



JOURNEES NATIONALES
MACONNERIE

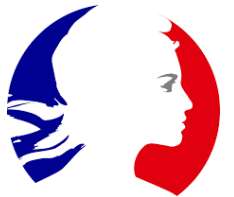
5ème édition – Bordeaux

12 et 13 Juin 2025



PROPOSITION D'UNE APPROCHE DE MODÉLISATION THERMOMÉCANIQUE HYBRIDE DEDIEE AUX STRUCTURES MAÇONNEES TOUCHÉES PAR LE FEU

Boukham, A., Parent, T., Dubois, F., Morel, S., MINDEGUIA, J.C.



Contexte et enjeux



Flèche Saint-Michel



Cathédrale de Strasbourg



Château de Chambord



Musée national du Brésil 2018



Notre Dame de Paris 2019



Basilique Saint-Donatien de Nantes 2015



La vieille bourse de Copenhague 2024



Exemples

Projet ANR DEMMEFI



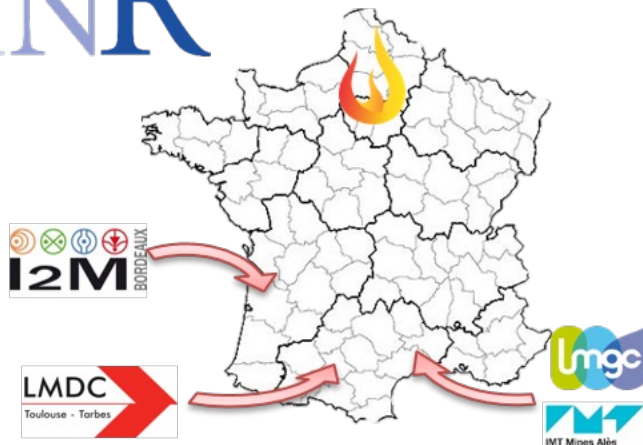
- *Essais mécaniques – Assemblages & Matériaux quasi-fragiles*



