Structural fire simulations in timber heritage buildings

WULAN SHOFA AISYAH

University College London

Supervisors:
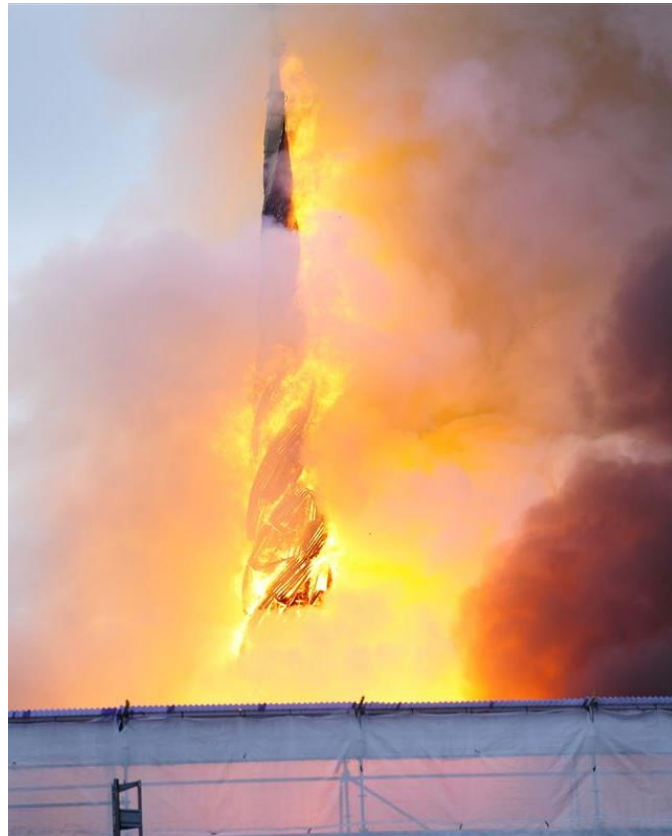
Jose Torero Cullen, Augustin Guibaud, Alejandra Albuerne

