



# Textile composites modelling

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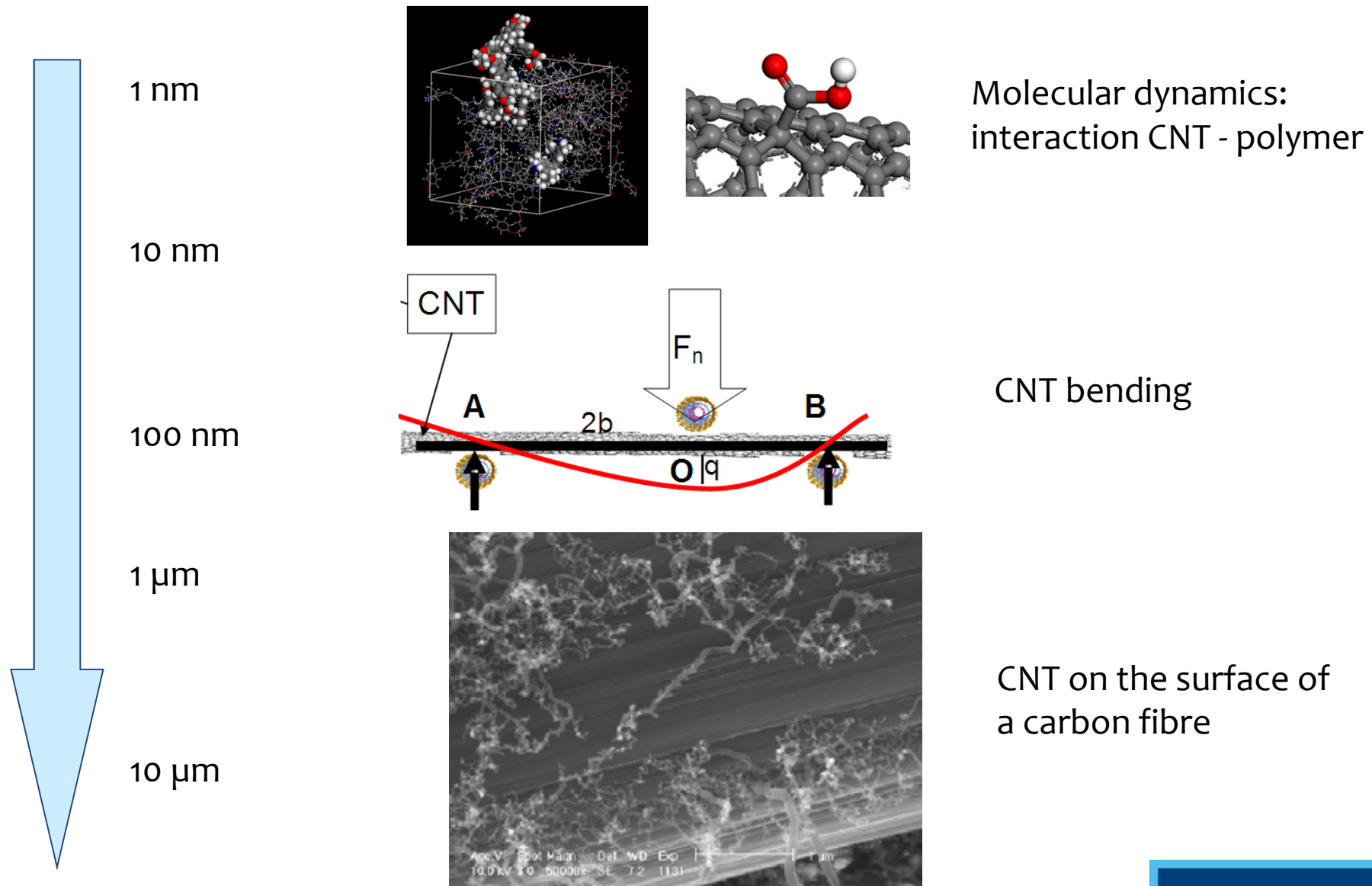


1. Introduction. Meso-scale modelling of textile composites
2. Internal geometry of textile composites and meso-FE models
3. Permeability of textile reinforcements
4. Micromechanics
5. Conclusion

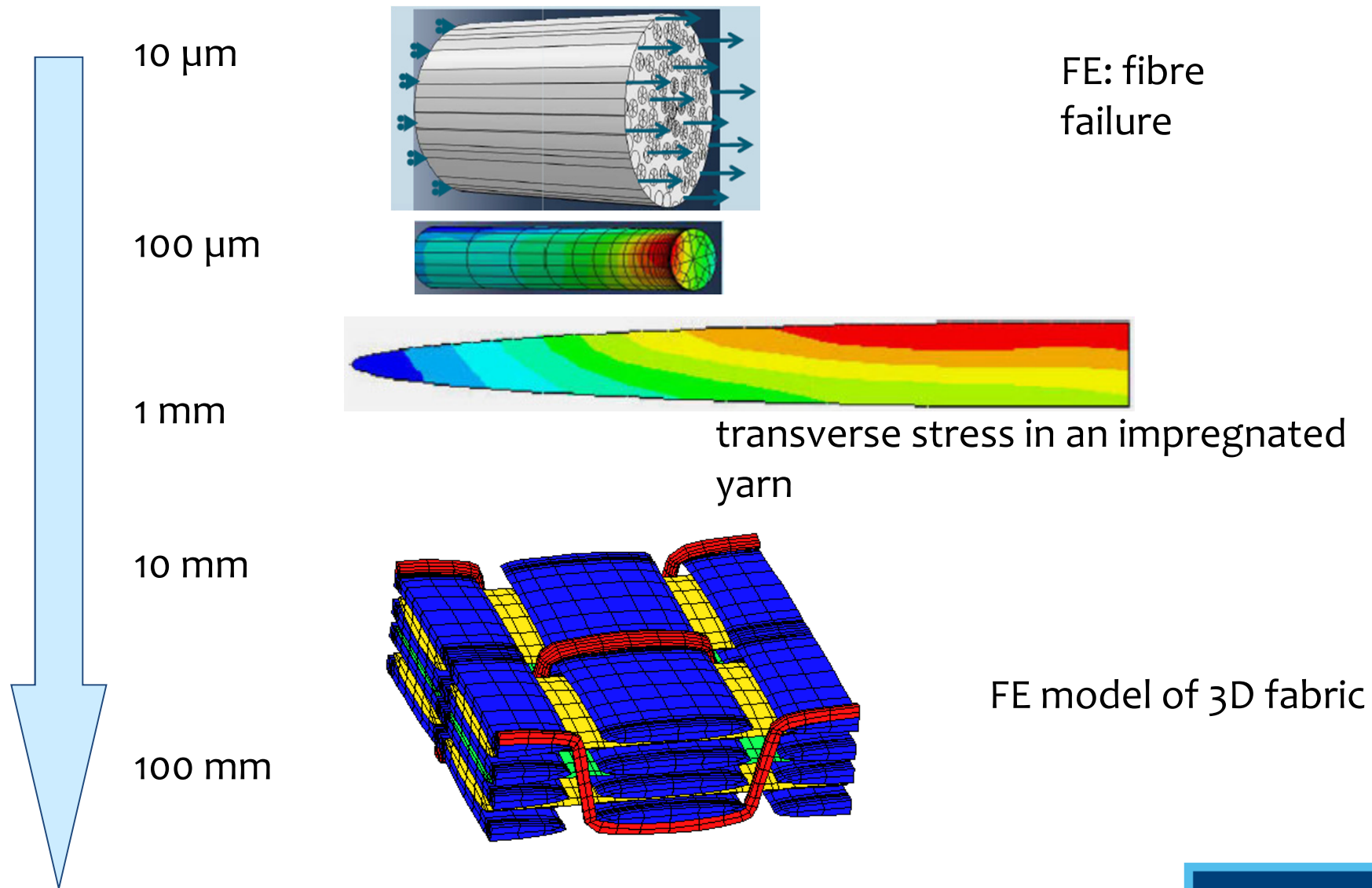
# **1. Introduction. Meso-scale modelling of textile composites**

- 2. Internal geometry of textile composites and meso-FE models
- 3. Permeability of textile reinforcements
- 4. Micromechanics
- 5. Conclusion

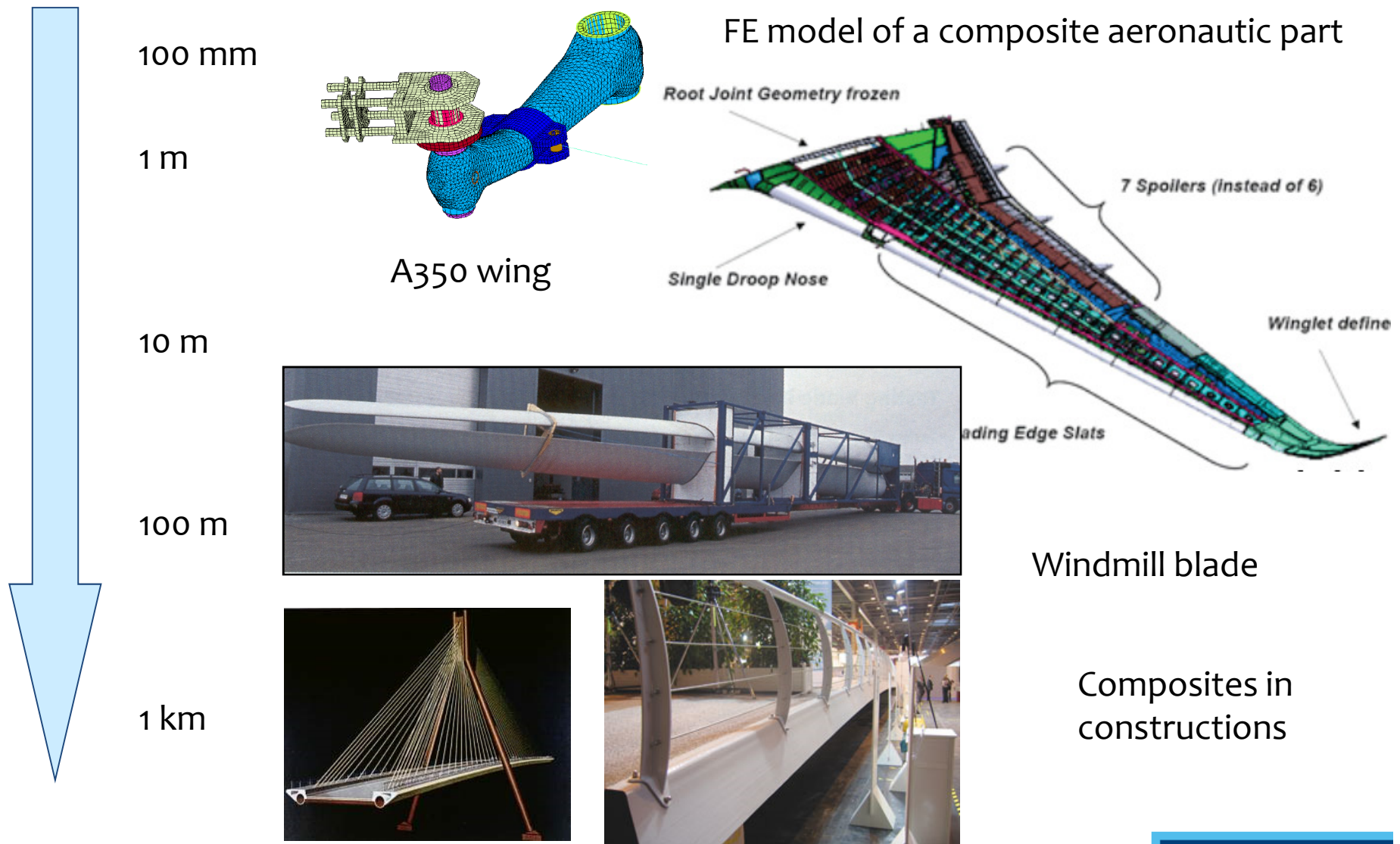
# Hierarchy of scales: nano – $\mu$ cro



# Hierarchy of scales: $\mu$ icro – meso

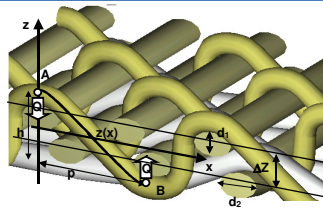


# Hierarchy of scales: meso–Macro–Mega





# Integrated Design Tool: textile composites

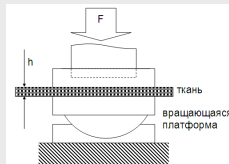


## Internal architecture of the reinforcement

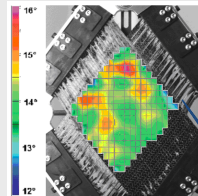
Production

### Deformation resistance and change of geometry

Compr.



