Consequence-oriented fire intensity optimisation for structural design under uncertainty

A. Franchini, C. Galasso, J. L. Torero

Structures in fire forum

London, 29-07-2023

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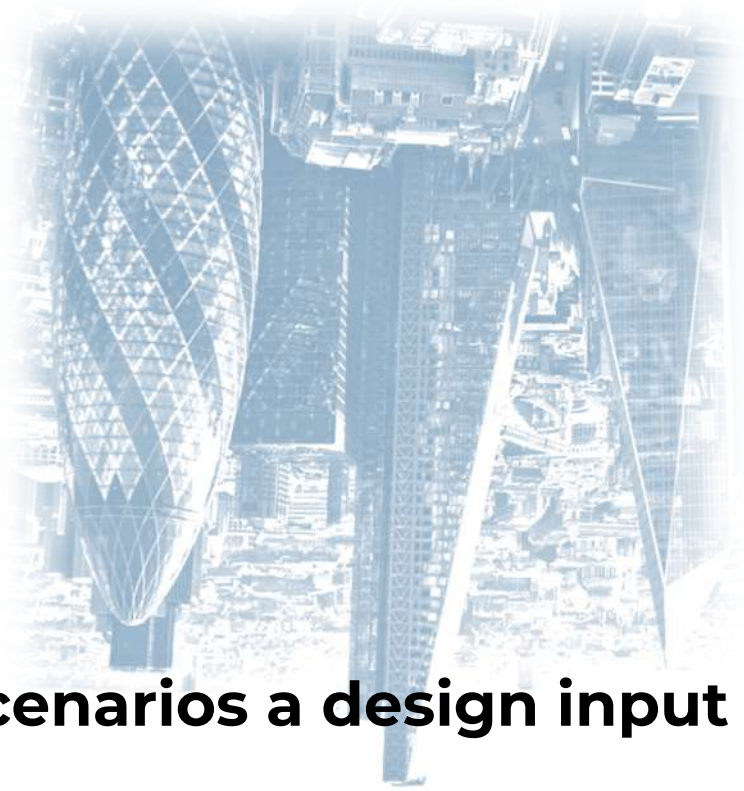
ndrfranchini.github.io/



Are fire scenarios a design input or output?

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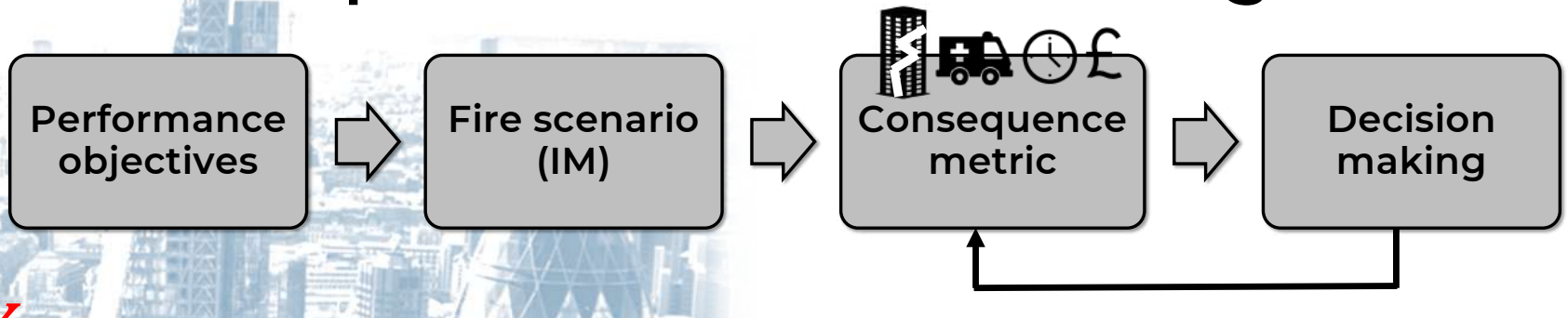
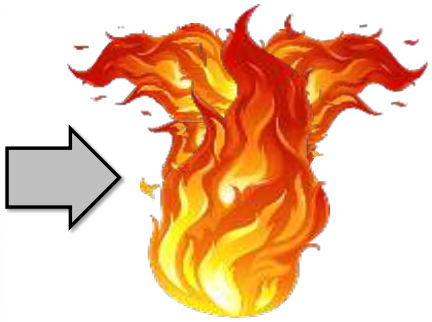
Probabilistic performance-based design



Fire **I**ntensity **M**easure?

$$T_{beam} = f(\boldsymbol{p}, time, Design\ var.\boldsymbol{X}, \dot{q}''(..., \boldsymbol{X}_{strat}, fuel))$$

