# MULTI-FIDELITY MODELLING OF GLULAM BEAM AND COLUMN CONNECTION UNDER SCENARIO FIRE LOAD

9/26/24

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Tongchen Han, PhD student




# STRUCTURES IN FIRE FORUM – 10TH MAY 2024
# NOVOTEL LIVERPOOL PADDINGTON VILLAGE

# MOTIVATION

# FPInnovations' CLT handbook

State-of-the-art peer-reviewed technical source for designers that facilitates use of CLT as alternative solution (2013)


First edition (2013)


Second edition (2019)



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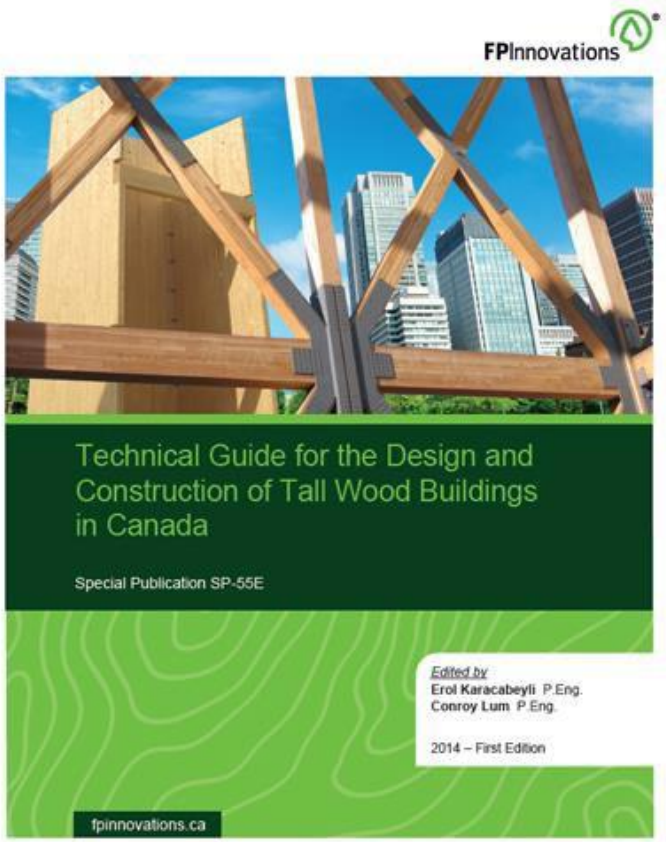
# “Tall Wood” initiatives

TALL WOOD



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# Origine, Quebec City (13 Storeys)

https://www.thinkwood.com/our-projects/origine-tallest-wood-building-in-eastern-north-america

# Brock Commons, UBC Vancouver (18 Storeys)

https://www.thinkwood.com/our-projects/brock-commons-tallwood-house

# B.C. building code adjusted upwards to allow 12-storey wood buildings

"...the building code changes come one year ahead of expected changes in the national building code, which are also expected to increase height limits for wood buildings to 12 storeys..."

2019

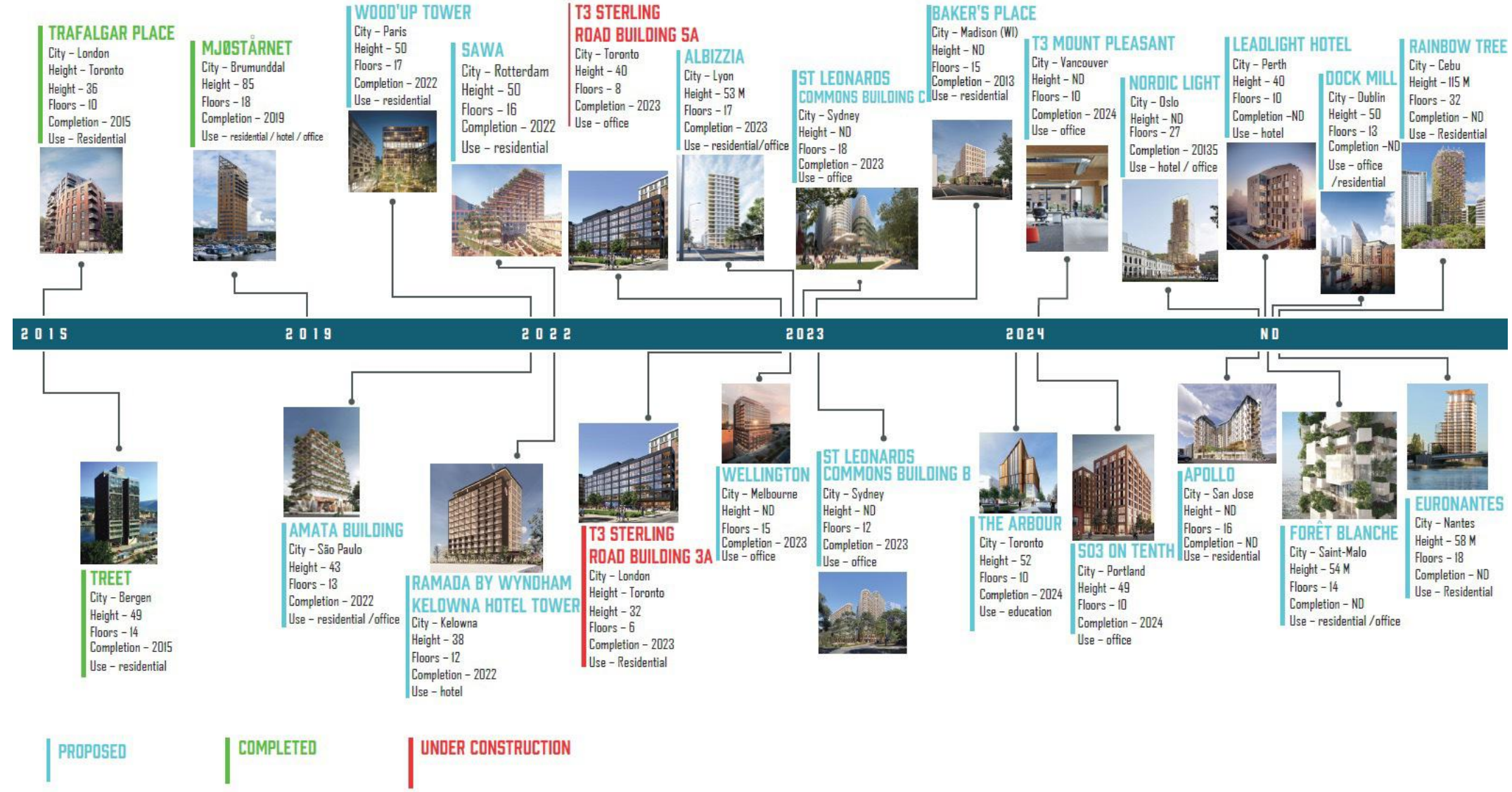
# B.C. building code to allow mass timber in buildings up to 18 storeys, up from 12

- Increased the height limit for mass timber residential and office buildings to 18 storeys,
- Expanded the types of buildings that can be constructed with mass timber to include schools, shopping centres and industrial facilities, and
- Allowed more exposed mass timber or fewer layers of encapsulation in buildings (depending on building height).