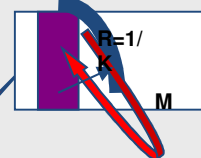
Shear



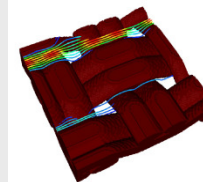
Tension



Bending

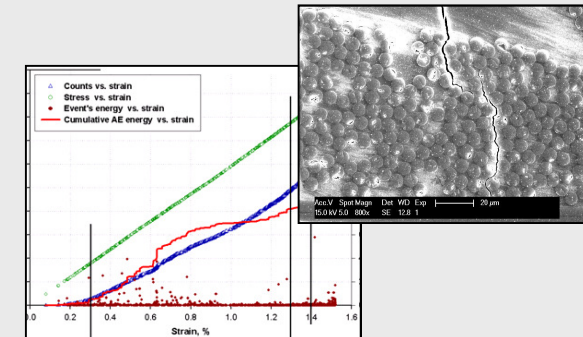


### Permeability

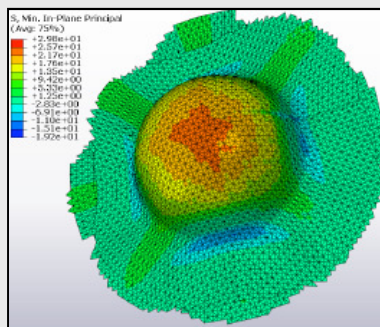


Performance

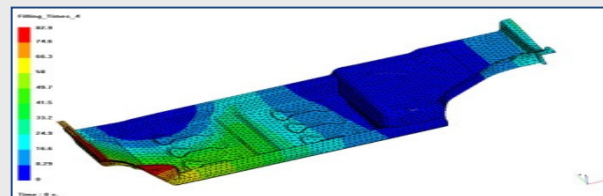
### Mechanical properties and damage



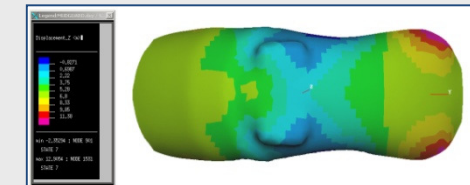
### Drapeability and formability



### Impregnation

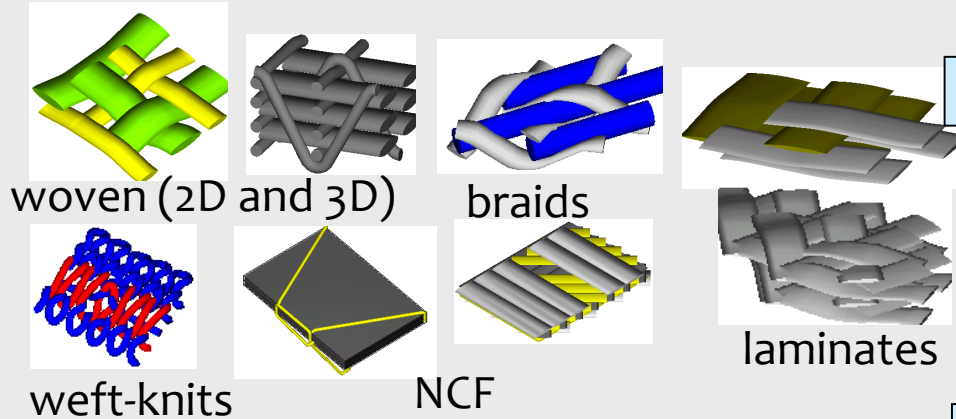
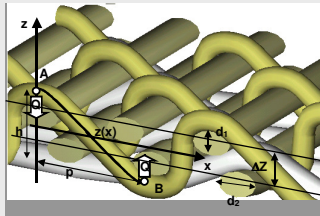


### Structural analysis

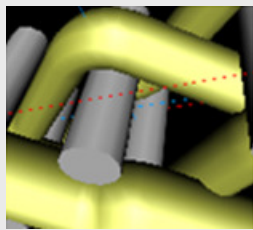


# WiseTex: Virtual textiles/composites

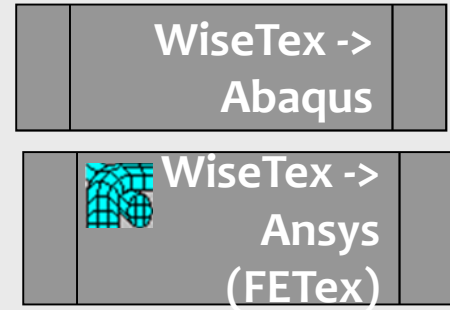
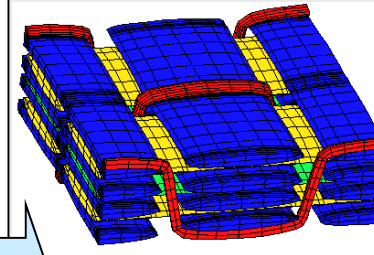
## Internal geometry: textile unit cell



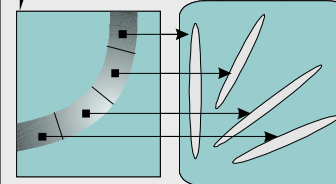
## Virtual reality



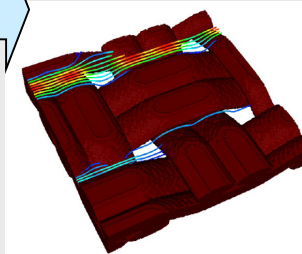
## meso-FE



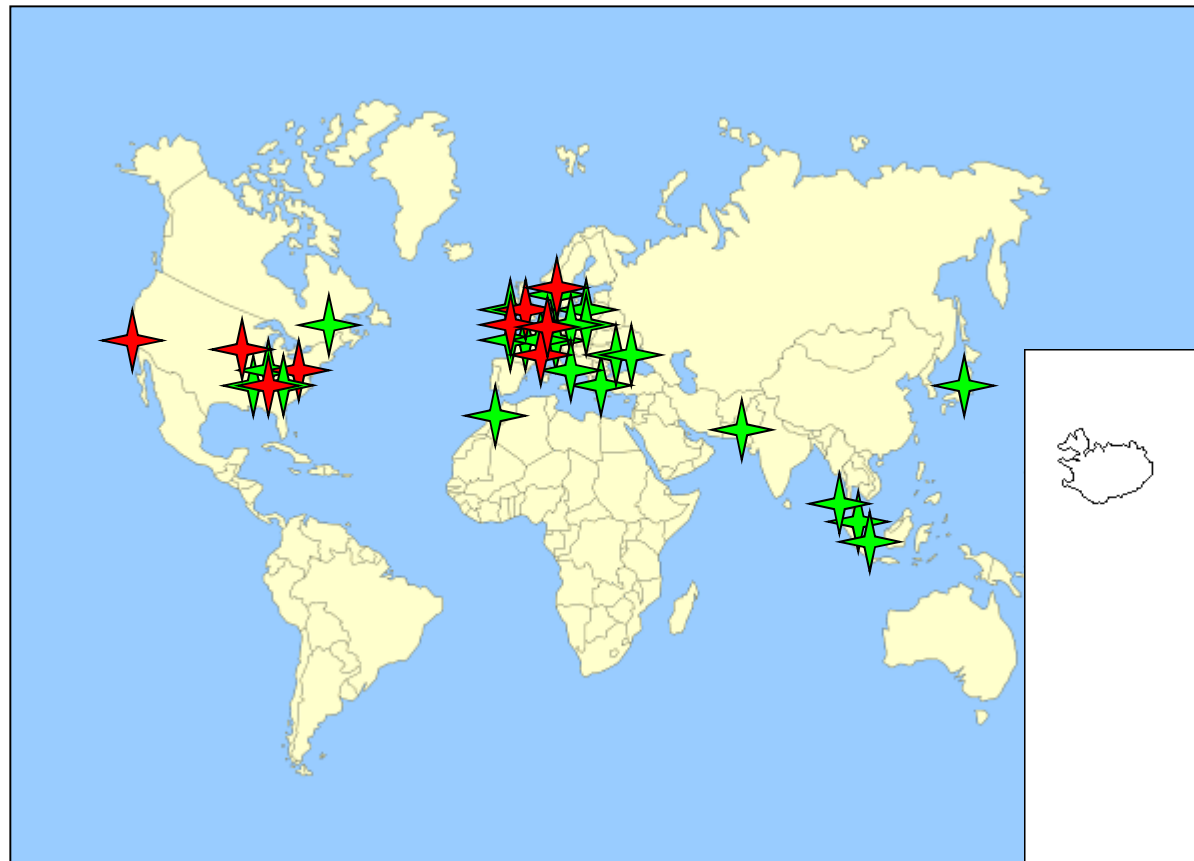
## Composite micromechanics (fast stiffness calculations)



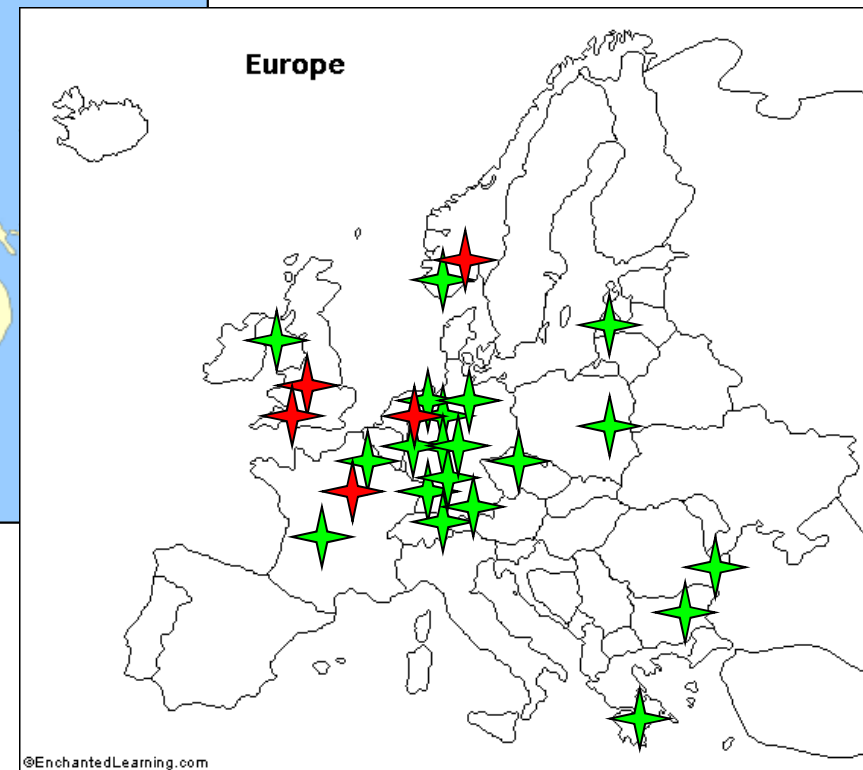
## Permeability





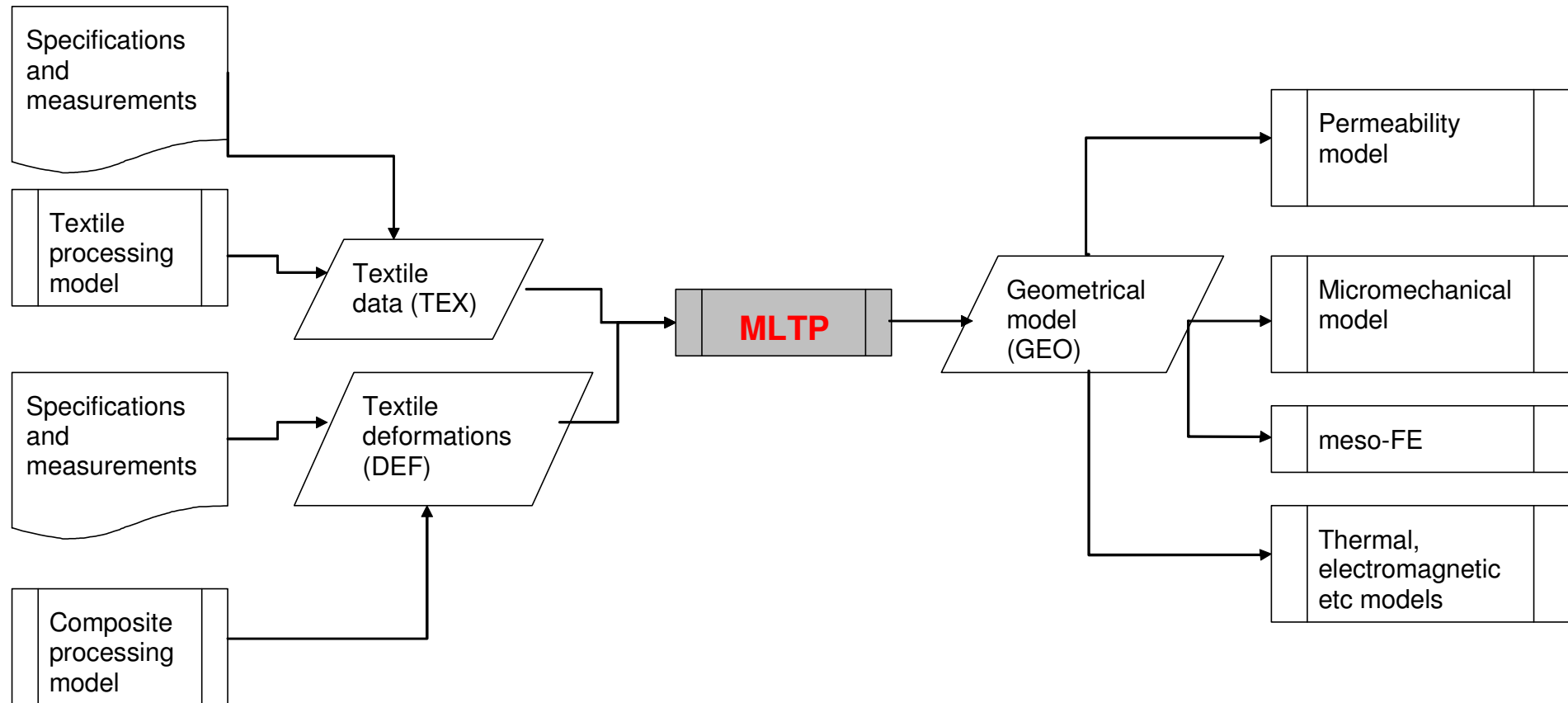


- licences:
- ★ industrial (11)
  - ★ university (35)



