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*maîtriser le risque
pour un développement durable*

TOWARDS MODELLING THE INTERACTION OF UNDER- VENTILATED FIRE WITH WATER MIST CASE: NOTRE-DAME

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Context and objectives

2019, Avril the 15th : Tragic fire at Notre-Dame Cathedral in Paris

- Decision to rebuild the building exactly as it was historically
- Timber frame and lead roofing

Fire safety to be improved

- Fire safety system design
- Numerical modelling as a tool
- Highly specific configuration



A strategy to define safety systems

Highly specific configuration

- Unusual fire load with numerous pieces of wood
- A particular behaviour of the lead cover
- Impossibility to apply standard systems
 - Smoke vents, sprinkler, fire wall, ...

A need to integrate safety concepts into the architectural constraints

- 2 main steps
- Passive system to limit the fire spread
- Fire fighting system with a limited consumption of water

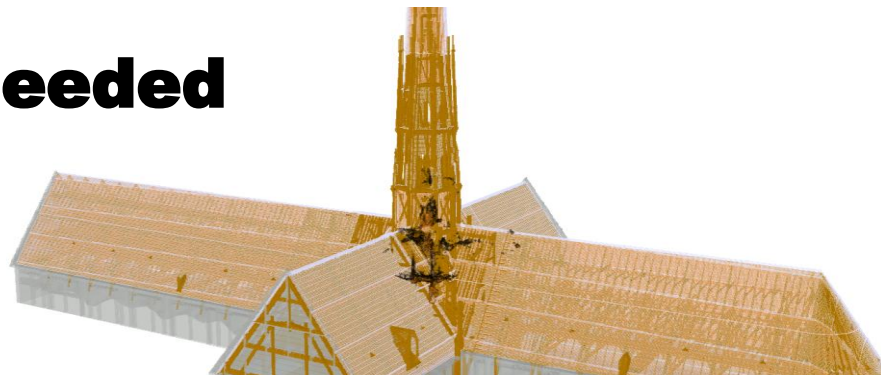


Coupling modelling and experiments is crucial in such an unconventional configuration

A fire modelling tool is needed

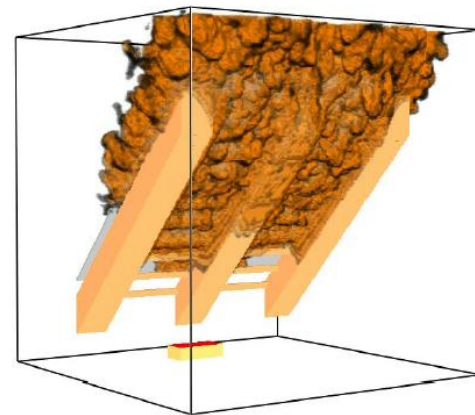
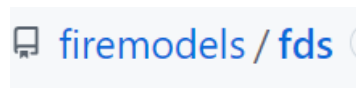
Criteria for selecting the calculation tool

- Ability to model fire spread
- Ability to predict the effects of protective measures as the modification of roof battens that support the lead
- Modification of fire ventilation: fire / ventilation interaction
- Influence of fire fighting system (water mist)
- The ability to model a fire in the cathedral's entire roof structure



Selection criteria

- Propagation : Not acceptable to use a prescribed propagation curve
→ fire spread SHOULD be computed
- Pyrolysis to be accounted for
 - 2 step combustion
 - Reference temperature and pyrolysis zone