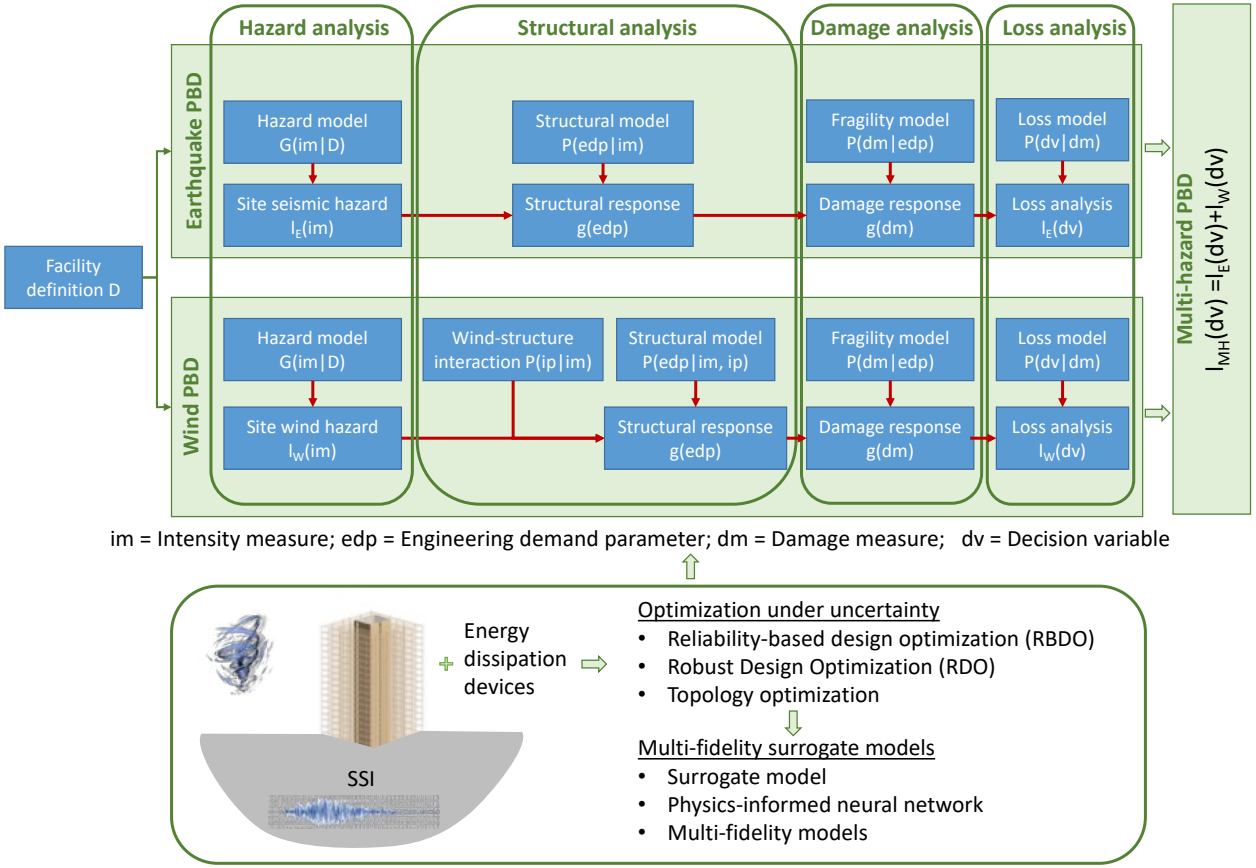
2024

# B.C. building code to allow mass timber in buildings up to ?? storeys, up from 18

2029


TRAFALGAR PLACE
City – London
Height – Toronto
Height – 36
Floors – 10
Completion – 2015
Use – Residential
MJØSTÅRNET
City – Brumunddal
Height – 85
Floors – 18
Completion – 2019
Use – residential / hotel / office
WOOD'UP TOWER
City – Paris
Height – 50
Floors – 17
Completion – 2022
Use – residential
SAWA
City – Rotterdam
Height – 50
Floors – 16
Completion – 2022
Use – residential
T3 STERLING ROAD BUILDING 5A
City – Toronto
Height – 40
Floors – 8
Completion – 2023
Use – office
ALBIZZIA
City – Lyon
Height – 53 M
Floors – 17
Completion – 2023
Use – residential/office
ST LEONARDS COMMONS BUILDING C
City – Sydney
Height – ND
Floors – 18
Completion – 2023
Use – office
BAKER'S PLACE
City – Madison (WI)
Height – ND
Floors – 15
Completion – 2013
Use – residential
T3 MOUNT PLEASANT
City – Vancouver
Height – ND
Floors – 10
Completion – 2024
Use – office
NORDIC LIGHT
City – Oslo
Height – ND
Floors – 27
Completion – 20135
Use – hotel / office
LEADLIGHT HOTEL
City – Perth
Height – 40
Floors – 10
Completion –ND
Use – hotel
DOCK MILL
City – Dublin
Height – 50
Floors – 13
Completion –ND
Use – office /residential
RAINBOW TREE
City – Cebu
Height – 115 M
Floors – 32
Completion – ND
Use – Residential
2015
2019
2022
2023
2024
ND
TREET
City – Bergen
Height – 49
Floors – 14
Completion – 2015
Use – residential
AMATA BUILDING
City – São Paulo
Height – 43
Floors – 13
Completion – 2022
Use – residential /office
RAMADA BY WYNDHAM KELOWNA HOTEL TOWER
City – Kelowna
Height – 38
Floors – 12
Completion – 2022
Use – hotel
T3 STERLING ROAD BUILDING 3A
City – London
Height – Toronto
Height – 32
Floors – 6
Completion – 2023
Use – Residential
WELLINGTON
City – Melbourne
Height – ND
Floors – 15
Completion – 2023
Use – office
ST LEONARDS COMMONS BUILDING B
City – Sydney
Height – ND
Floors – 12
Completion – 2023
Use – office
THE ARBOUR
City – Toronto
Height – 52
Floors – 10
Completion – 2024
Use – education
503 ON TENTH
City – Portland
Height – 49
Floors – 10
Completion – 2024
Use – office
APOLLO
City – San Jose
Height – ND
Floors – 16
Completion – ND
Use – residential
FORÊT BLANCHE
City – Saint-Malo
Height – 54 M
Floors – 14
Completion – ND
Use – residential /office
EURONANTES
City – Nantes
Height – 58 M
Floors – 18
Completion – ND
Use – Residential
PROPOSED
COMPLETED
UNDER CONSTRUCTION

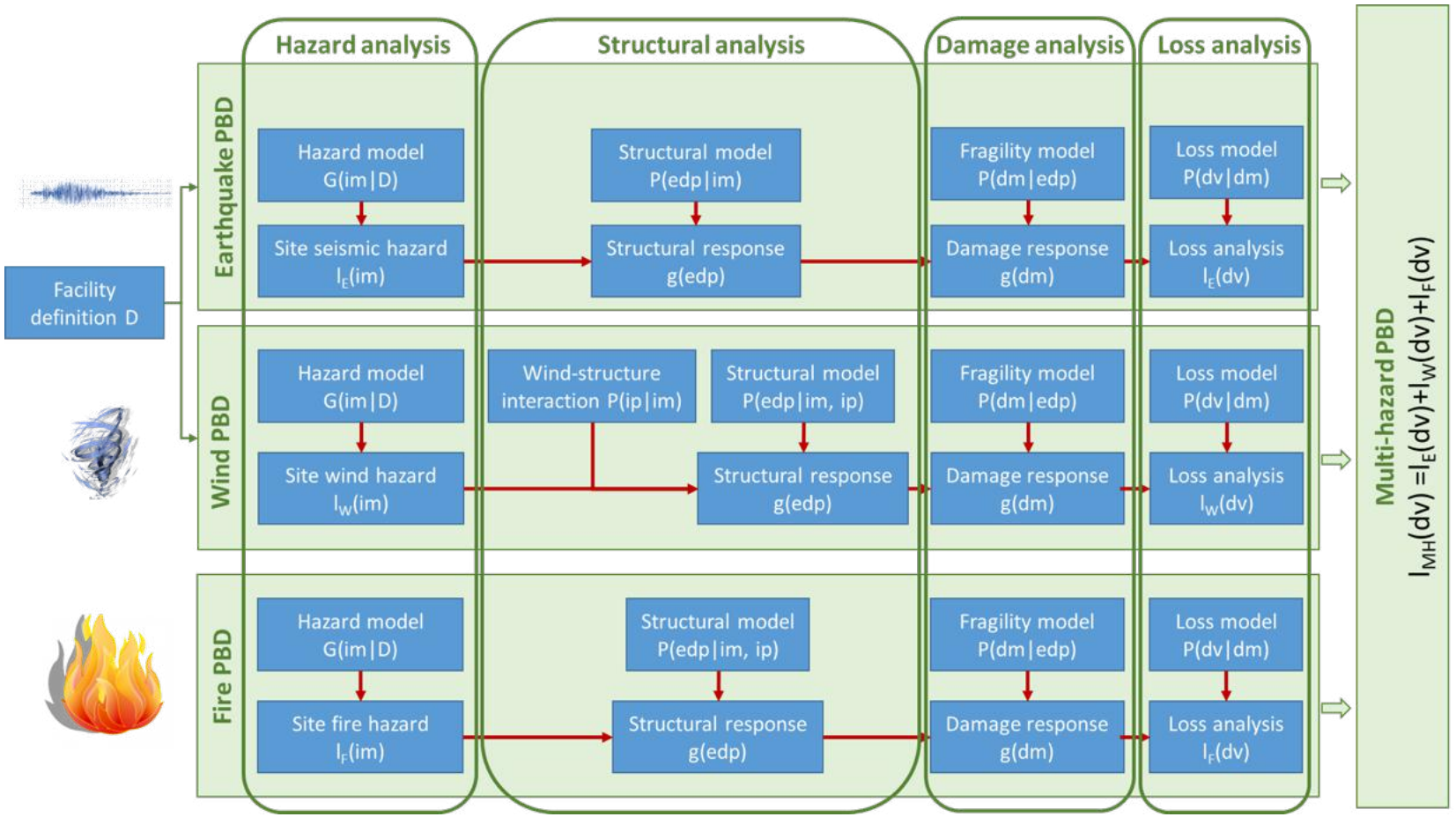
# Multi-hazard performance based design



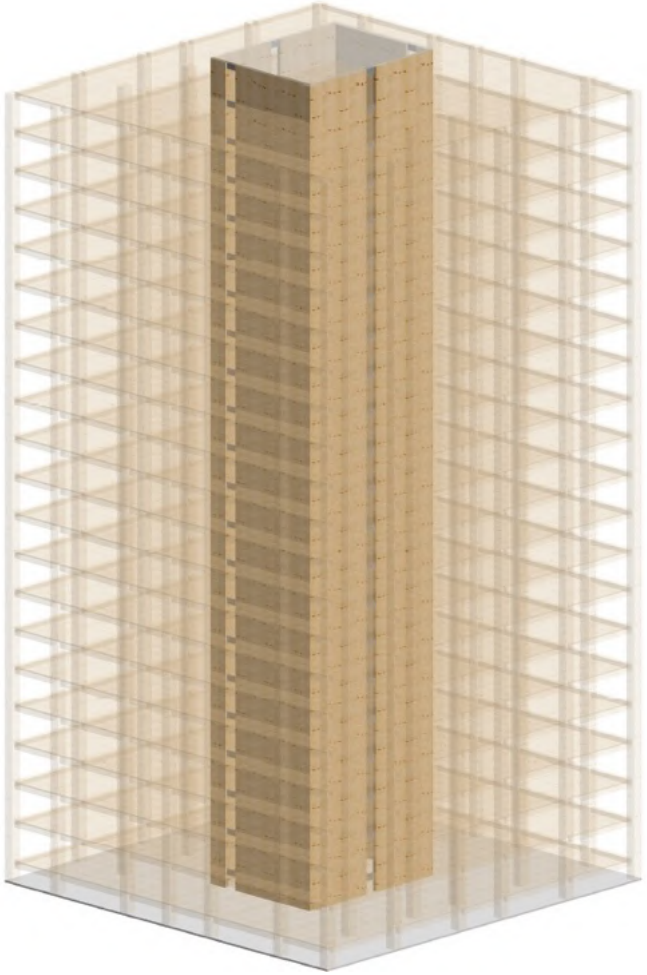

Tesfamariam, S. 2022. Performance-based design of tall timber buildings under earthquake and wind multi-hazard loads: Past, present and future. ***Frontier in Built Environment: Earthquake Engineering****, 8:848698. doi: 10.3389/fbuil.2022.848698.*

