Real-time surgical simulation using a lattice-continuum approach

Implementation and verification

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SOFA

Some words about me

- PhD at University of Grenoble (November 2013)

  Multiscale approach of concrete structure failure

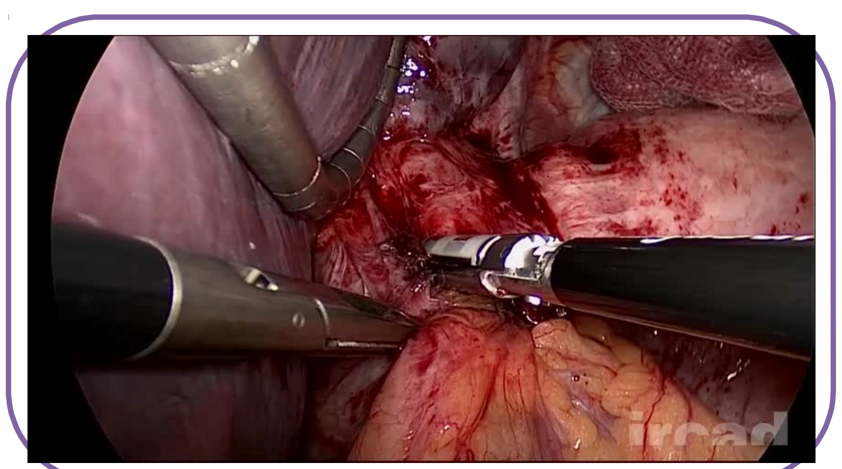
- Lecturer (ATER) at 3SR laboratory (2014)

  Segmentation of cracks in concrete structure

- Arrived in Strasbourg (September 2014)

Context

- Surgery: complex practice
  - Experiences of surgeons
  - A number of risks



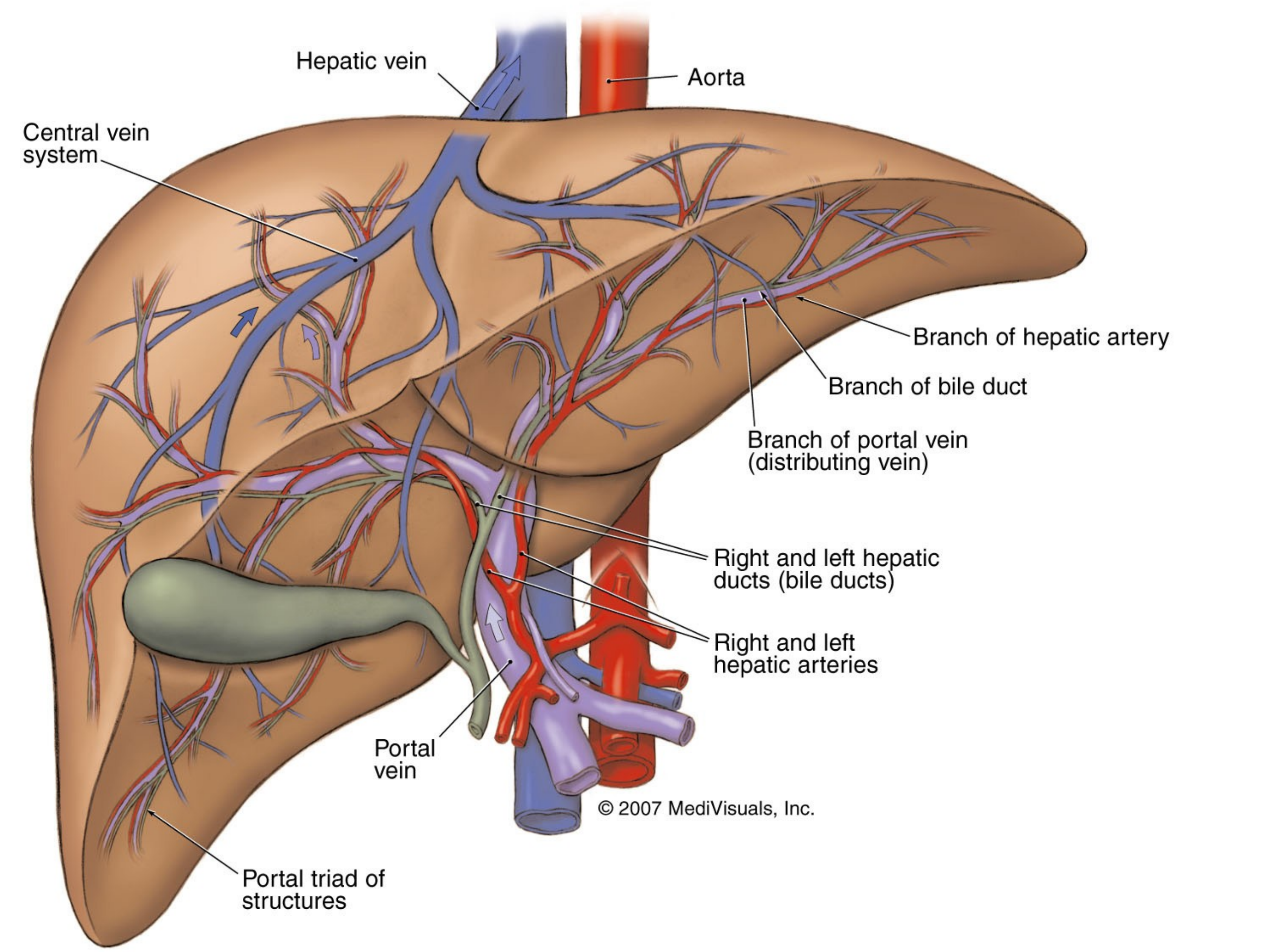
Context

Courtecuisse *et al*, 2013

- **Computer-based simulation**
  - Surgical training
  - Guidance
  - Surgical robotics

- **Challenges:** cutting, tearing, needle insertion, ...
  - Topological changes
  - Contacts
  - Microstructure of the tissue (discontinuities, holes,)

Internal Anatomy of Liver



 HP Bui, University of Strasbourg

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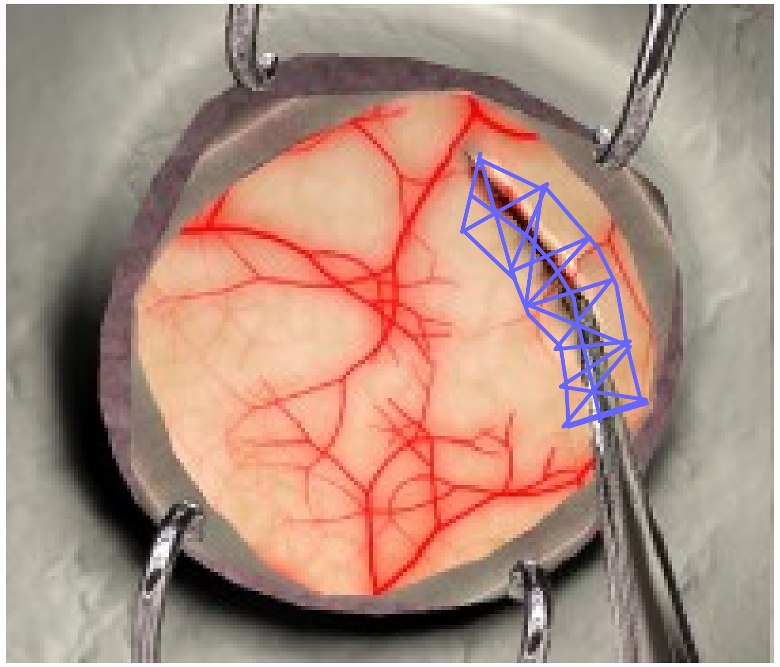
Objectives

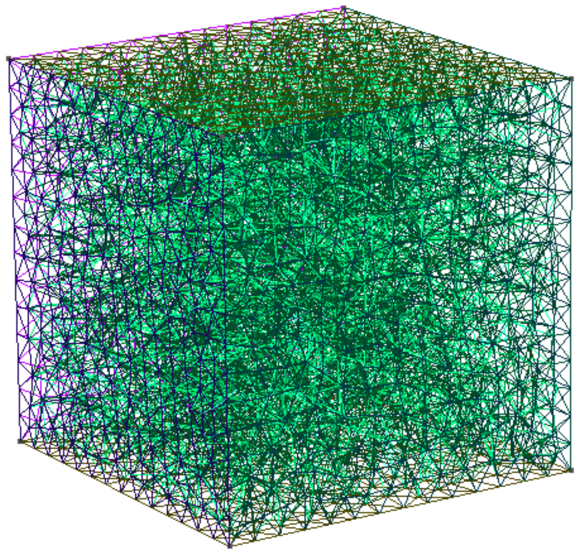
- Development of numerical tool
  - Real-time simulation
  - Multi-domain: continuum-lattice approach
  - Multiscale: macro, mesoscopic scale (material scale)