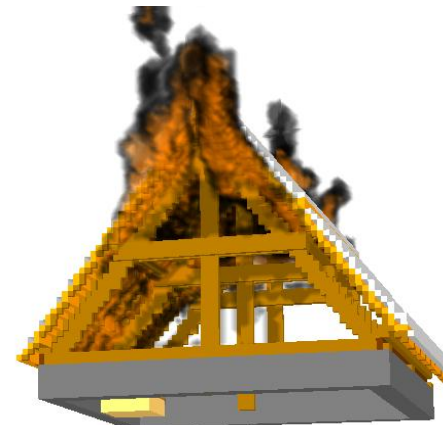
With a specific validation

First simplified validation

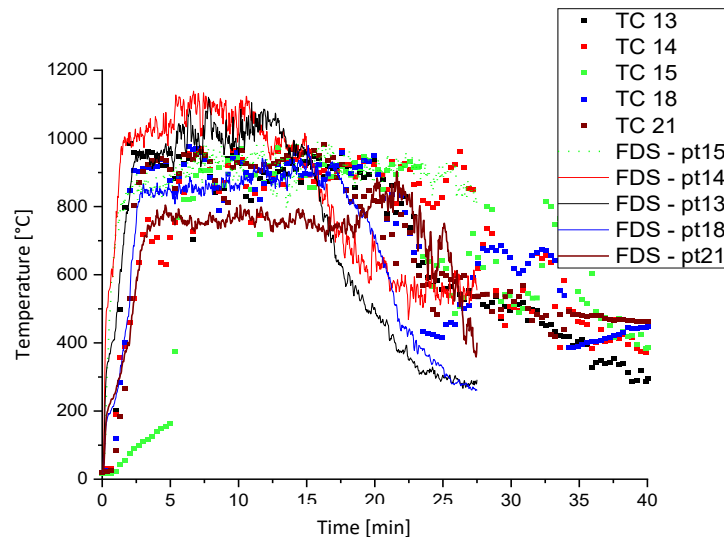
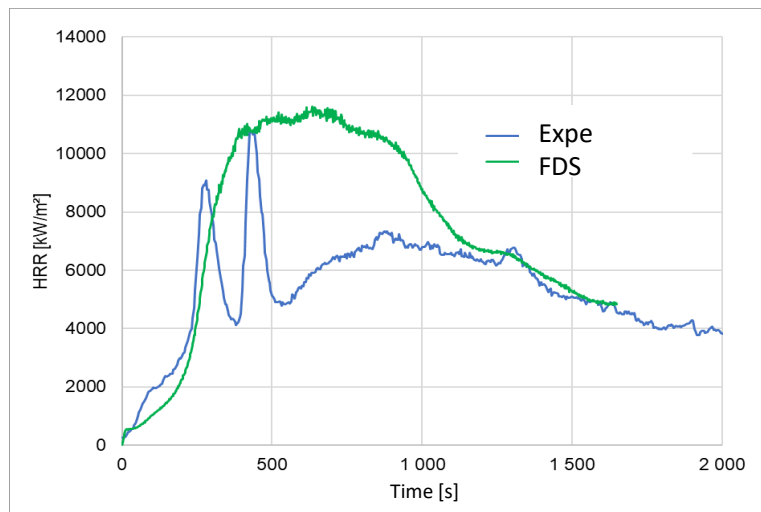
- Pine based structure instead of oak
- Aluminium cover instead of lead by modifying the cover thickness to get the same thermal loading
- Small scale mock-up : 5 x 5 m x 4 m

Validation of

- The fire spread through the HRR curve (OC and CDG calorimetry)
- The flame global geometry and behaviour
- The temperature range



A quite good comparison

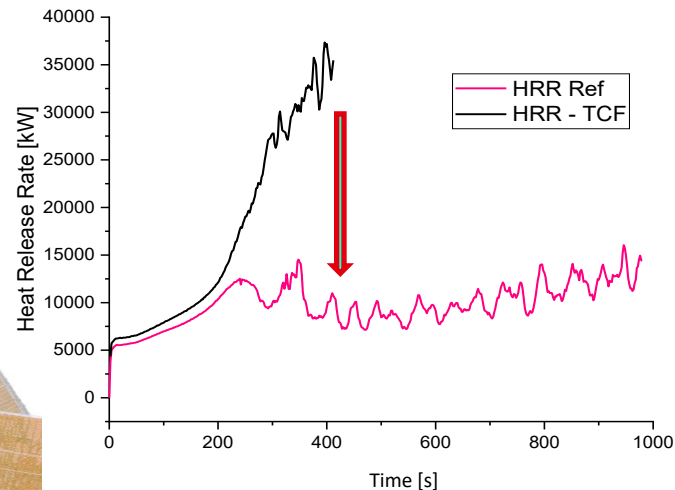
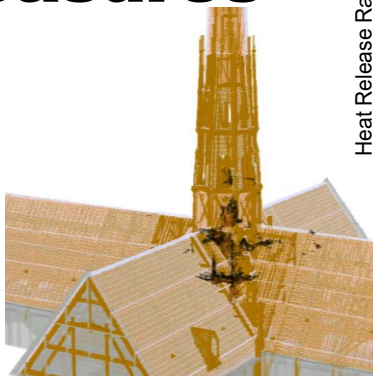


Step 1: Passive measures

A requirement: understand the fire propagation mechanism

A specific fire wall

- Prevent the spread between parts of the roof structure
- To control the fire ventilation



Increase of the wood battens

- fire ventilation control by the limiting the flow through the cathedral spire
- potential under-ventilated fire



Step 2: Fire fighting system

Specific constraints due to the cathedral characteristics

- Limitation of the total amount of water
- A dense cluster of wooden pieces
- Should be efficient wherever the ignition occurs

Testing the fire fighting system characteristics is not realistic

- Water mist should be designed thanks to numerical modelling
- 0.4 validation fire test
 - With the three-bay layout of the cathedral's nave (about 7 m x 7 m x 7 m)
 - A roof of hammered lead laid over the battens
- Strong ignition (1 MW)
 - Fast initial fire spread
 - Sizing conditions for the fire fighting system