# FIRE RESEARCH AND SAFETY

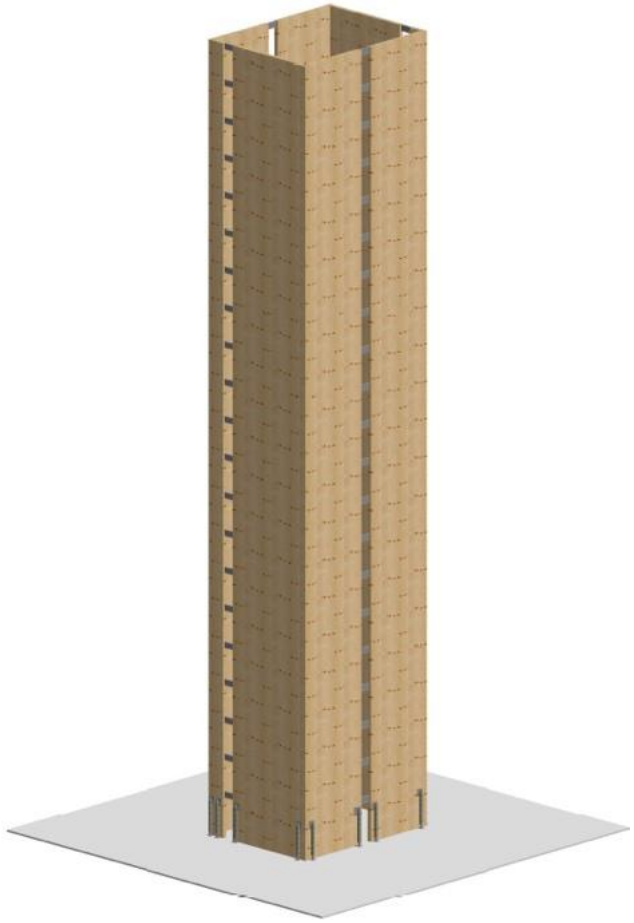
University of Waterloo Fire Research Group


Hazard analysis
Structural analysis
Damage analysis
Loss analysis
Earthquake PBD
Wind PBD
Fire PBD
Facility definition D
Hazard model G(im|D)
Site seismic hazard $I_E$(im)
Structural model P(edp|im)
Structural response g(edp)
Fragility model P(dm|edp)
Damage response g(dm)
Loss model P(dv|dm)
Loss analysis $I_E$(dv)
Hazard model G(im|D)
Site wind hazard $I_W$(im)
Wind-structure interaction P(ip|im)
Structural model P(edp|im, ip)
Structural response g(edp)
Fragility model P(dm|edp)
Damage response g(dm)
Loss model P(dv|dm)
Loss analysis $I_W$(dv)
Hazard model G(im|D)
Site fire hazard $I_F$(im)
Structural model P(edp|im, ip)
Structural response g(edp)
Fragility model P(dm|edp)
Damage response g(dm)
Loss model P(dv|dm)
Loss analysis $I_F$(dv)
Multi-hazard PBD
$I_{MH}(dv) = I_E(dv) + I_W(dv) + I_F(dv)$

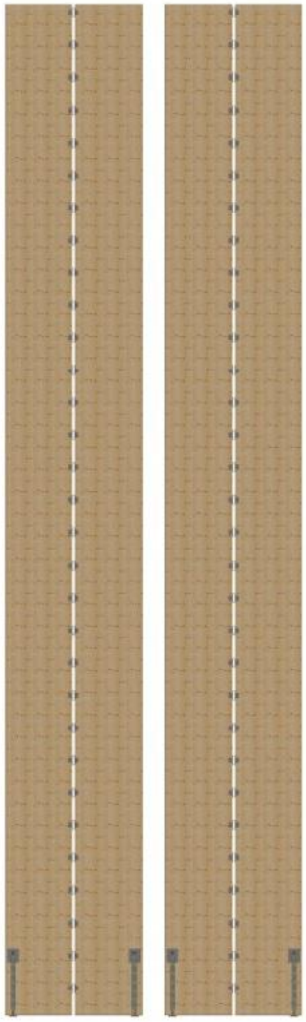
# CLT SHEAR WALLS – TIMBER MOMENT RESISTING FRAMES



3D building (gravity and core)