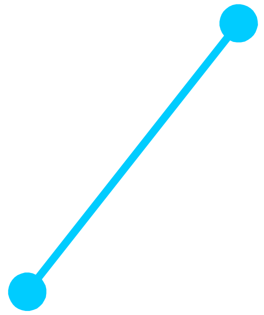
⇨
- Computational gains
- Increase the quality of the cut

- The algorithm is implemented into SOFA framework

Lattice approach

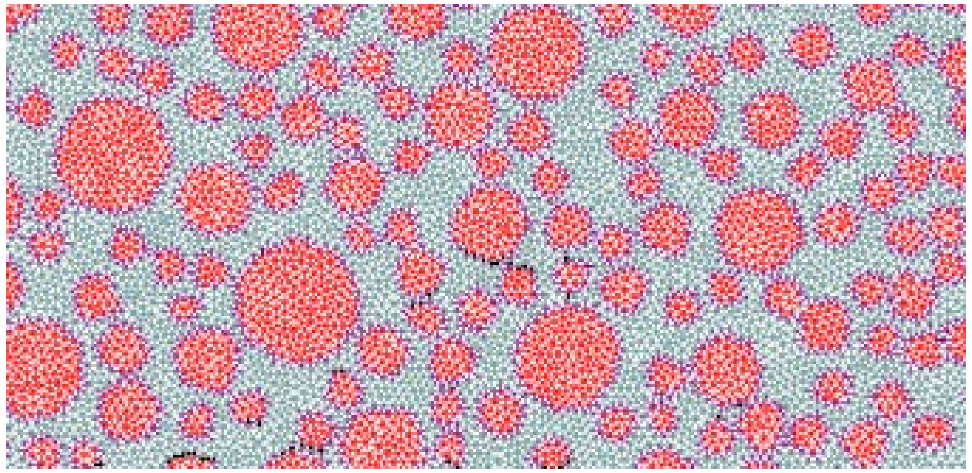


Discretization by 1D elements



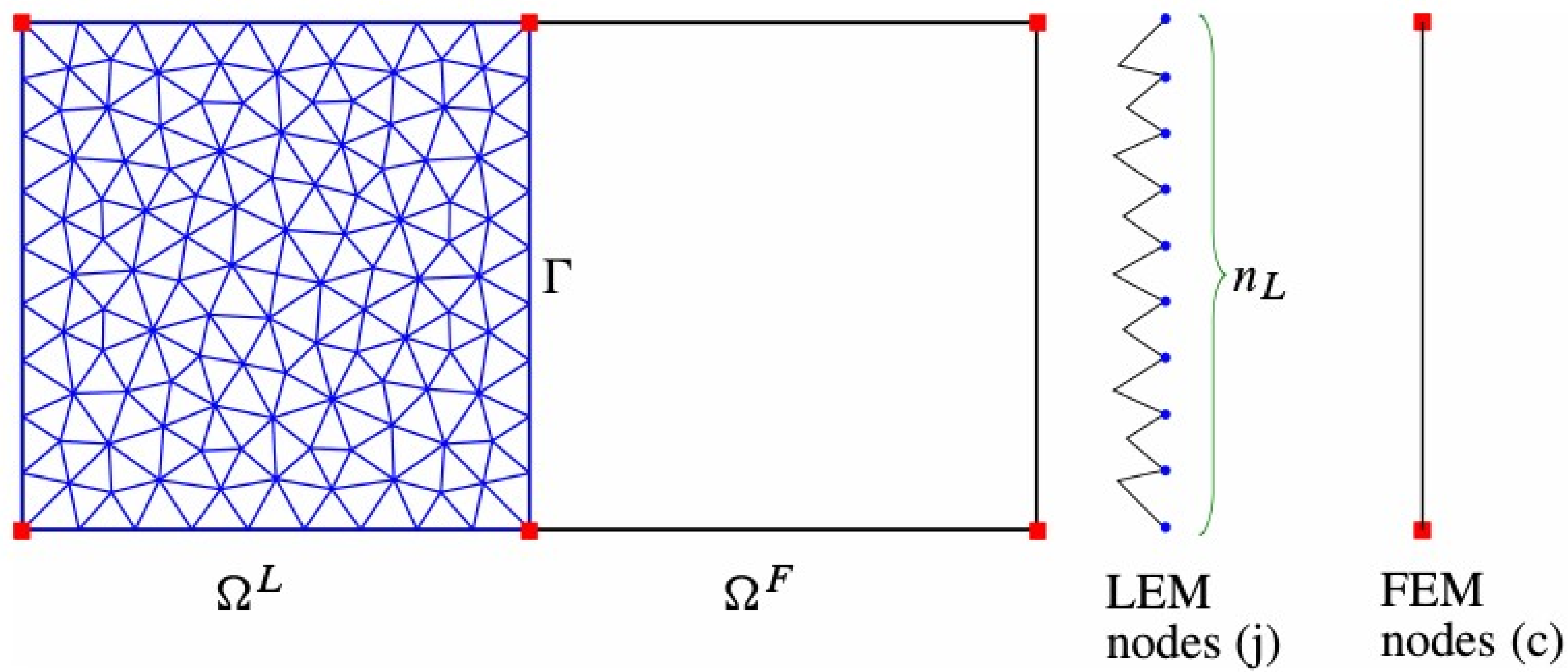
- ○ Beam element
- ○ Truss element

- ▲ Discrete model: suitable for discontinuity problems
- ▲ Simplicity to incorporate fracture, cutting
- ▲ Modeling of material heterogeneity



▼ Computational cost

Continuum-lattice approach



$$\mathbf{u}_j^L = \mathbf{N} \cdot \mathbf{u}_c^F = N_c(\mathbf{x}_j) \cdot u_c, \forall j = \{1, 2, \ldots, n_L\}$$

Coupling methods

1. Penalty method: with penalty coefficients $\alpha >> 1$

$$\int_{\Gamma_i} \alpha \left\| (\mathbf{u}^F - \mathbf{u}^L) \right\|^2 \mathrm{d}\Gamma_i$$

2. Lagrange multipliers:

$$\int_{\Gamma_i} \boldsymbol{\lambda} (\mathbf{u}^F - \mathbf{u}^L) \, \mathrm{d}\Gamma_i$$

3. Master/slave approach (*Belytschko et al, 2000*):
   F :master, L: slave

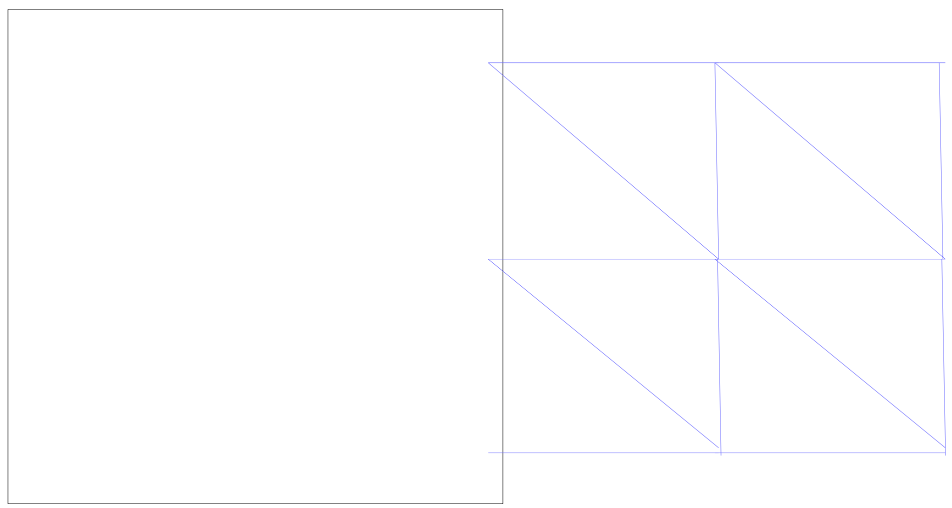
$$\mathbf{u}^L = \mathbf{J}\mathbf{u}^F$$