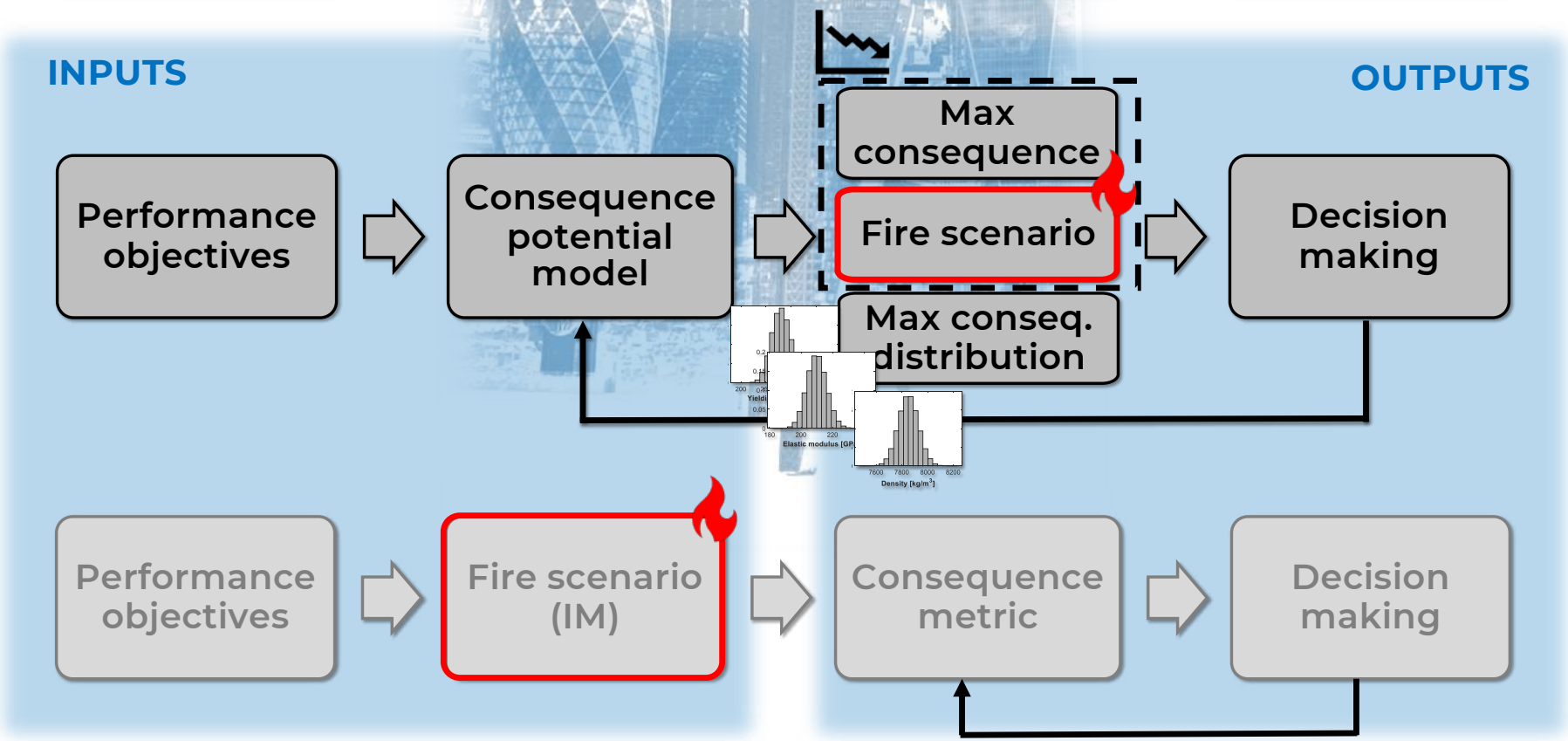


The structure defines fire intensity

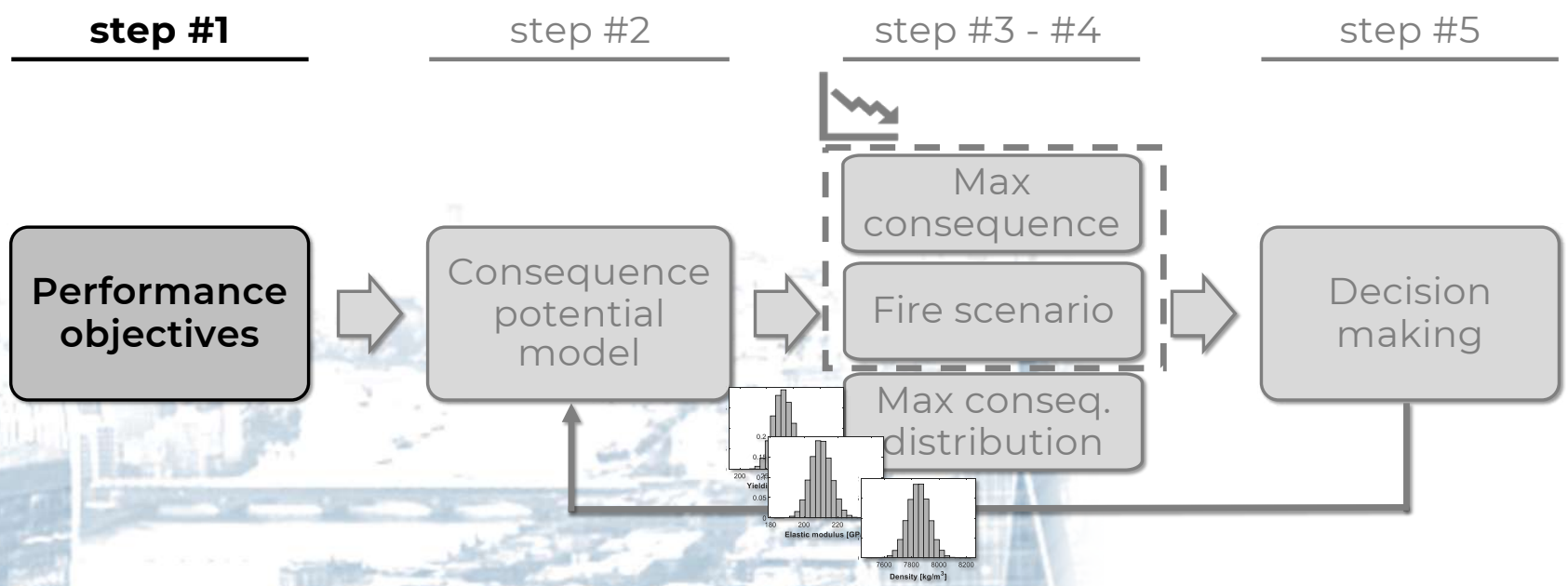
Fire scenarios can be design variables!

Fire intensity → 0?

Consequence-oriented Fire intensity Optimisation

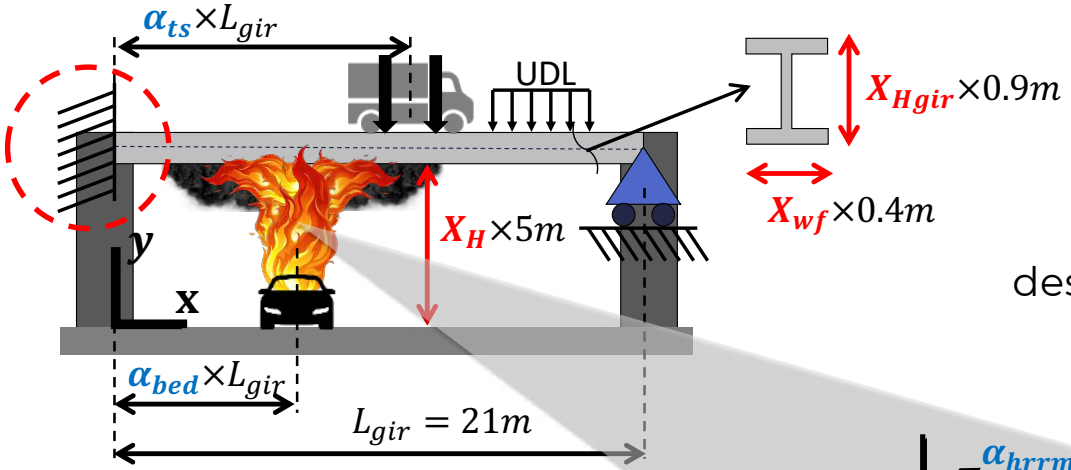


Illustrative example



Illustrative example

PERFORMANCE OBJECTIVES AND INITIAL DESIGN

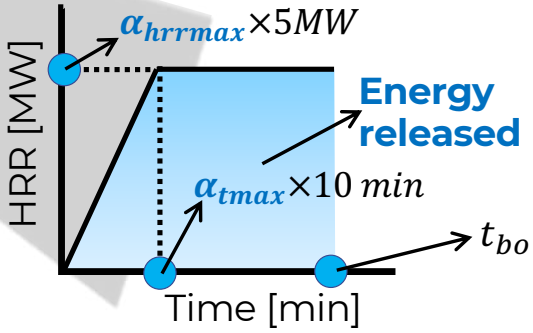


Objective

Time to collapse:
$t_c(\boldsymbol{X}, \boldsymbol{\alpha}) \geq 20\ min$

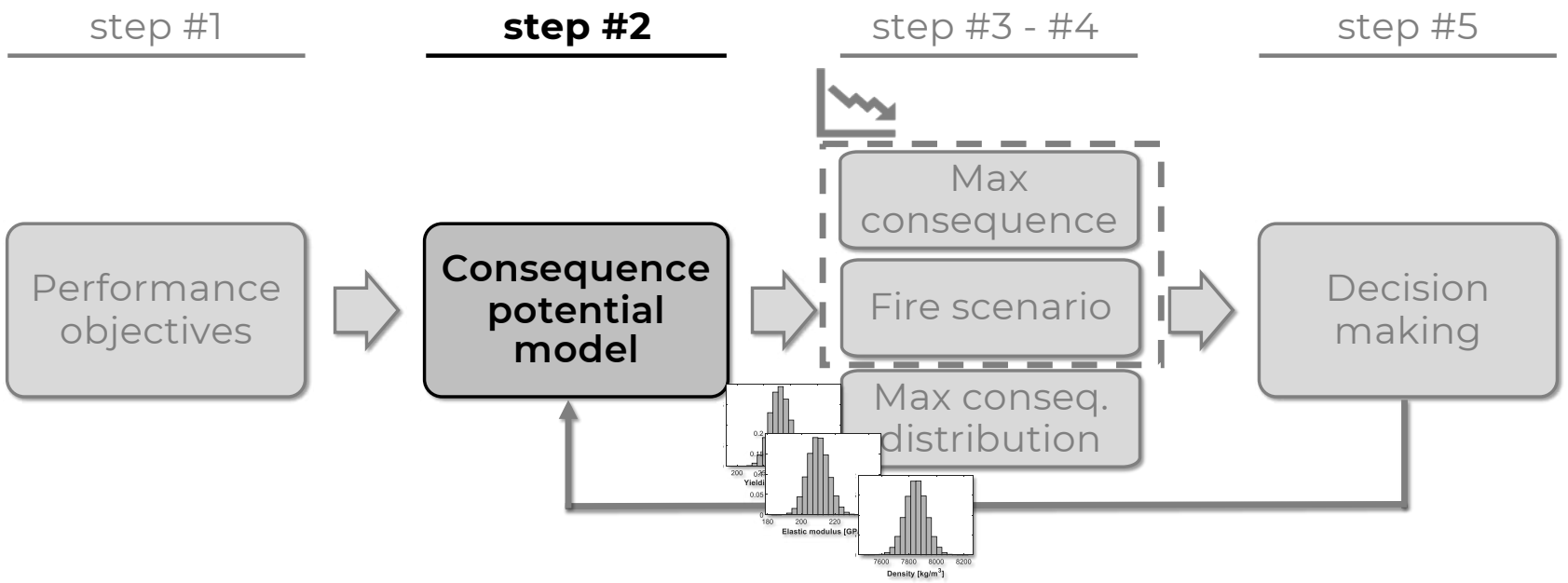
design variables fire scenario variables