# Meso Level Textile Preprocessor data

## flow



# WiseTex 3.0: data open to a user

## WiseTex 3.0:

- open XML input and output formats

- “command line” version

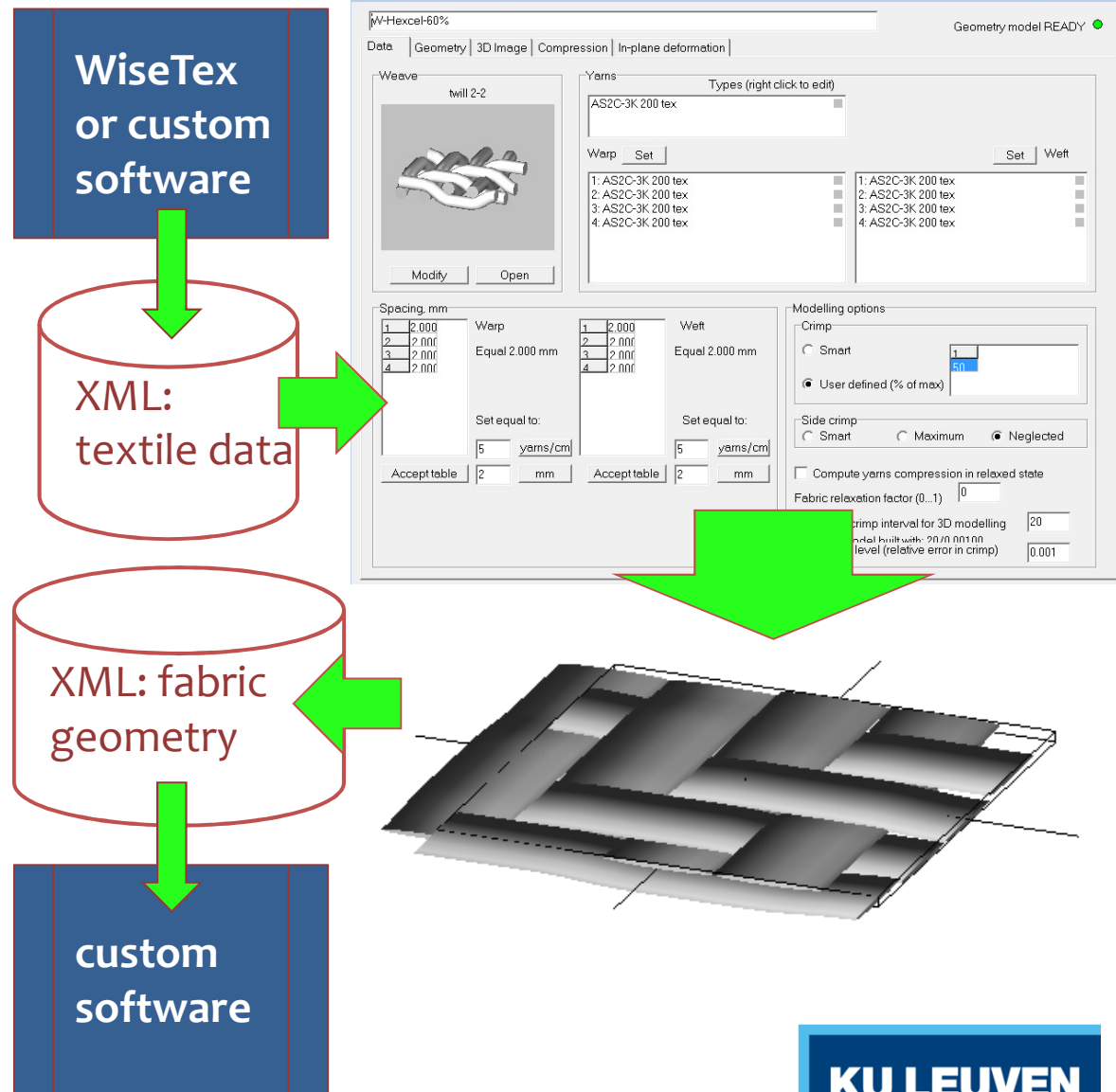
## New possibilities:

## easy integration:

- upstream, with user-defined process models (e.g., braiding process)
- downstream, with user-defined models of composite (e.g. meso-FE)

## scripting:

- parametric studies
- look-up tables (e.g., shear angle)



# WiseTex 3.0: scripting

## WiseTex 3.0:

- open XML input and output formats

- **“command line” version**

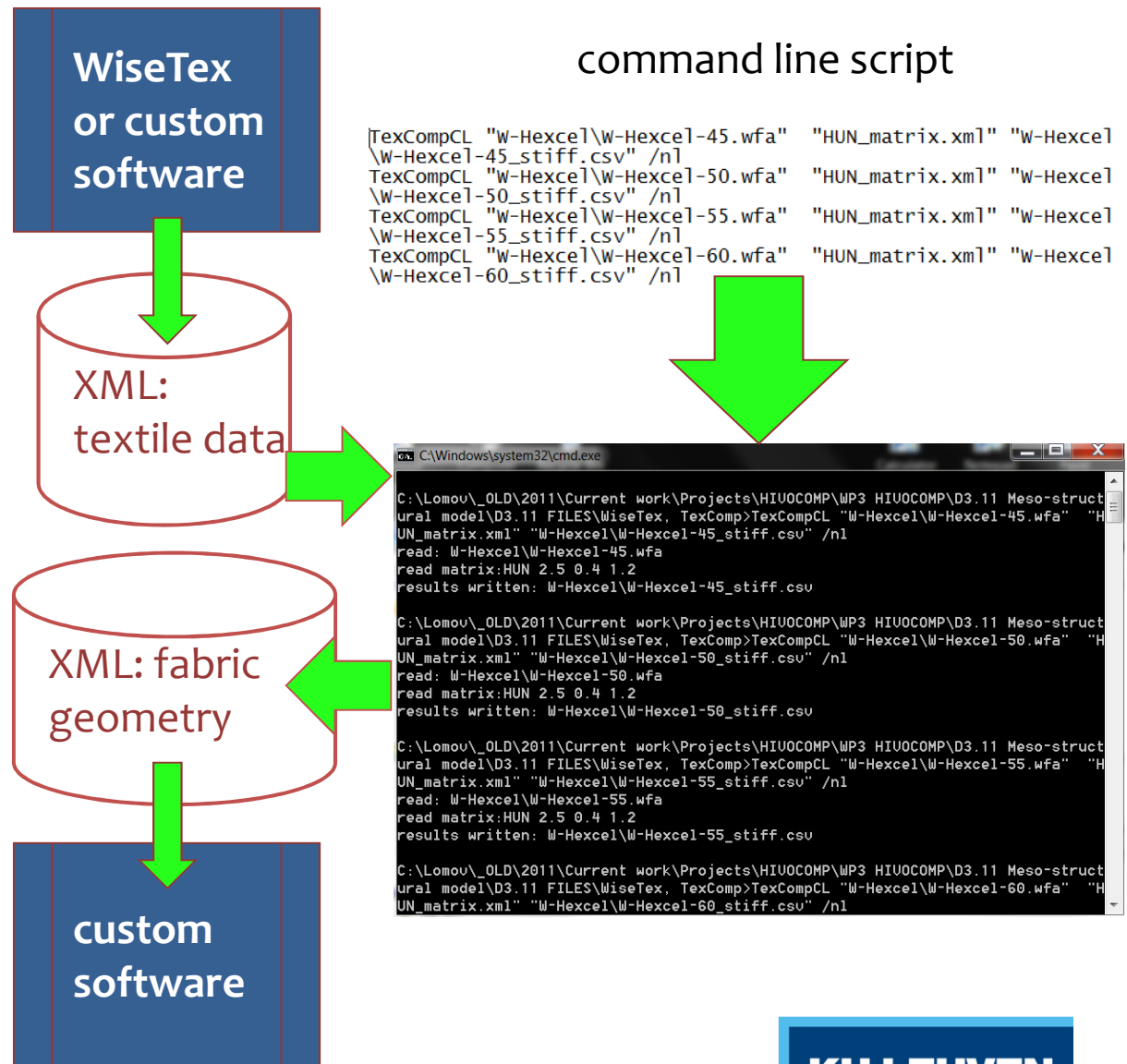
## New possibilities:

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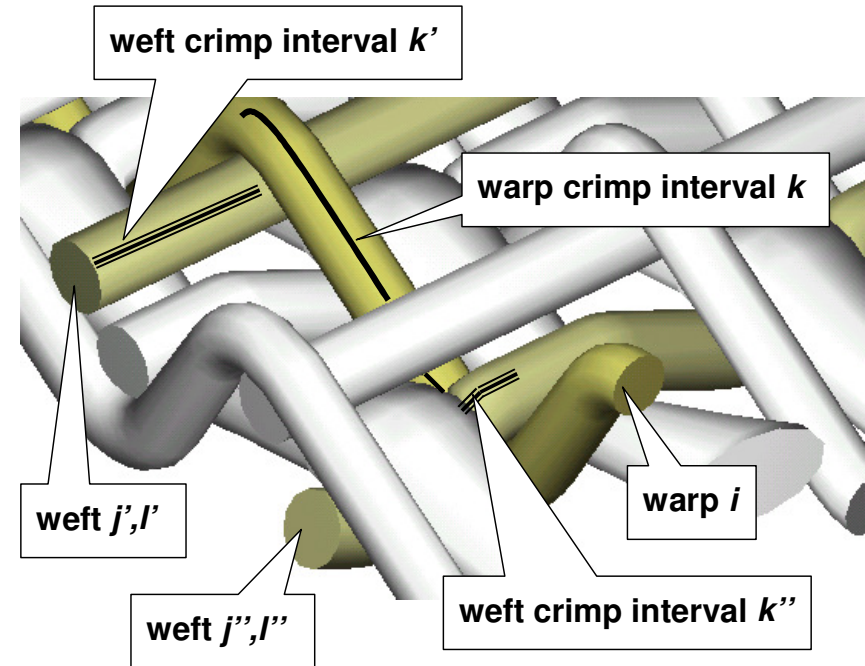
1. Introduction. Meso-scale modelling of textile composites

