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KU LEUVEN

MATERIALS ENGINEERING

Textile composites: from microstructure to mechanical properties

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Contents

1. Introduction
2. Internal geometry of textile composites: WiseTex software
3. Micro-CT reconstruction of the fibrous microstructure
4. Conclusion



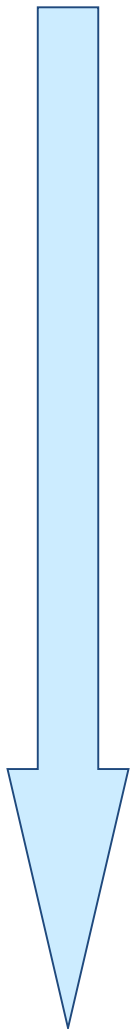
1. Introduction

2. Internal geometry of textile composites: WiseTex software and around it
3. Micro-CT reconstruction of the fibrous microstructure
4. Conclusion



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Hierarchy of scales: MACRO to meso



1 km



Composites in constructions

100 m

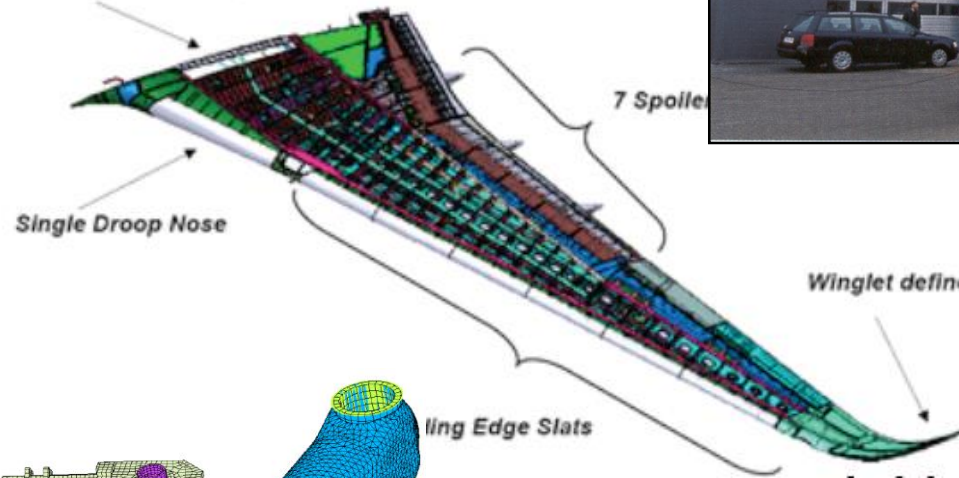
Windmill blade



10 m

Root Joint Geometry frozen

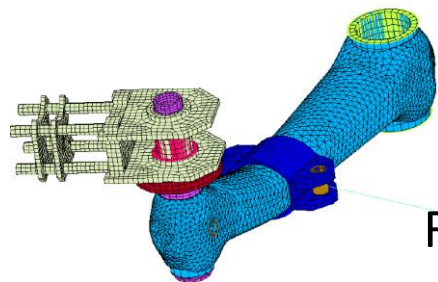
7 Spoiler



A350 wing

1 m

100 mm

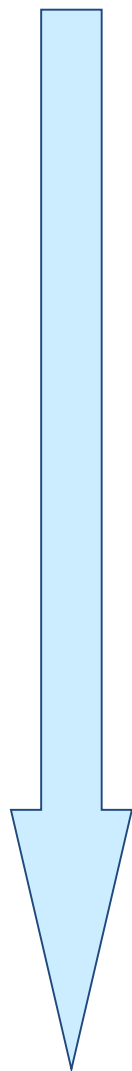


FE model of a composite aeronautic part

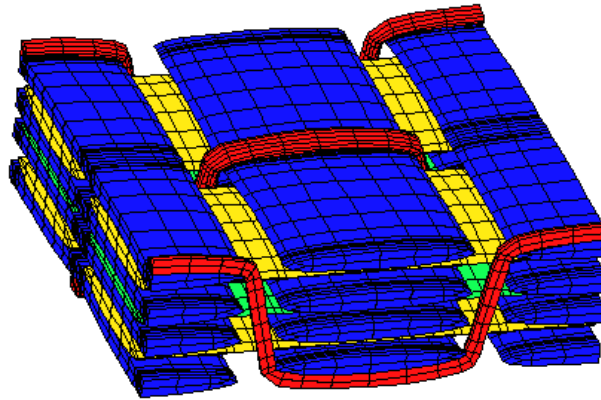


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Hierarchy of scales: meso to μ icro