Structures in Fire Forum – May 2024

Recent fires in historic buildings

Before fire

16 April 2024
Børsen fire, Copenhagen

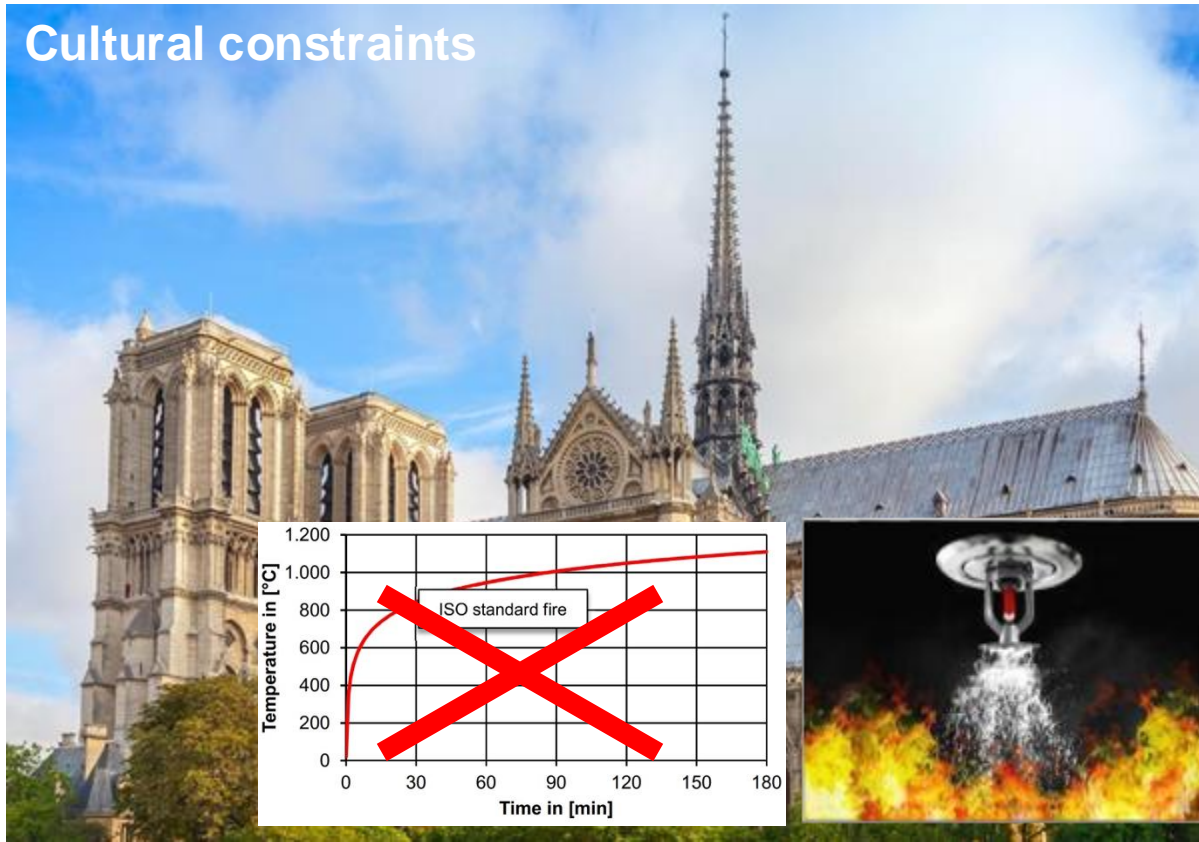**15 April 2019**
Notre Dame fire, Paris

After reconstruction

Fire protection: historic structures are not old versions of modern buildings
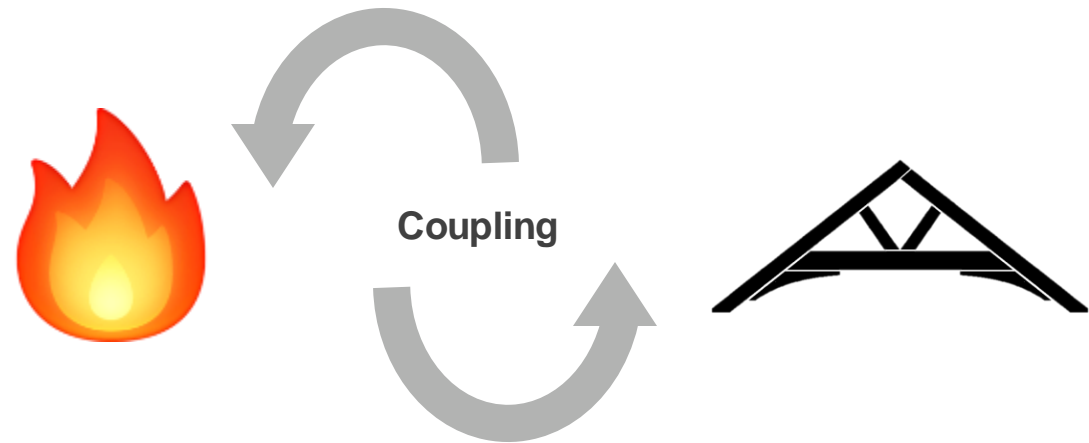

Cultural constraints

Combustible structure

Can numerical modelling predict the failure mechanisms of a historic timber structure in a fire?

Methodology:

1- Develop and validate a large-scale fire model

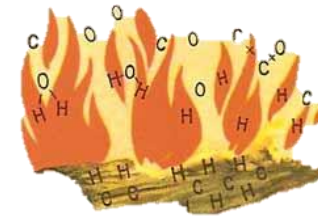2- Develop and validate a structural model

3- Integrate coupling mechanisms

Coupling

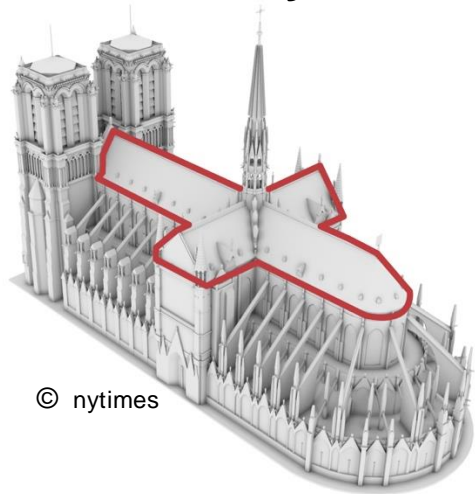# 1- Fire modelling: Computational Fluid Dynamics (CFD)
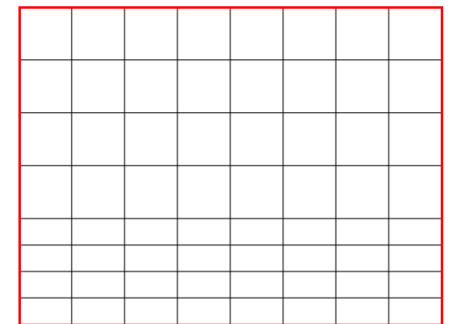
Material properties