## **2. Internal geometry of textile composites and meso-FE models**

3. Permeability of textile reinforcements

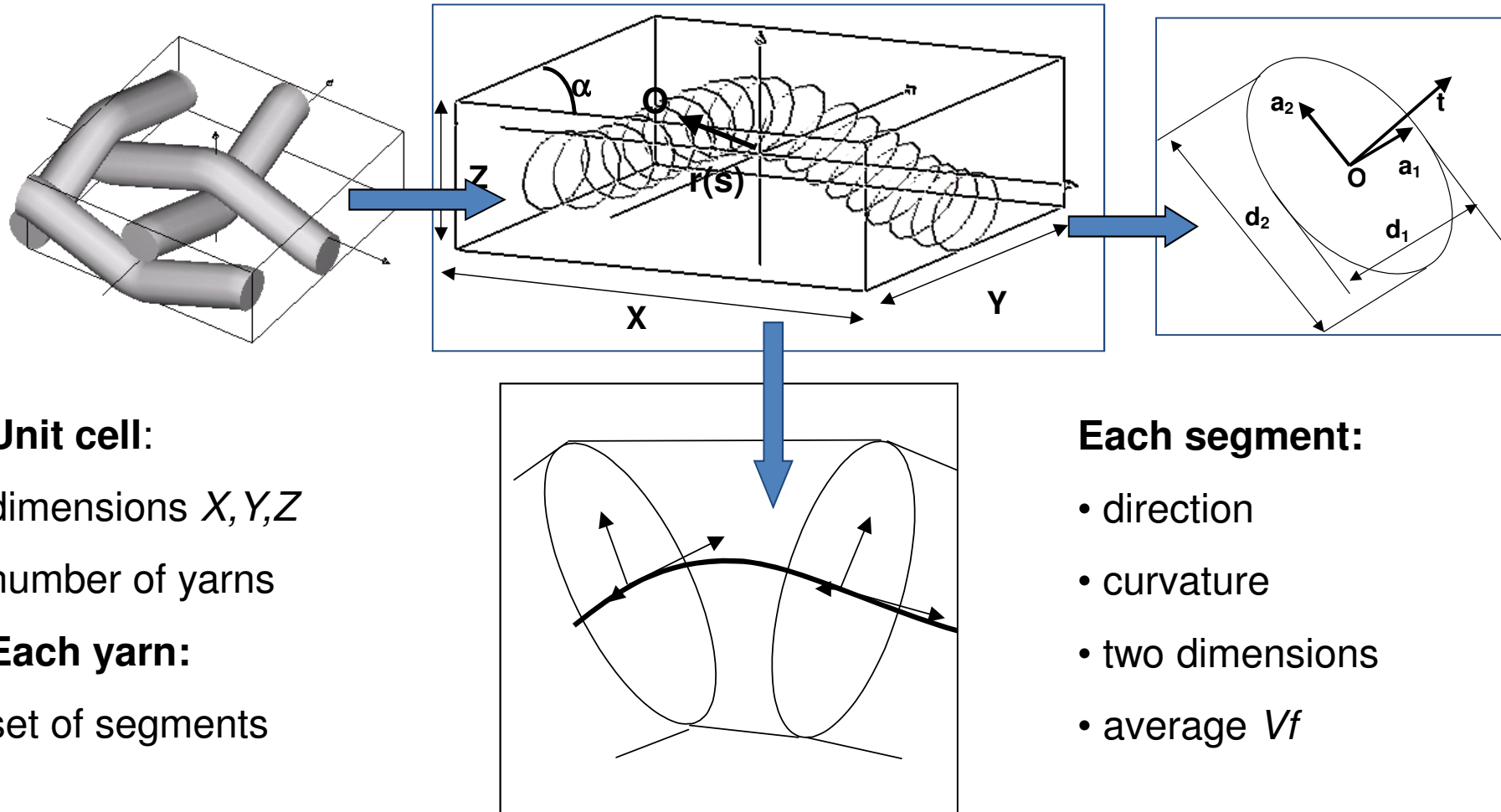
4. Micromechanics

5. Conclusion


$$W_{\Sigma} = \sum_{i,k} \frac{B_{ik}^{Wa}(\kappa_{ik}^{Wa})}{p_{ik}^{Wa}} F\left(\frac{h_{ik}^{Wa}}{p_{ik}^{Wa}}\right) + \sum_{j,l,k} \frac{B_{jlk}^{We}(\kappa_{jlk}^{We})}{p_{jlk}^{We}} F\left(\frac{h_{jl}^{We}}{p_{jlk}^{We}}\right) \rightarrow \min$$



# Generalised description of yarns



## Unit cell:

dimensions  $X, Y, Z$

number of yarns

## Each yarn:

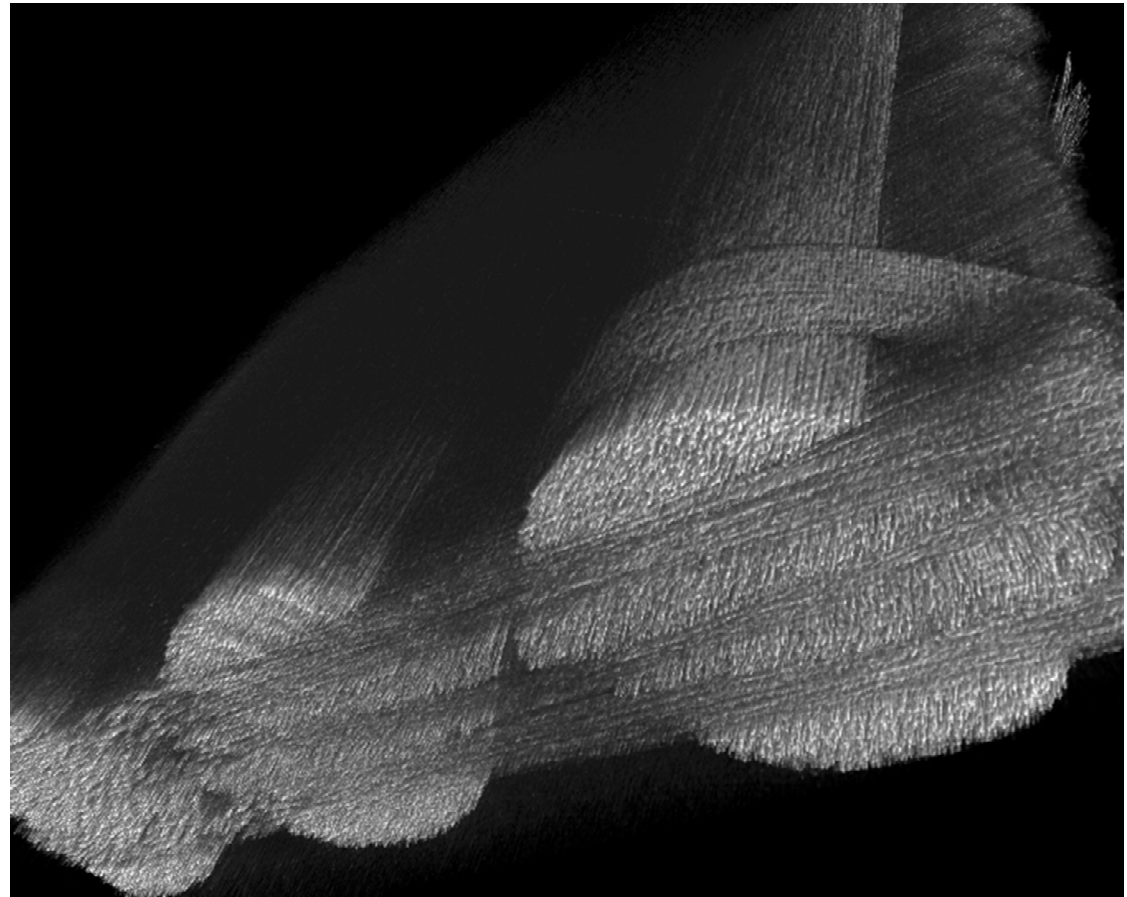
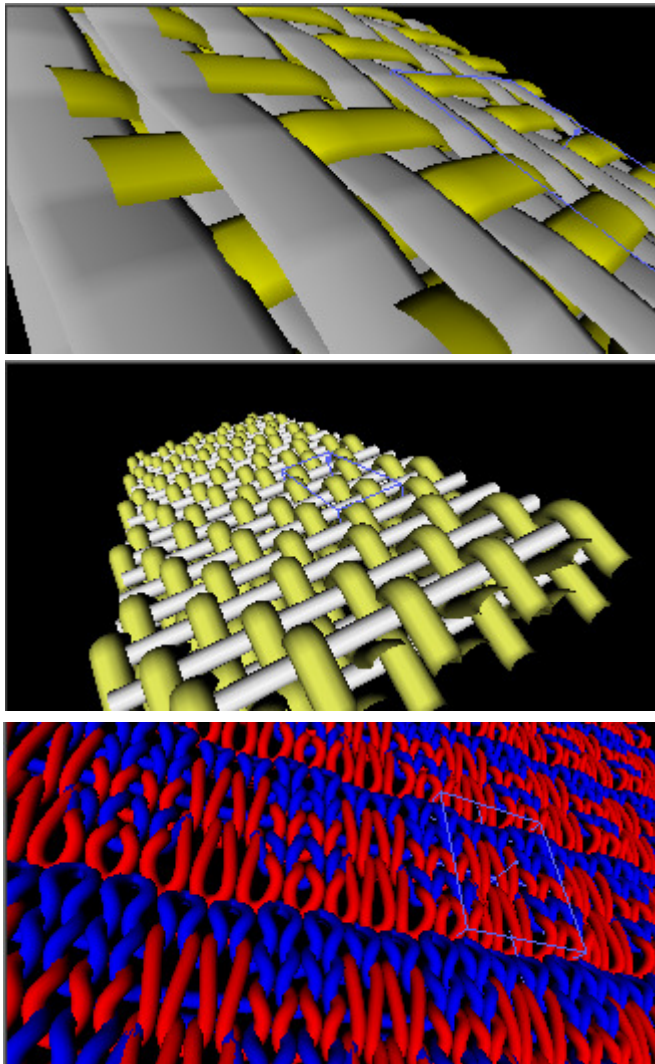
set of segments

## Each segment:

- direction
- curvature
- two dimensions
- average  $V_f$

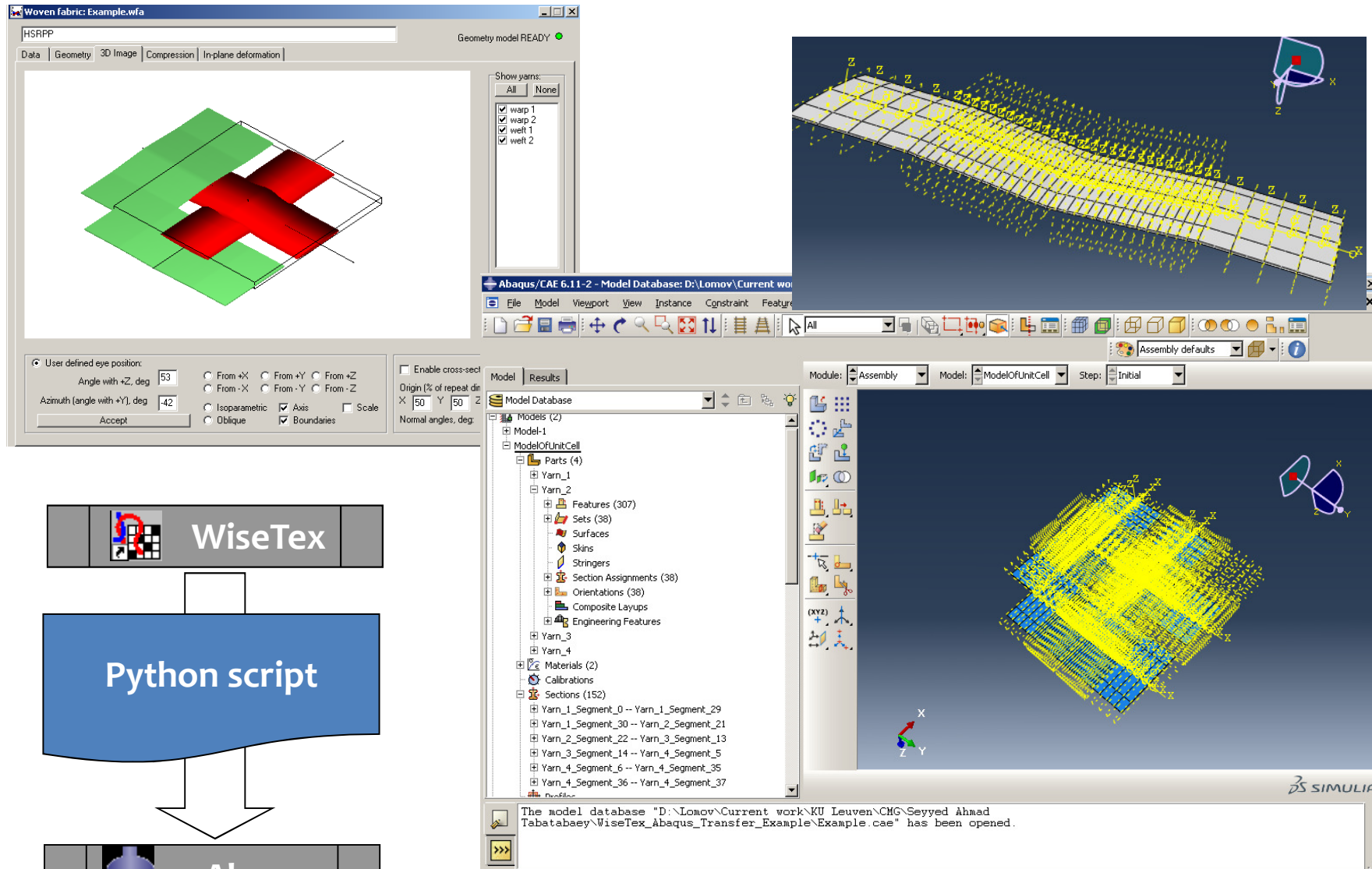
The same description is used for a deformed textile