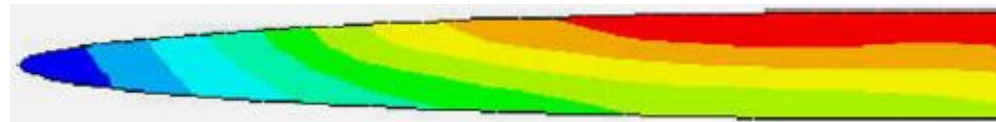
100 mm



FE model of 3D fabric

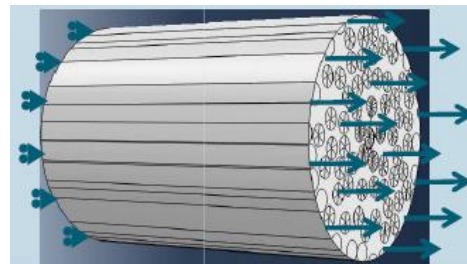
10 mm

1 mm



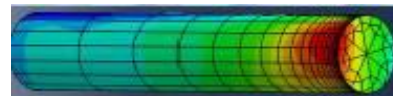
transverse stress in an impregnated yarn

100 μ m



FE: fibre failure

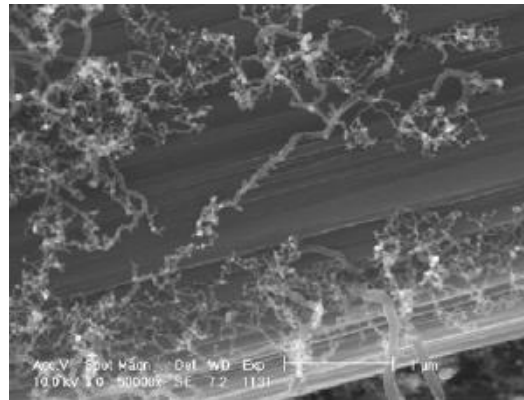
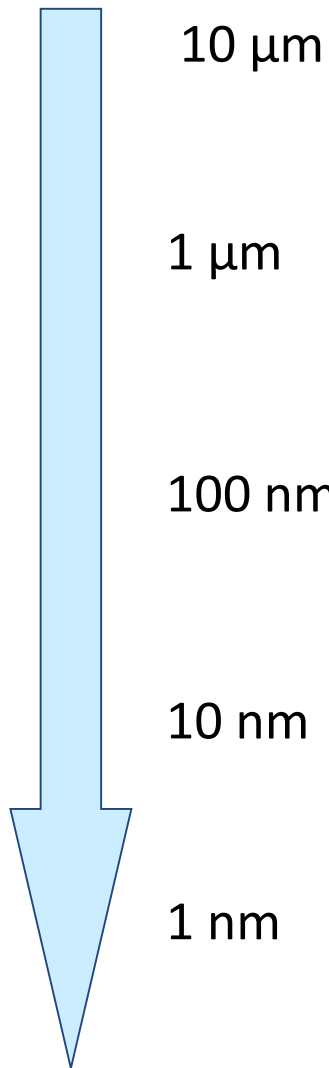
10 μ m



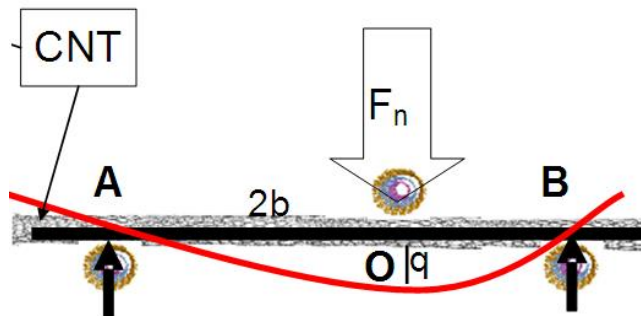


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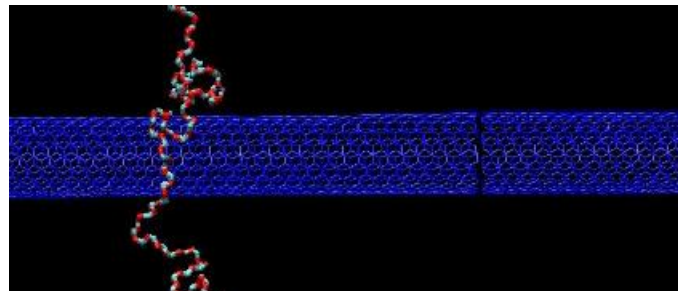
Hierarchy of scales: nano to μ micro



