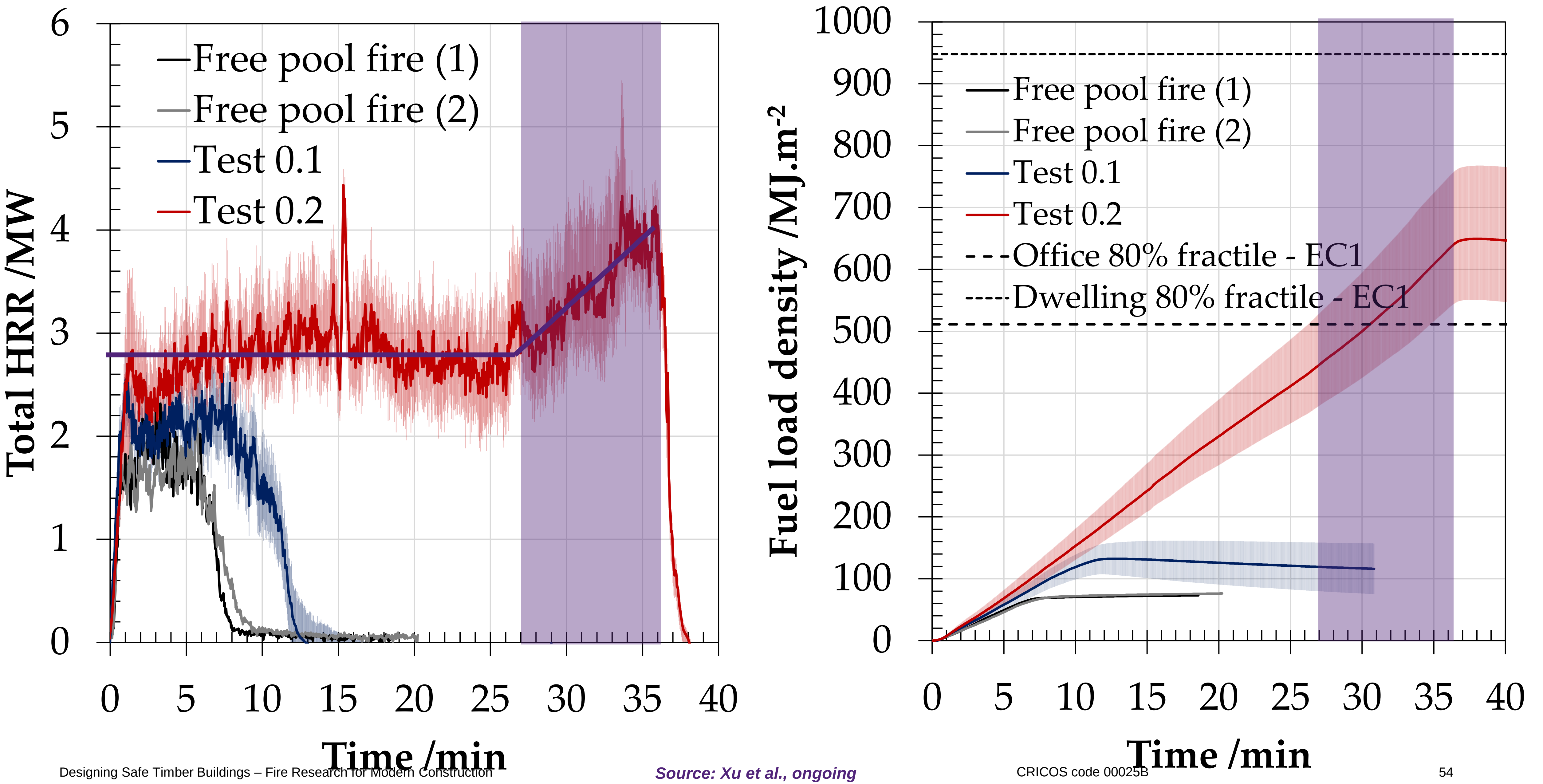


Contribution of timber to the heat release rate of the fire

…

after failure of plasterboard or timber reaching the pyrolysis onset

Source: Xu et al., ongoing



Source: Xu et al., ongoing

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AUSTRALIA

Test 0.1
short fire = low fuel load

Test 0.2
long fire = low fuel load

Front wall

THE UNIVERSITY OF QUEENSLAND AUSTRALIA

Test 0.2
long fire = low fuel load

Left wall

Test 0.2
long fire = low fuel load

Back wall

The University of Queensland
AUSTRALIA

Test 0.2
long fire = low fuel load

Ceiling

Test 0.2
long fire = low fuel load

Right wall

Test 0.2
long fire = low fuel load

Summary

- Fire safety is critical to enable future mid- and high-rise timber buildings.