- *Développement des lois de contacts– Calcul ED*

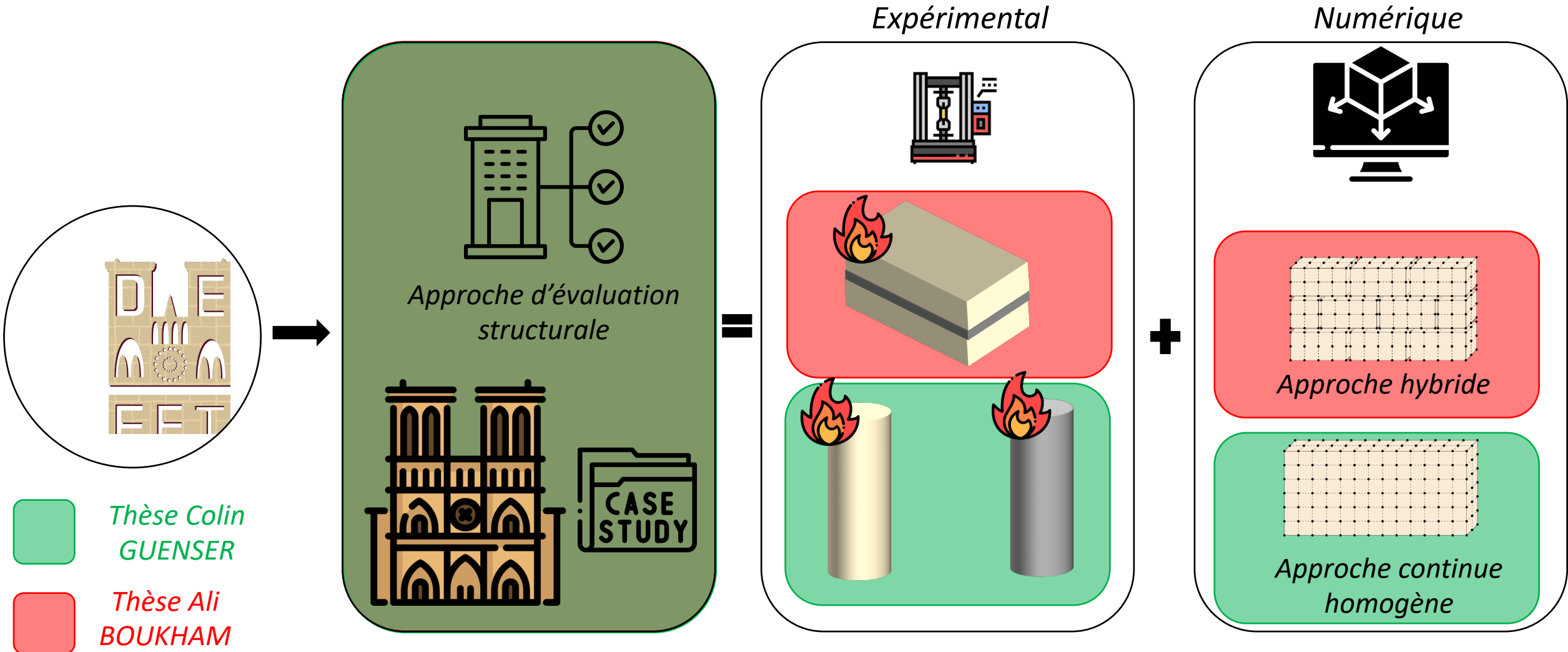


AGENCE NATIONALE DE LA RECHERCHE
ANR

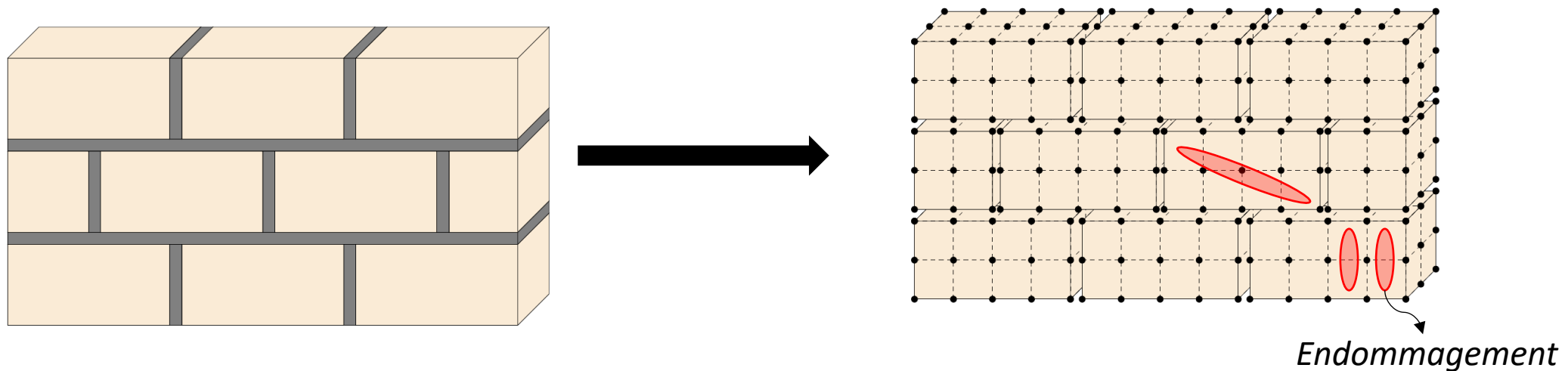
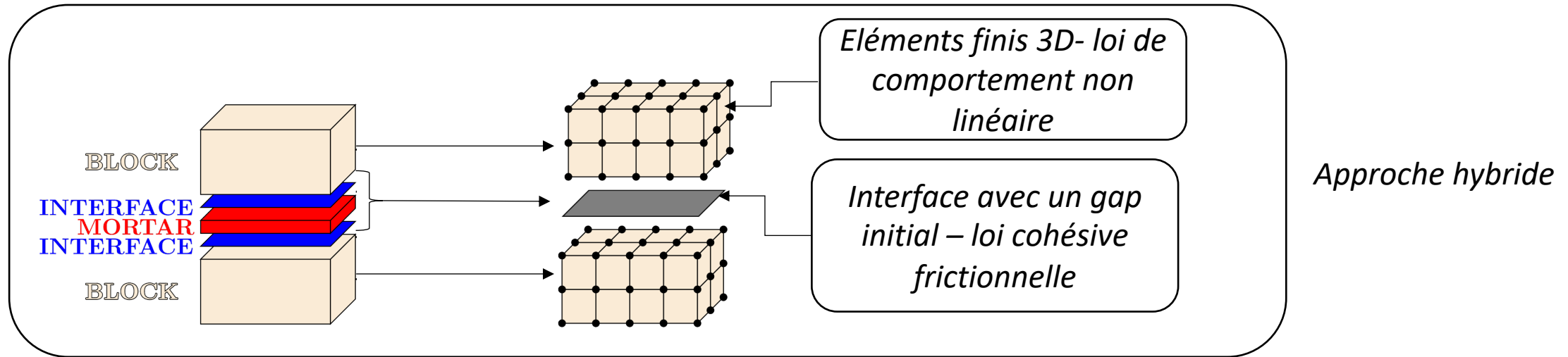


- *Essais mécaniques – Matériaux quasi-fragiles*
- *Développement des modèles d'endommagement – Calcul EF*

Projet ANR DEMMEFI



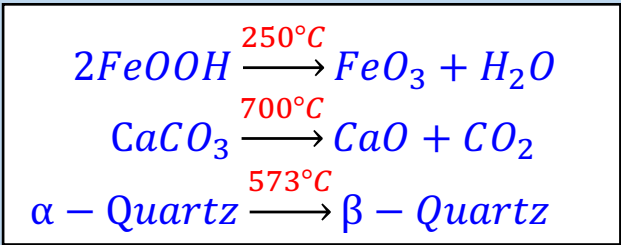
Approche de modélisation mécanique hybride



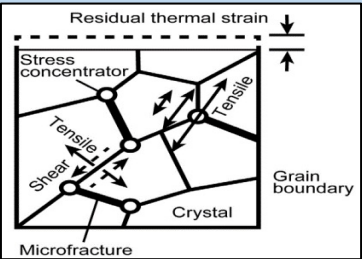
Intégration de l'effet de la température



500 °C



Réactions physico-chimiques



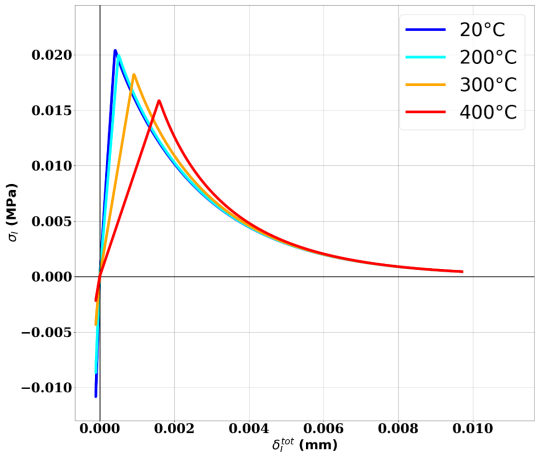
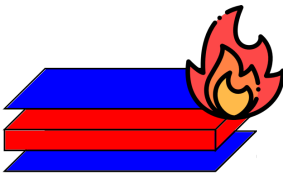
Dilatations différentielles

Aspects matériaux

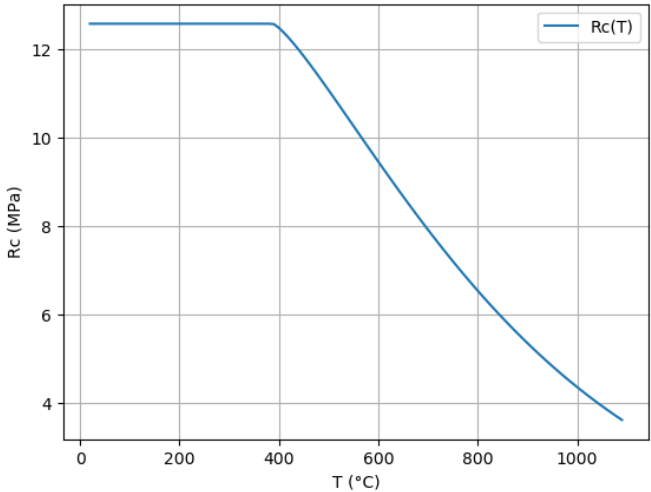
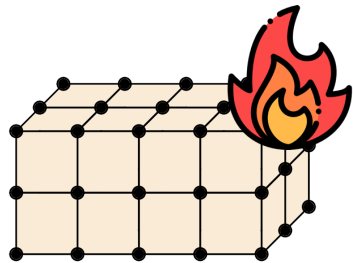
Pierre / mortier/interface