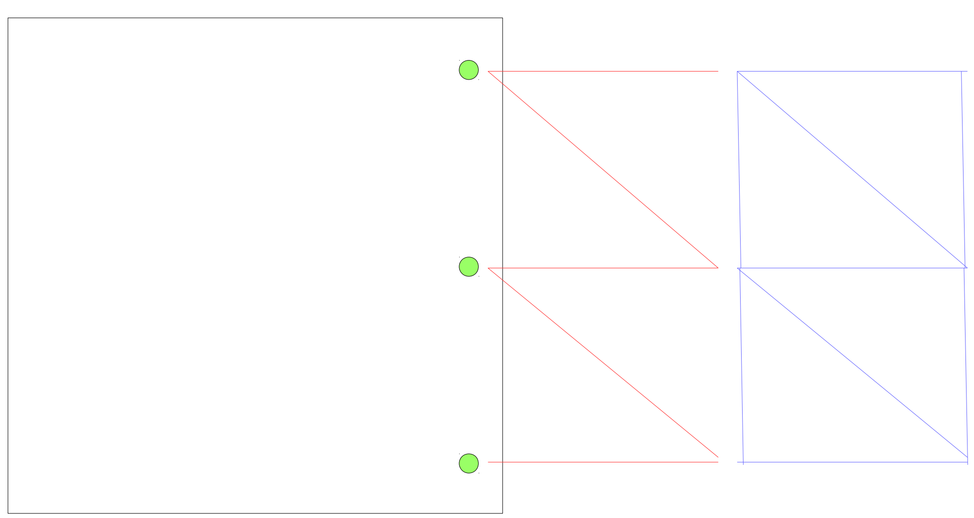
$$\mathbf{F}^F = \mathbf{F}^F + \mathbf{J}^T \mathbf{F}^L$$