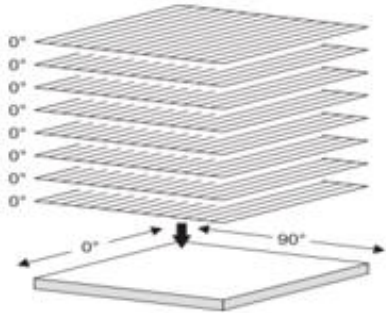
Carbon nanotubes (CNT) on the surface of a carbon fibre



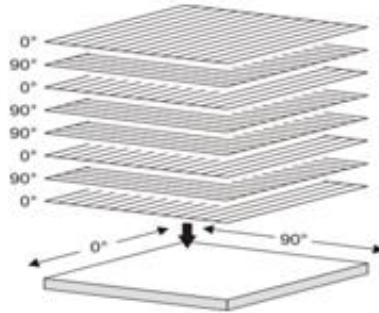
CNT bending



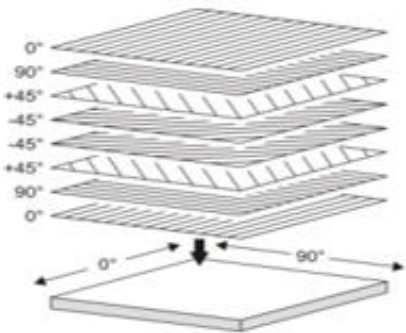
Molecular dynamics: interaction CNT - polymer



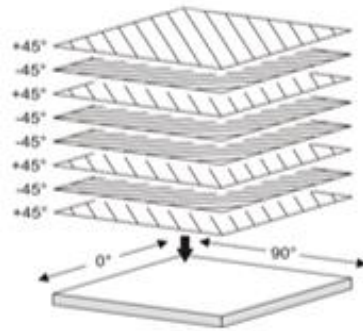
$[0^\circ]_8$



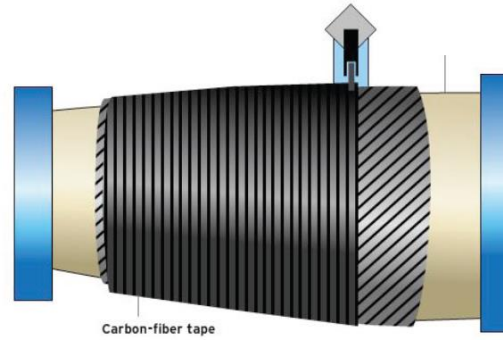
$[0^\circ, 90^\circ]_2^s$



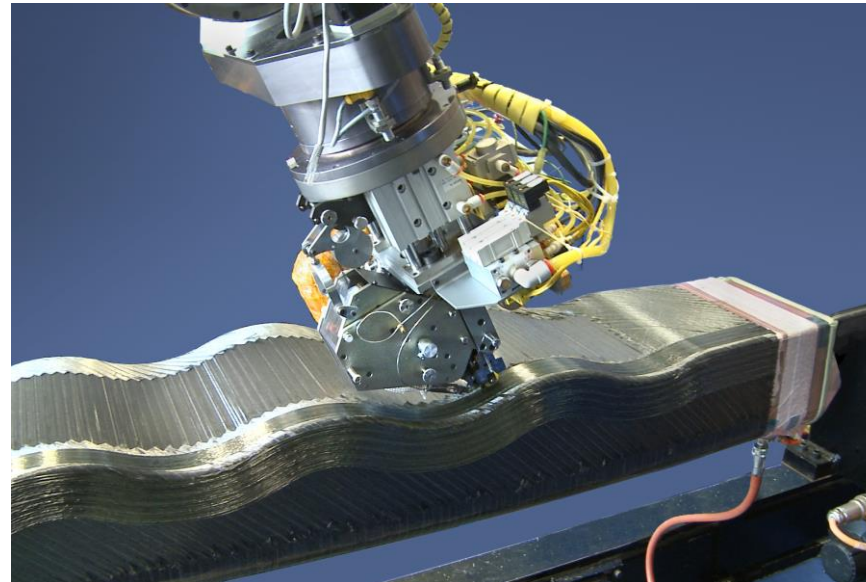
$[0^\circ, 90^\circ, +45^\circ, -45^\circ]_8^s$