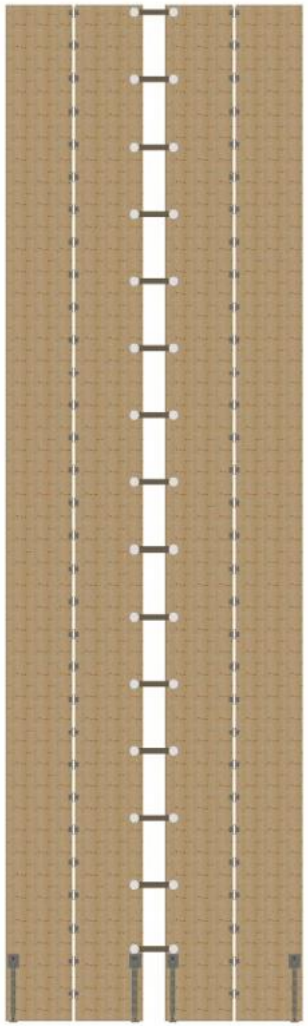


CLT-balloon shear-walls

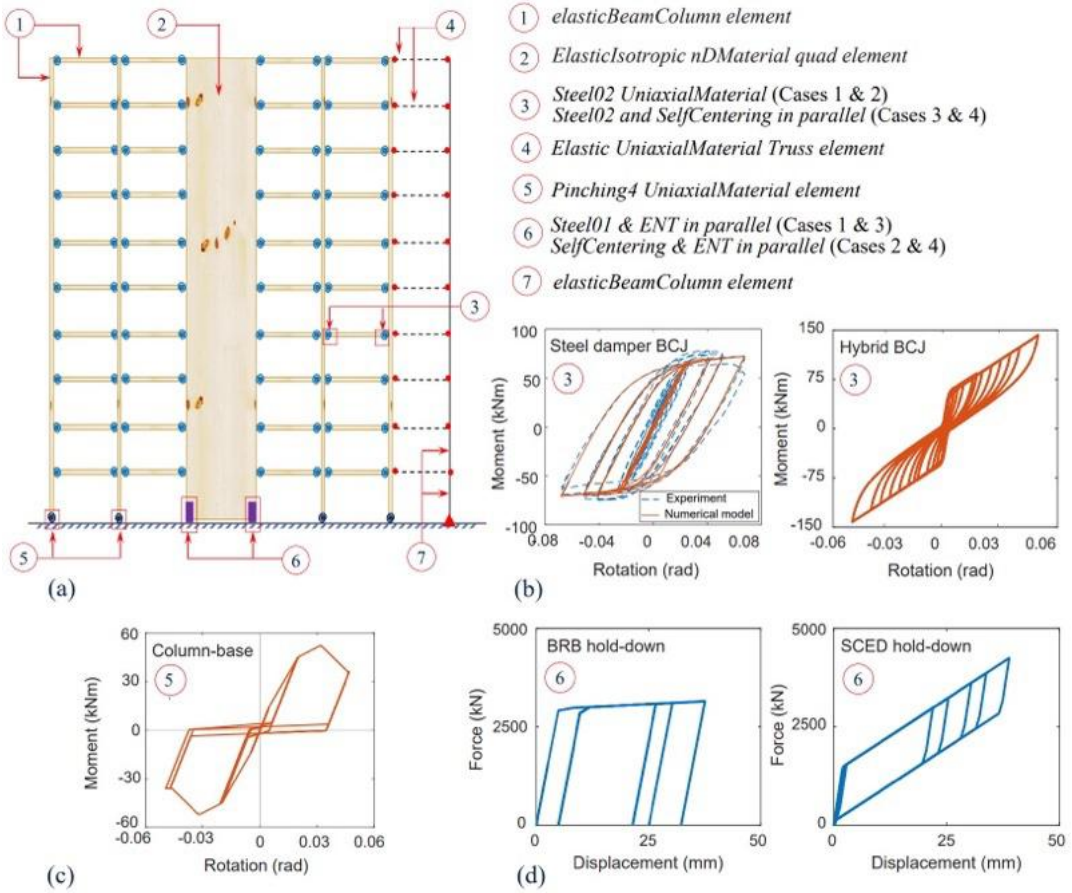


Uncoupled CLT walls

Energy dissipation BRB hold-down

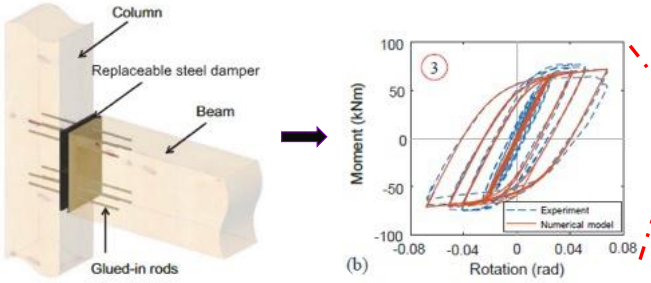


Fully coupled CLT walls



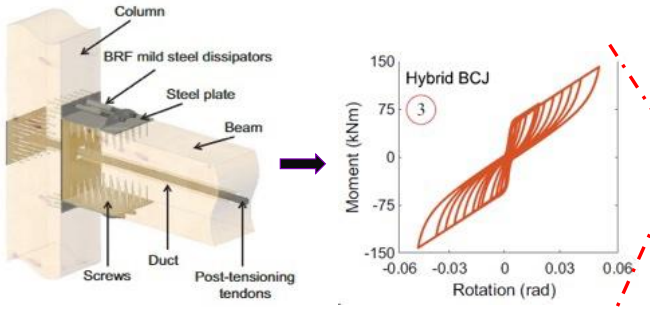

**Teweldebrhan**, B.T. and Tesfamariam, S. 2023. Seismic design of CLT shear-wall and glulam moment-resisting frame coupled structure. *Journal of Structural Engineering*. 149(12):04023169.

Beam-column joint with steel damper

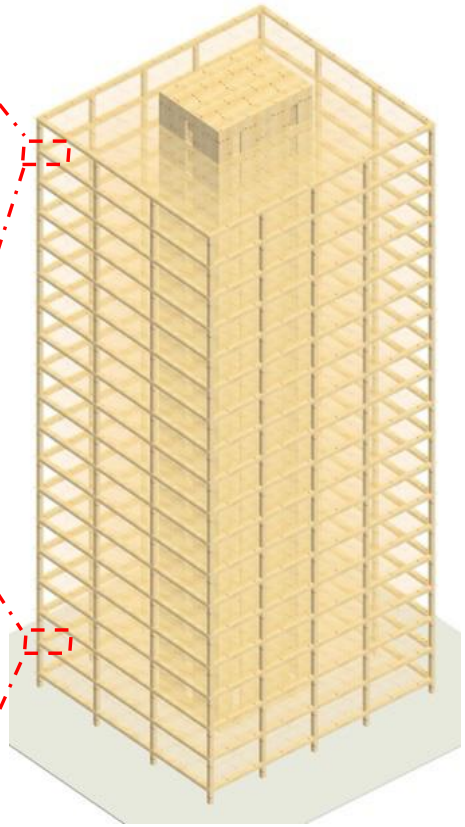



Wakashima et al. (2010)

Hybrid beam-column joint

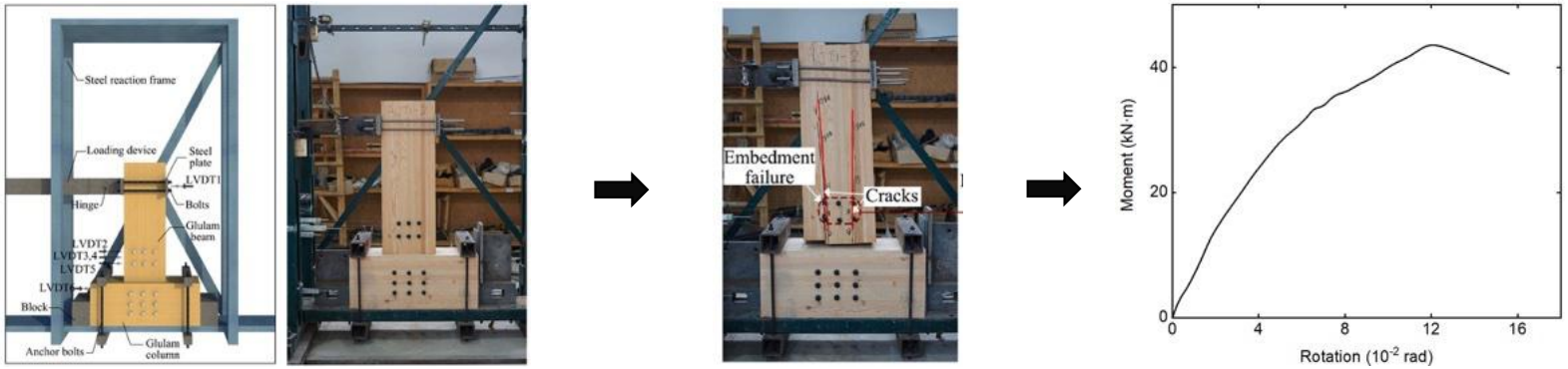



Teweldebrhan and Tesfamariam (2023)



# HIGH-FIDELITY MODEL AND CALIBRATION

# Beam-column joint test

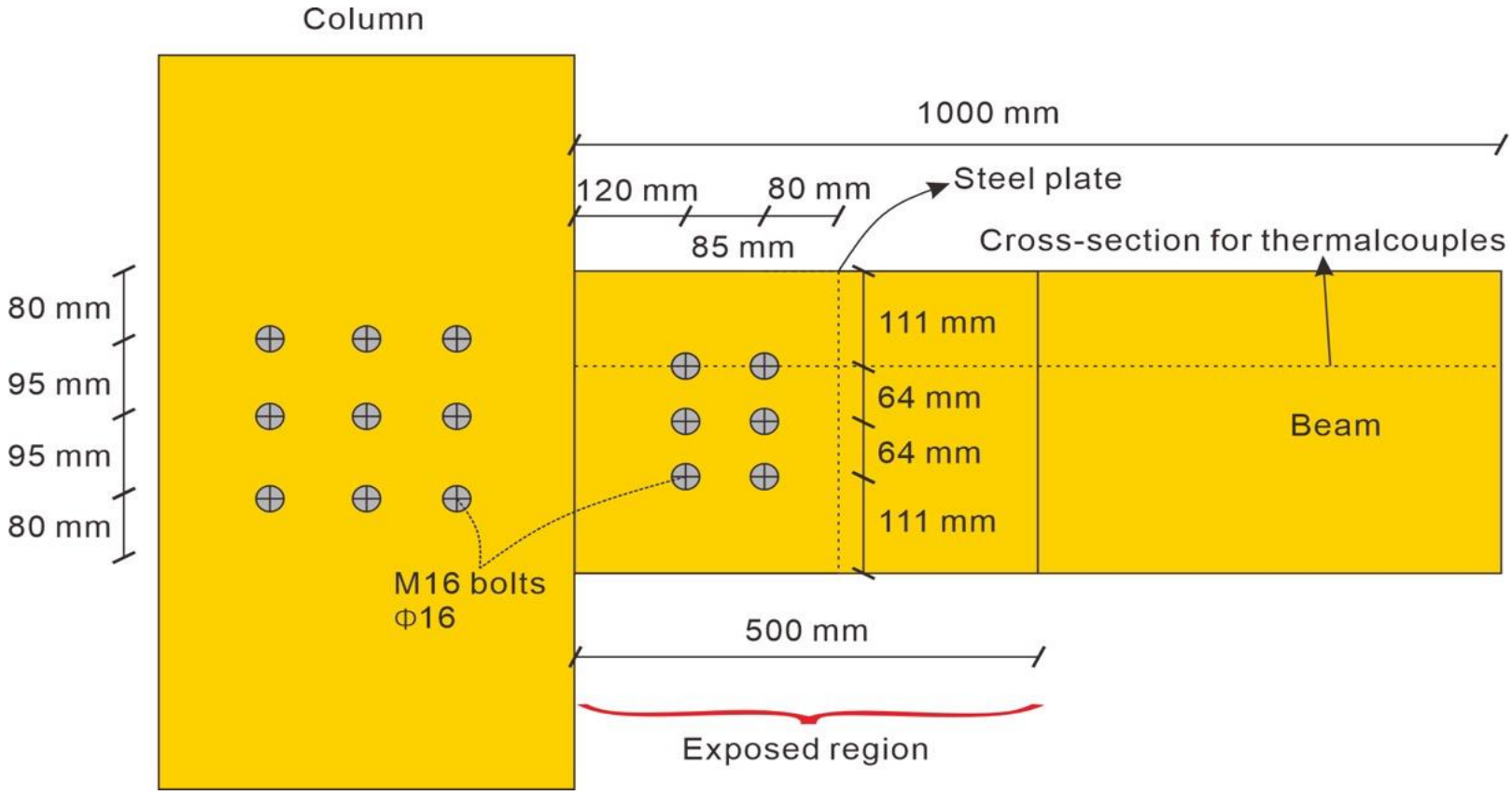



Loading test under ambient temperature


Loading test under ISO fire heating

Luo, J., He, M., Li, Z., Gan, Z., Wang, X., and Liang, F. 2022. Experimental and numerical investigation into the fire performance of glulam bolted beam-to-column connections under coupled moment and shear force. *Journal of Building Engineering*, 46, 103804.