Mapping mechanism in SOFA

FEM-LEM coupling

FEM LEM





⇒ **Multi-mapping** mechanism in SOFA

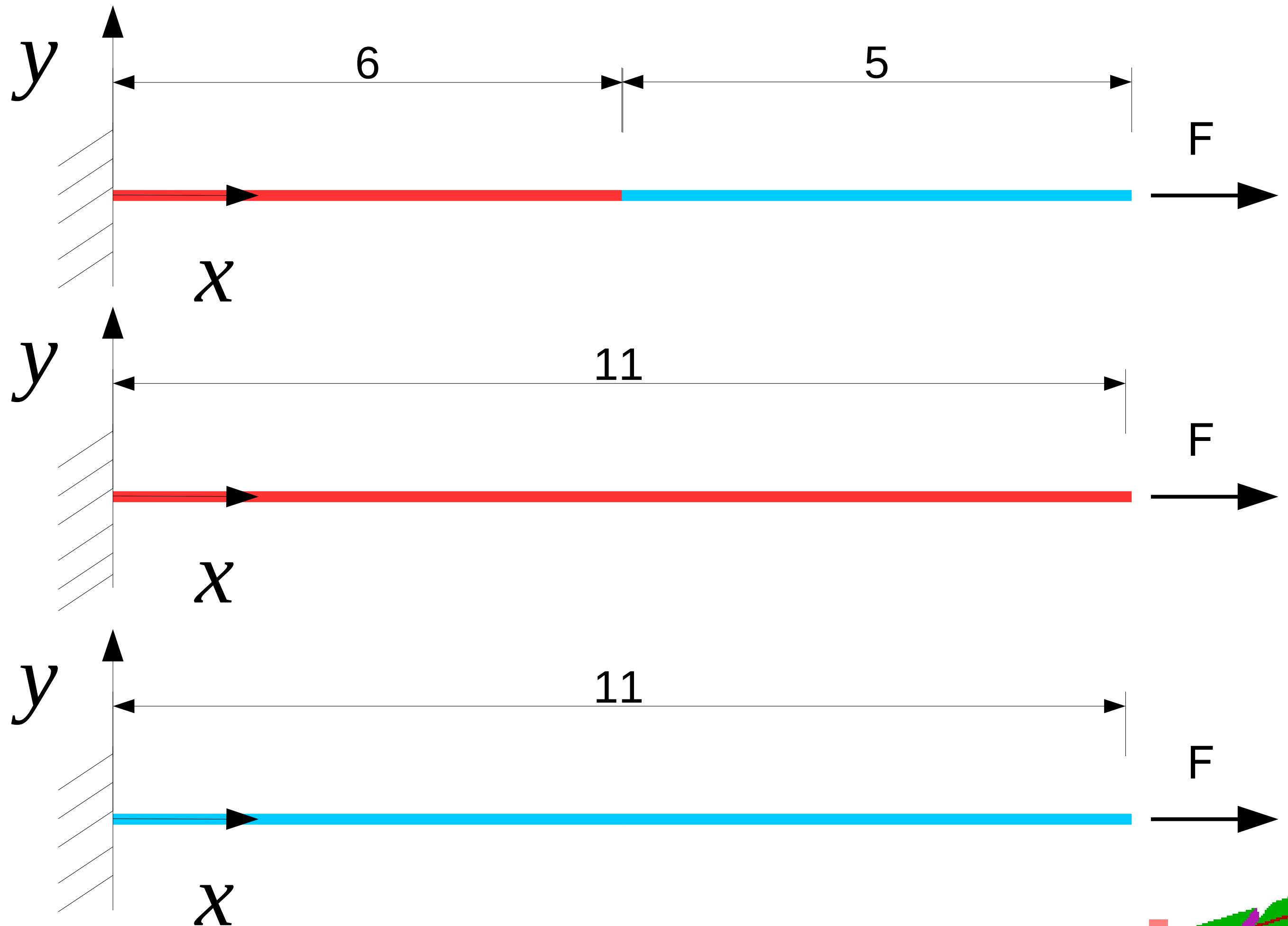
Verification tests

Verification tests: 3D tensile test

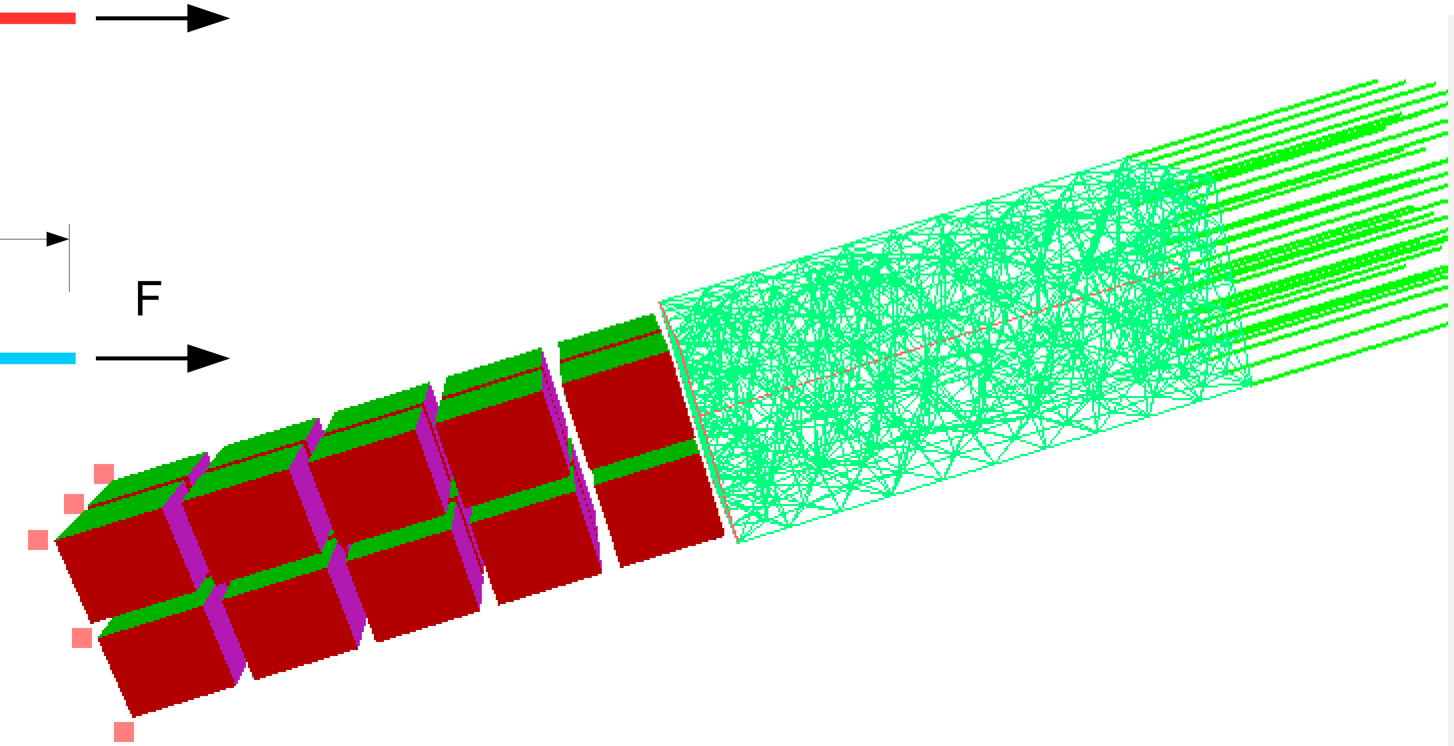
Coupling

FEM

LEM



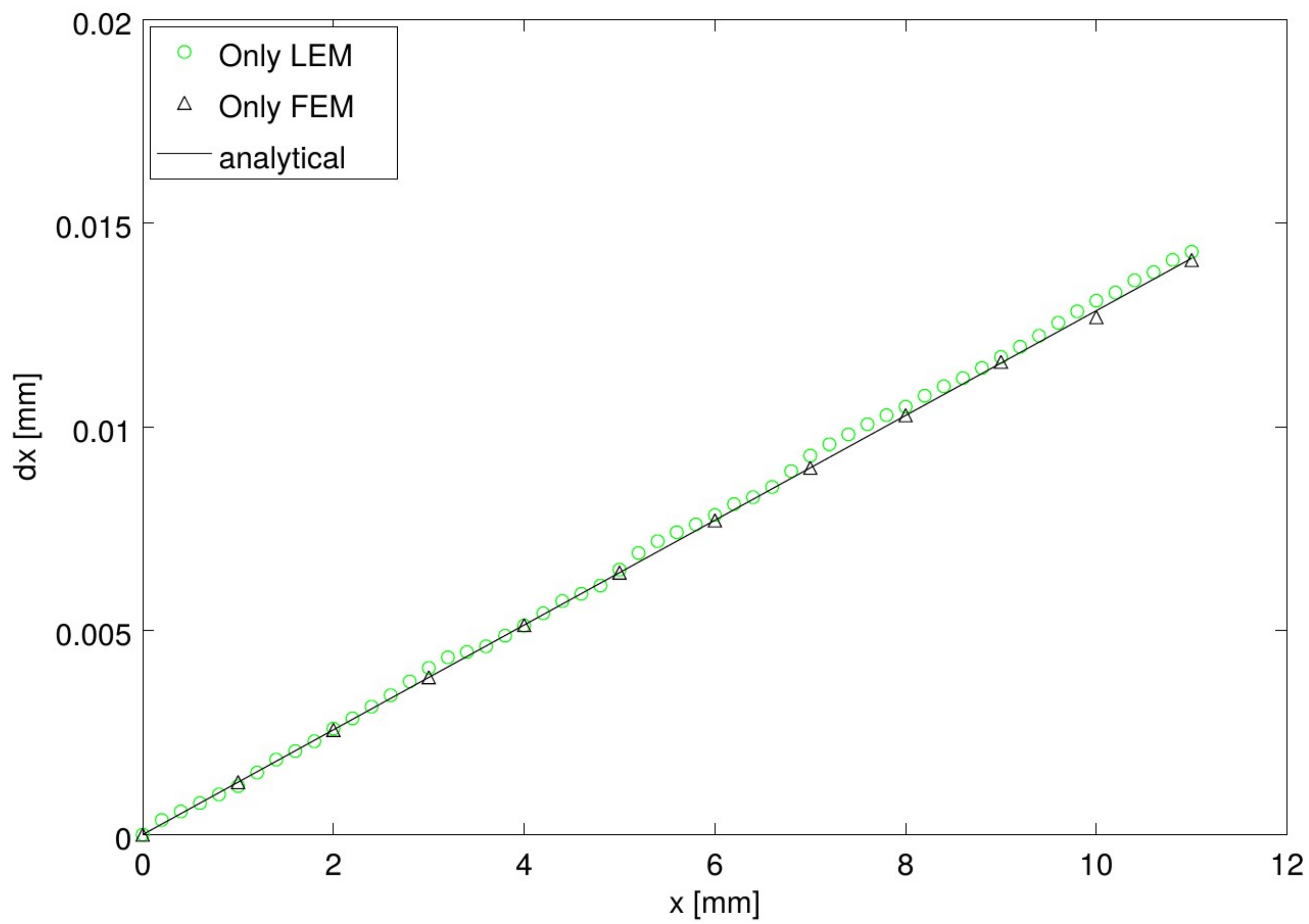
E = 19.5 GPa
ν = 0.1
bxh = 2x2 mm
F = 100 N