$[+45^\circ, -45^\circ]_2^s$



filament winding
Boeing fuselage



Automated
fibre
placement
(AFP)



Short fibres

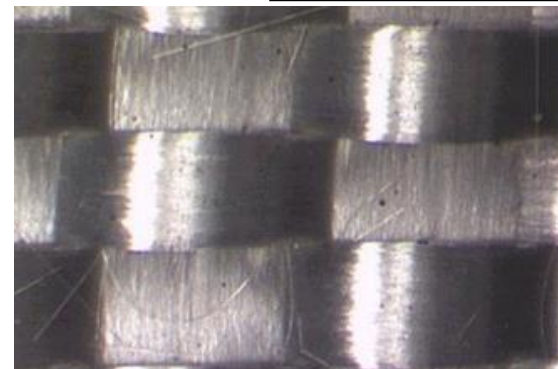
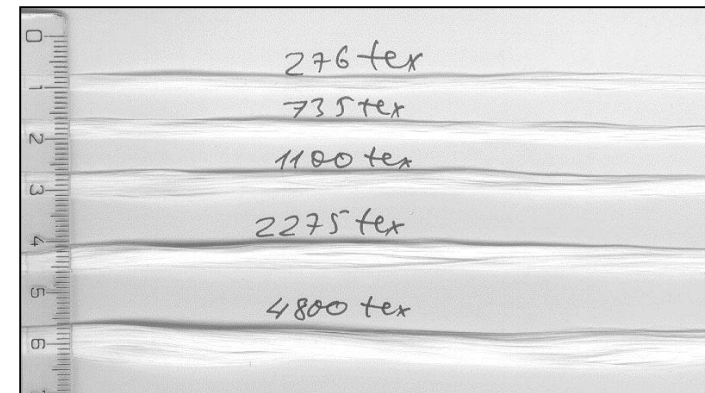
- chopped
- non-woven

Long fibres

- tapes (5...500 mm)
- tows (1000 ... 80.000 fibres = 1K ... 80K)
- twisted (50...5000 tex)
- commingled (fibres+matrix)

Textile

...





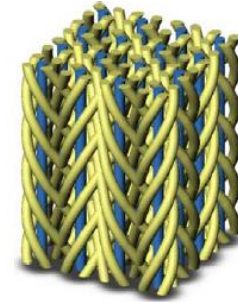
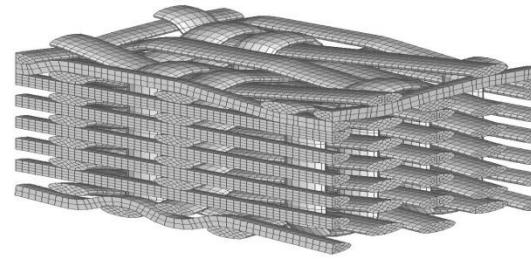
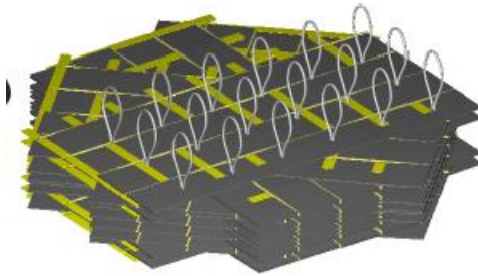
2D textile reinforcements

According to textile manufacturing technology

Type	Structure	Fibre orientation in plane
Random fibre mats		Random orientation; fibres can be chopped (short and straight) or continuous (curved)
UD layers		Perfectly straight in layers, placed on desired angles
Stitched multi-ply		Almost straight in layers, placed on desired angles; voids formed by stitching
Woven fabrics		Two orthogonal directions (three in triaxial fabrics - rare), slight crimp in z-direction.
Braided fabrics		Two non-orthogonal directions or three if there are inlays, slight crimp in z-direction.
Knitted fabrics		Regular but widely distributed fibre orientation