Non impactée par le gradient

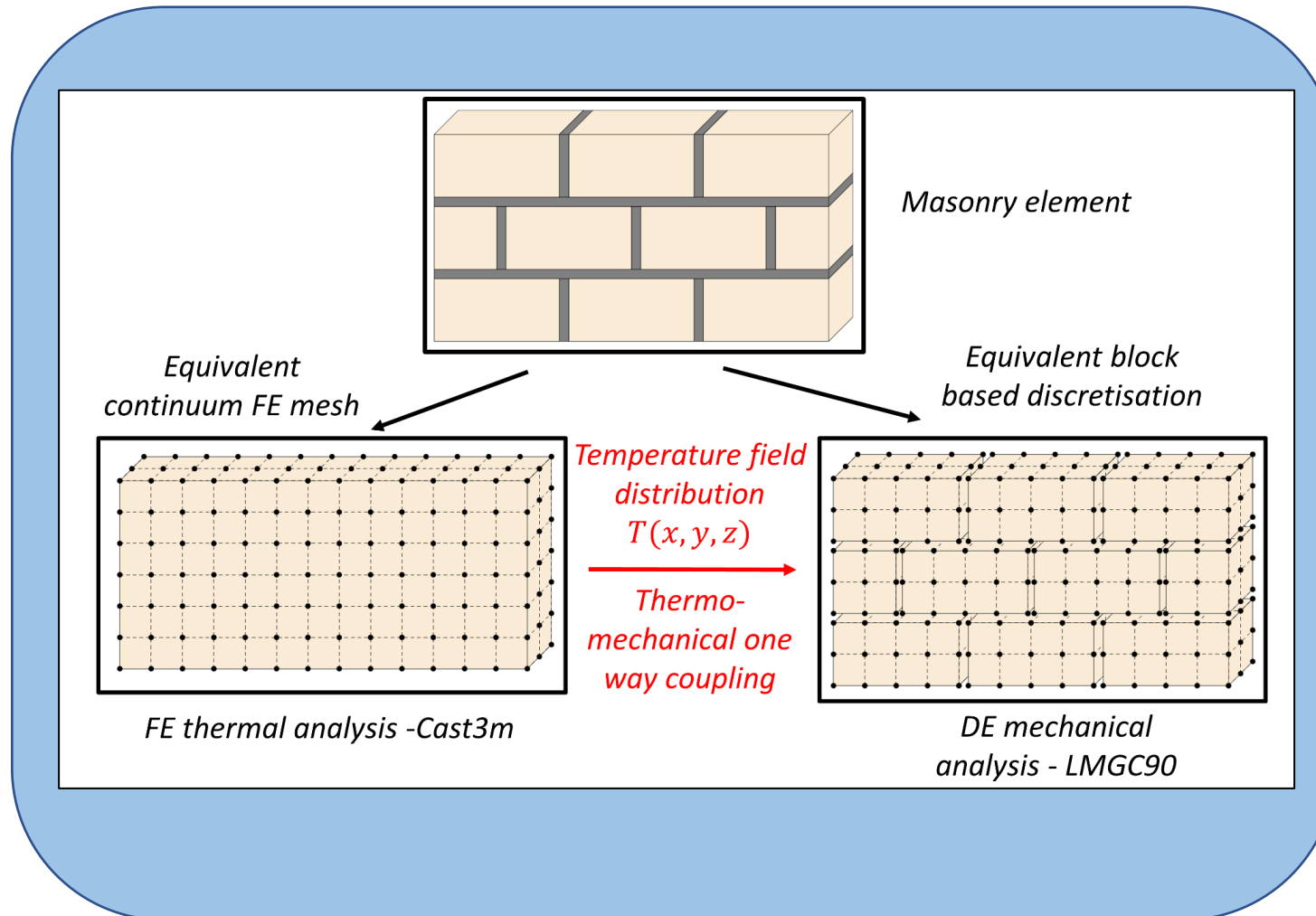
INTERFACE
MORTAR
INTERFACE



Guenser et al, 2024



Approche de modélisation thermomécanique

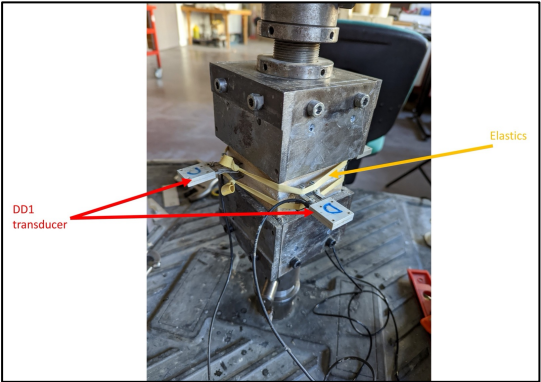


*Approche de modélisation
thermomécanique
=
Modèle thermique
+
Approche mécanique hybride
+
Effets matériaux et structuraux
de la température*