- Research urgently required to promote a framework that enables performance solutions.

- Two main research lines:
  - ‘Engineering tools’ for explicit (quantitative) design.
  - Improved ‘fire performance’ using treatment techniques.

Summary

- **Remaining questions:**

  - Are the current reaction-to-fire and fire resistance frameworks fit for purpose when using mass timber construction?
    - Fire scenarios representative of actual fire growth?
    - Furnace testing heat exposure vs actual fires?

  - Design for self-extinction yet to be completely developed.

Acknowledgements

Carmen Gorska

Aidon Browning

Hangyu Xu


Fire Safety Engineering Research Group
UQ Fire
The University of Queensland
www.civil.uq.edu.au/fire

The University of Queensland
AUSTRALIA
CREATE CHANGE

FUTURE TIMBER HUB

5th Pacific Timber Engineering Conference (PTEC 2019)

10-12 July 2019
Brisbane, AUSTRALIA

On the 10-12 July 2019, some of the biggest names in timber construction will gather at the Brisbane Convention & Exhibition Centre for the 5th Pacific Timber Engineering Conference (PTEC 2019).

Run by the The University of Queensland’s School of Civil Engineering, together with the ARC Future Timber Hub, PTEC 2019 aims to promote the use of **TIMBER** in buildings across Australia – from tall and mid-rise to domestic structures.

5th Pacific Timber Engineering Conference (PTEC 2019)

10-12 July 2019
Brisbane, AUSTRALIA

Conference Program

The three-day PTEC 2019 conference program features participants from more than 10 countries including New Zealand, the UK, USA, Canada, China, Finland, Chile, Japan and South Korea who will join a large Australian contingent.

Presenters are world-renowned experts from multiple fields and concerns regarding timber construction, from fire safety to logistics.

Registration

Registration includes lunch, morning and afternoon refreshments, Welcome Reception on Wednesday 10 July 2019 and the Banquet Dinner on Thursday 11 July 2019.

Registration closes on Friday 5 July 2019.
Full Rate – AUD$850.00
Student Rate – AUD$500 or AUD$350.00 (excluding Banquet Dinner)
Day Rate – AUD$450.00

For more details and to register go to:
www.civil.uq.edu.au/ptec-2019

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

Thank you

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Questions

Keynote Speakers

Professor José Torero
University College London

Presenting on “Explicit Design of Fire Safe Timber Structures by Separation of Risks”

Professor José L. Torero is Professor Civil Engineering and Head of the Department of Civil, Environmental and Geomatic Engineering at University College London. Professor Torero works in the field of Fire Safety Engineering where he specialises in the behaviour of fire in complex environments such as forests, tall buildings, novel architectures, tunnels, aircraft and spacecraft.

Keynote Speakers

Toby Hodsdon
ARUP

Presenting on “Our Timber Journey – using design and research to build better”

Toby is an Associate Structural Engineer with 15 years’ experience in the design and construction of building structures. He has delivered a wide range of projects in Australia and internationally, including timber structures in the UK, United States, Malaysia and Australia.

Keynote Speakers

Professor Frank Lam
University of British Columbia, Canada

Presenting on “Opportunities and Challenges in Timber Engineering Research”

Professor Lam is a Senior Chair Professor Wood Building Design and Construction. With more than 30 years research, Professor Lam has contributed towards better understanding of the performance of engineered wood products and systems. In recognition of his contribution to the knowledge of wood as an engineering material, he was awarded the L.J. Markwardt Wood Engineering Award in 1999.

Keynote Speakers

Ben Owen
Lendlease Building

Presenting on "Implementation and the buildability benefits of timber in construction"

Ben is the Senior Construction Manager with Lendlease Building (ACT). Ben was the Senior CM on the recent ANU redevelopment, a residential hall that is the first student residence in Australia to be built with cross laminated timber, an engineered wood that is making the construction of timber buildings a reality.

Keynote Speakers

Professor Minjuan He
Tongji University, China

Presenting on "The Recent Development on Timber Engineering in China - Research, Codes and Construction Projects"

Professor He has been working at Tongji University as a full Professor of structural engineering since 2001. She is active in academic activities on timber engineering. Her research interests include load bearing capacity of timber connections, lateral resistance and seismic performance of timber structures, structural performance of wood based hybrid constructions and so on. She has published more than 200 academic papers.

Keynote Speakers

Anna Charalambous
Lendlease DesignMake

Presenting on “The evolution of mass timber from a Lendlease perspective and the future direction of utilising digital design and manufacturing principles.”

Anna is a qualified Industrial Designer and Project Manager with Lendlease DesignMake business which focuses on applying advanced design, manufacturing and assembly principles to the mass timber built form.