Chemistry

Geometry

Mesh and boundaries

© nytimes
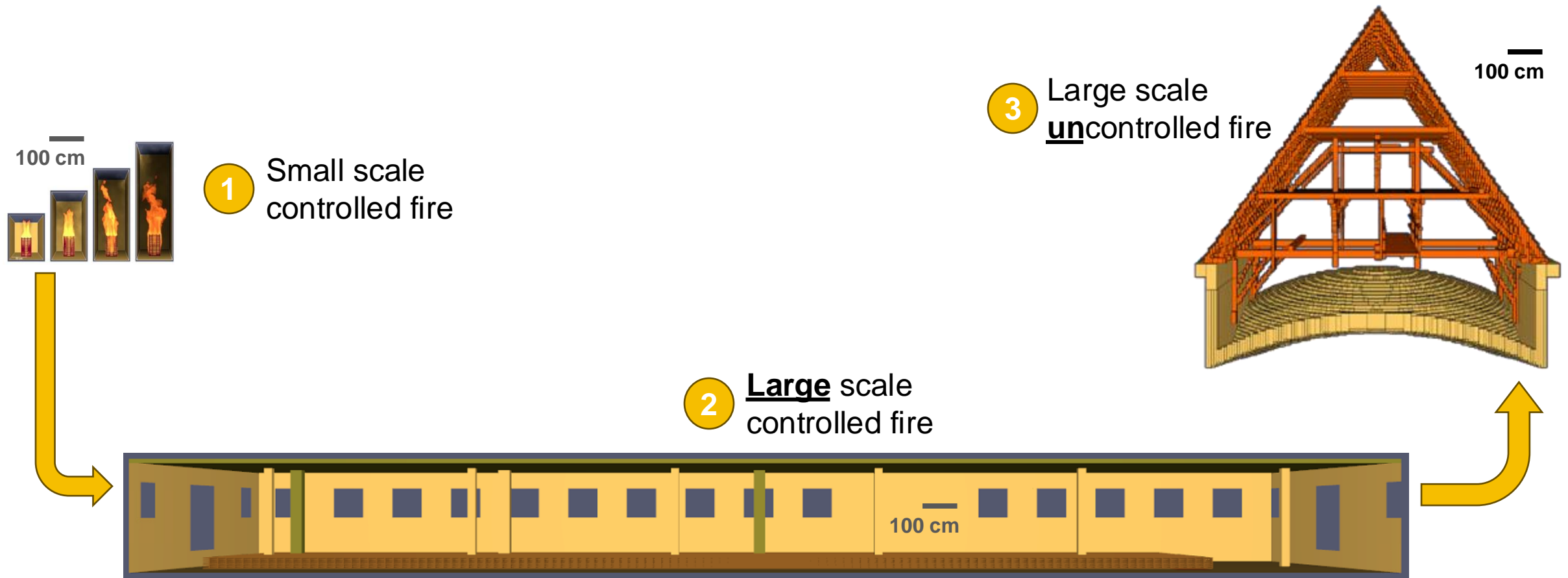
Dozens of degrees of freedom in the model !

Structural interaction

Initial conditions

1- CFD validation: learning across scales

1 Small scale controlled fire

100 cm

2 **Large** scale controlled fire

100 cm

3 Large scale **un**controlled fire

100 cm

1.1-Small-scale validation: Delichatsios, 1976
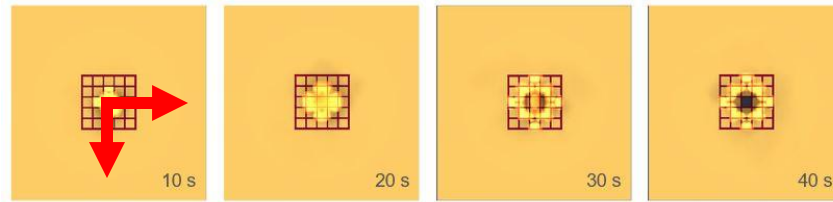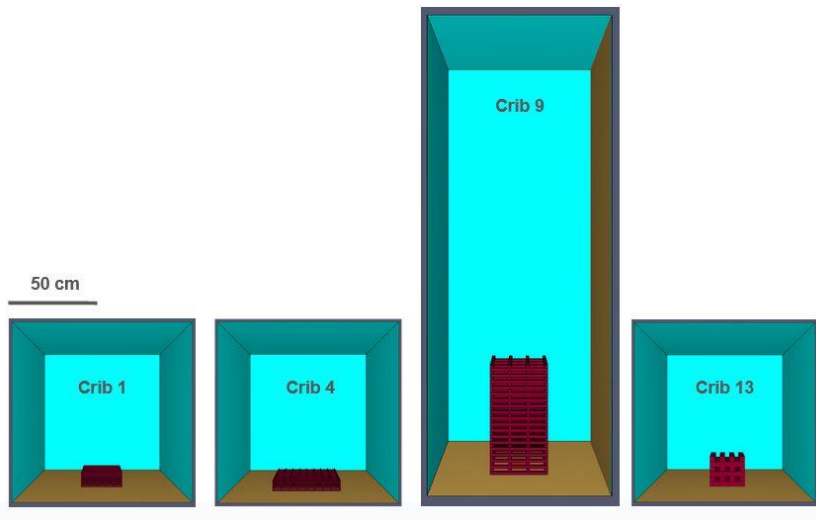
Spread rate (mm/s)				
Crib number	1	4	9	13
Experiment	1.9	1.3	4.6	2.4
Simulation	3.0	0.8	6.2	22.0