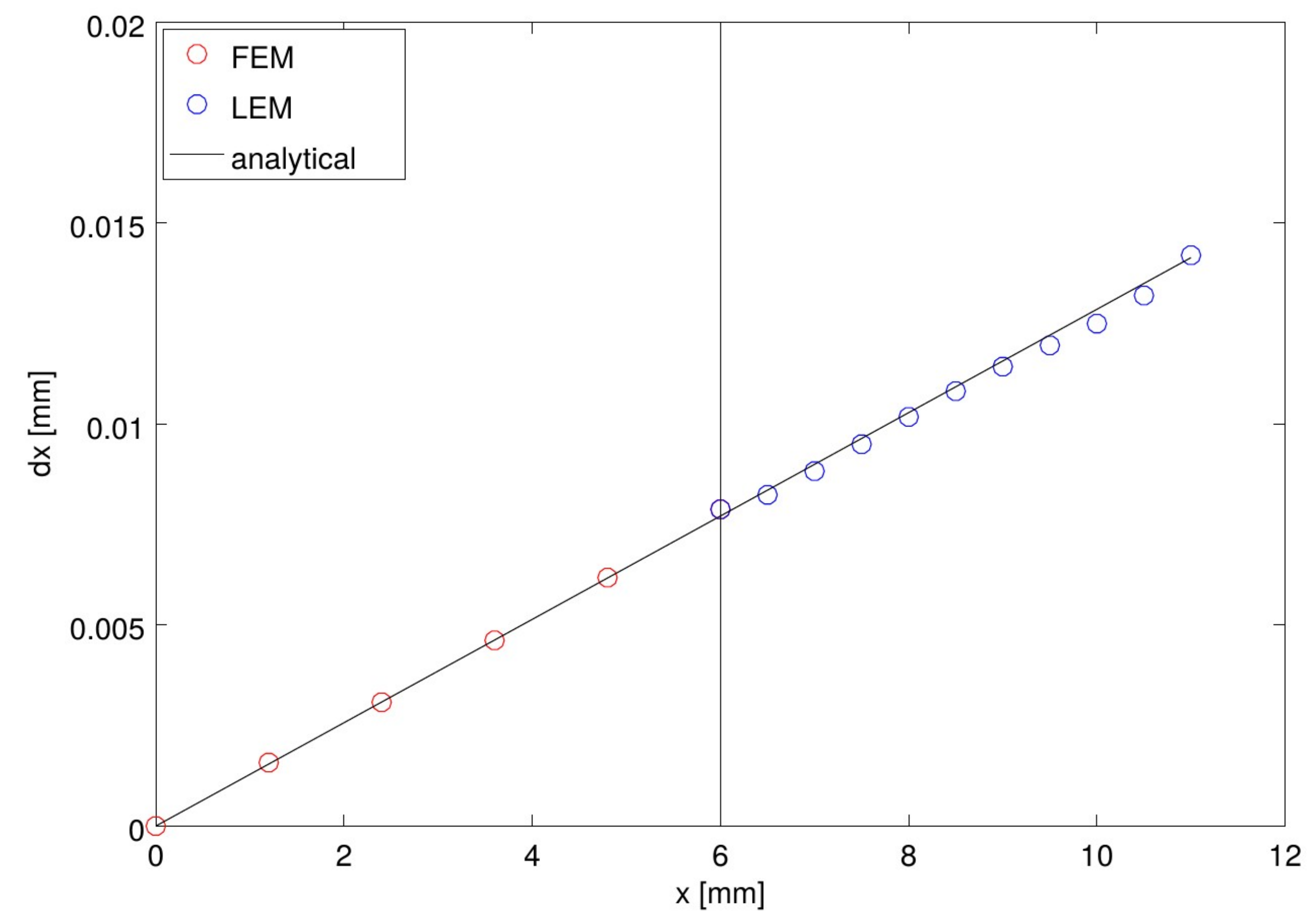


Analytical solution

$$u(x) = \int \frac{F}{EA}\mathrm{d}x = \frac{F}{EA}x$$

Verification tests: 3D tensile test



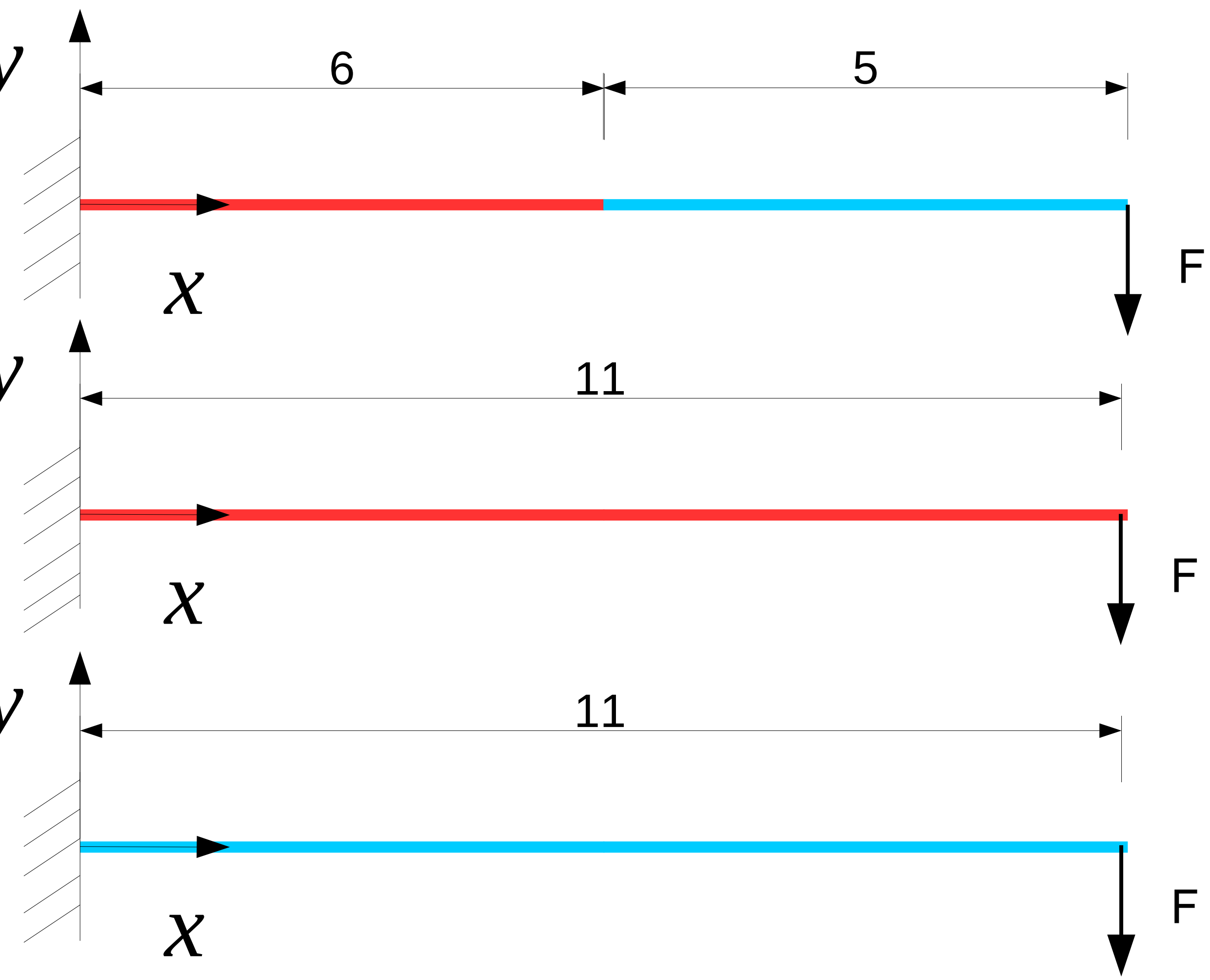


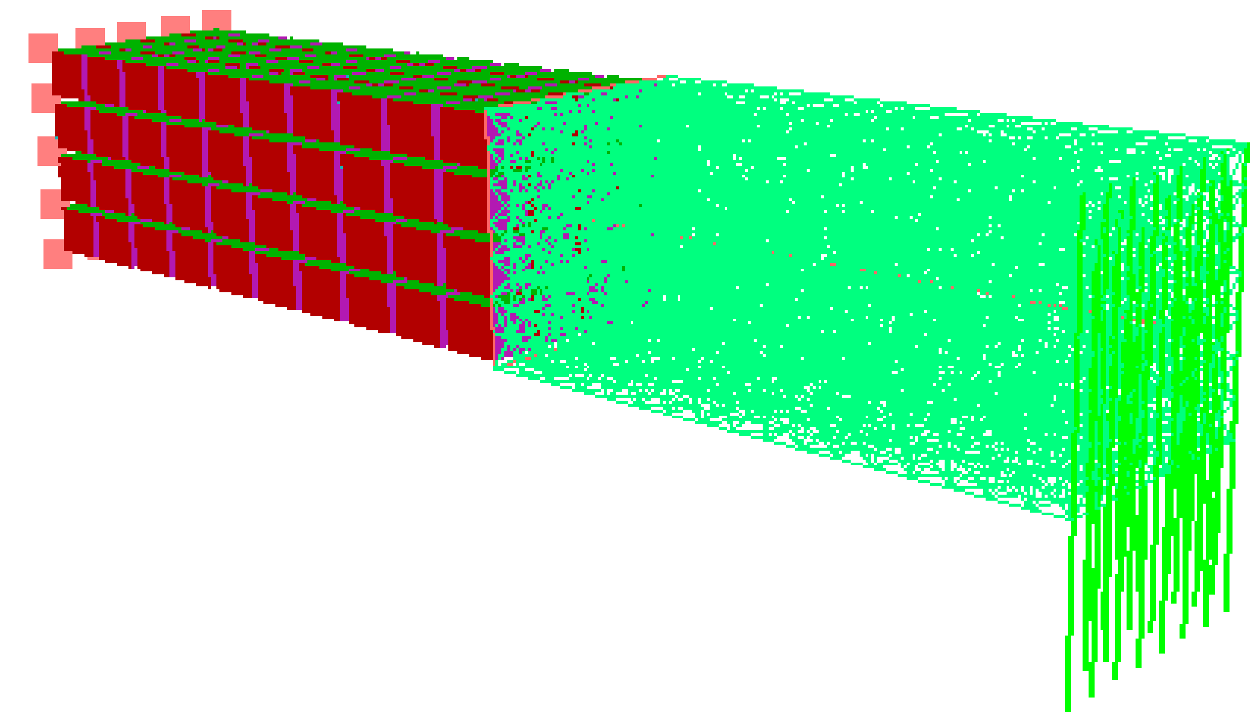