Design variables	
X_H	Bridge clearance
X_{Hgir}	Girder height
X_{wf}	Flange width



Mohod Tohir and Sperarpoint, 2013

Illustrative example



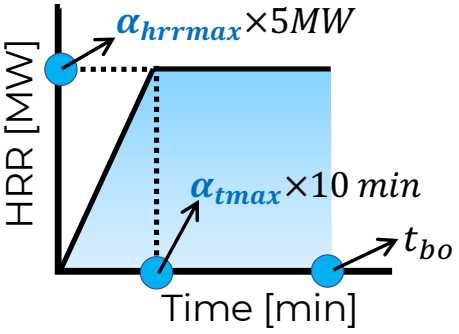
Illustrative example

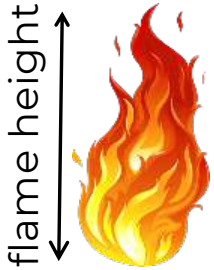
CONSEQUENCE POTENTIAL MODEL

$t_c(\boldsymbol{X}, \boldsymbol{\alpha})$

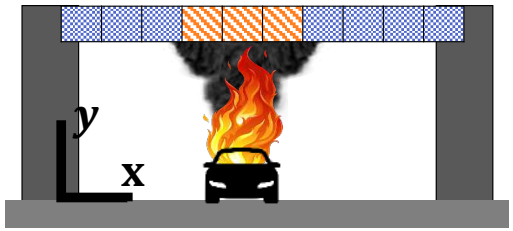
design variables fire scenario variables

Fire modelling → **Thermal response** → **Structural response**

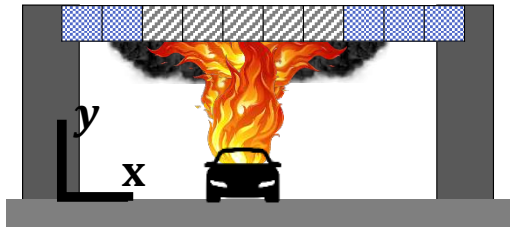




No flame impingement



Flame impingement



Point source Heskestad's correlation
Convective heat flux $\dot{q}'' = 85kW/m^2$

Illustrative example

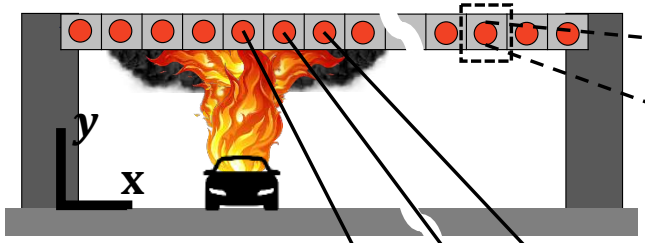
step #1 | **step #2** | step #3 - #4 | step #5

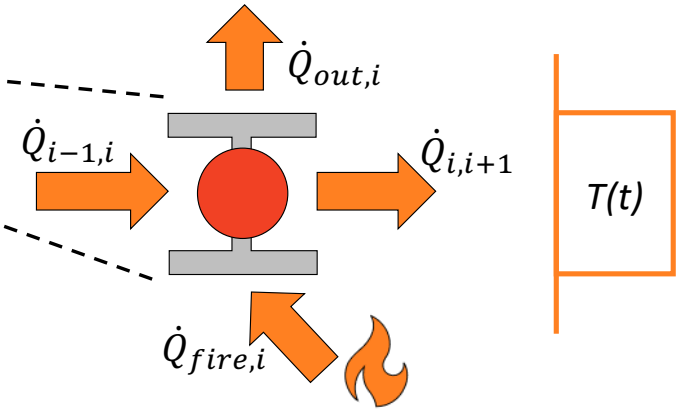
CONSEQUENCE POTENTIAL MODEL

$$t_c(\boldsymbol{X}, \boldsymbol{\alpha})$$

design variables — fire scenario variables

Fire modelling → **Thermal response** → **Structural response**





$$\Delta T_i = \frac{dt}{V_i \rho c_p(T)} \times \left(\dot{Q}_{fire,i} - \dot{Q}_{out,i} + \dot{Q}_{i-1,i} + \dot{Q}_{i,i+1}\right)$$

Illustrative example

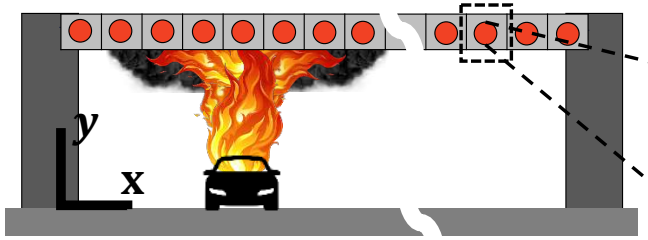
step #1 | **step #2** | step #3 - #4 | step #5

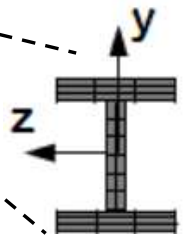
CONSEQUENCE POTENTIAL MODEL

$$t_c(\boldsymbol{X}, \boldsymbol{\alpha})$$

design variables fire scenario variables

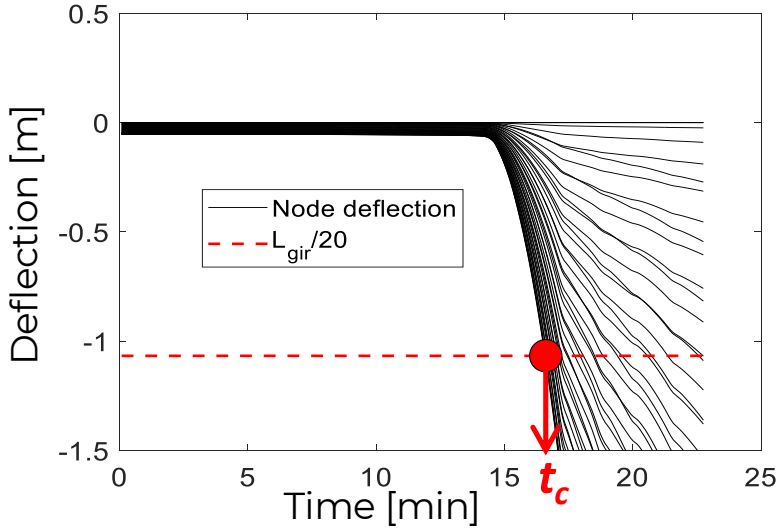
Fire modelling → **Thermal response** → **Structural response**



