Integrated modelling of woven materials
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**Kinematic Modelling**
- Unit cell weaving simulation
  - As woven unit cell geometries
  - Tessellation
  - Full scale as woven preforms geometries
  - Macro-scale compaction simulation
    - Compacted preforms

**Mechanical Modelling**
- Mechanical properties extraction
  - Reinforcement geometries, Volume fractions
    - Micro mechanical models
      - Equivalent material properties
      - Homogenised properties
    - Meso-scale models
    - Macro model
      - Boundary Conditions
An initial *unit cell loose geometry* is built based on the fabric architecture and the number of fibres per yarn. Thermal load is applied to the bundles of beam elements to simulate the weaving process. The thermal load simulates the fabric consolidation during weaving.

*Initial yarn paths*  
*Weaving simulation*
Macro-scale kinematic models

Realistic unit cell geometries can be tessellated to simulate the draping and compaction on a structural scale.
Macro-scale models using Voronoi homogenization

A novel Voronoi homogenization technique was developed to build computationally efficient mechanical models of woven composites.

Voronoi models used to calculate 3D woven composite elastic constants, a) High fidelity weft direction (showing only yarn elements), b) High fidelity warp direction, c) High fidelity shear specimen, d) Homogenized weft direction, e) Homogenized warp direction, f) Homogenized shear specimen.
## Macro / Meso scale models

<table>
<thead>
<tr>
<th></th>
<th>Experimental (GPa)</th>
<th>Meso-Scale (GPa)</th>
<th>Macro-Scale (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Young’s modulus warp</strong></td>
<td>63.9</td>
<td>64</td>
<td>63</td>
</tr>
<tr>
<td><strong>Young’s modulus weft</strong></td>
<td>60.8</td>
<td>61</td>
<td>60</td>
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<tr>
<td><strong>In-plane shear modulus</strong></td>
<td>4.65</td>
<td>4.75</td>
<td>4.3</td>
</tr>
</tbody>
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*In-plane transverse strain*  
*Out of plane transverse strain (Z)*
Global/Local analysis

- Voronoi homogenization can be applied to complex 3D woven components.
- Areas with high stress concentration can be identified.
- Single or multiple meso-scale models can be built for the critical regions to gain a high fidelity image of the stress state.

Homogenized Mechanical models of complex parts

Kinematic modelling of complex shapes

Hybrid multi-scale models of critical regions
Smeared crack progressive damage models has been introduced to high fidelity meso-scale models. These models are used to predict the failure behaviour of woven composites.

Postmortem images of open tension sample.

Matrix cracking in the meso-scale region of the open hole specimen.

The damage pattern on the V-notch shear specimen.