Validation tests: 3D bending test

Coupling

FEM

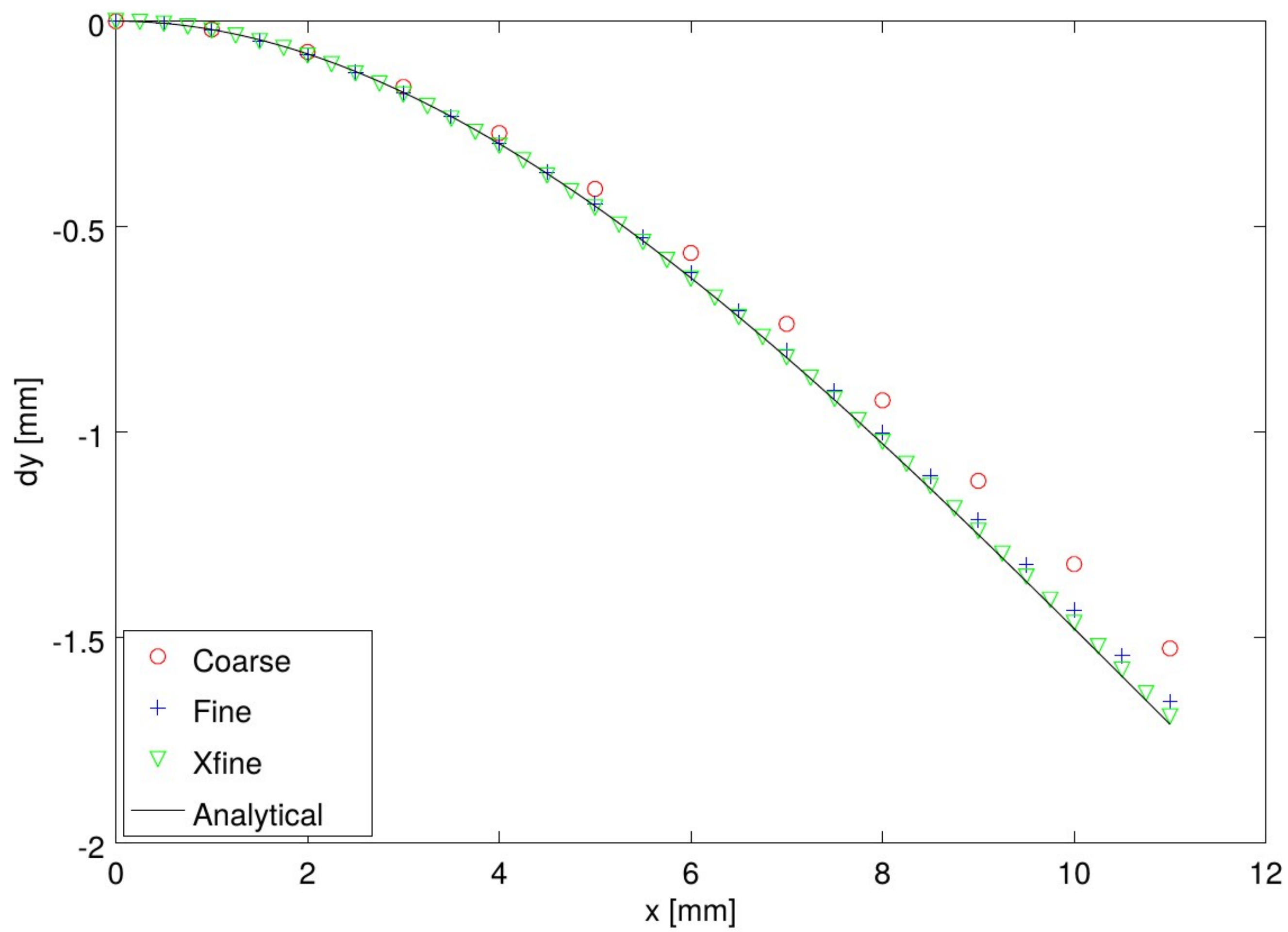
LEM



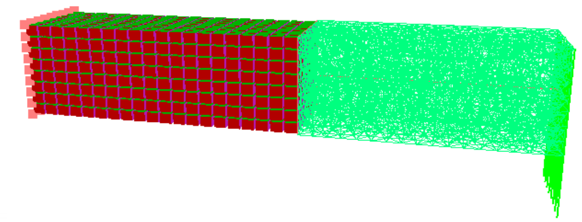


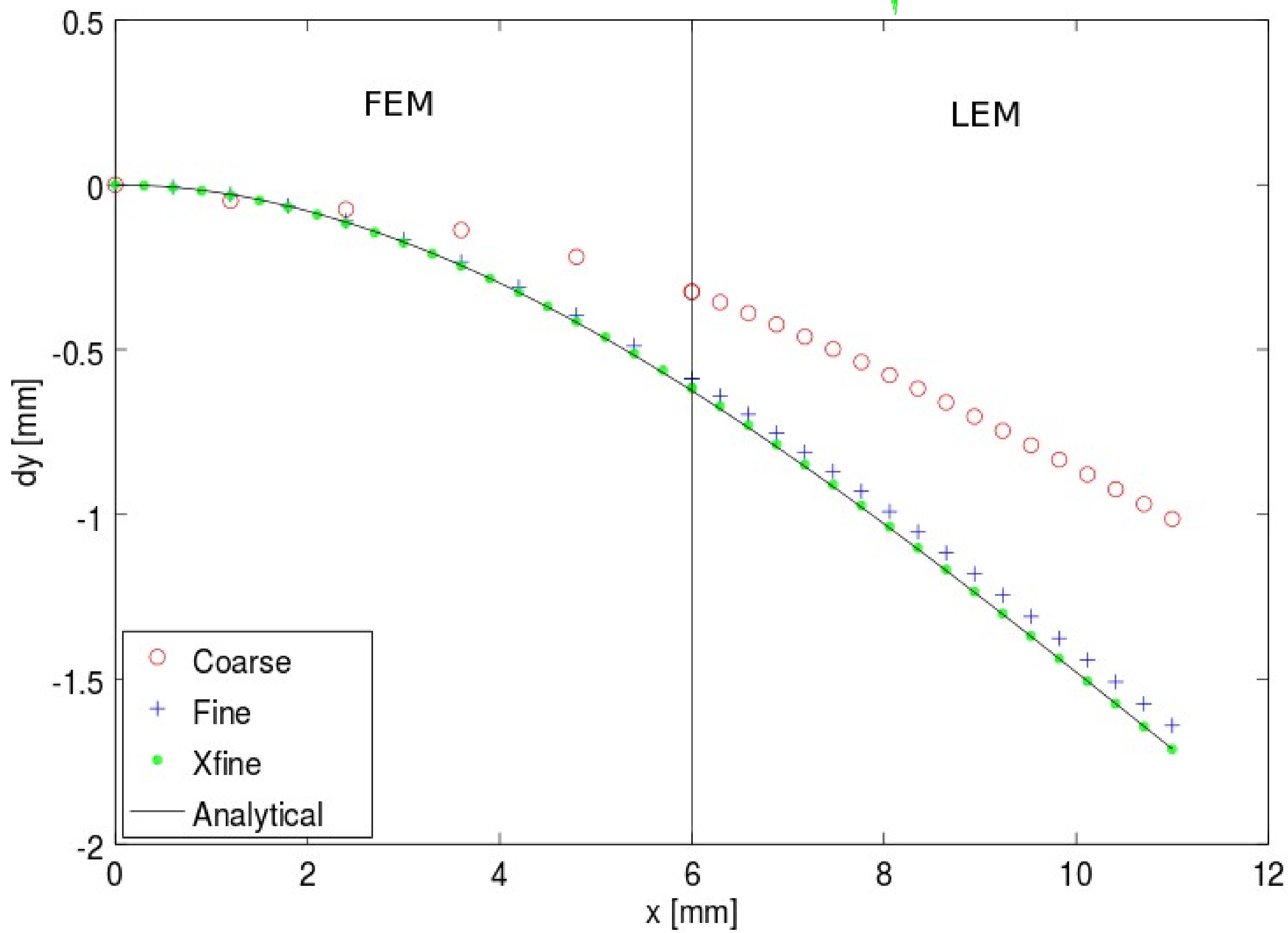
Analytical solution $$v(x) = \frac{-Fx^2}{6EI}(3L - x)$$