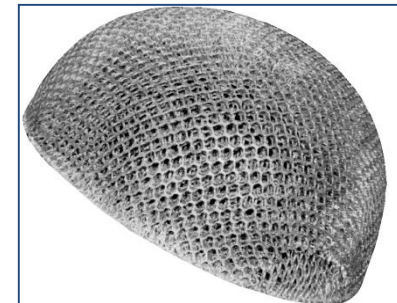
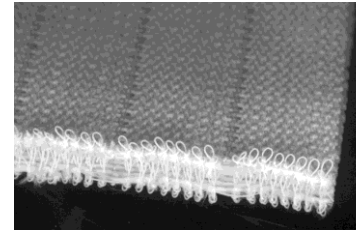
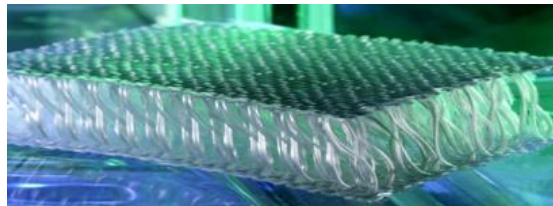
Solid 3D

- woven
- braided
- stitched



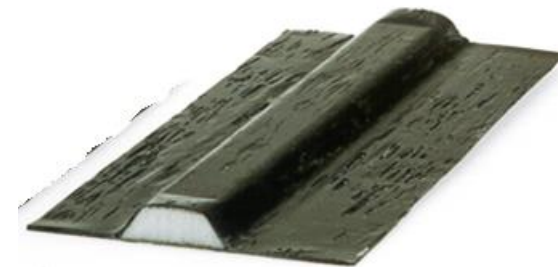
Textile sandwiches

- woven
- knitted



3D shapes

- braided
- knitted
- stitched



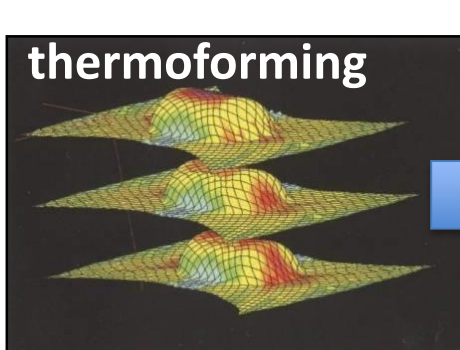
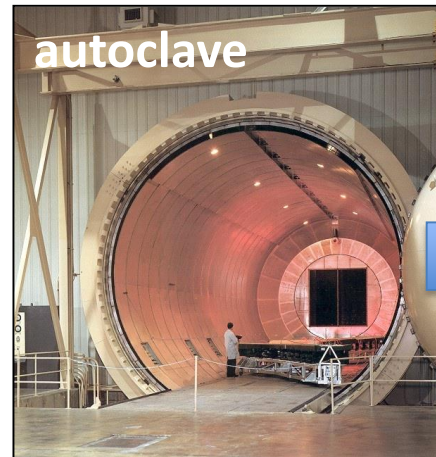
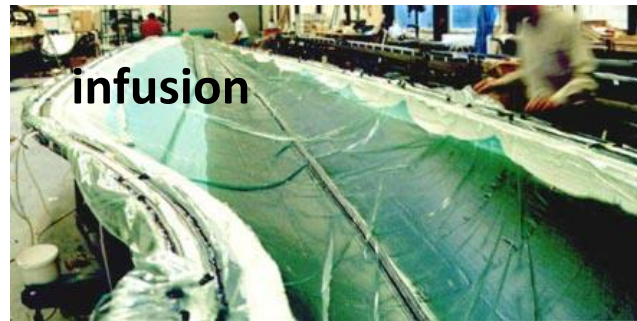


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Applications and manufacturing

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1. Introduction

2. Internal geometry of textile composites: WiseTex software

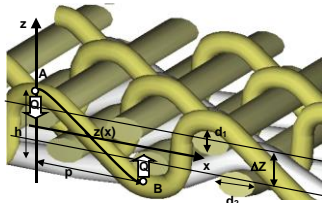
3. Micro-CT reconstruction of the fibrous microstructure

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Integrated simulations of textile composites