# Visualisation and $\mu$ CT validation



$\mu$ CT: Ilya Straumit

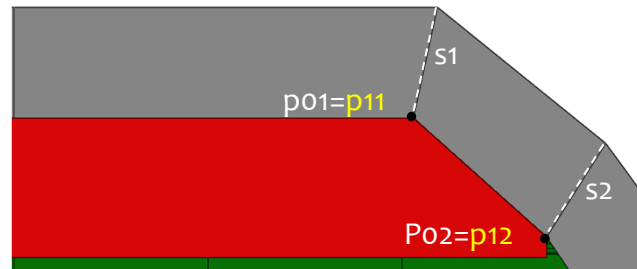
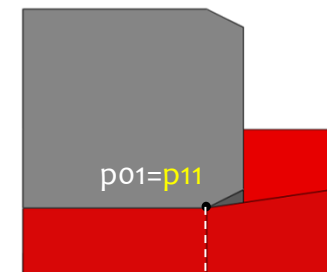
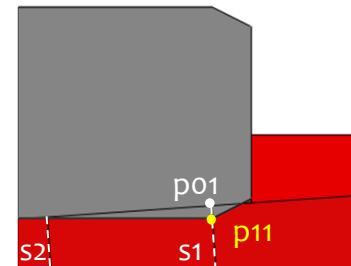
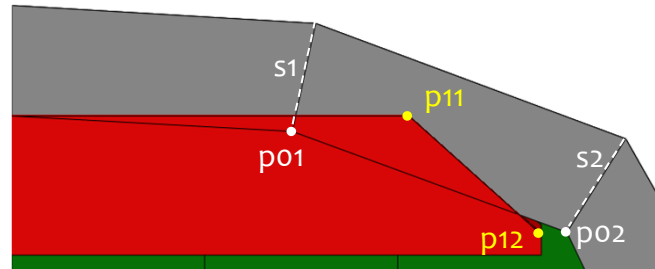
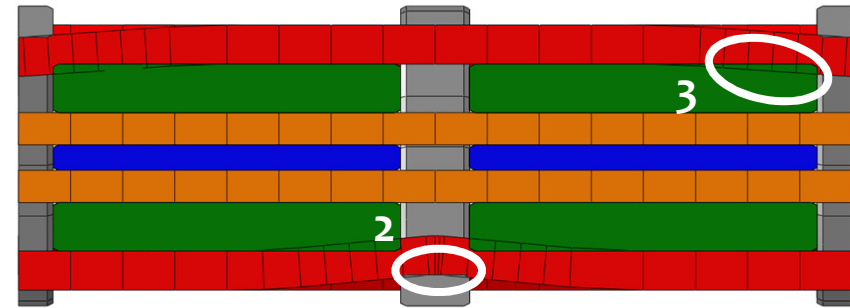
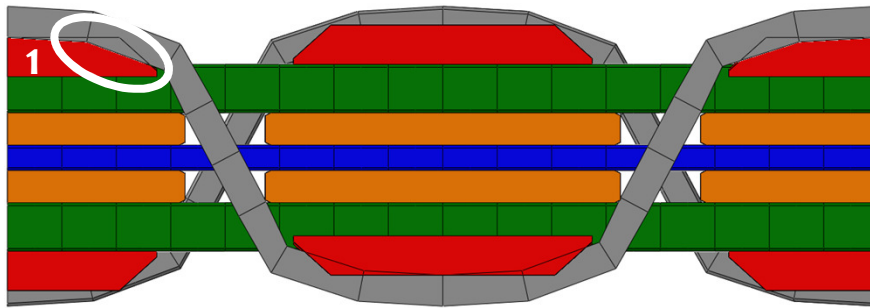
# Transformation into FE model



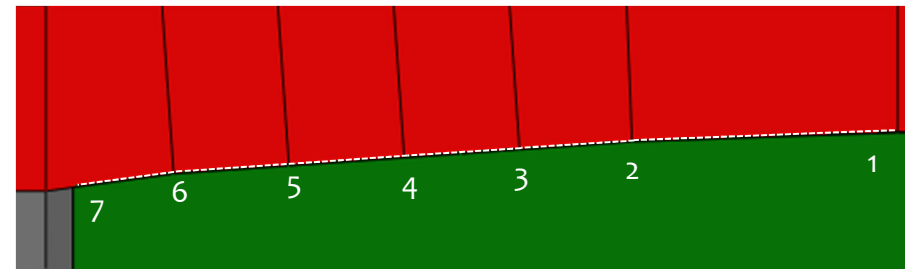
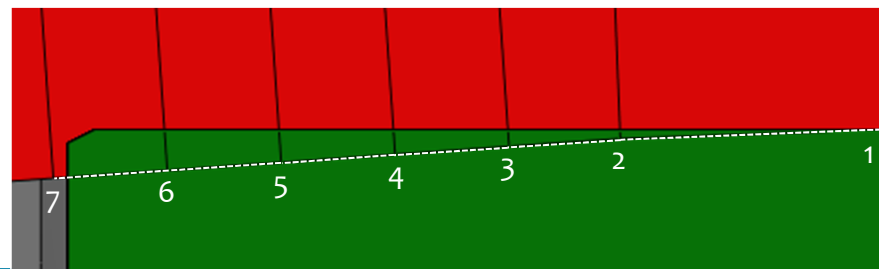
D.S. ivanov, S.A. Tabatabaei, 2013

KU LEUVEN

# Resolution of yarn interpenetrations

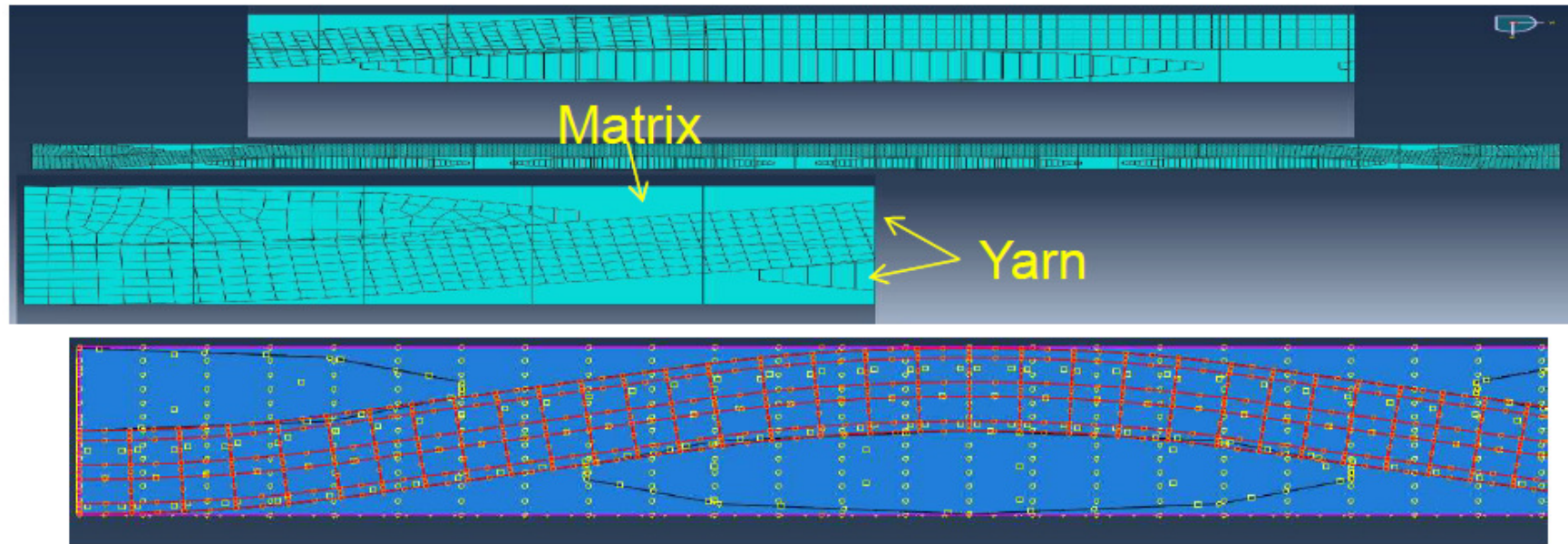


Enrico Bedogni, 2013

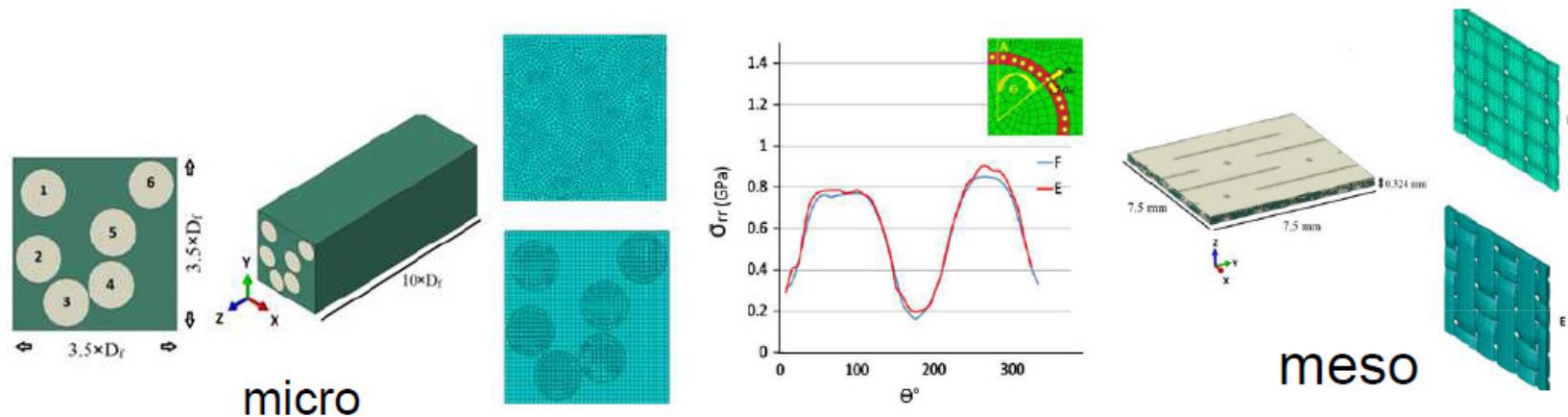




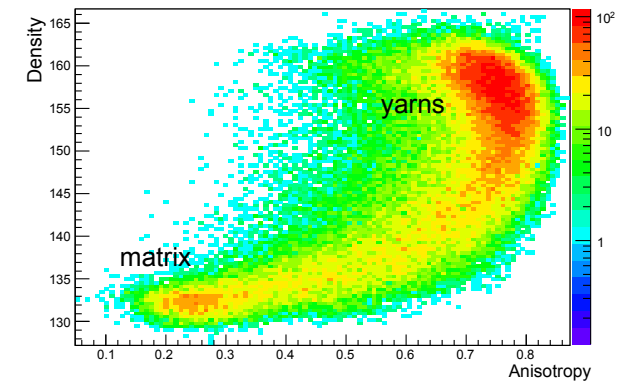
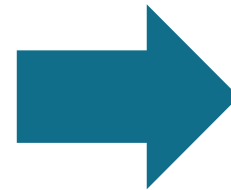
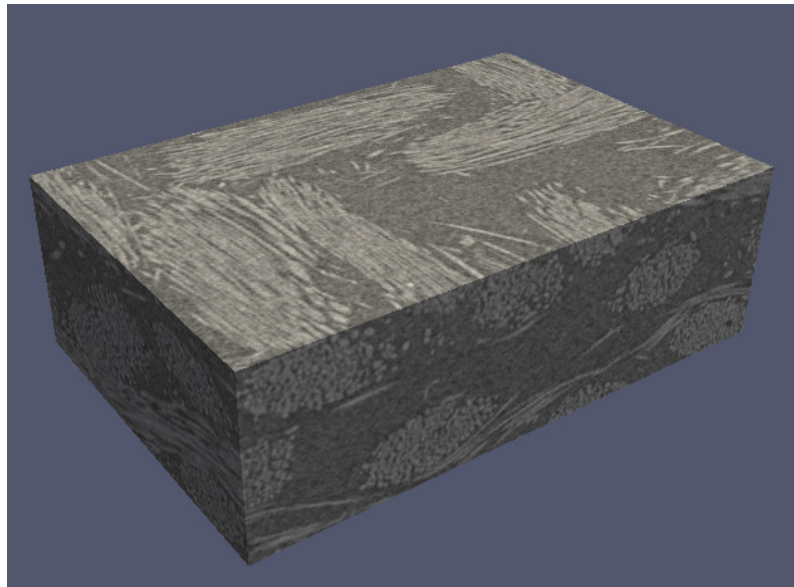
# Embedded elements