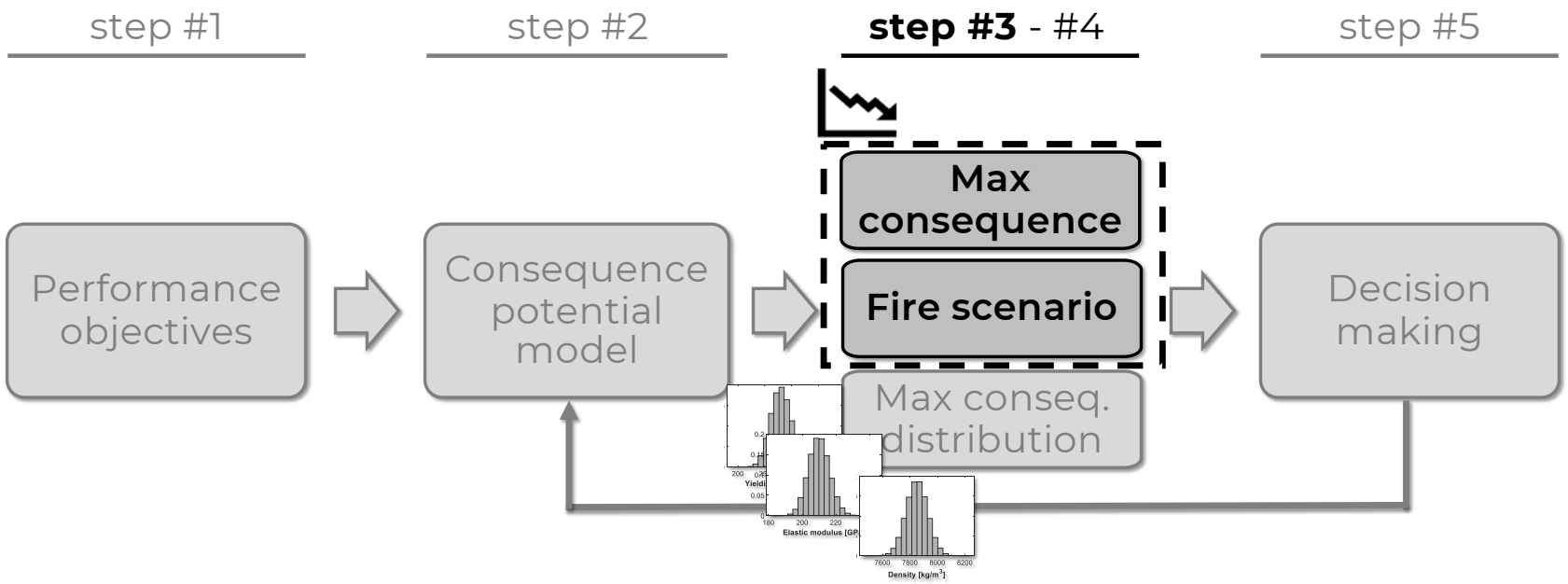


OPENSEES FOR FIRE

Thermal fiber section
Material: Steel01Thermal
Elements size: 0.50 m



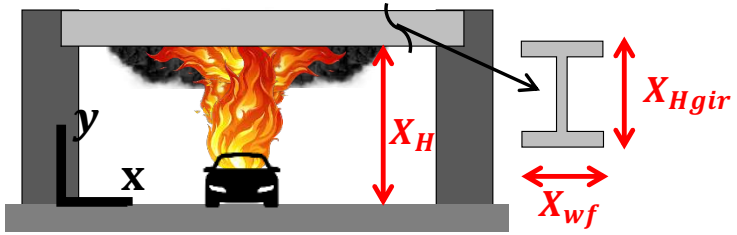
Illustrative example



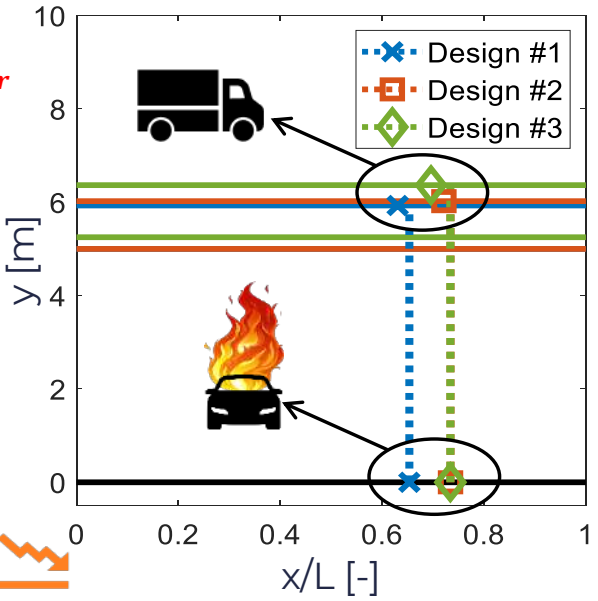
Illustrative example

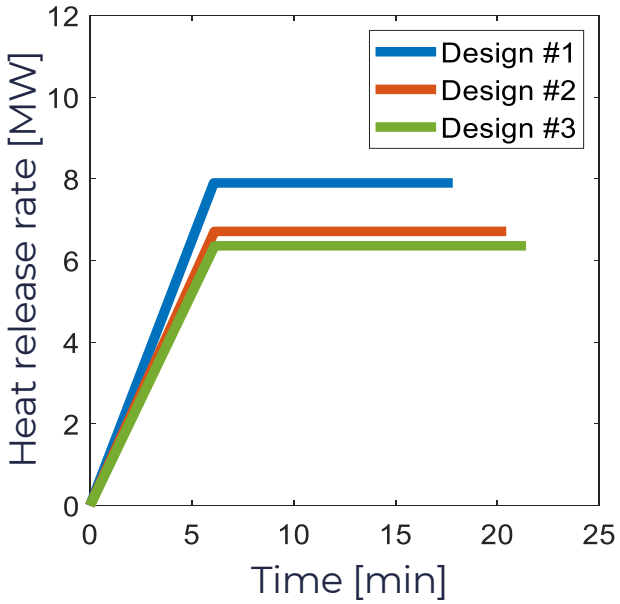
step #1 | step #2 | **step #3** - #4 | step #5

CALCULATE MAX CONSEQUENCE AND FIRE SCENARIO



Design	#1	#2	#3
X_H [-]	1.00	1.00	1.05
X_{Hgir} [-]	1.00	1.10	1.20
X_{wf} [-]	1.00	1.20	1.15
t_c[min]	11.47	19.33	20.23





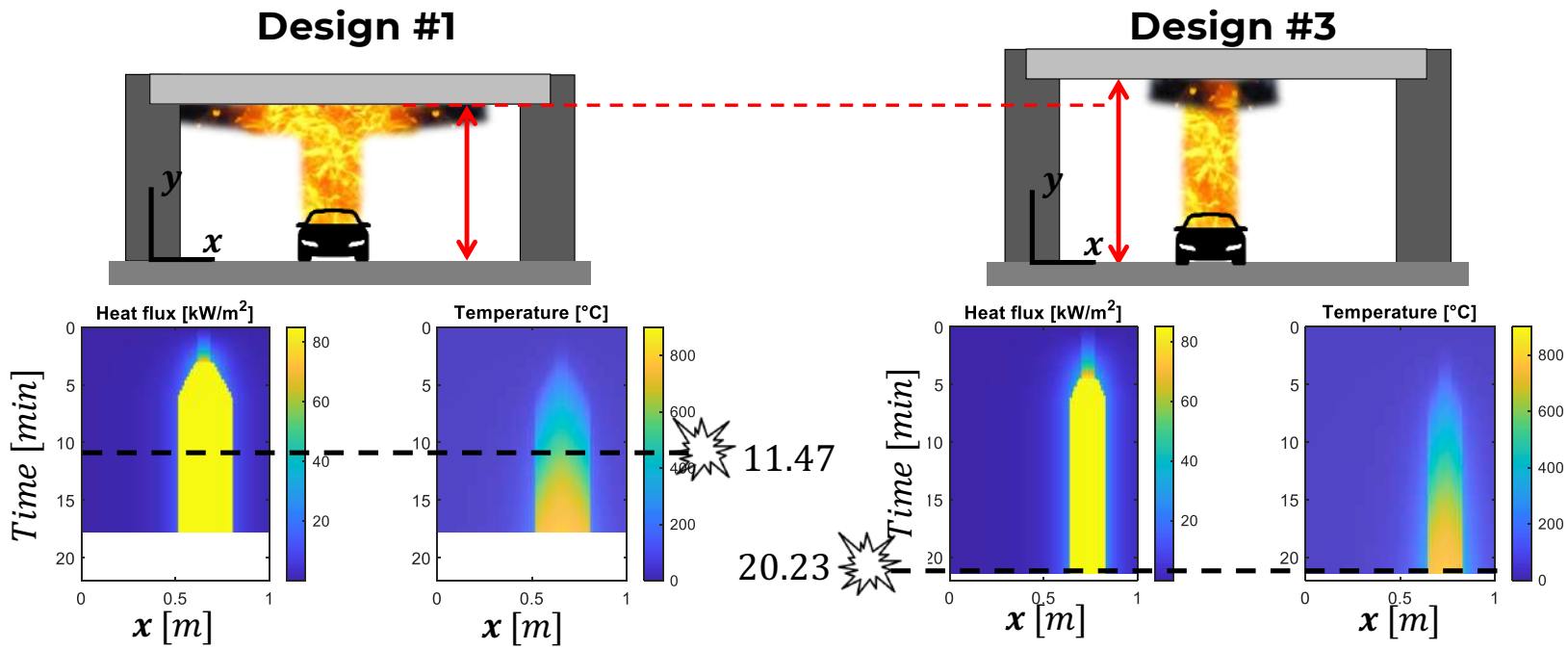
Fire scenarios maximising consequences are structure-specific.