Numerical evaluation

Several water mist distribution and characteristics

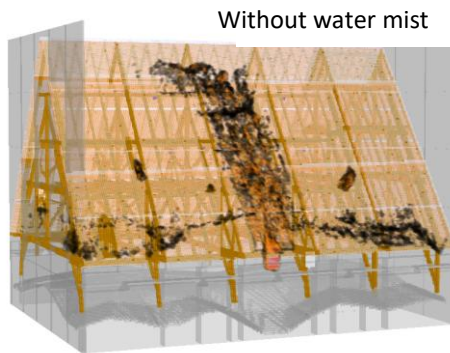
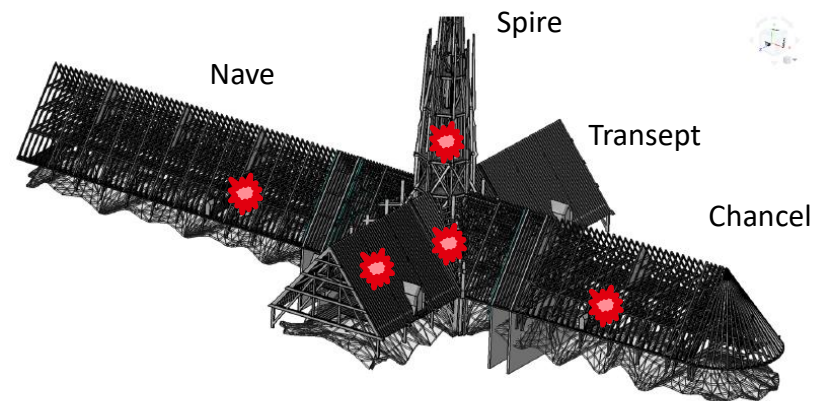
4 different ignition locations:

- Fire starting in the nave, similar to the case of the chancel
- Fire starting in a transept
- Fire starting in the spire
- Fire starting at the base of the spire

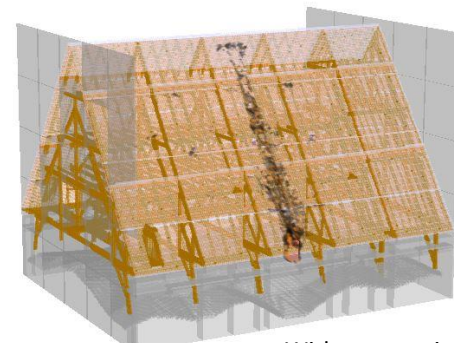
Evaluation of water mist influence on the fire propagation and temperature reached

The geometry consider the passive protection

High positive influence of the water mist



Without water mist



With water mist

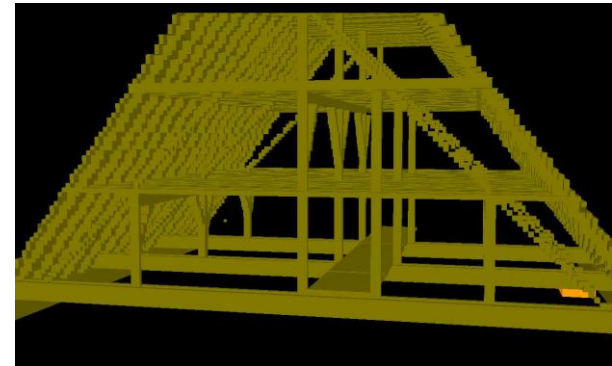
Validation remains needed

Experimental comparison for the designed configuration (nozzles position and characteristics, pressure, ...)