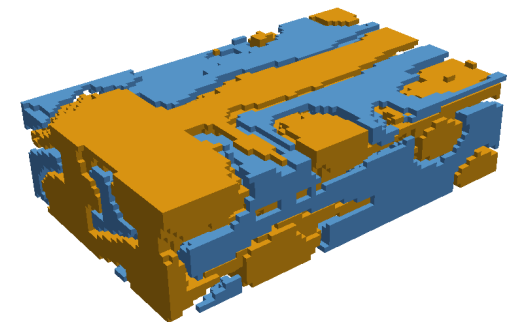
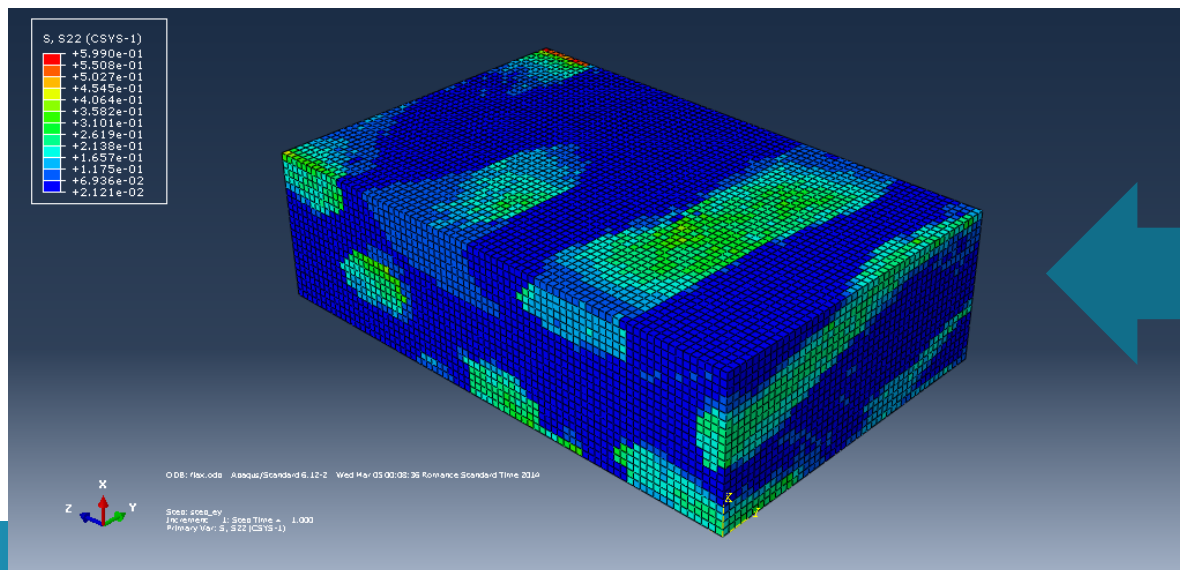
Validation on different scales



# $\mu$ CT – voxel FE model



segmentation and  
identification of local  
fibre directions





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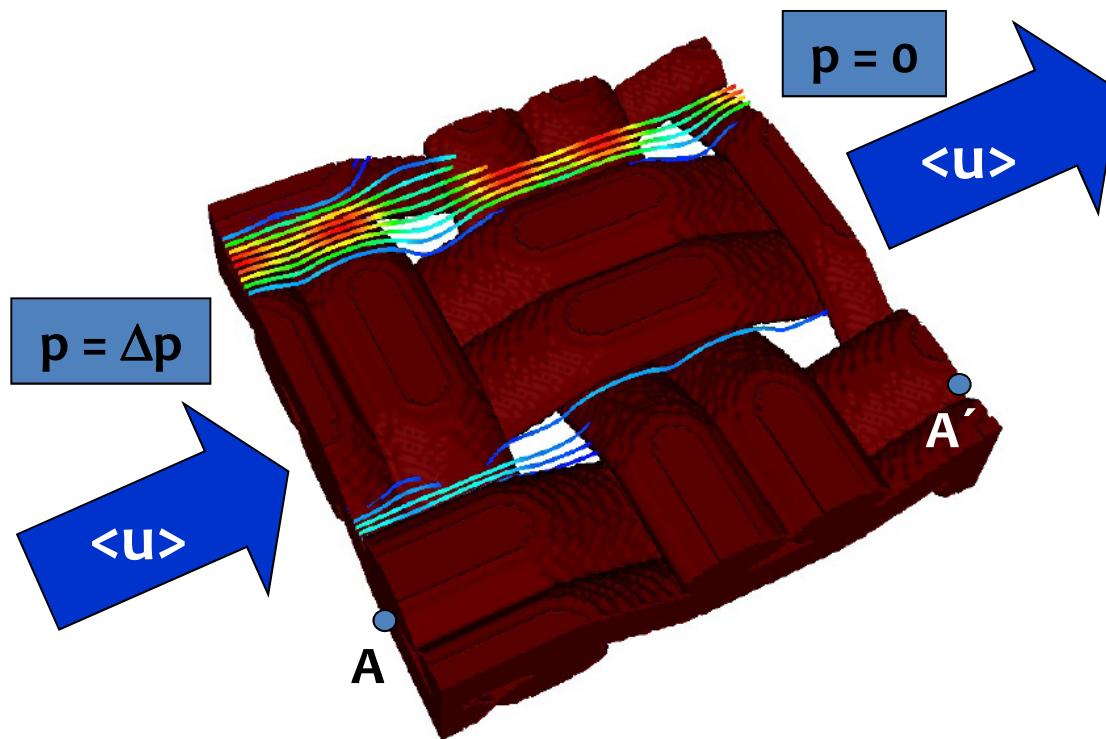
# Darcy permeability: homogenisation

The Navier-Stokes equations:

$$\begin{cases} \frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla) \mathbf{u} = -\nabla p + \frac{1}{\text{Re}} \Delta \mathbf{u} \\ \nabla \cdot \mathbf{u} = 0 \end{cases}$$

The Stokes equations:

$$\begin{cases} \text{Re} \nabla p - \Delta \mathbf{u} = 0 \\ \nabla \cdot \mathbf{u} = 0 \end{cases}$$



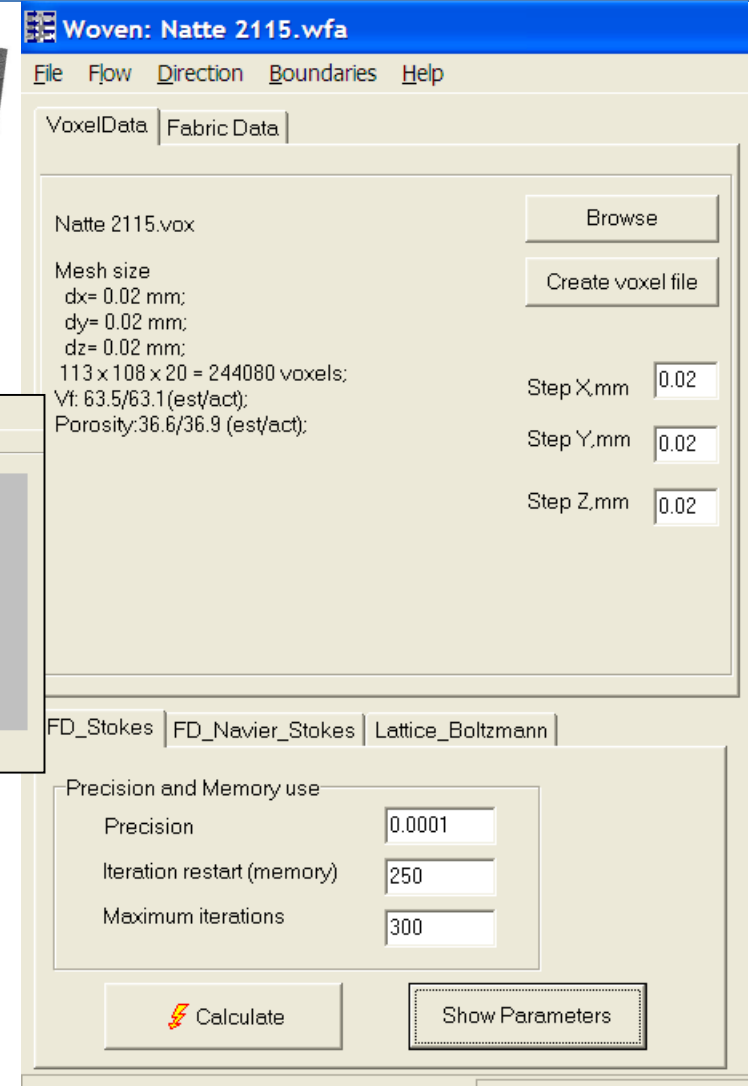
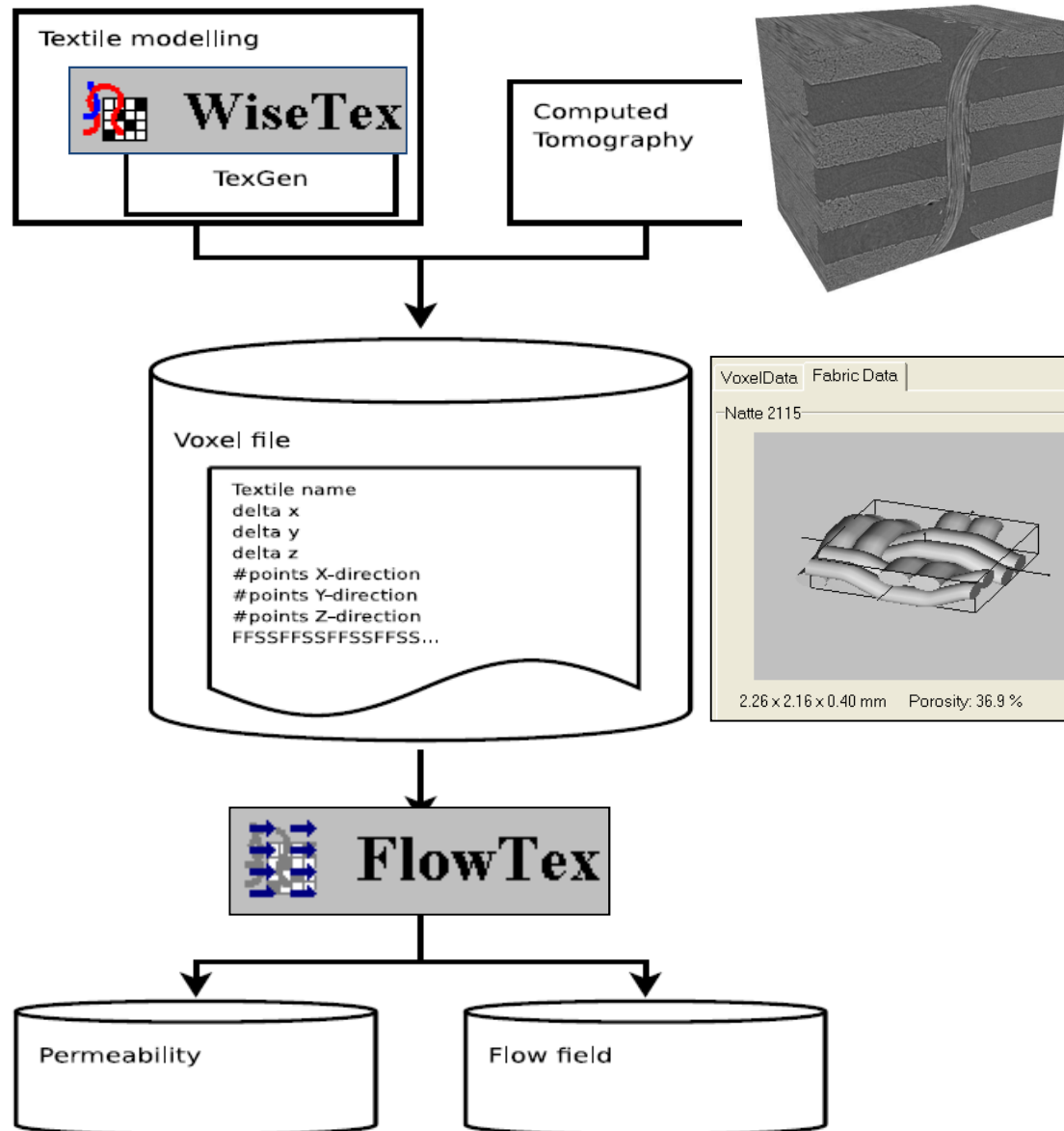
$$\langle \mathbf{u} \rangle = -\frac{1}{\nu \rho} \mathbf{K} \cdot \langle \nabla p \rangle$$