Internal architecture of the reinforcement

Production

Deformation resistance and change of geometry

Permeability

Performance

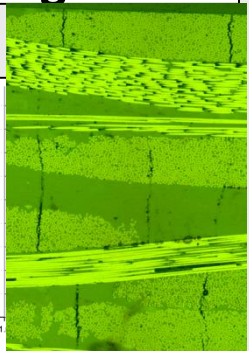
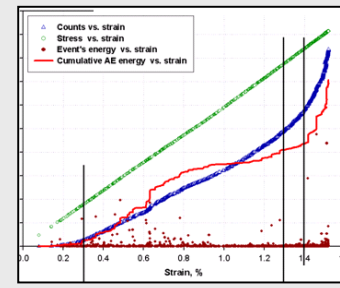
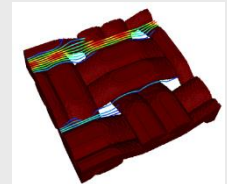
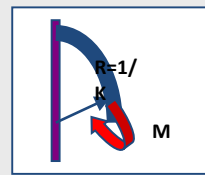
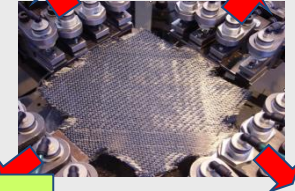
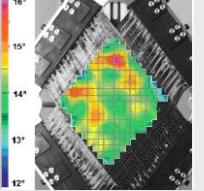
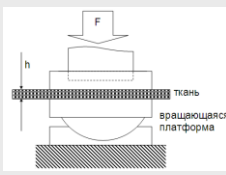
Mechanical properties and damage

Compr.

Shear

Tension

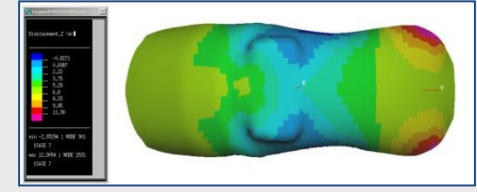
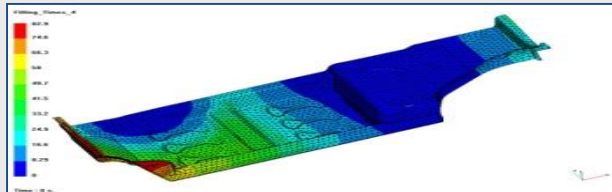
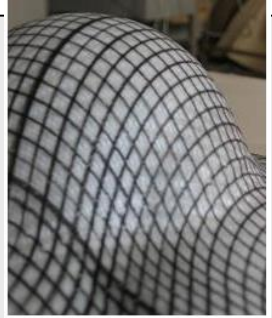
Bending