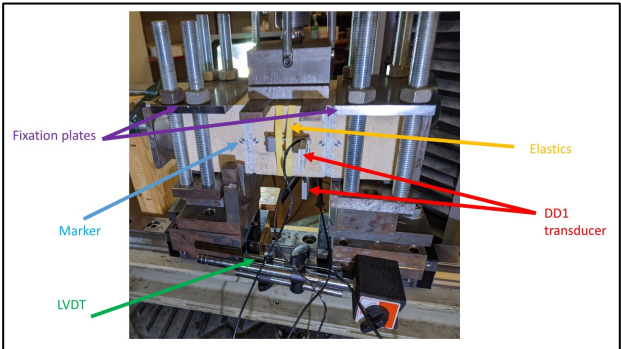
Caractérisation mécanique à haute T°



Nbr des
essais :
169



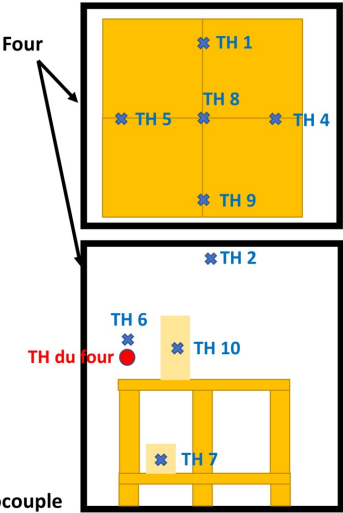
Essai de traction
directe



Essai de
compression/cisaillement :
0,1/0,2/0,3/0,4/0,6/0,8 MPa

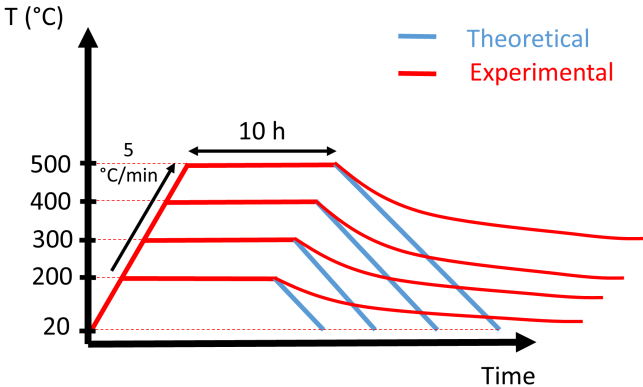


- Vitesse de chauffe : 5°C/min
- Plateau de maintien : 10h

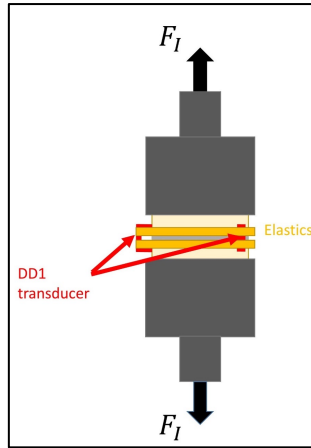


TH : thermocouple

Protocole de chauffe :
200/300/400/500 °C



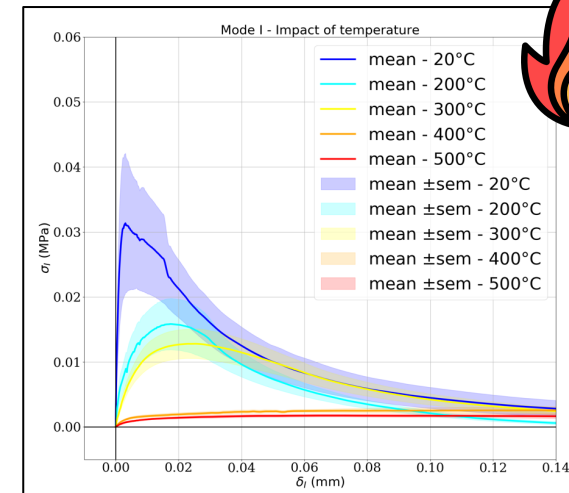
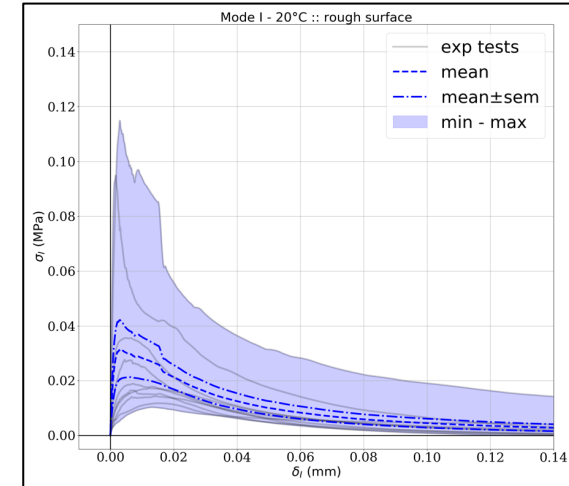
Traction direct - assemblage



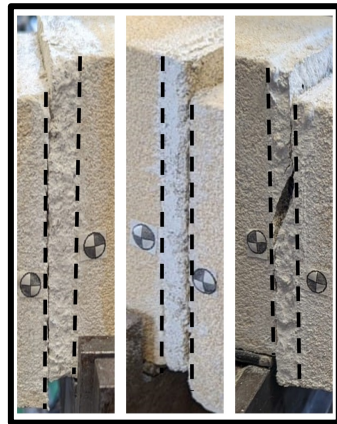
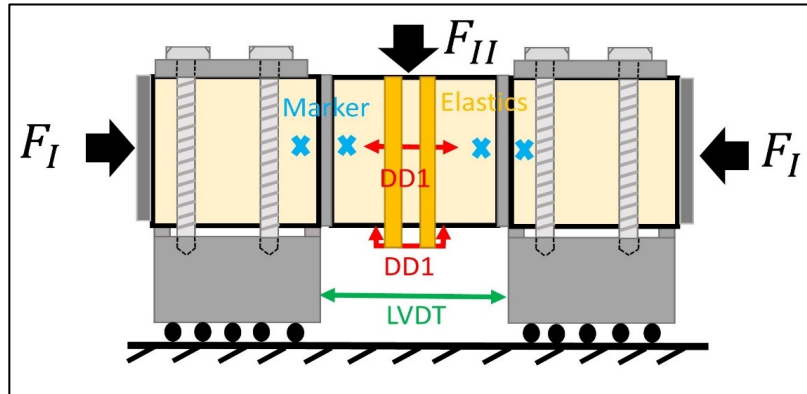
20/200/300 °C