Illustrative example

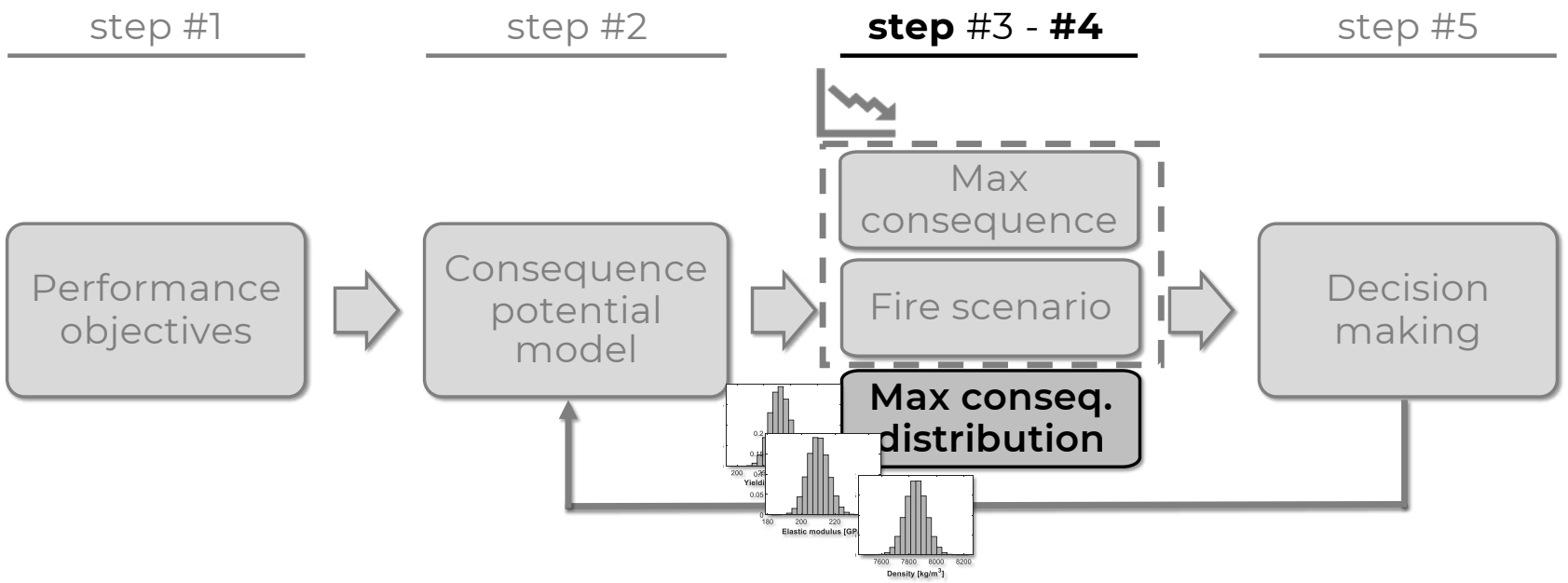
step #1 | step #2 | **step #3** - #4 | step #5

CALCULATE MAX CONSEQUENCE AND FIRE SCENARIO

CFO: design both the fire and the structure!

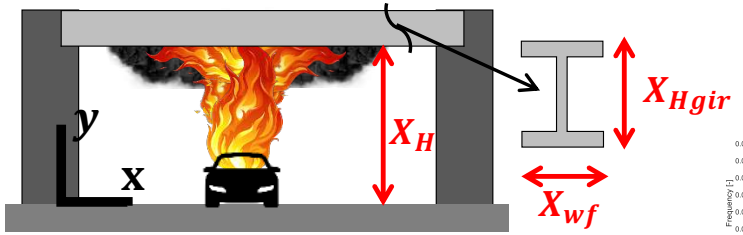


Illustrative example



Illustrative example

INPUT UNCERTAINTY EFFECT (STEEL MATERIAL)