Bending test: FEM approach



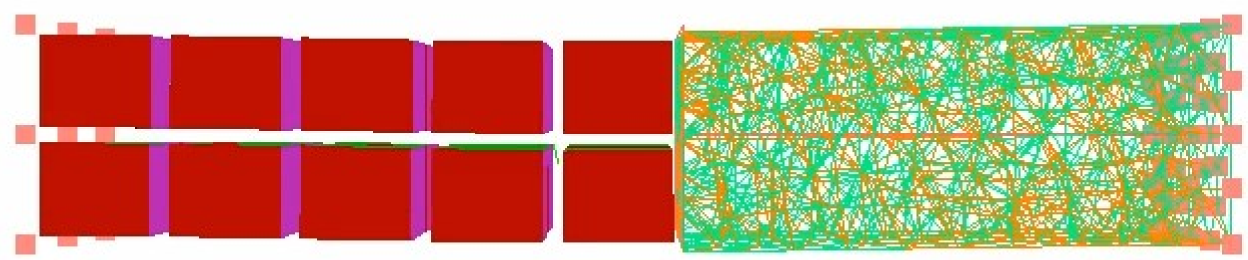
Bending test: FEM-LEM approach



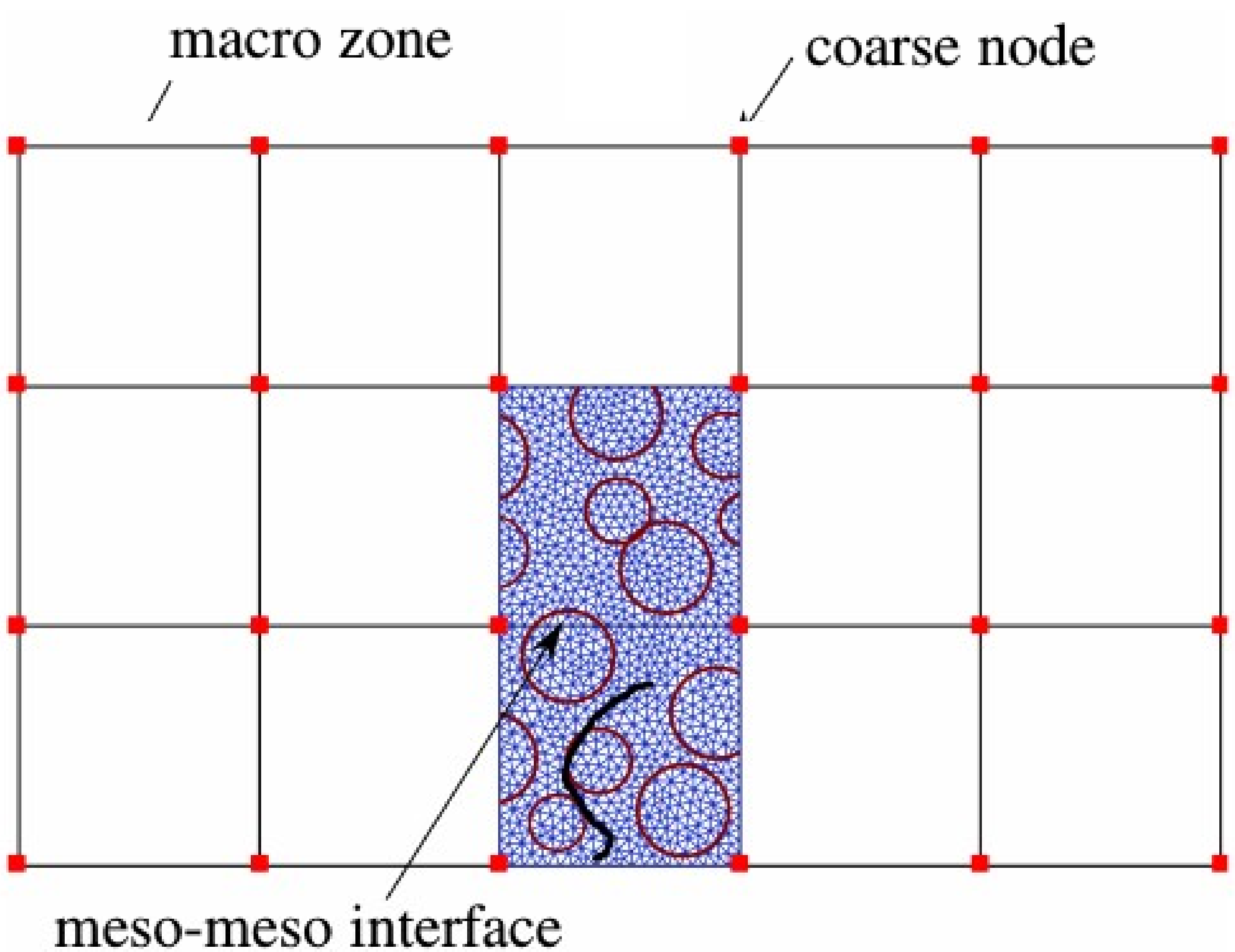


Fracture application

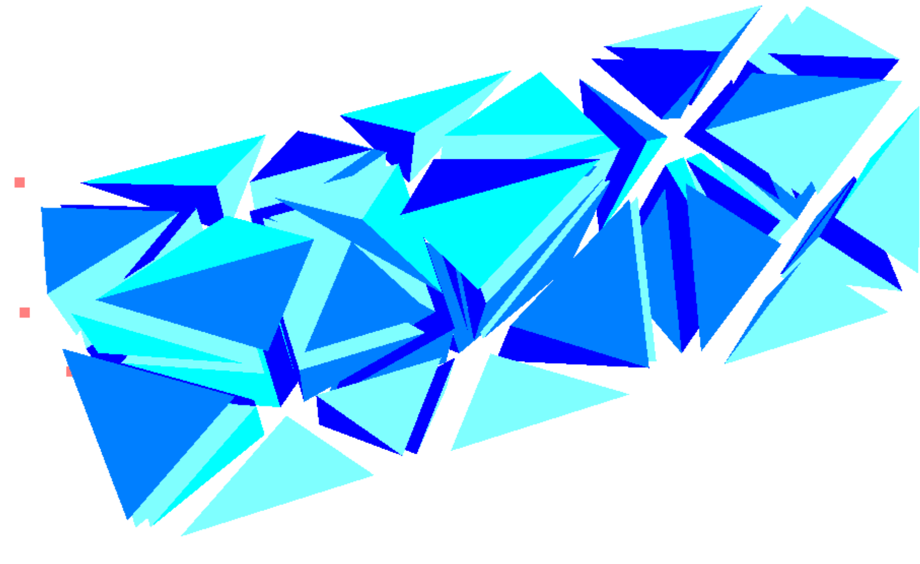
Failure due to tearing

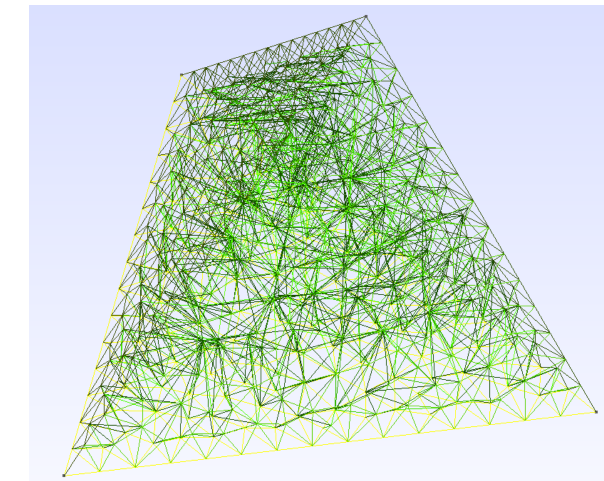


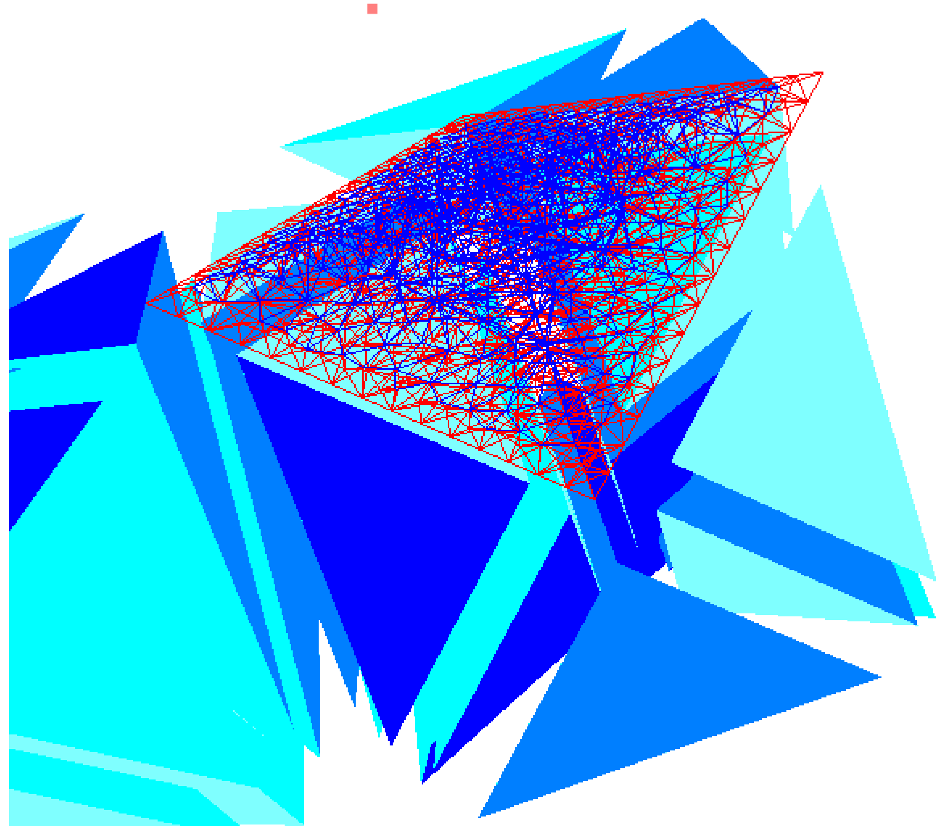
Dynamically Topological Changes

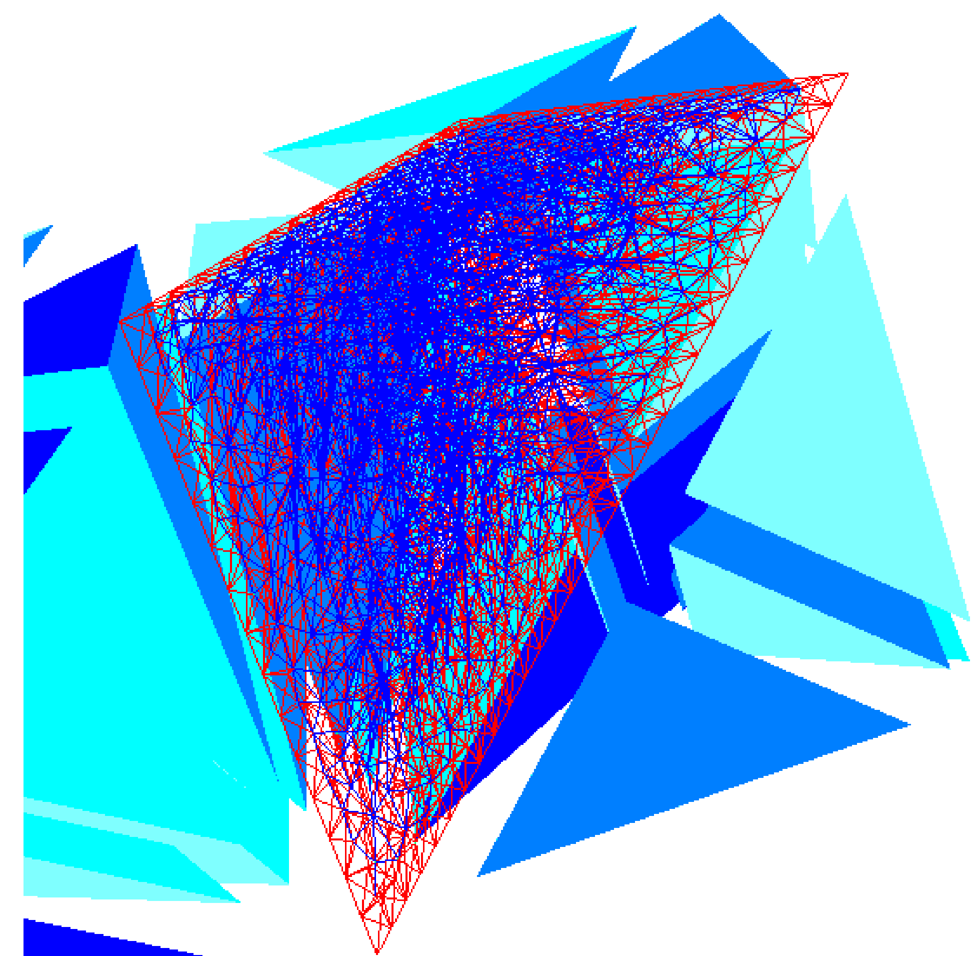