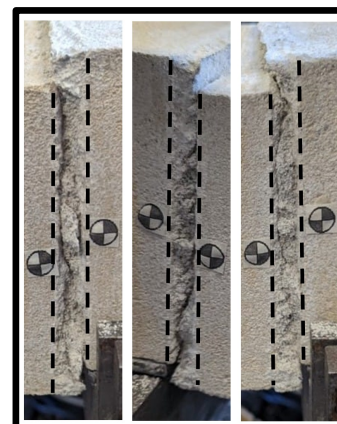
400/500 °C



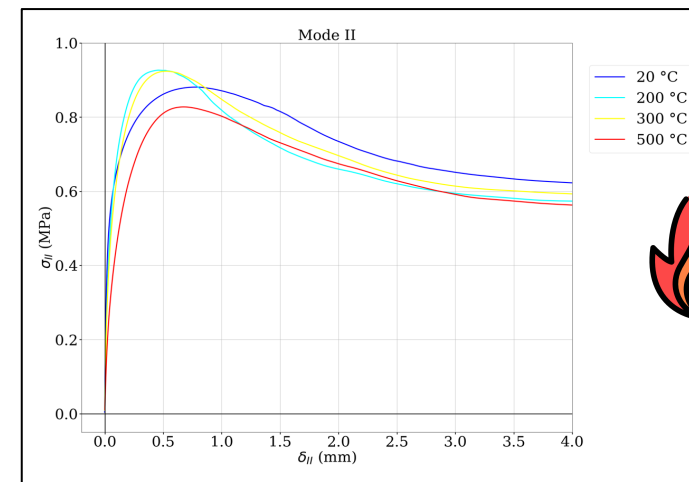
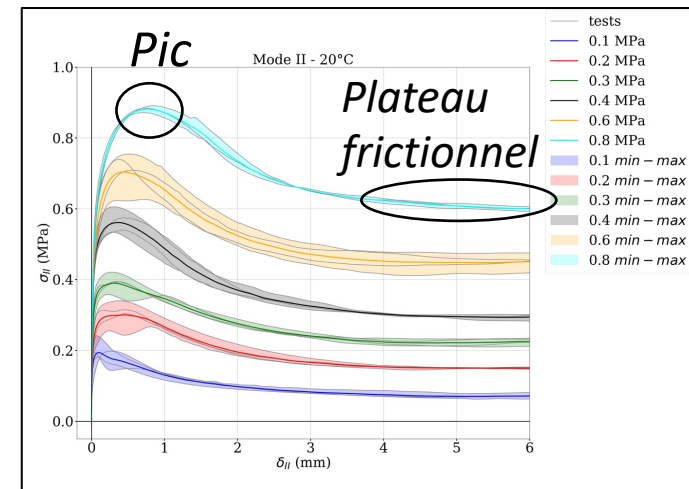
Cisaillement/compression - assemblage



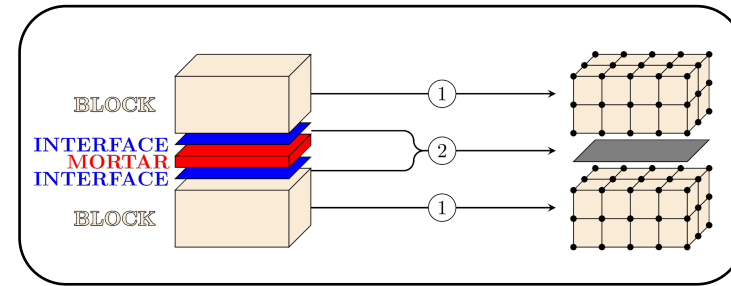
$\sigma_N = 0,1 \text{ MPa}$



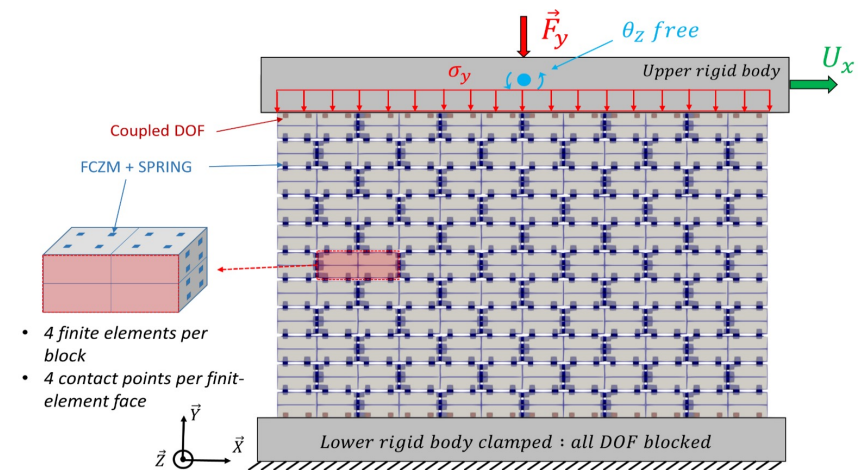
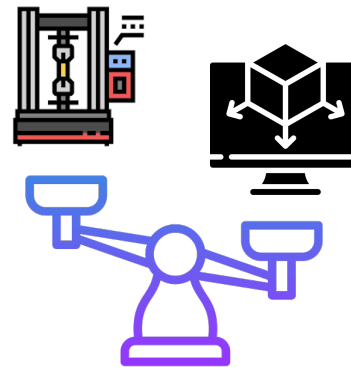
$\sigma_N = 0,8 \text{ MPa}$



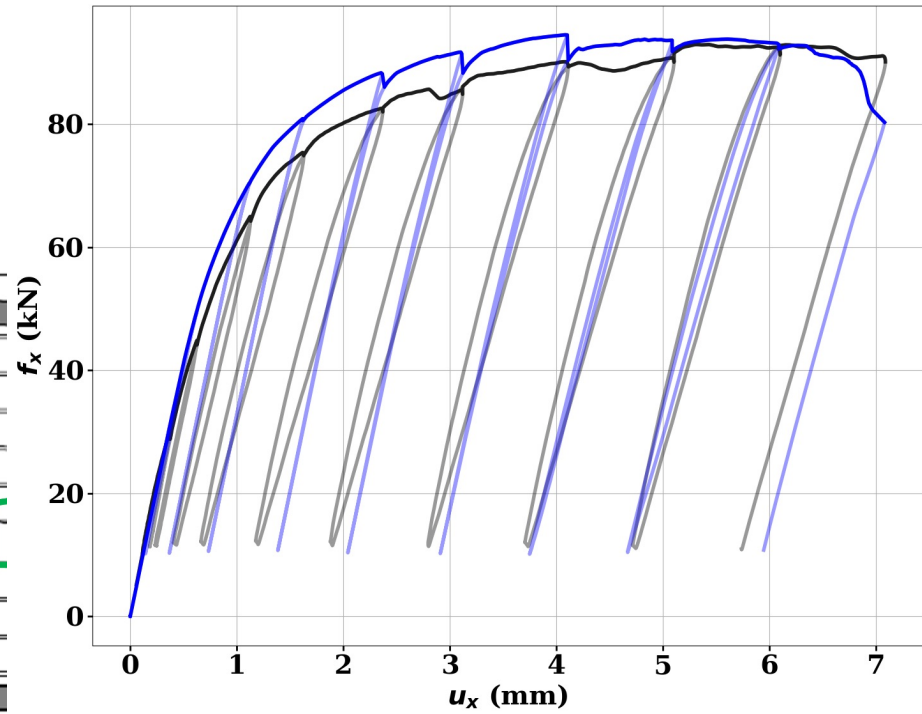
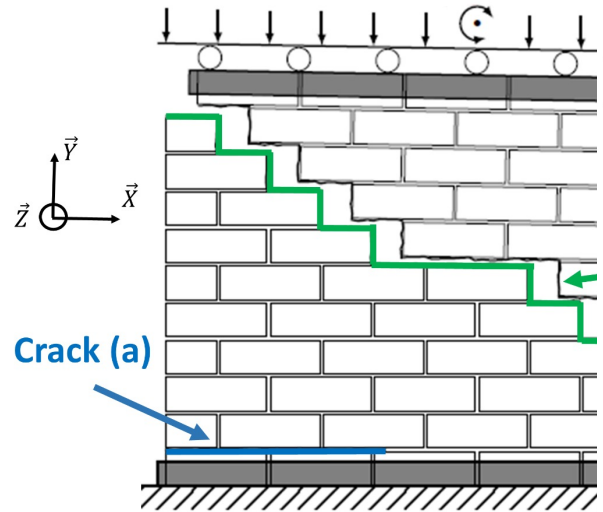
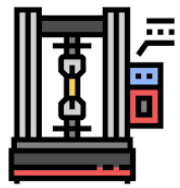
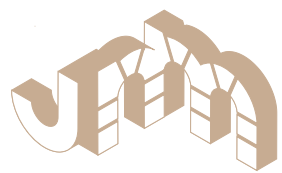
Validation mécanique – mur en cisaillement