# Dimensions and mechanical properties



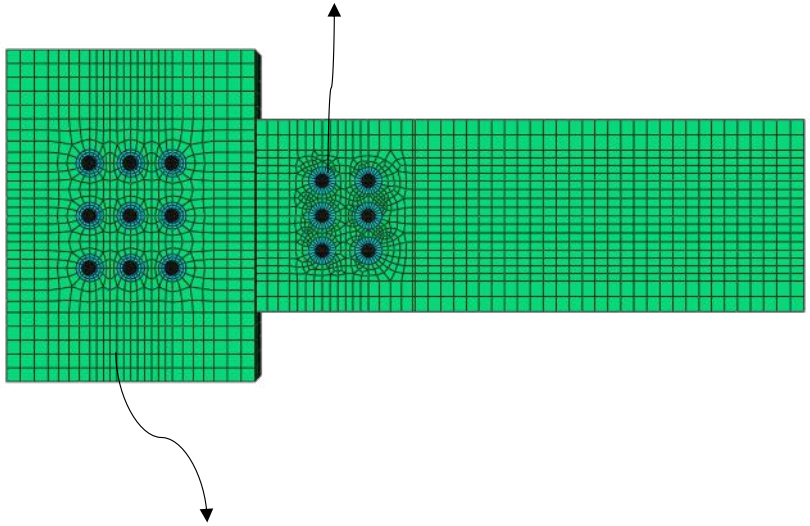
# Dimensions and mechanical properties

| Material properties | Elastic modulus (MPa) | $f_y(MPa)$ | $f_u(MPa)$ | $\epsilon_u$ |
|---|---|---|---|---|
| Steel plate | 210000 | 345 | 470 | 0.1 |
| Bolts | 210000 | 640 | 800 | 0.1 |

| Material properties | Elastic modulus (MPa) | | | | Poisson's ratio | | Syrength (MPa) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $E_1$ | $E_2/E_3$ | $G_{1,2}/G_{1,3}$ | $G_{2,3}$ | $v_{1,2}/v_{1,3}$ | $v_{2,3}$ | $f_1$ | $f_2/f_3$ | $f_{1,2}/f_{1,3}$ | $f_{2,3}$ |
| Timber | 11534 | 313 | 639 | 108 | 0.37 | 0.44 | 44.03 | 2.03 | 7.58 | 2.16 |
| Bolt hole region | 2503 | 560 | 432 | 194 | 0.37 | 0.44 | 44.03 | 2.03 | 7.58 | 2.16 |

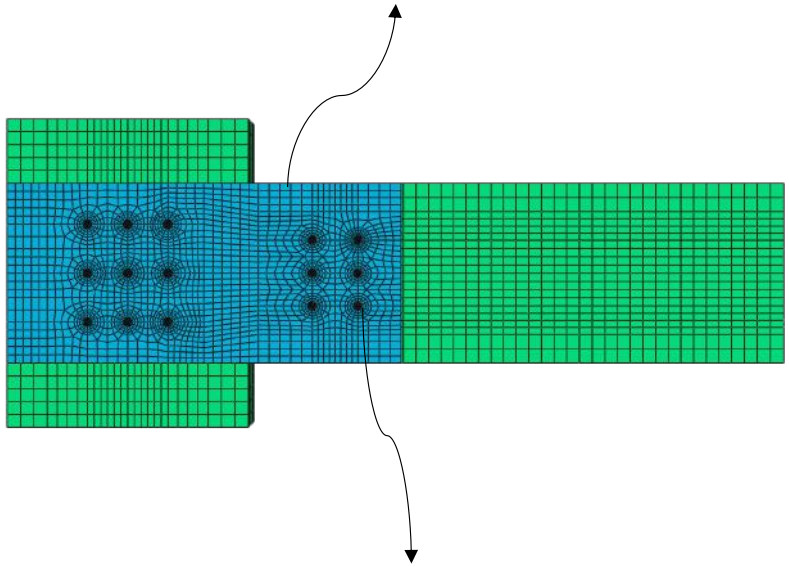
# Dimensions and mechanical properties

Bolt hole region (Perfect elastic-plastic, Hill yield criterion )



Timber (Perfect elastic-plastic, Hill yield criterion )

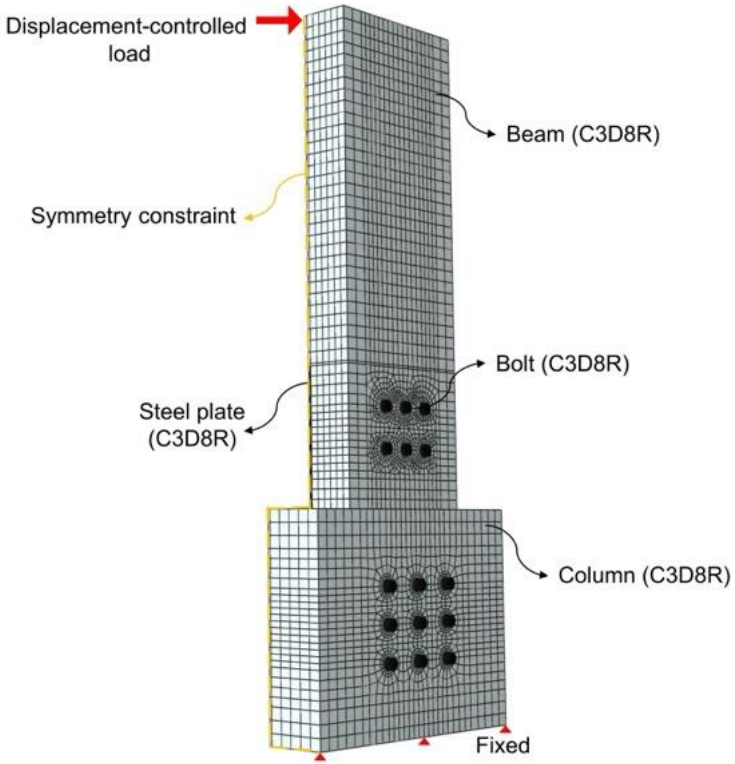
Steel plate (Trilinear, isotropic hardening)



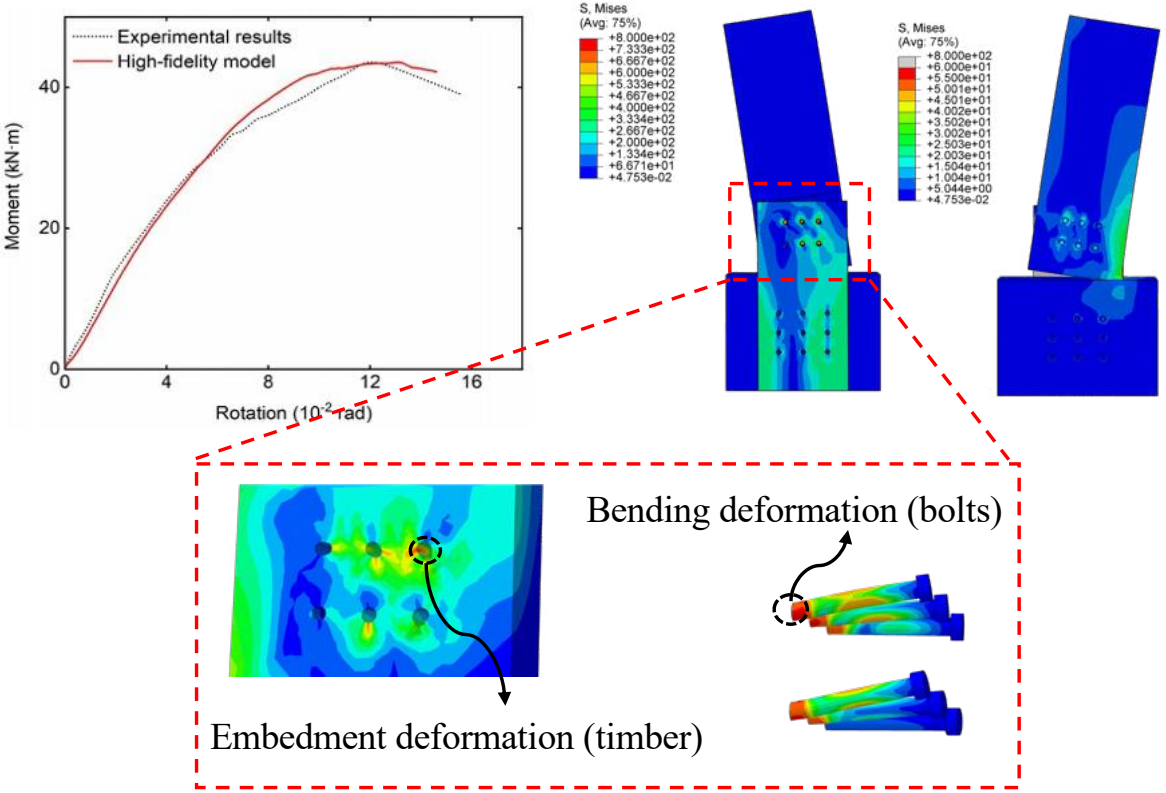
Bolts (Trilinear, isotropic hardening)