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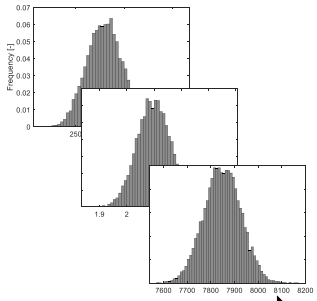
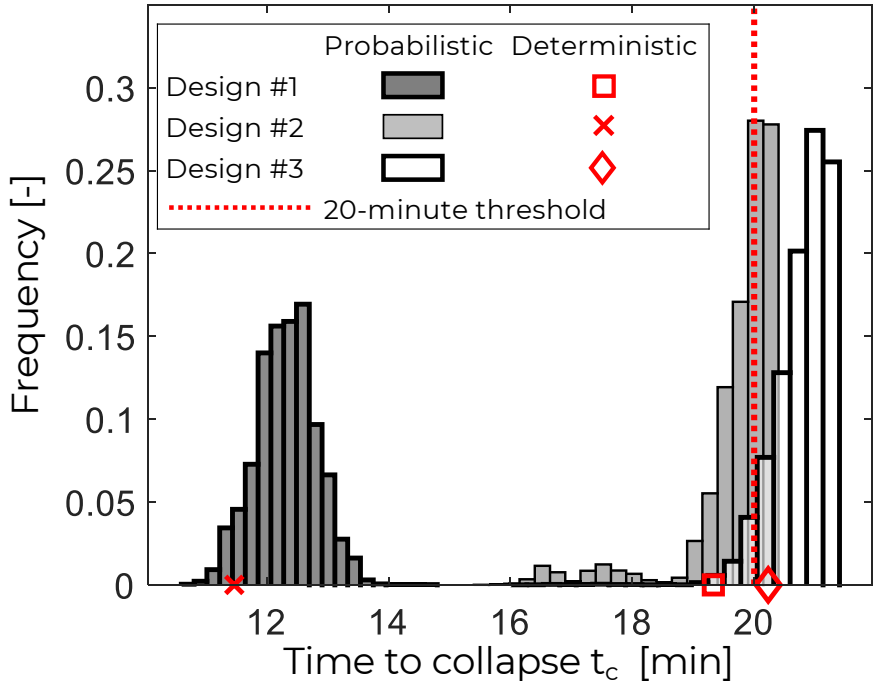
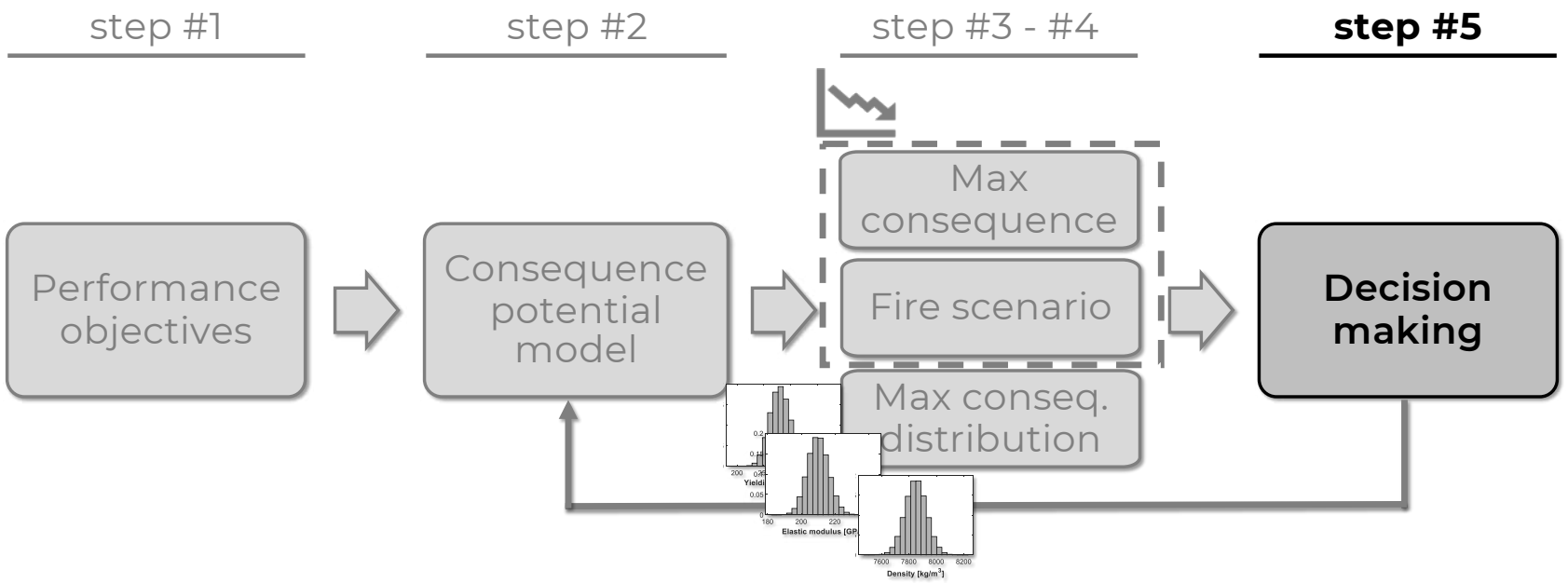
X_{Hgir} [-]	1.00	1.10	1.20
X_{wf} [-]	1.00	1.20	1.15
t_c[min]	11.47	19.33	20.23
$Pr(\bar{t}_c < 20)$	1.000	0.216	0.026



Monte Carlo Simulation



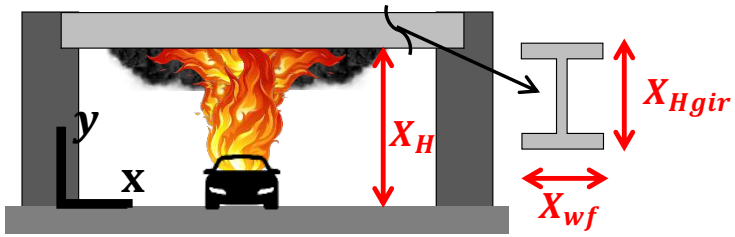
Illustrative example



Illustrative example

step #1 | step #2 | step #3 - #4 | **step #5**

DECISION MAKING



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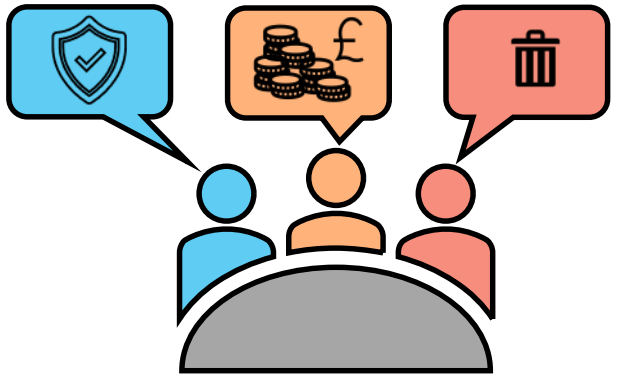
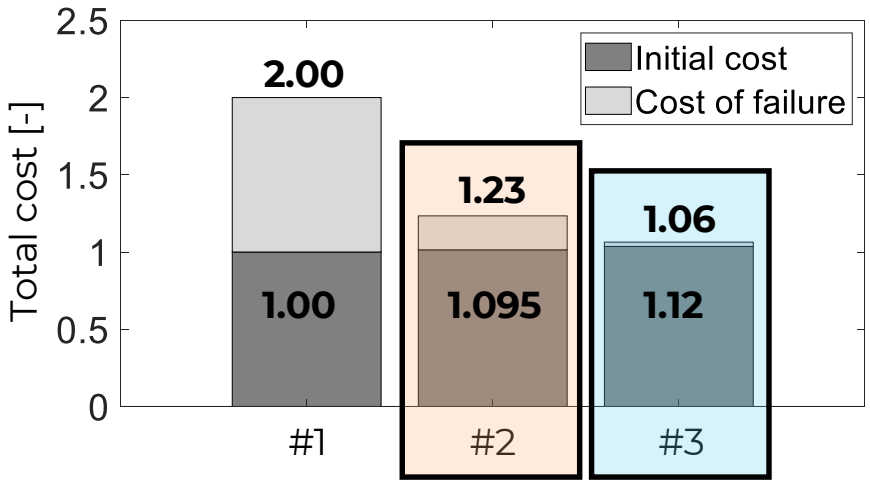
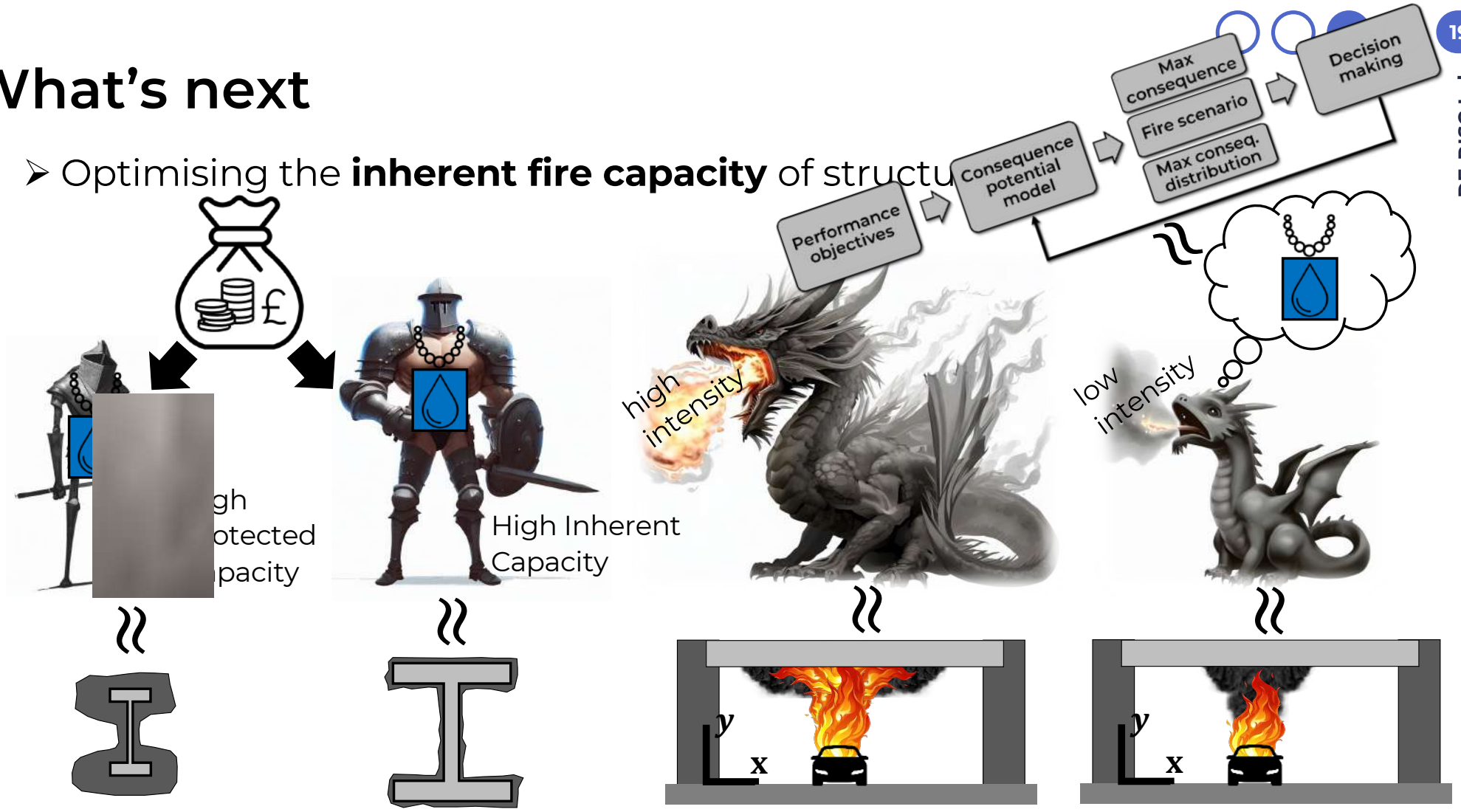