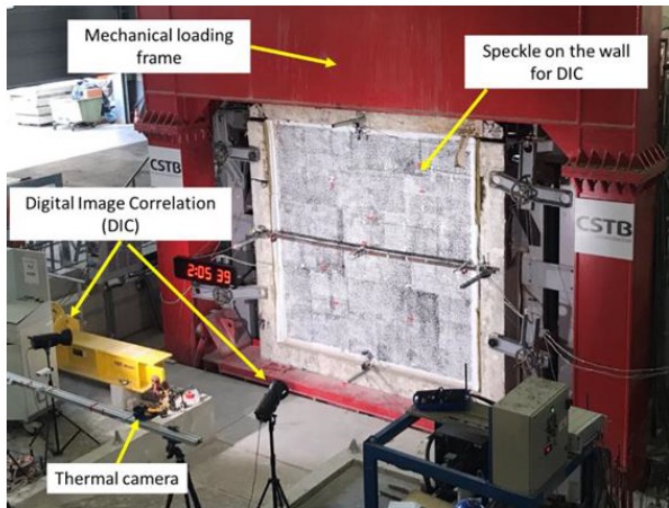
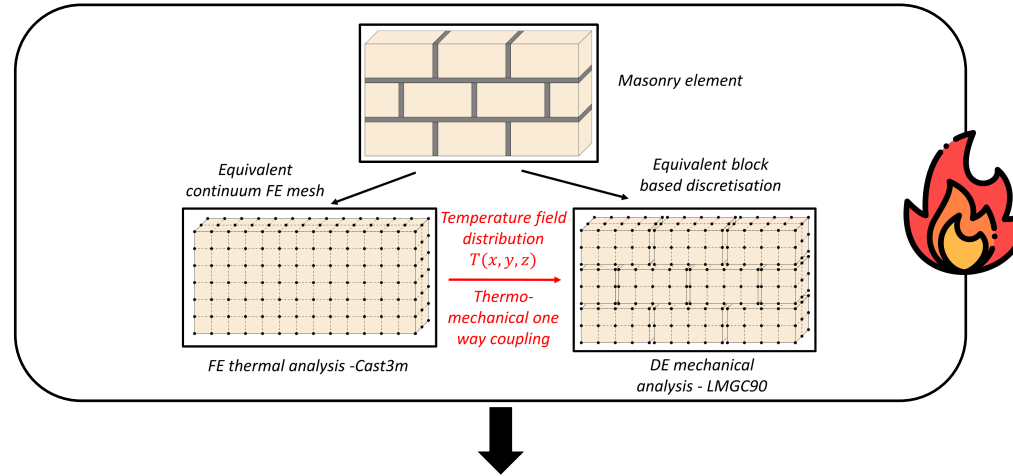
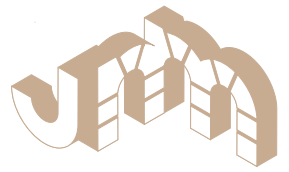
Venzal, 2020



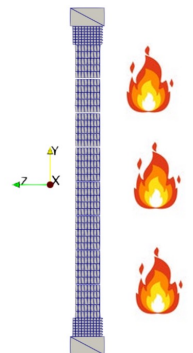
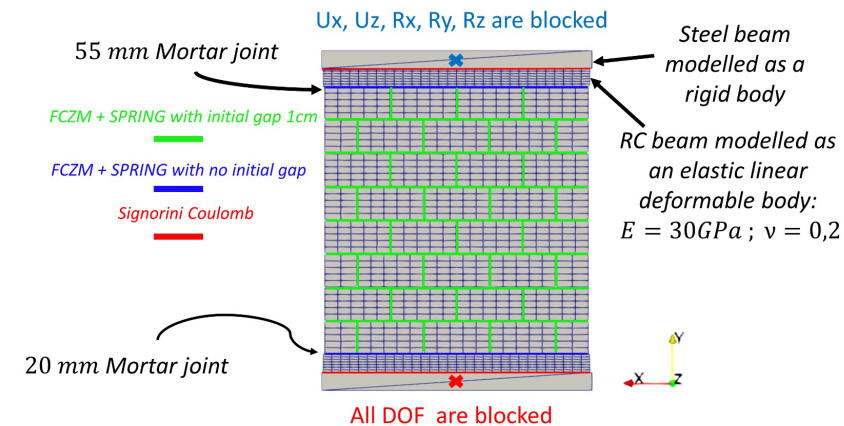
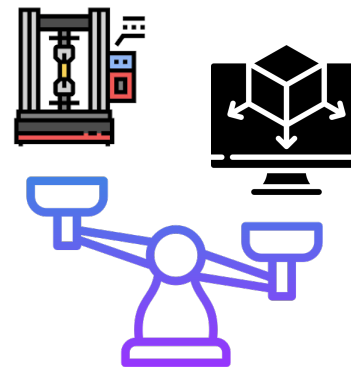
Résultats