- Right mechanism, overall good agreement of flame spread rates
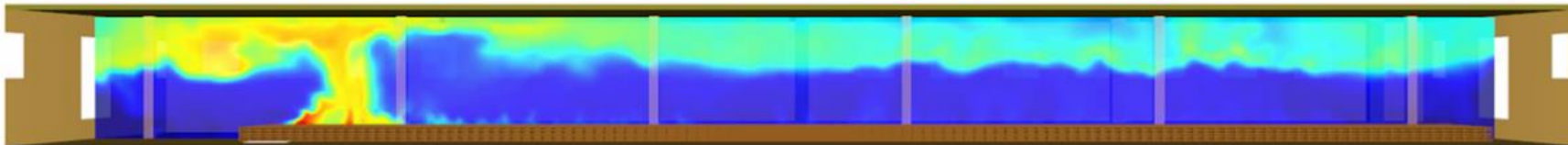- Need improvement: Influence of element size
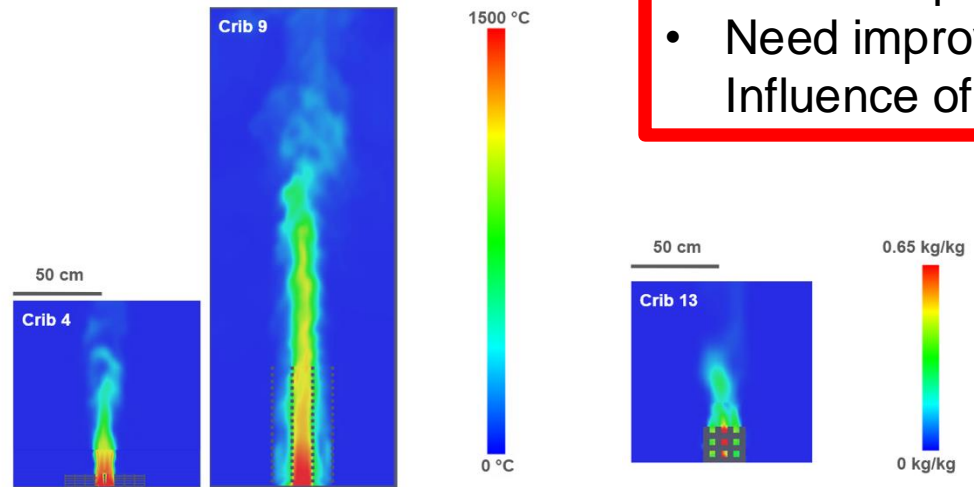
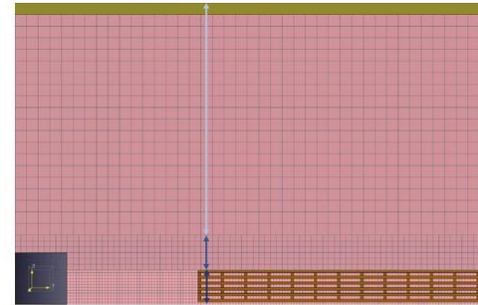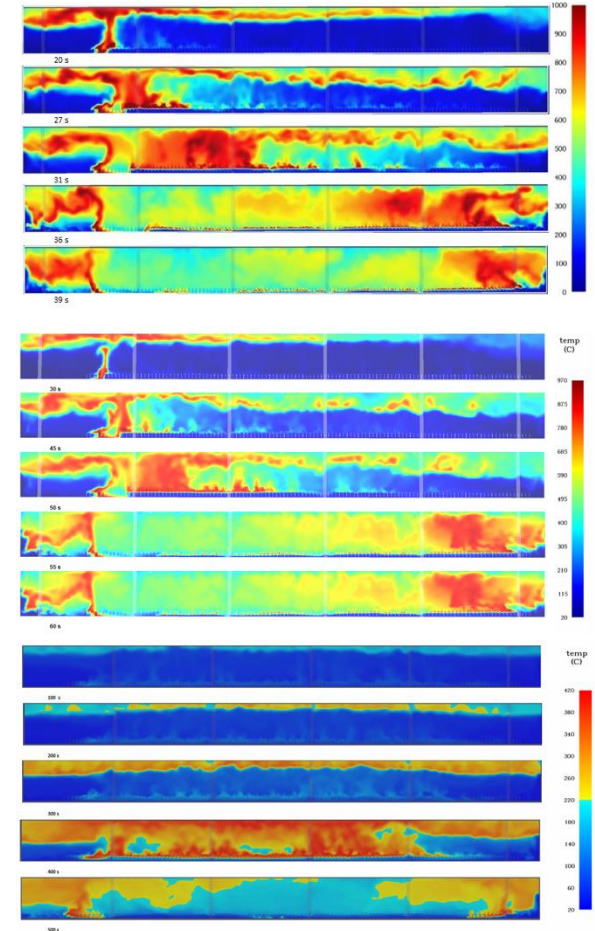# 1.2-Large-scale validation: CodeRed, 2021