# Loading under ambient temperature

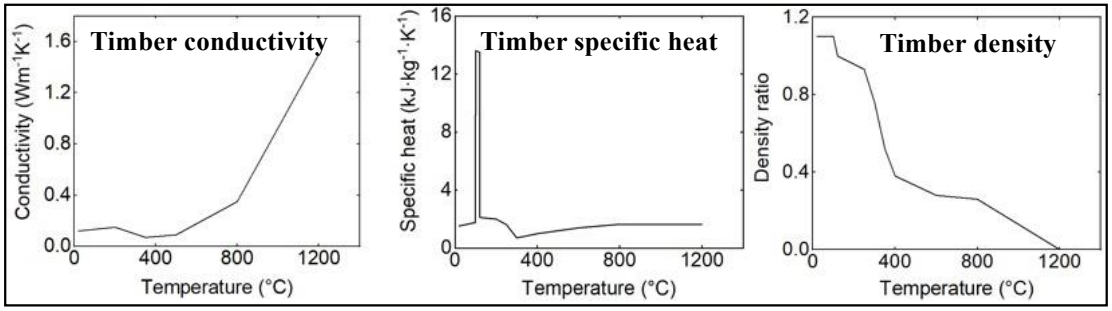
Elements and boundary conditions

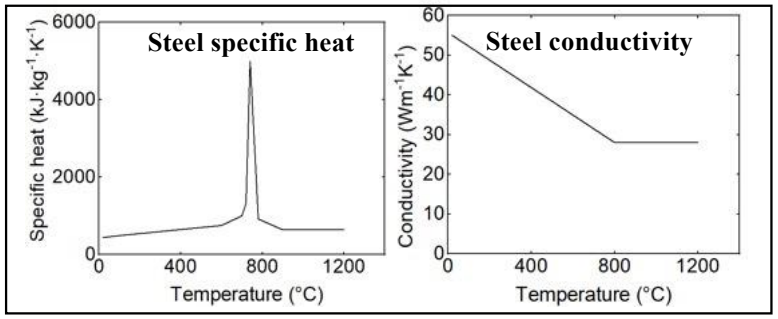


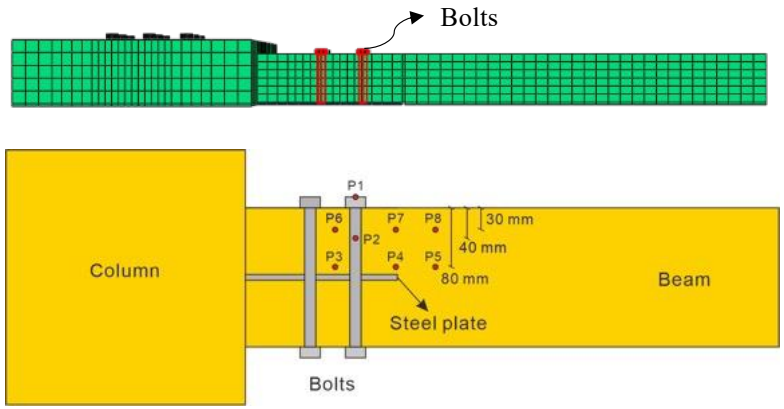

Loading curve and model deformation



# Heat transfer analysis

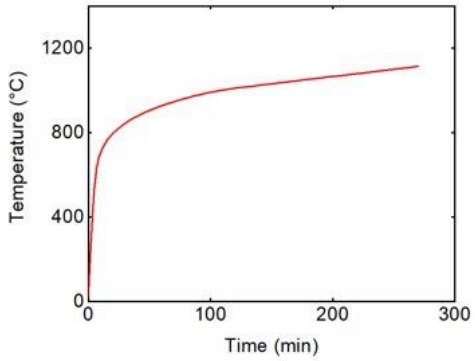


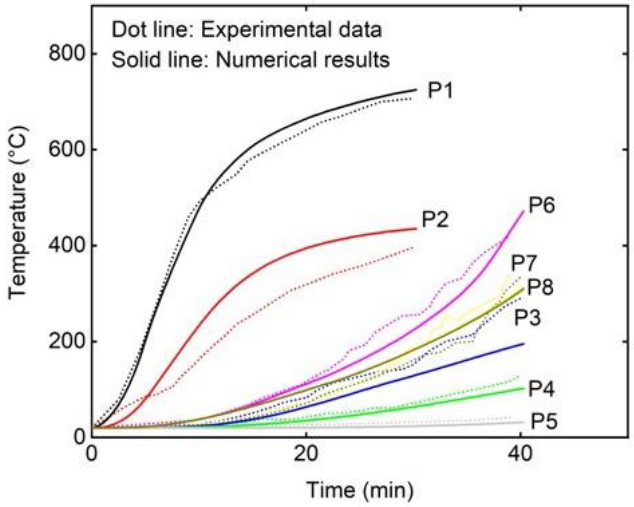




Location of thermocouples

+




ISO fire heating



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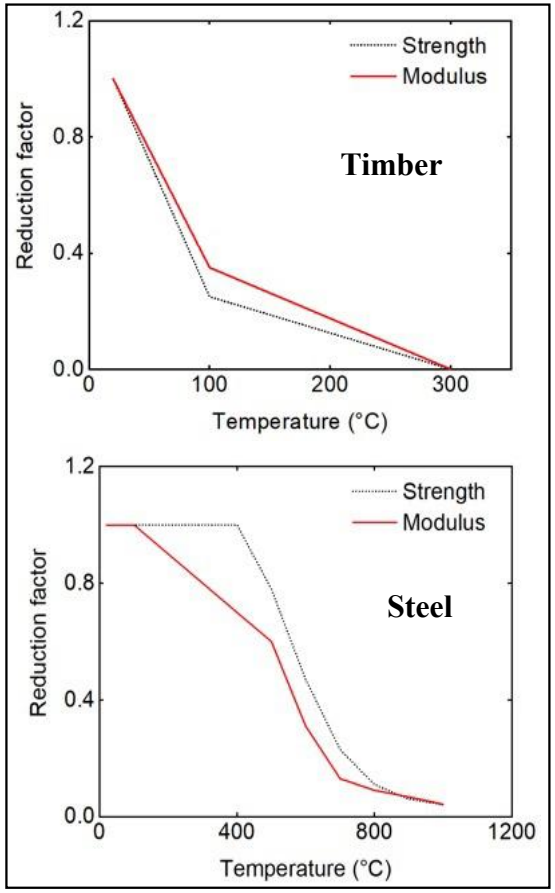
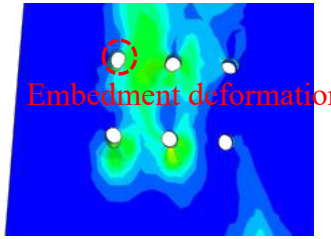
# Structural analysis