Validation thermomécanique – mur soumis à chargement thermique ISO834



Pimienta et al, 2023

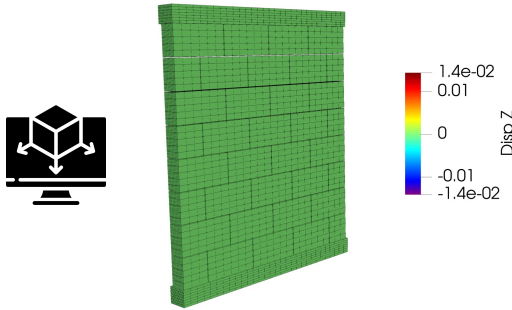


Résultats

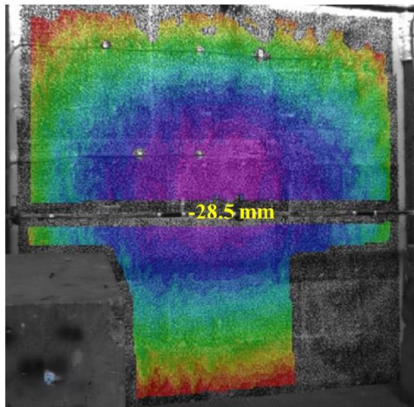
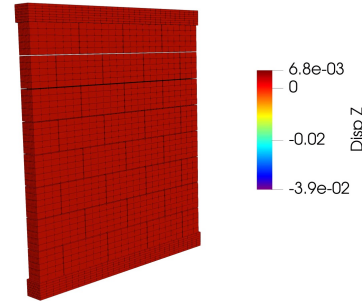