$$u(A) - u(A') = \text{const}(A)$$

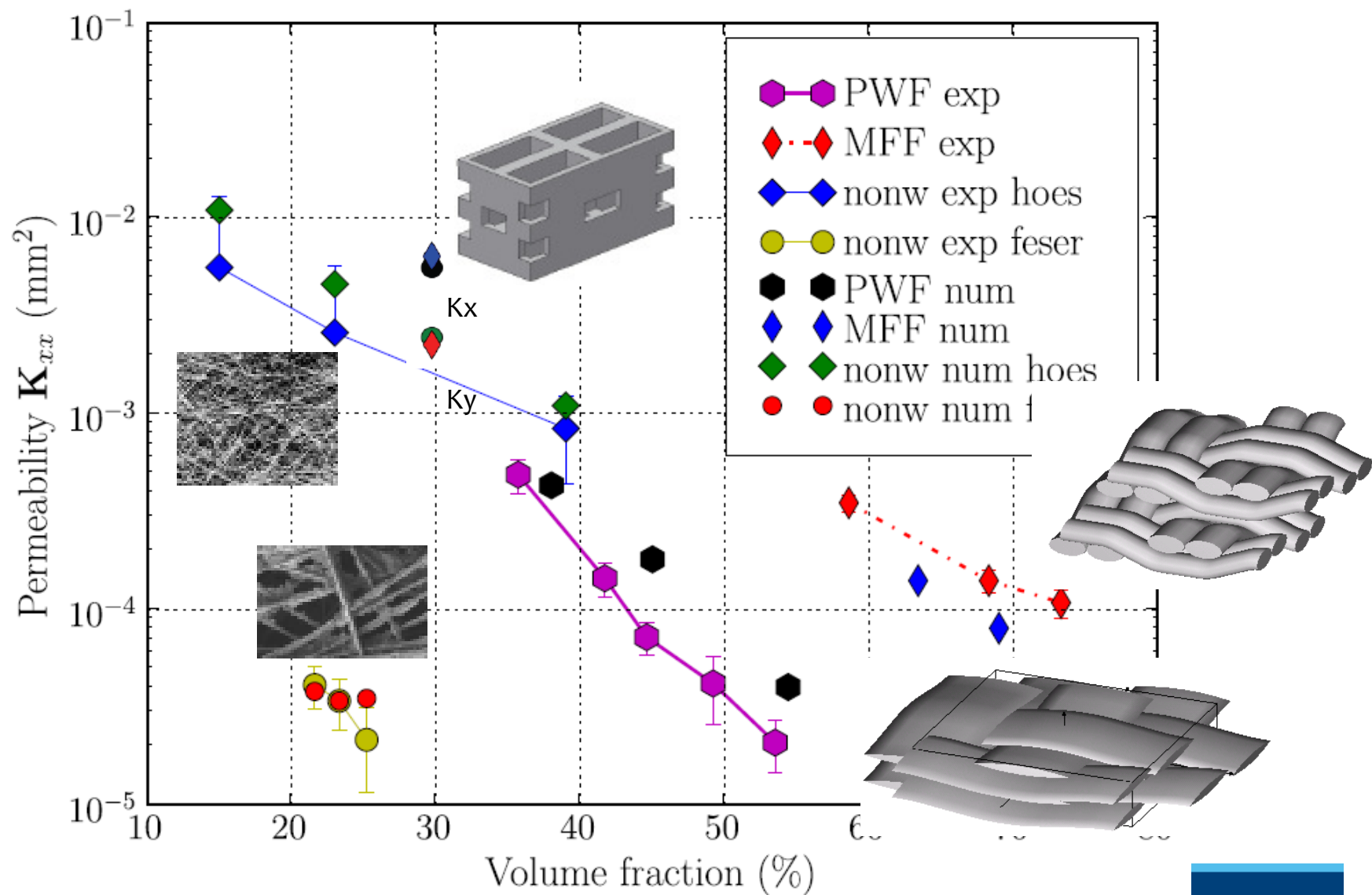
$AA'$  = periodic translation

$$\mathbf{K} = \begin{bmatrix} K_x & 0 & 0 \\ 0 & K_y & 0 \\ 0 & 0 & K_z \end{bmatrix}$$

# FlowTex software



# Experimental validation



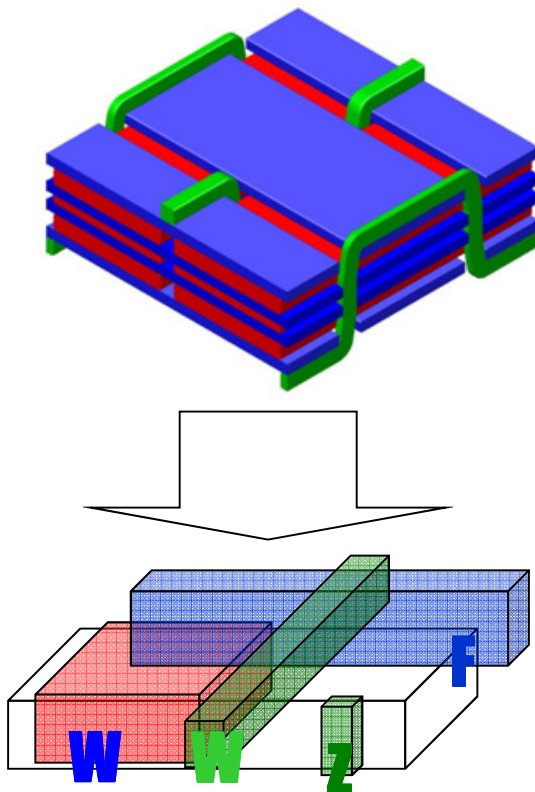
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# Orientation averaging

The textile structure is subdivided into elements; each element is represented by a UD composite; homogenised stiffness is a weighted average of (tensorial) stiffnesses of the elements



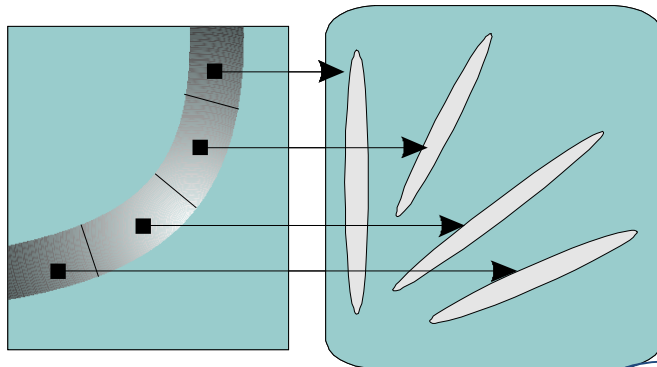
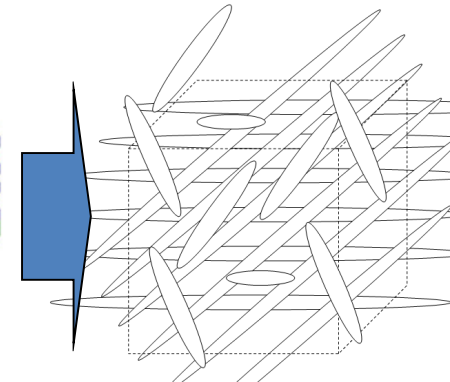
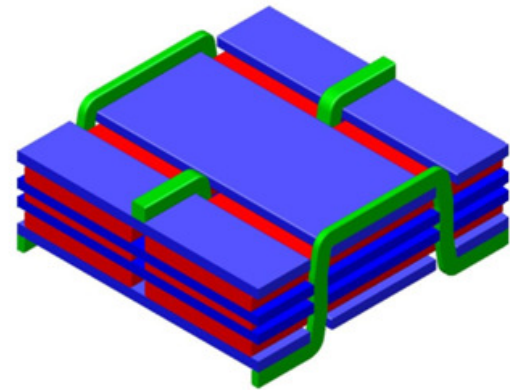
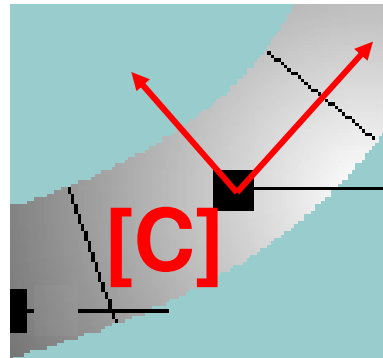
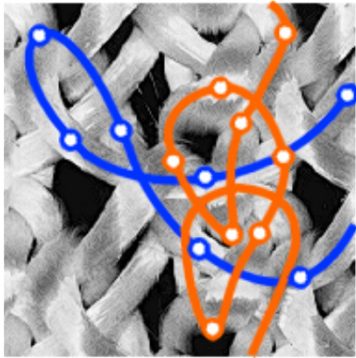
	exp	OA
$E_1$ , GPa	$24.3 \pm 1.2$	22.7
$E_2$ , GPa	$25.1 \pm 2.34$	22.8
$E_3$ , GPa	n/a	10.1
$G_{12}$ , GPa	n/a	3.38
$\nu_{12}$	$0.141 \pm 0.071$	0.109
$\nu_{13}$	n/a	0.377
$\nu_{23}$	n/a	0.380
$E_{45^\circ}$ , GPa	$12.9 \pm 0.5$	10.7
$G_{45^\circ}$ , GPa	n/a	10.3
$\nu_{45^\circ}$	$0.502 \pm 0.21$	0.581

- Reasonable predictions for fibre-dominated properties ...
- ... worse for tension stiffness in bias direction, shear moduli ...
- ... bad for complex non-orthogonal structures

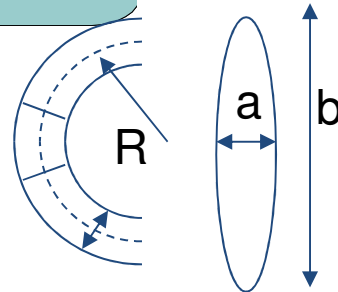
$$\overset{\text{global coordinates}}{\mathbf{C}^{eff} [GCS]} = \overset{\text{local coordinates}}{\mathbf{C}^m [GCS]} \cdot (1 - V_\Sigma) + \sum_{i=1}^N \mathbf{C}_i [CS_i \rightarrow GCS] \cdot V_i ; \quad V_\Sigma = \sum_{i=1}^N V_i$$



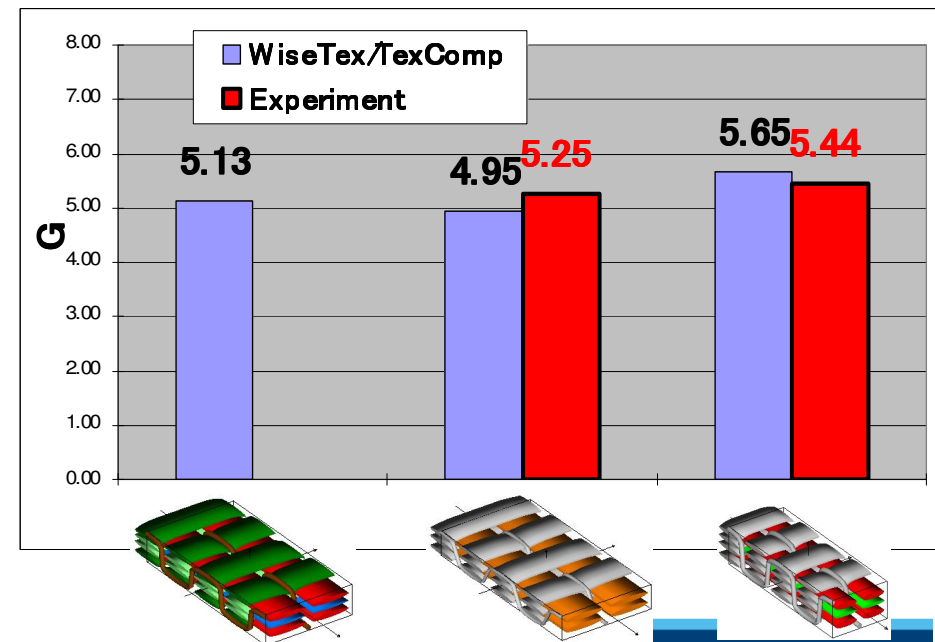
# Method of inclusions (TexComp)