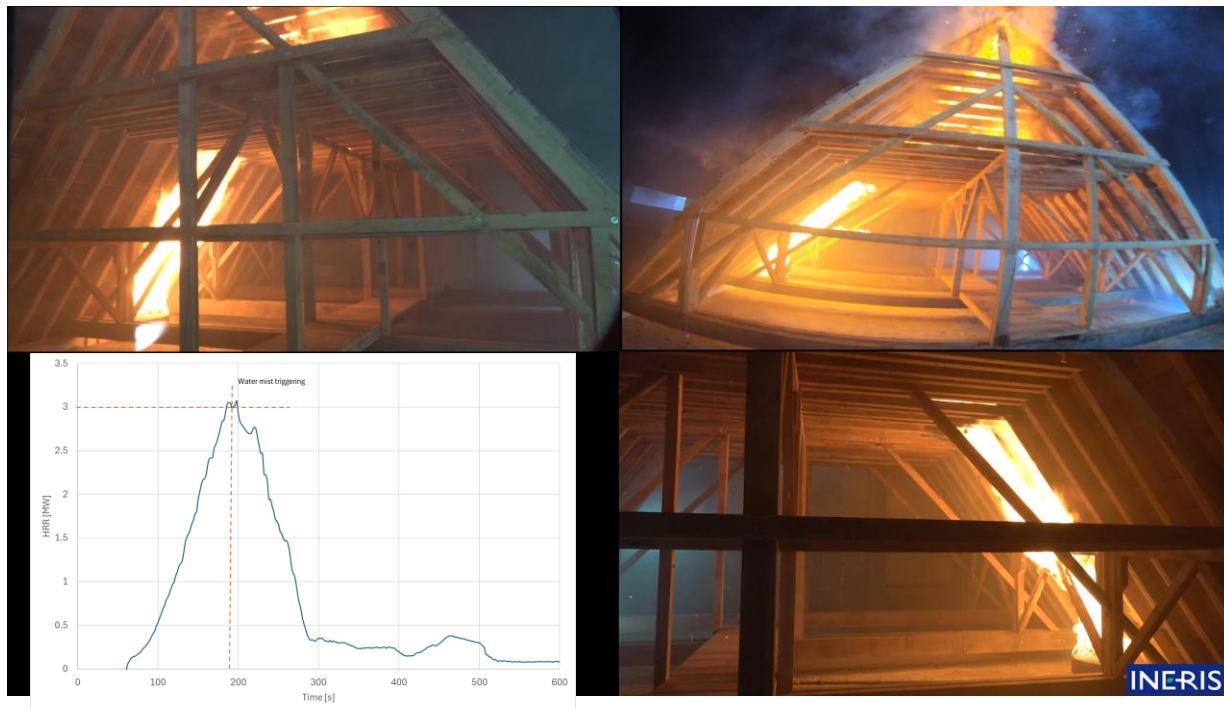
- At a given scale: 0.4 → scaling must preserve the physics
- Dimensionless number scaling
- Controlled parameter: the wood humidity

Comparison in terms of

- The HRR curve with a similar maximum value
 - Without water mist ≈ 45 MW, limited to 3 MW with the extinction system
- The numerical propagation is faster than the experimental one
- Quite good prediction of the water mist influence



An insight of the water mist efficiency

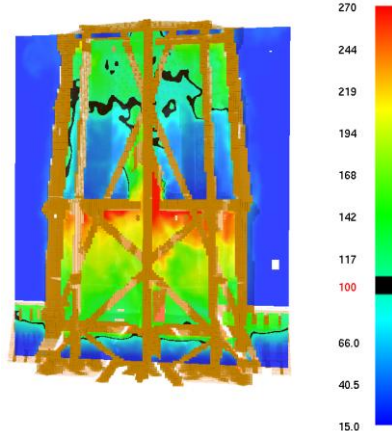


System efficiency

An impressive demonstration thanks to

- A large-scale test (0,4)
 - Geometry and water mist scaling
 - Fire control as soon as the system is activated
- Several numerical models
 - Integration of the multiplicity of fire ignition
 - Modelling of the full geometry

Before triggering



After triggering

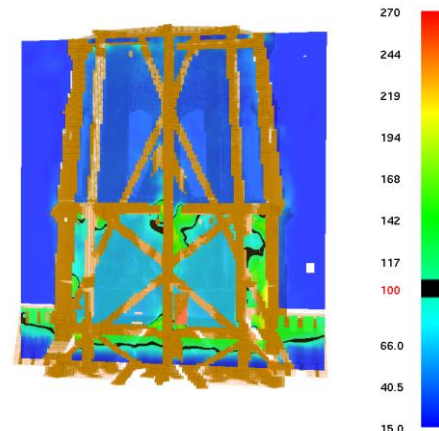


Table 1
Froude-based scaling laws.

Scaling parameters	Any Re_d regime
Droplet drag coefficient	$\propto Re_d^{-1}$
Dimension	S^1
Time	$S^{1/2}$
Operating pressure	S^1
All scalar parameters except droplet number density	S^0
Droplet number density	$S^{(2\alpha - 6)/(2\alpha - 2)}$
Velocity	$S^{1/2}$
Ventilation rate	$S^{5/2}$
Fire heat release rate	$S^{5/2}$
Total water discharge rate	$S^{5/2}$
Droplet size	$S^{(2 - \alpha)/(2 + 2\alpha)}$



The work in a nutshell

A safety measures design for a non-conventional structure including

- Evaluation of the FDS software in relation to full-scale tests
- Massively parallel use of the code (up to 1,028 processors)
- Modelling of fire spread in a timber structure
- Effect of ventilation and evaluation of passive measures
- Performance in modelling water mist

And then : A dedicated research program on this topic