© Arup
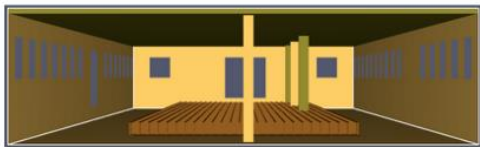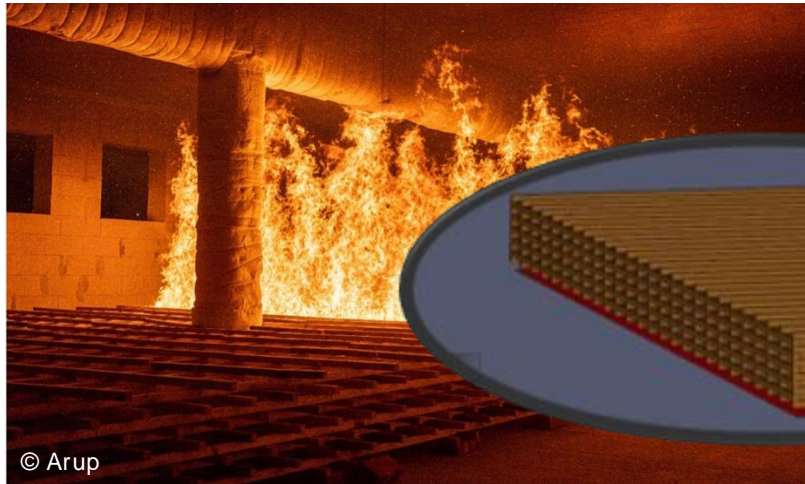
100 cm

Flame Spread Rate

100 cm

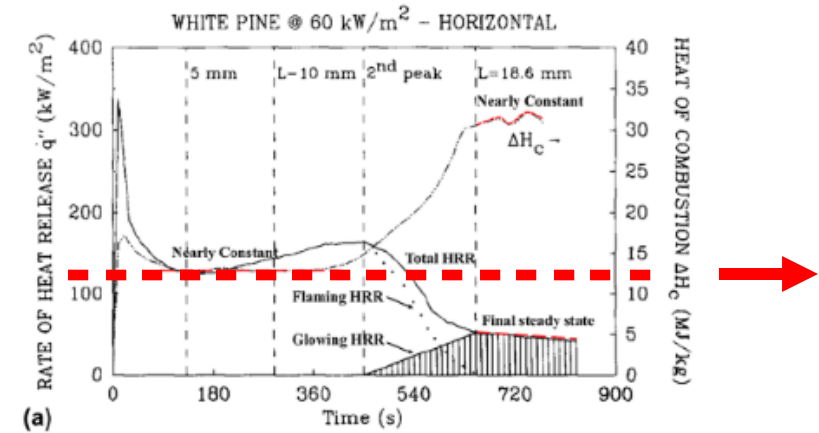Heat of Combustion:
19 MJ/kg
15 MJ/kg
11 MJ/kg