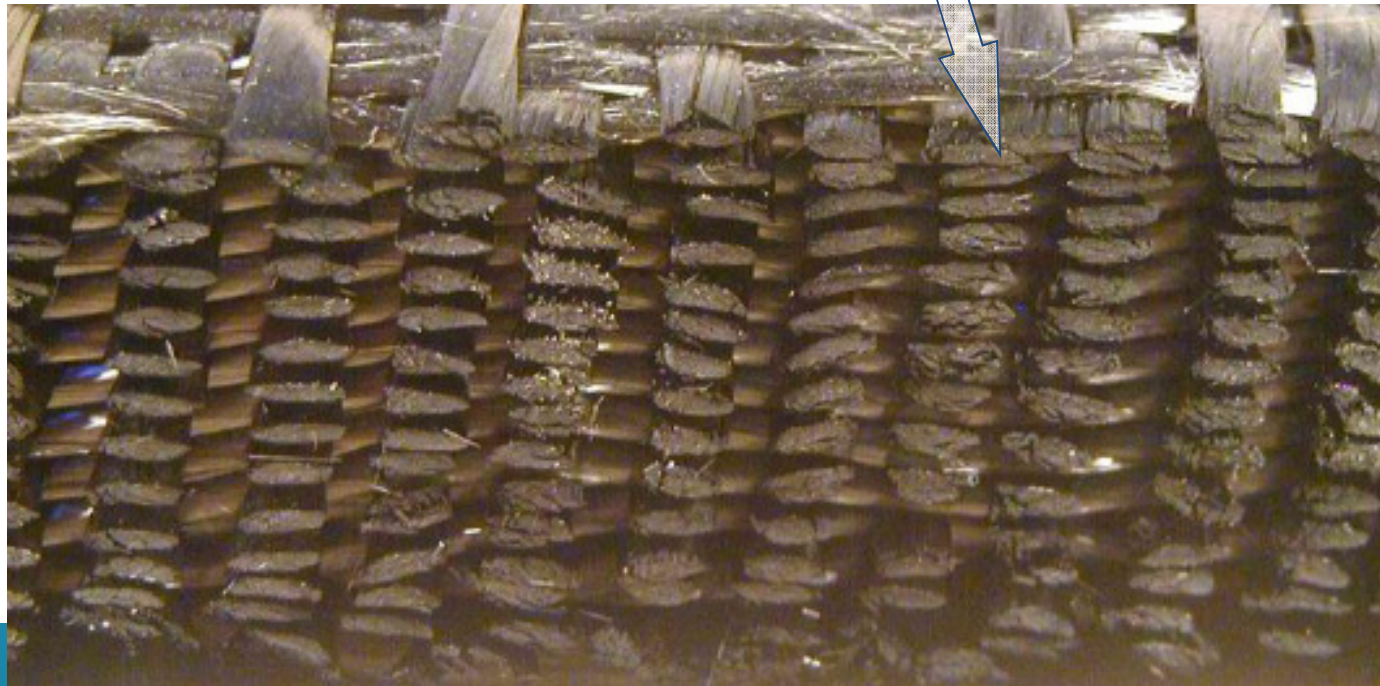
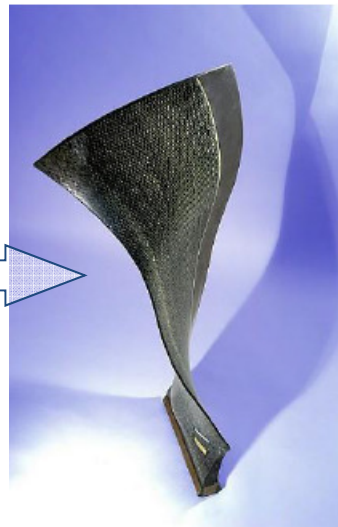
$$\frac{b}{a} = \beta \frac{R}{a}, \quad \beta \approx 3.14$$



- equivalent elliptical inclusions
- Mori-Tanaka homogenisation



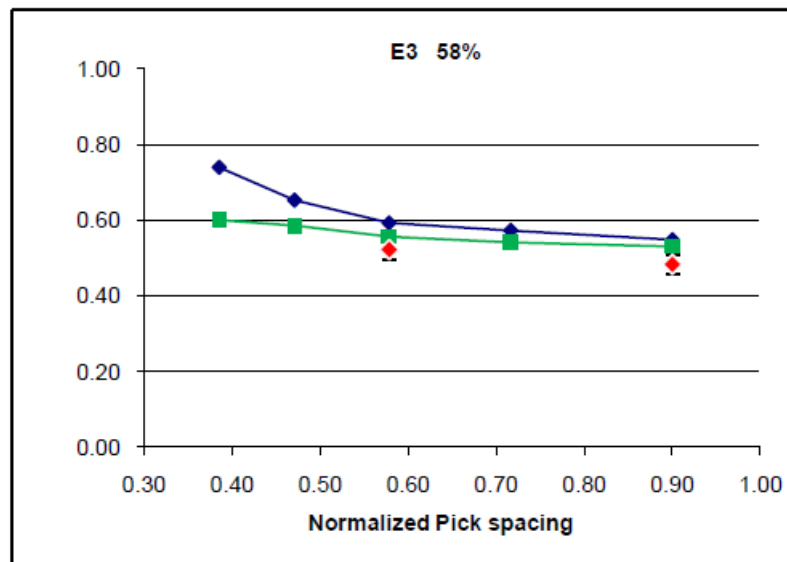
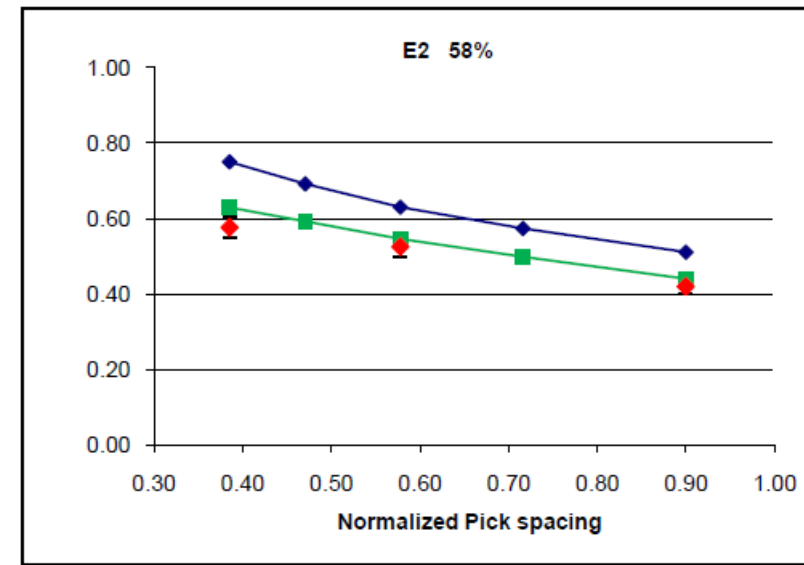
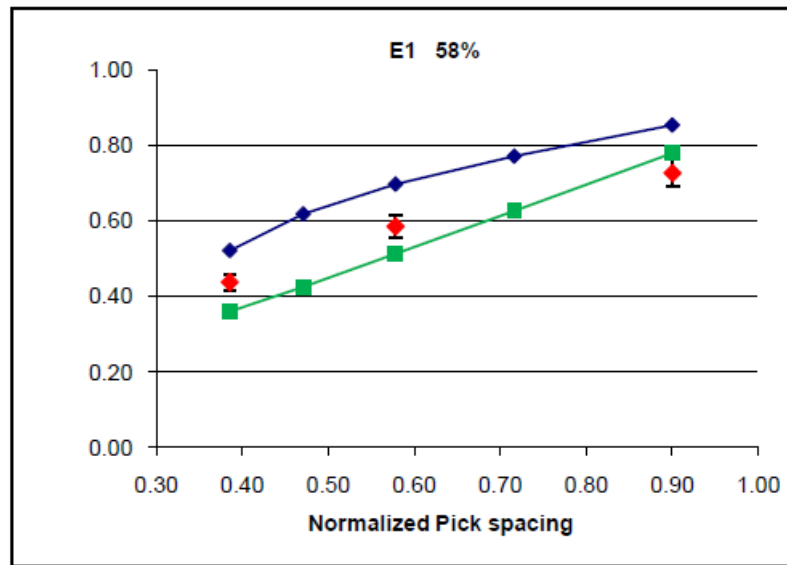
# Validation for complex textile structures



Snecma

G. Perie, 2008

# Young's moduli

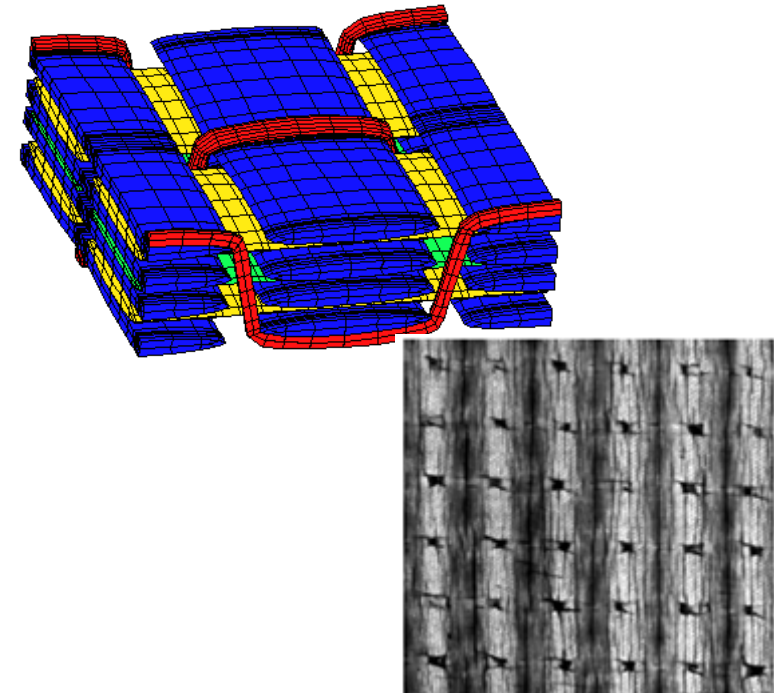
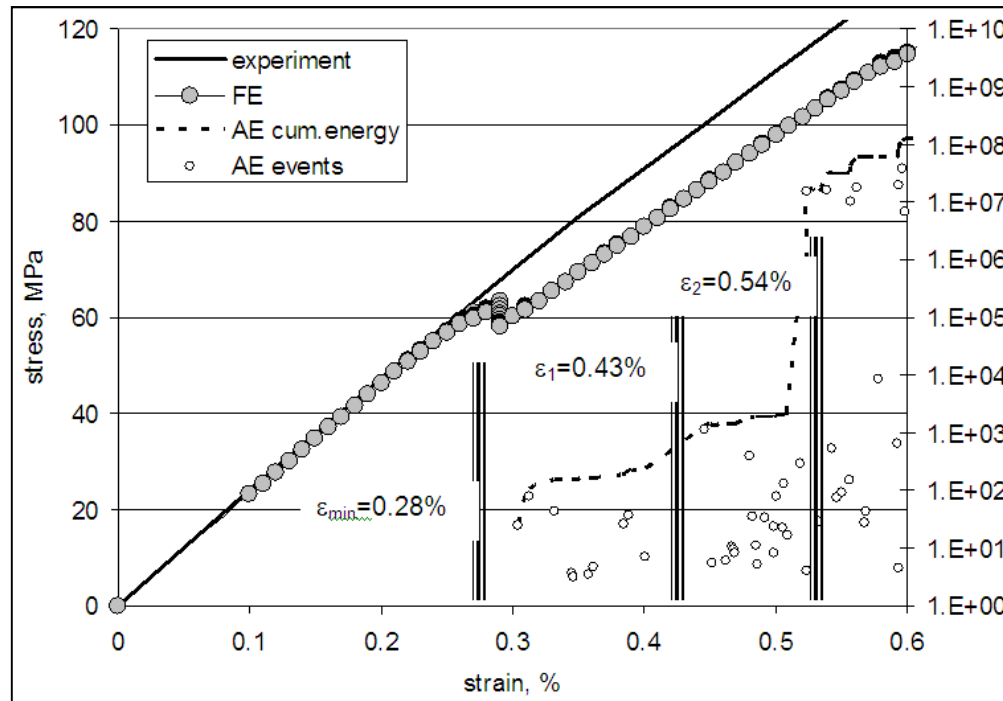


—◆— Iso-Strain  
—■— MoriTanaka  
—◆— Experiment

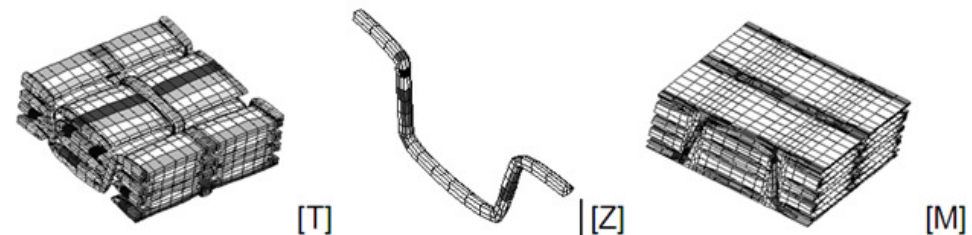
- E11 and E22 measured on tensile tests in warp and weft directions
- E33 measured on samples cut in the thickness direction



# Damage modelling



- correct modelling of degradation of stiffness
- reasonable evaluation of damage initiation threshold
- qualitative representation of intensity of damage



intensive transverse cracking: fill, Z; matrix cracking near Z-yarns

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Models	New developments in 2014 – 2015
meso-FE	Full model “on click”: WiseTex -> Abaqus
	Interpenetrations via contact algorithms
	Embedded elements for damage
	Fatigue models for textile composites
	Damage XFEM models for textile composites
μCT	VoxTex software
	Integration μCT – permeability models
	Integration μCT – voxel Abaqus models
Random fibres	Curved random fibres
	Debonding and strength
	Fatigue models for random fibre composites
New materials	Automated tape placement
	Steel fibre composites