What's next

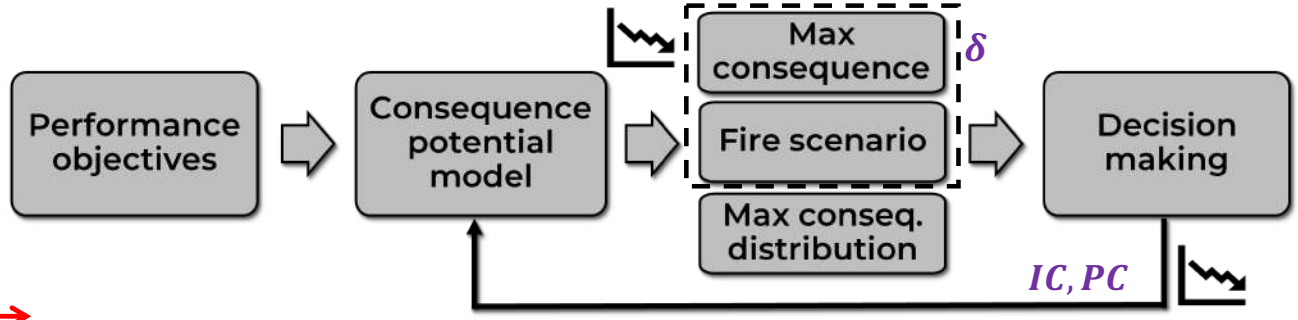
- Optimising the **inherent fire capacity** of structu



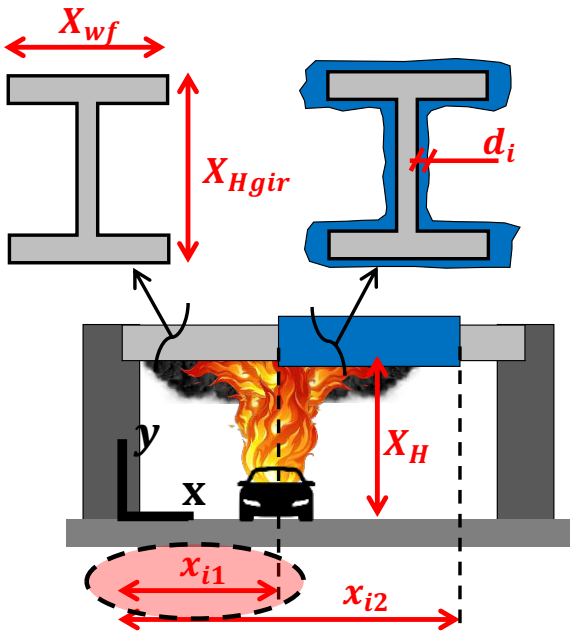
Microsoft Bing | Image Creator powered by DALL·E

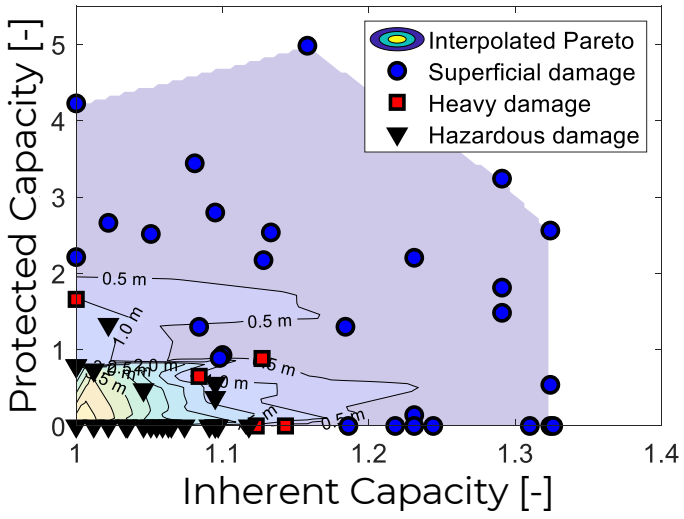
What's next

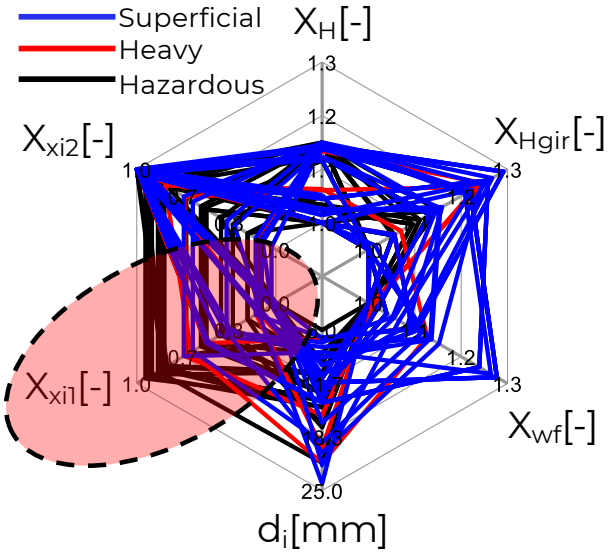
- Optimising the **inherent fire capacity** of structures



$$min\begin{Bmatrix}\delta: deflection\ @\ 1\ hr\\ Inherent\ Capacity\\ Protected\ Capacity\end{Bmatrix}$$







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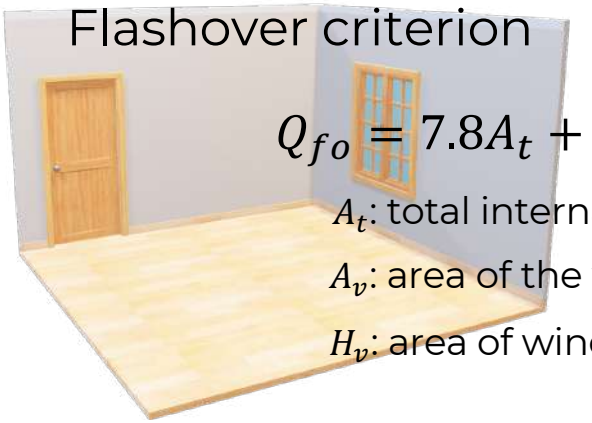
What's next

➢ **C**onsequence-oriented **F**ire intensity **O**ptimisation for buildings

Worst ignition location?