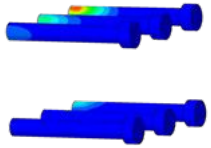


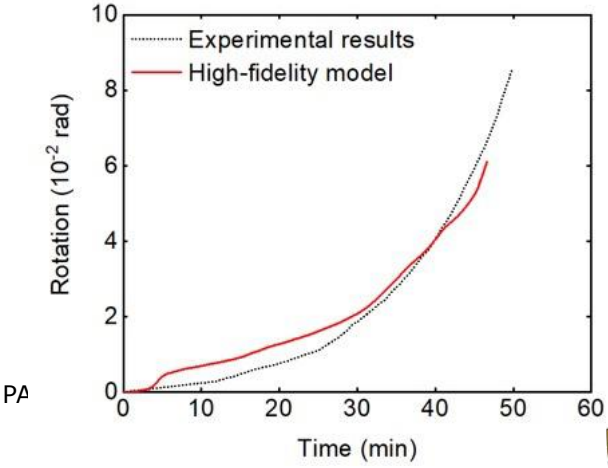

Reduction factors of materials


**Load factor: 0.15**

Keep elastic

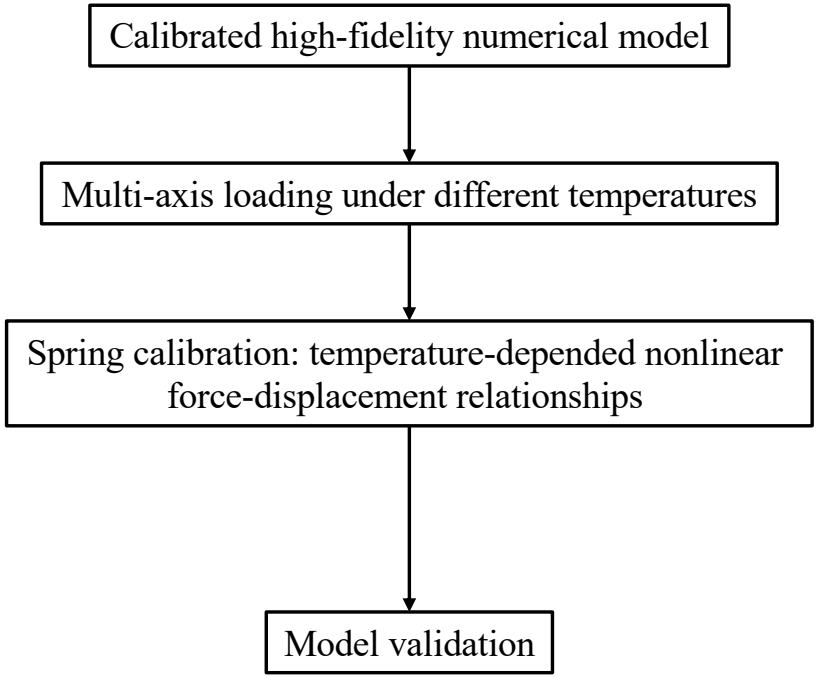




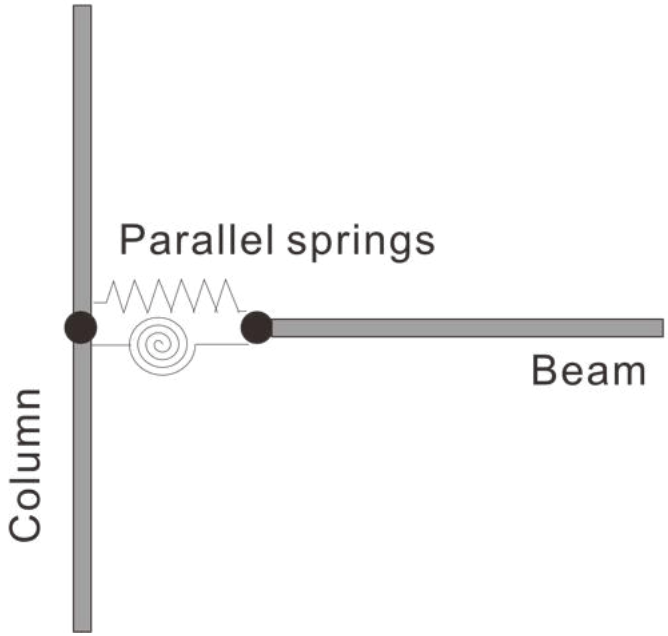

PA

# LOW-FIDELITY MODEL AND CALIBRATION

# Development of simplified numerical model

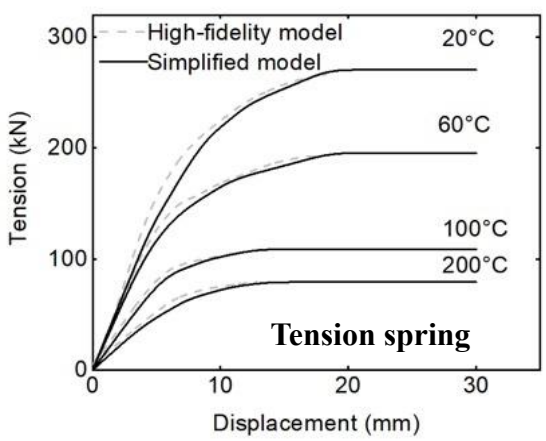


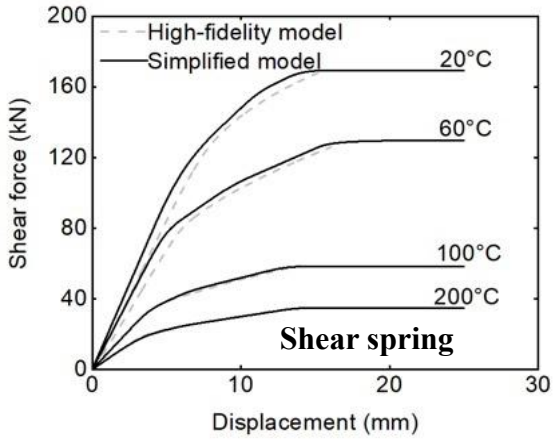

Flowchart

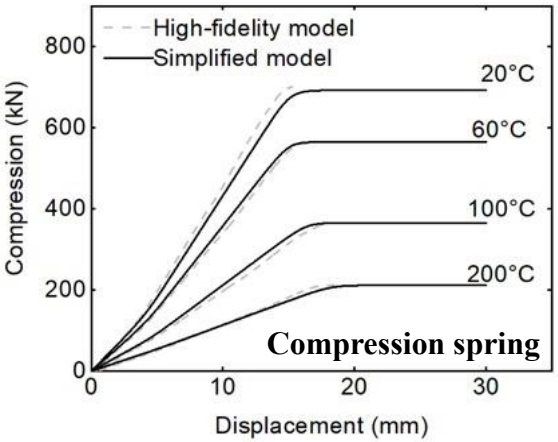


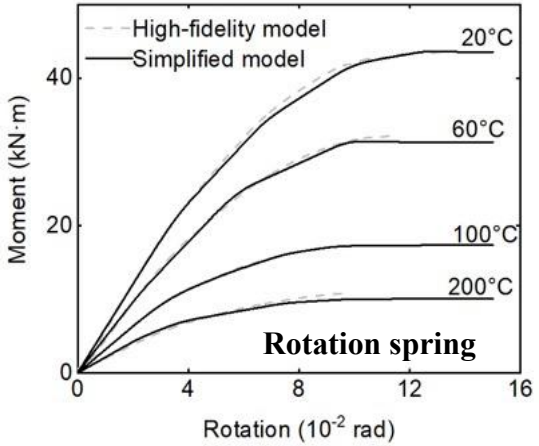

Simplfied numerical beam-column joint model

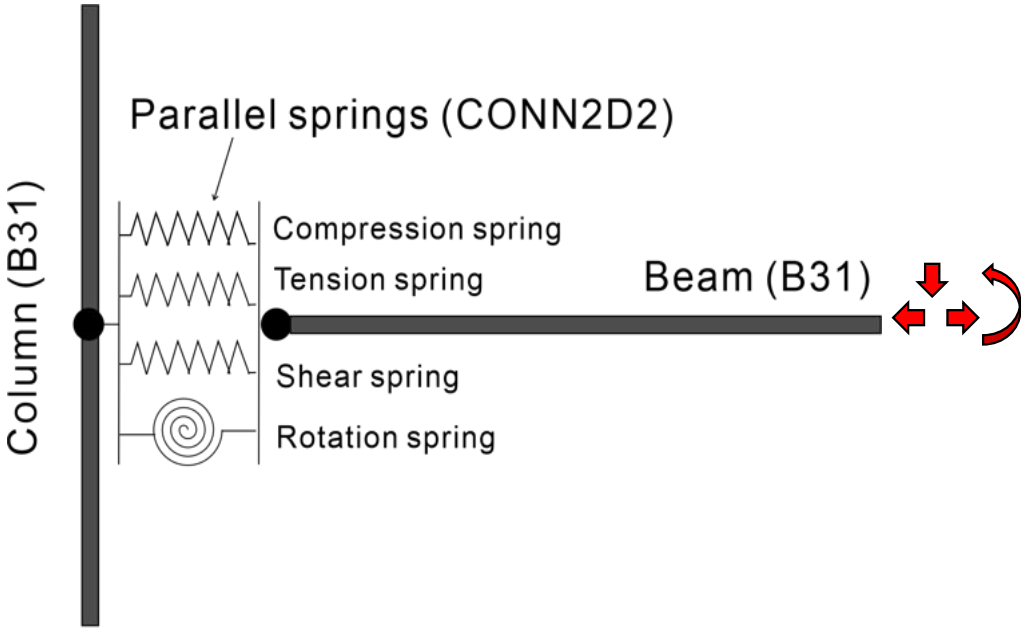