1.2-Large-scale simulation: heat of combustion

- Can capture the burning mechanism, but much faster flame spread rates
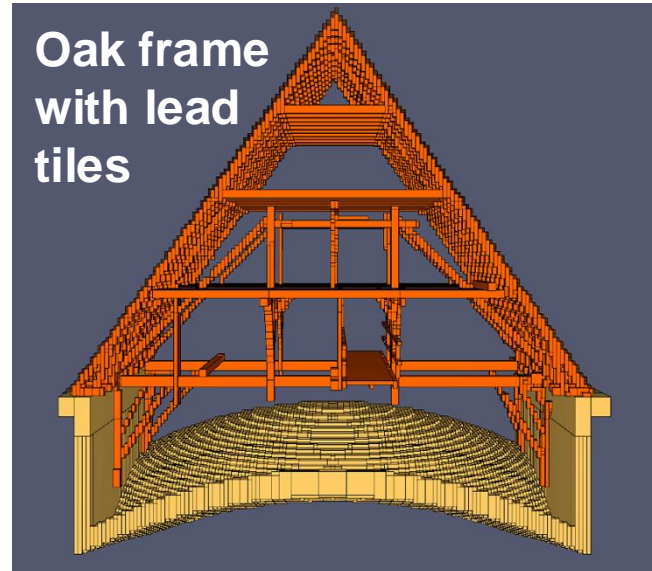- Flaming and glowing combustion → Heat of combustion

1.3- Extracting data from the 2019 Notre Dame fire
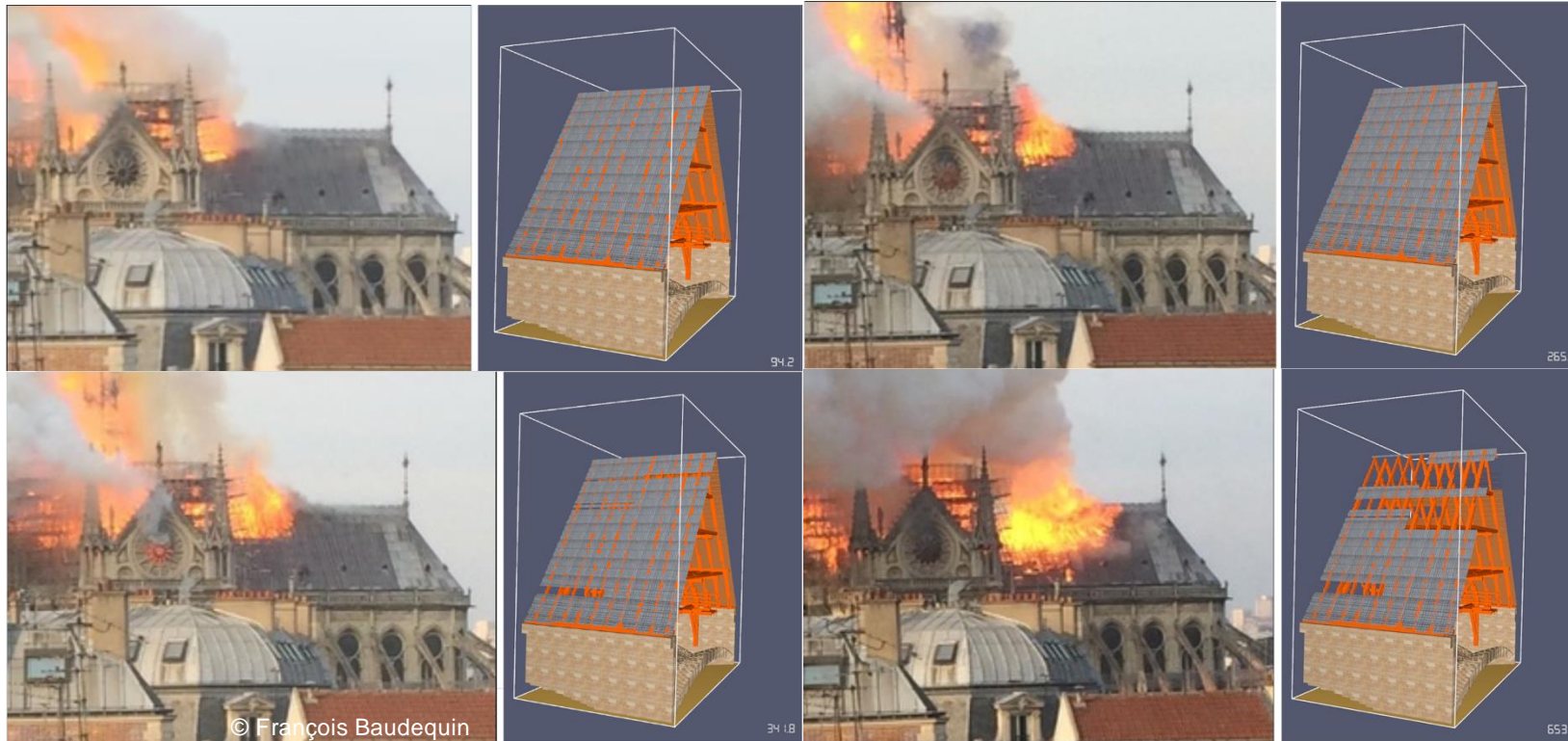