Déplacement hors plan

Avec endommagement thermique du mortier

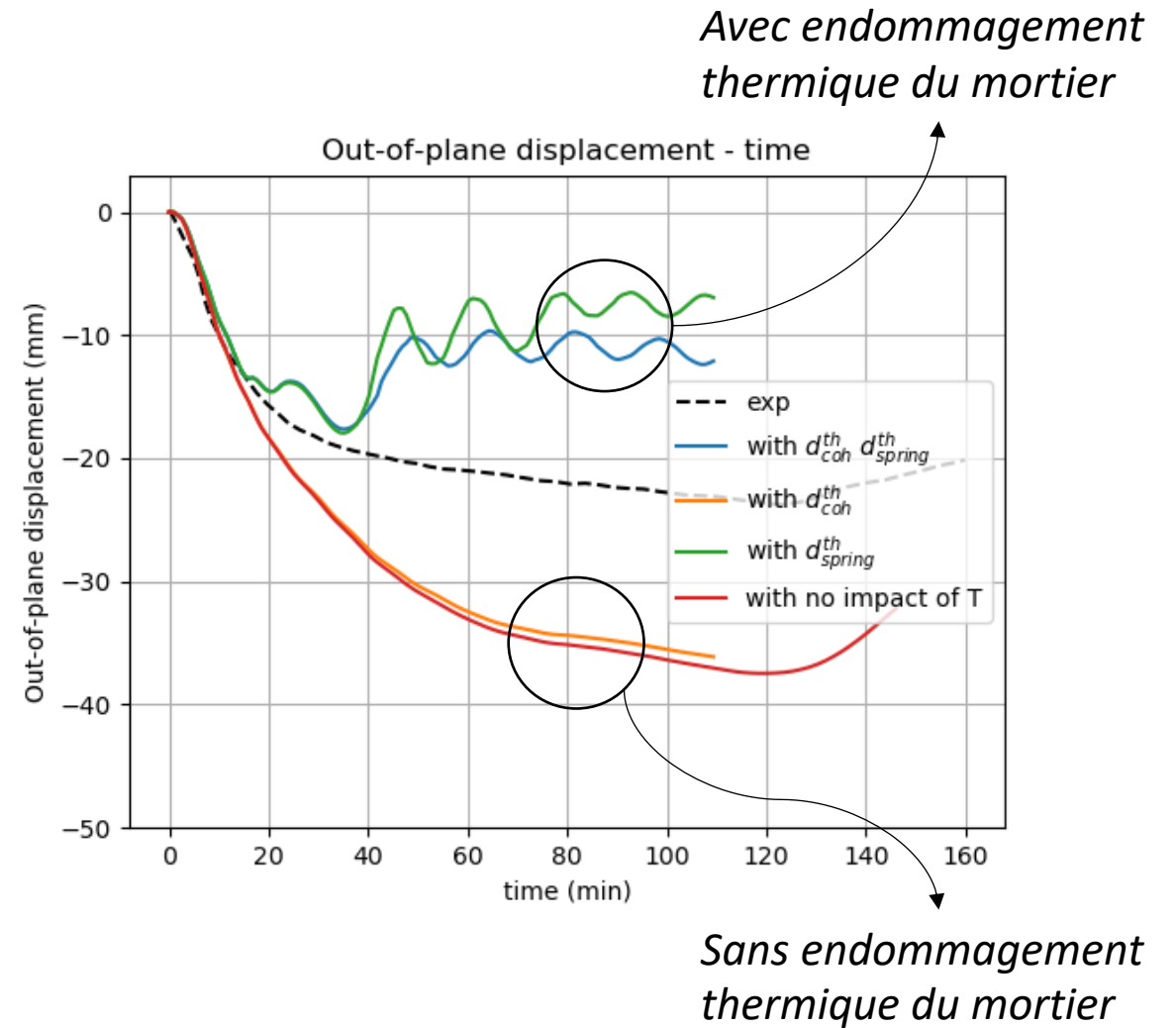


Sans endommagement thermique du mortier

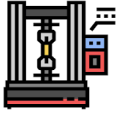


À la fin de la phase de chauffe

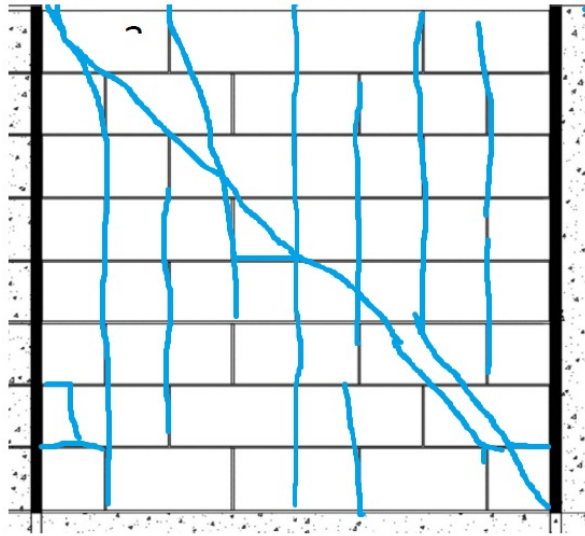
Pimienta et al, 2023



Résultats

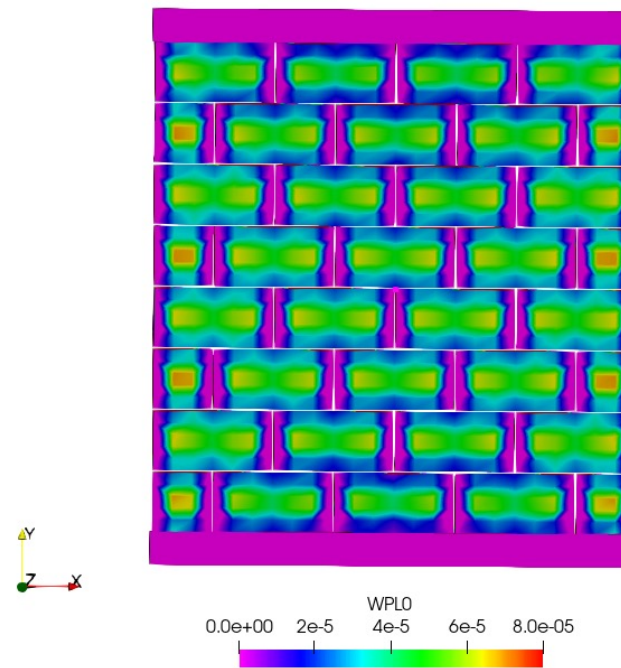


Pimienta et al, 2023



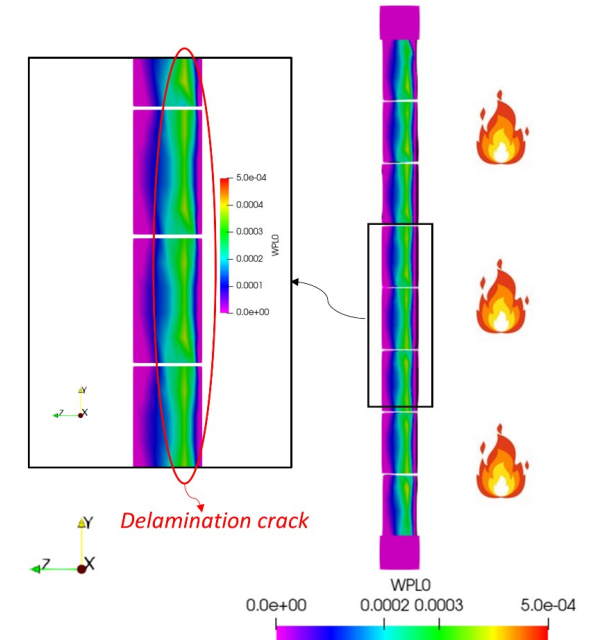
*Fissuration à la fin de la phase
de chauffe*

face non exposée



Fissuration à la fin de la phase de chauffe

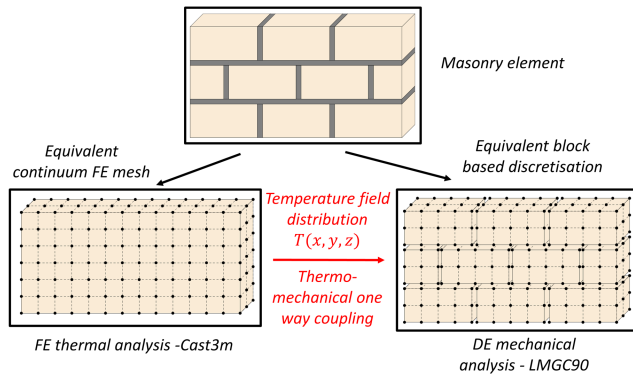
face non exposée



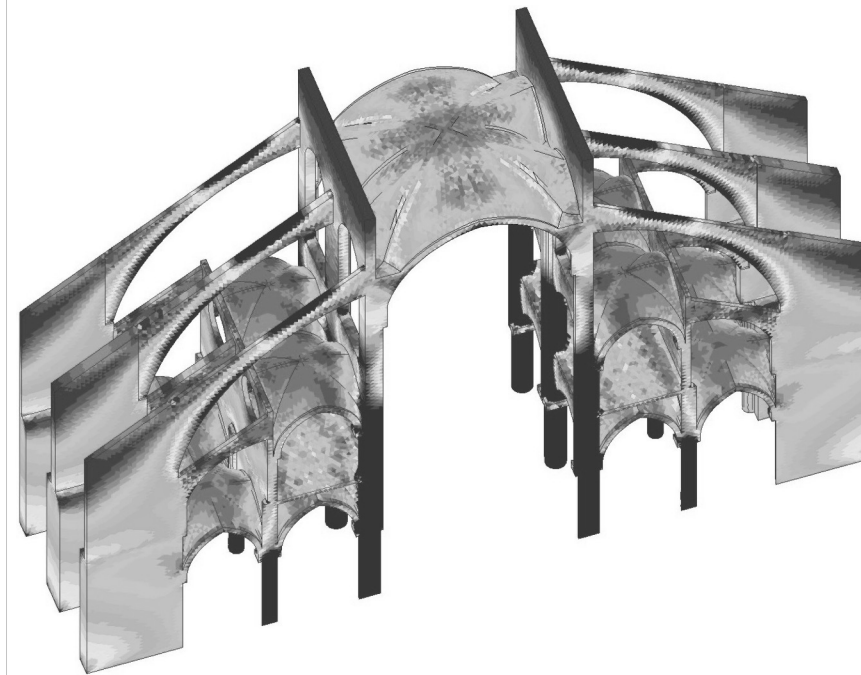
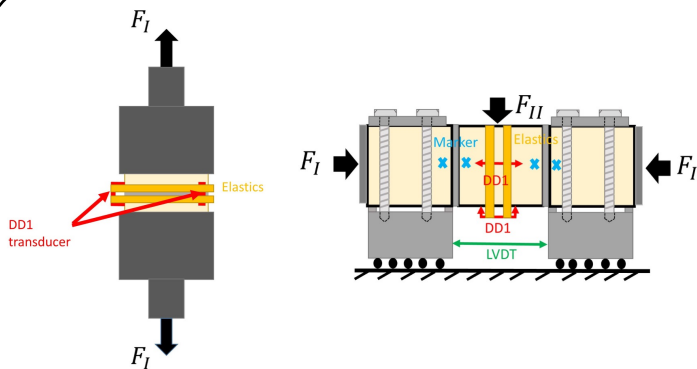
Conclusions & Perspectives



Approche hybride



Matériaux caractérisés



Évaluation structurale d'une travée du chœur de la cathédrale de NDP

- Typologie de la maçonnerie
- Chargement thermique
- Précise

- Temps de calcul : passage aux éléments joints – réduire la zone modélisée en hybride



Merci de votre attention

Contact :

BOUKHAM, ali.boukham@cea.fr