# Multi-axis loading calibration



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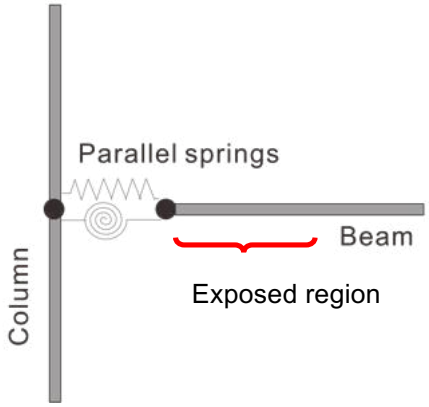
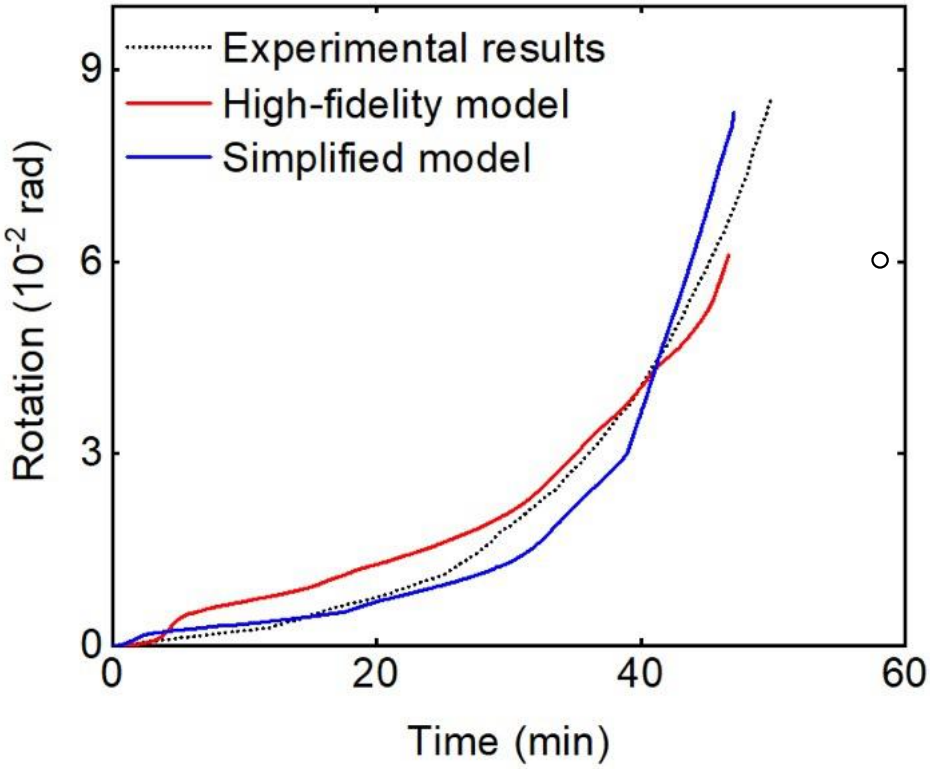
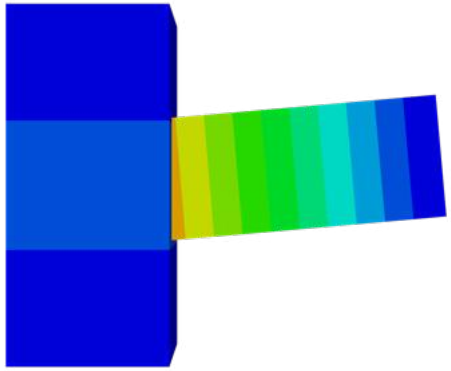
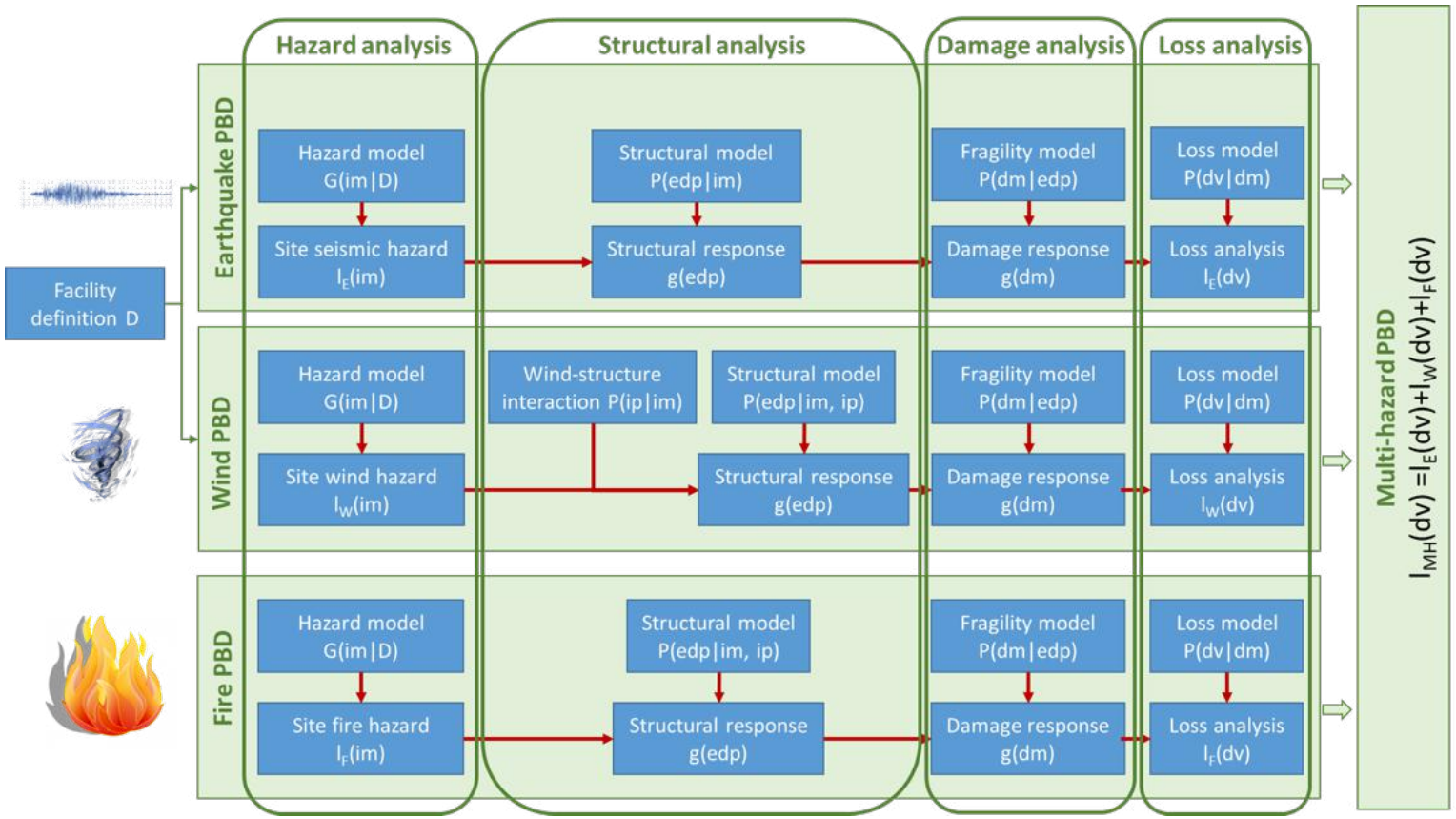
# Model validation



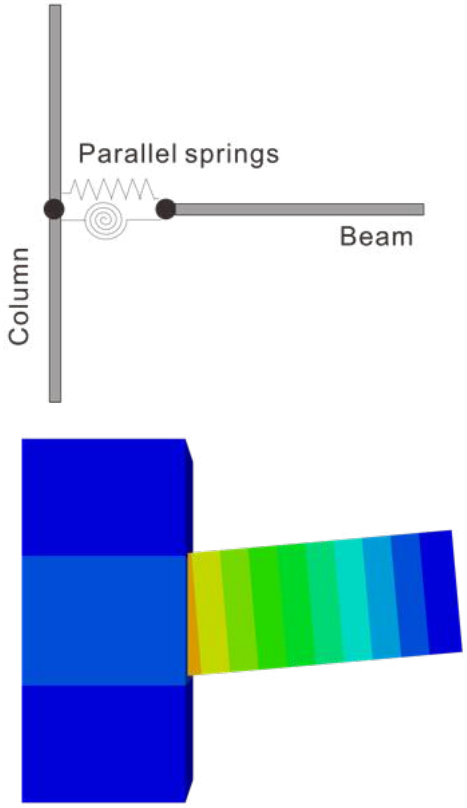



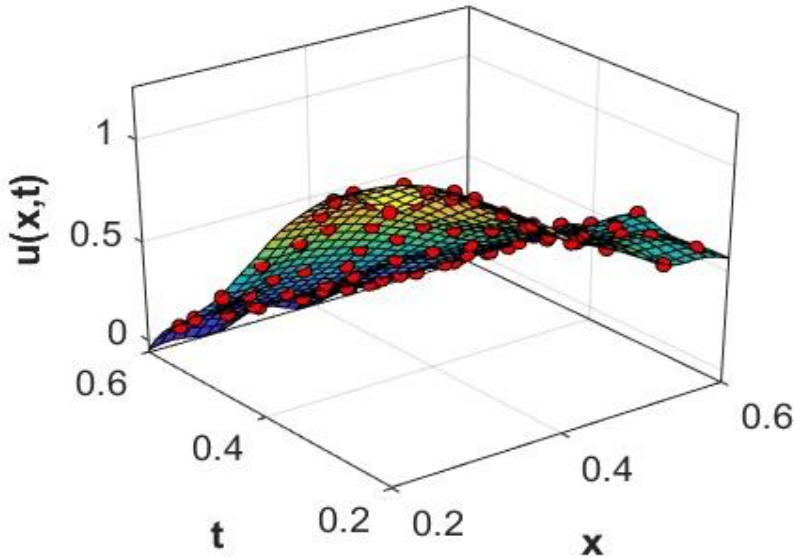



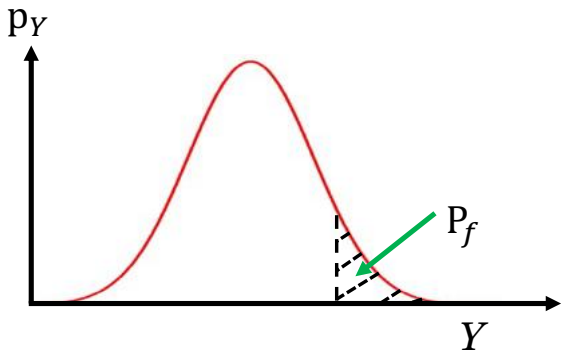
# Uncertainty propagation



# Uncertainty propagation



# Contact information

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Waterloo, ON

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