Reaction definition

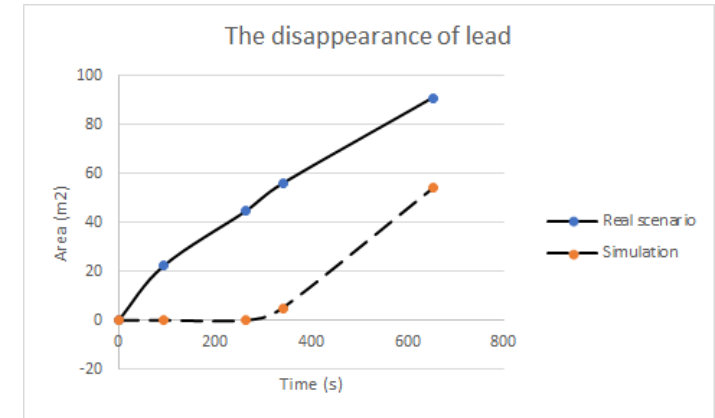**Oak frame with lead tiles**

1.3- Extracting data from the 2019 Notre Dame fire

© François Baudequin

- Can reproduce indirect observations
- Location is not well captured

The disappearance of lead

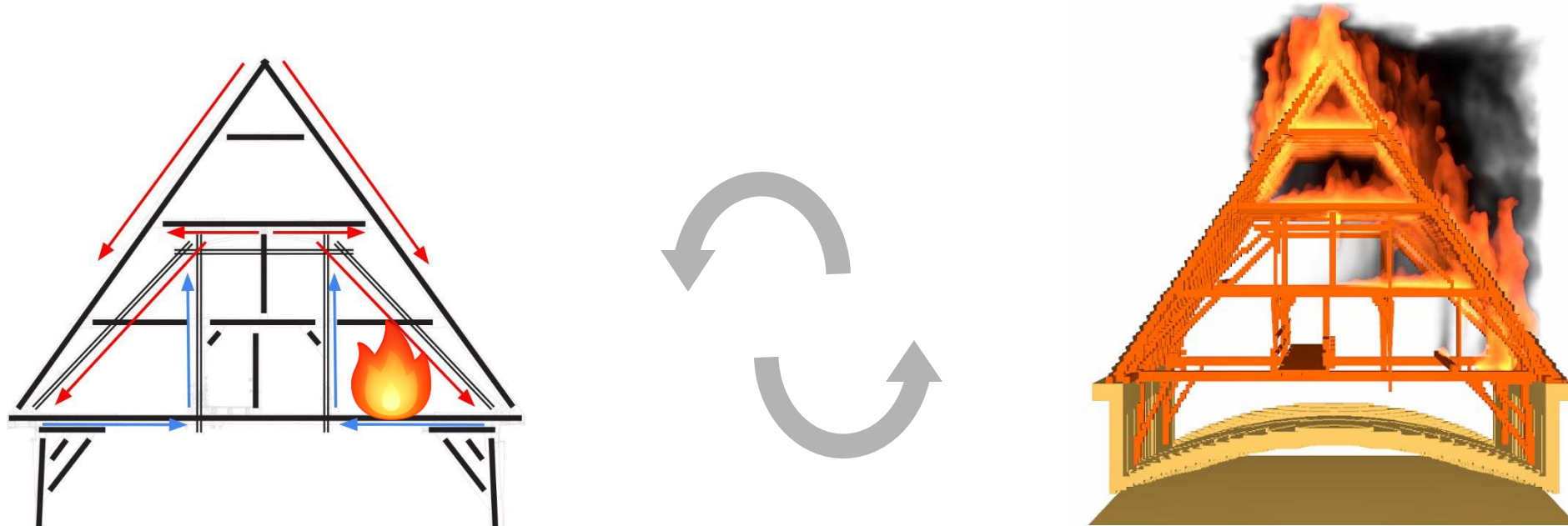# 2- 2D structural model of an A-frame before the fire
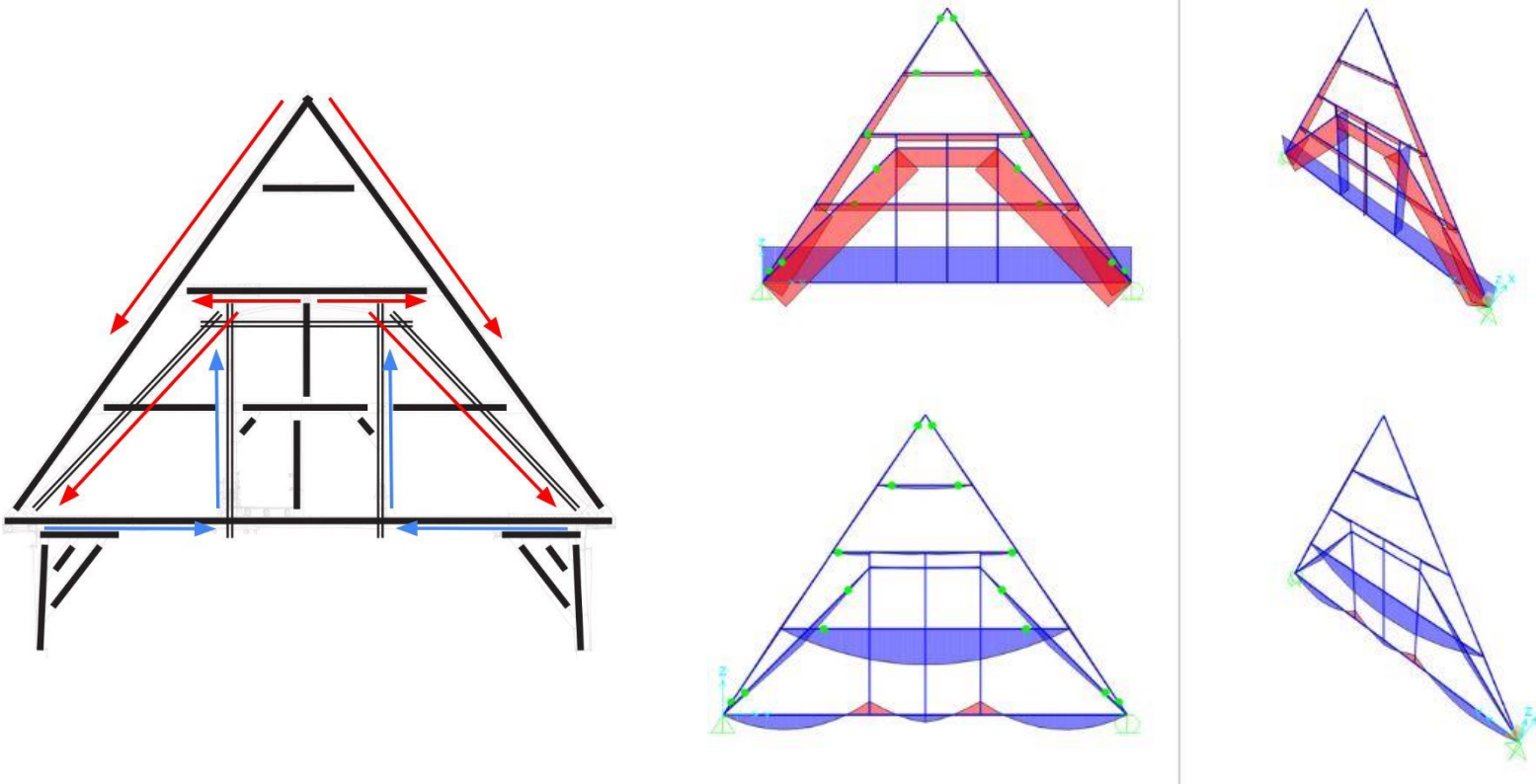
3- Future works: fire modelling → structural modelling

Heat flux

- Thermal model
  Temperature within the material

- Mechanical model
  Reduction in strength and expansion

3- Fire-structure interaction during the fire

- Batten and lead disappear
- Elements failure
- Develop a pile of fuel beneath the structure

Conclusions

🔥

1- Fire modelling
CFD can adequately capture the fire mechanism, however, the definition of the heat of combustion in large-scale simulation has a significant influence and needs further investigation.

Future works:

2- Structural modelling
Future works regarding structural analysis, with a multi-scale approach where analysis of the joints and elements are being done.
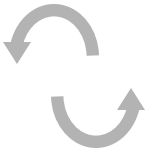
3- Fire-structure interaction → Improving fire strategies
Fire modelling: temperature field, visibility
Structural models: critical elements, collapse mechanism

Thank you for your attention! Any questions?

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