Dynamically Topological Changes

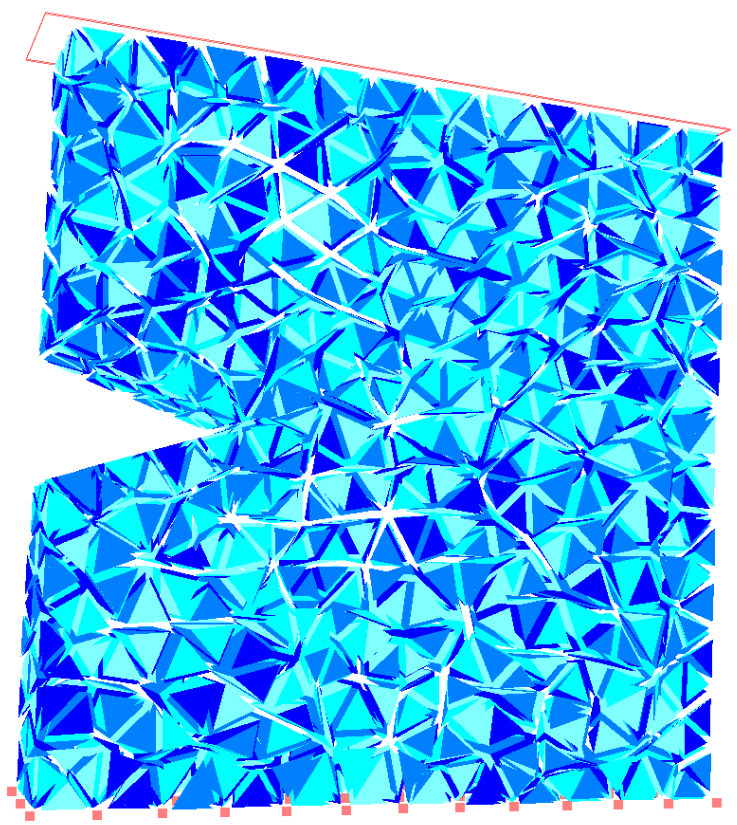


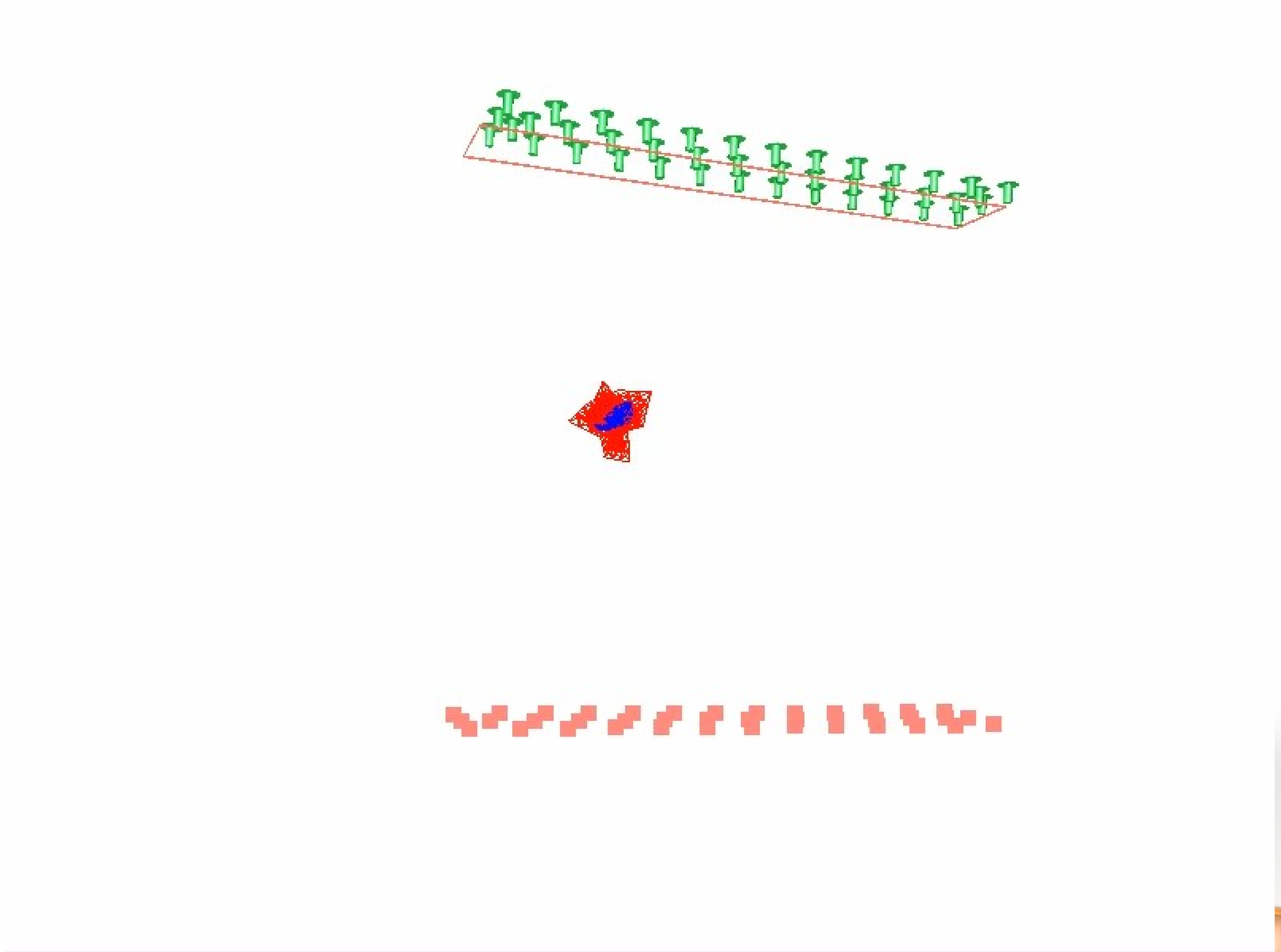






Dynamically Topological Changes





Conclusions & Perspectives

Conclusions

☺ Continuum-lattice coupling is verified

☺ Fracture simulation

Perspectives

☻ Cutting of soft tissue

☻ Implementation on GPUs

Thank you for your attention!