Flashover criterion



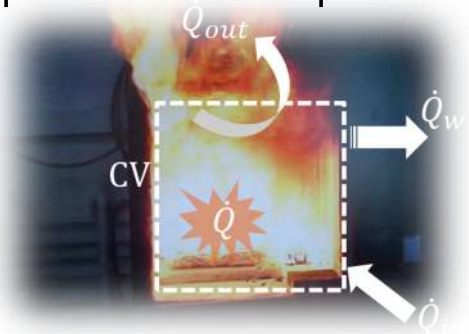
$$Q_{fo} = 7.8A_t + 378A_v\sqrt{Hv}$$

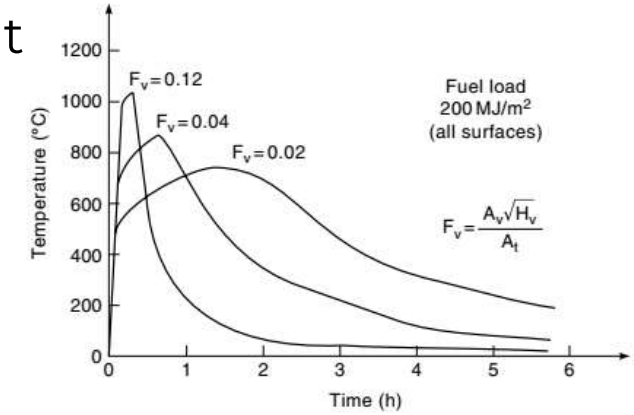
A_t: total internal surface area

A_v: area of the window opening

H_v: area of window opening

Optimise compartment





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Conclusions

- Are fire scenarios a design input or output?
- The structure defines the fire
- Consequence-oriented Fire intensity Optimisation (**CFO**):
  - ➢ The **fire scenario is a design variable** (output)
  - ➢ More optimised design
- Optimising the **inherent fire capacity** of structures

Thank you!

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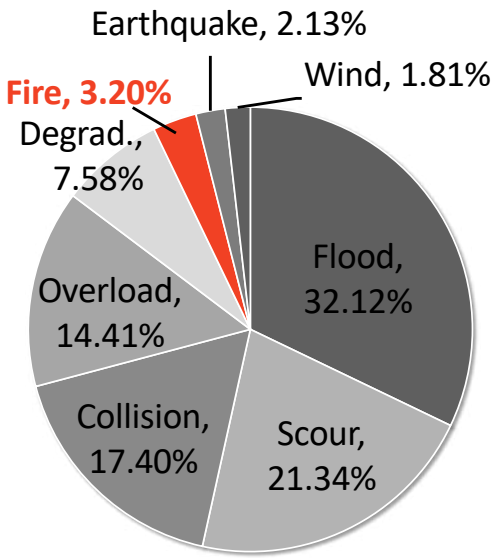
ndrfranchini.github.io/

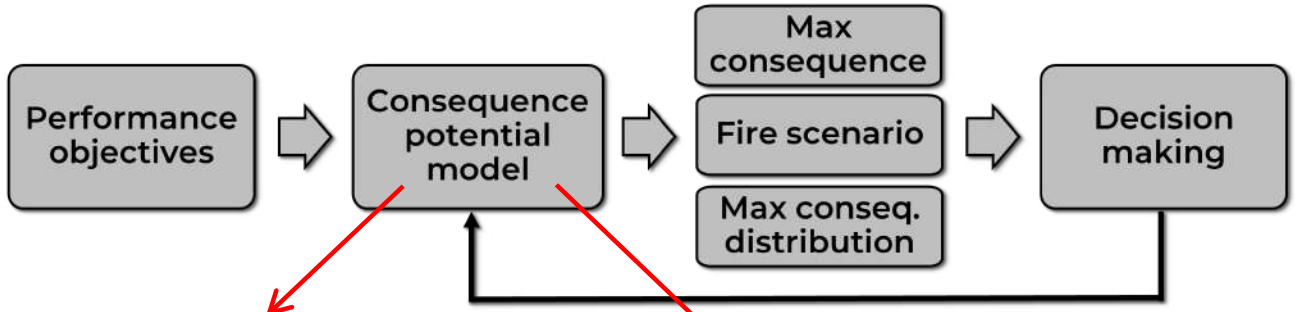
The Institution of StructuralEngineers

Appendix - Bridge Fires

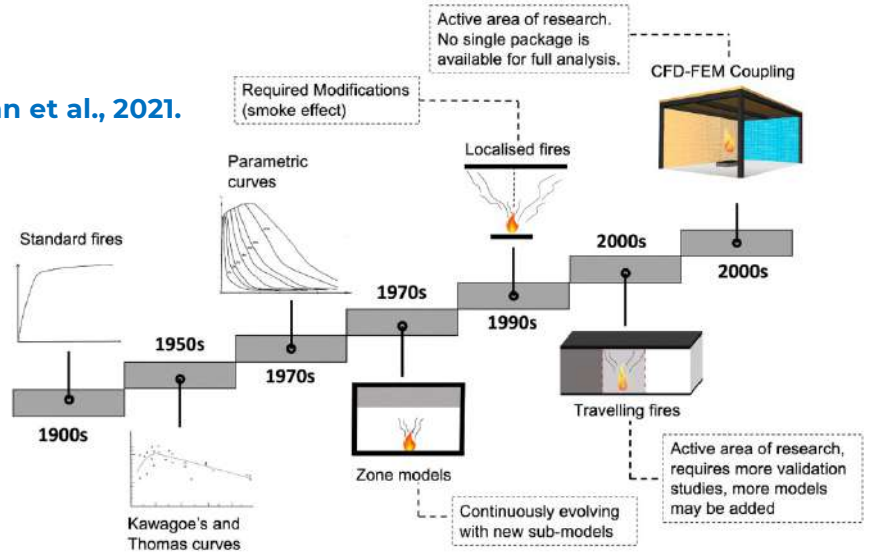


Appendix – what's next

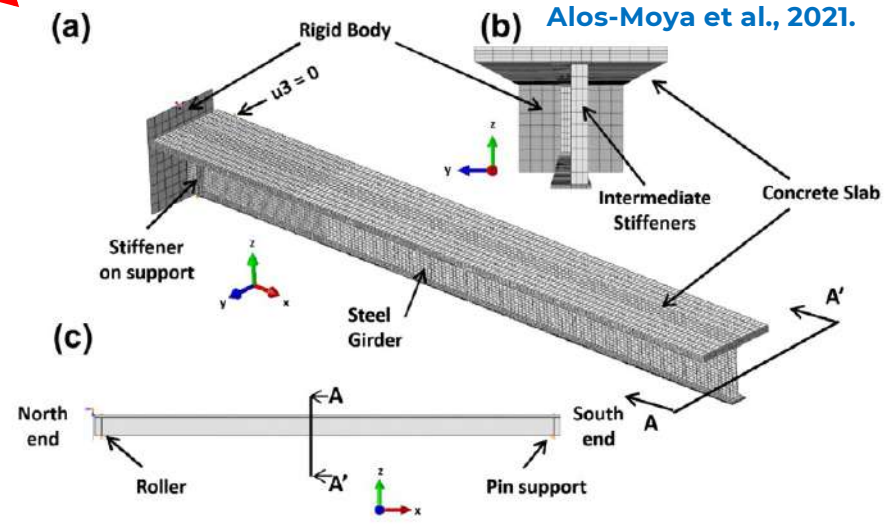
- Improving the model(s)



Kahn et al., 2021.



Alos-Moya et al., 2021.



Appendix – Optimising IC