Drapeability and formability

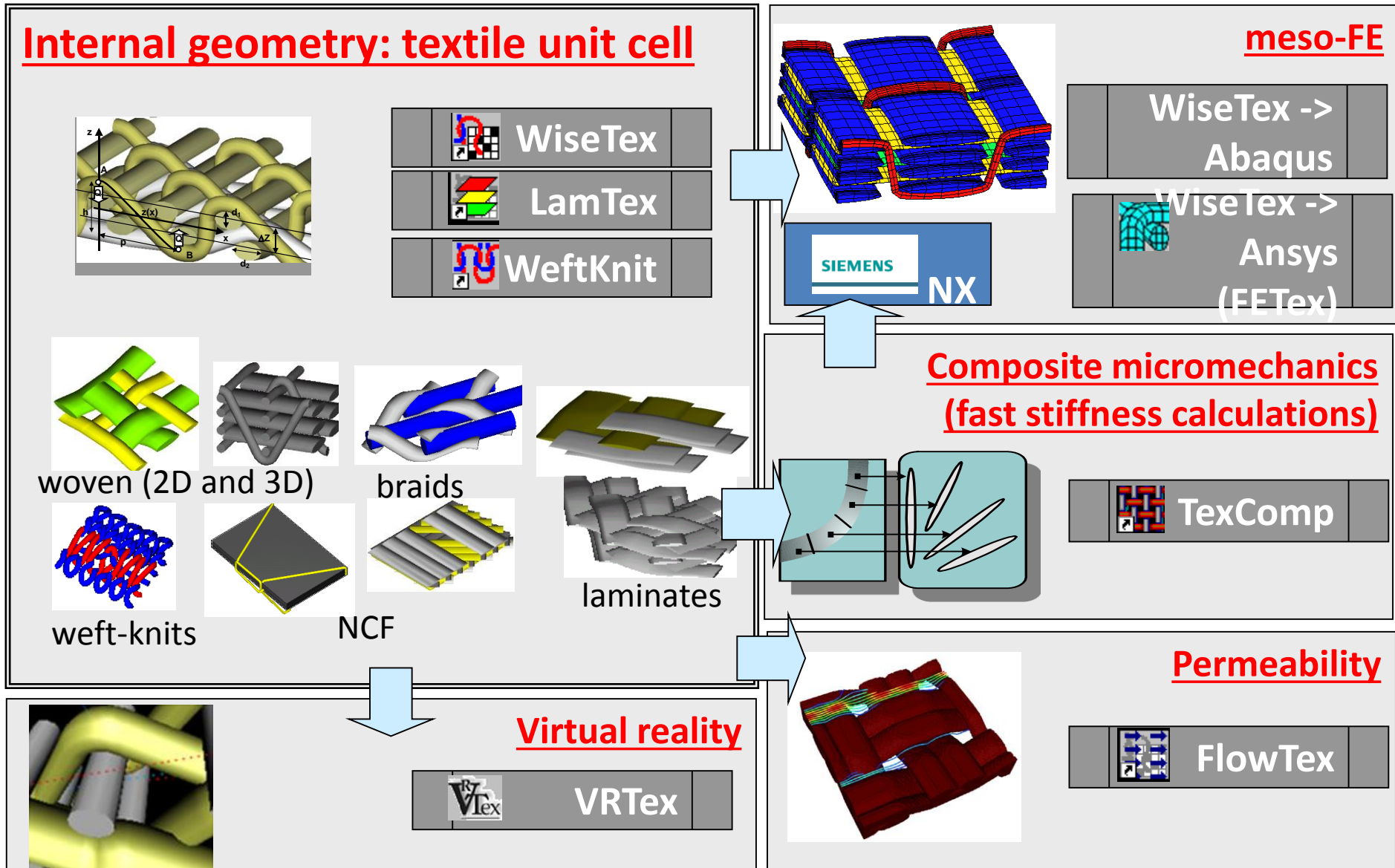
Impregnation

Structural analysis





WiseTex: virtual textile composites



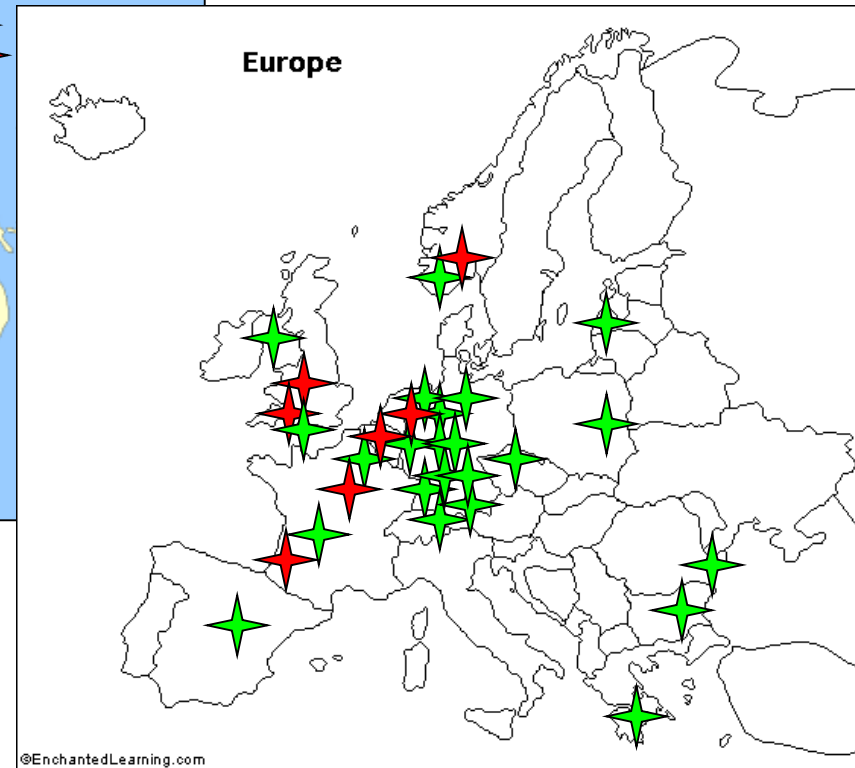


WiseTex worldwide



licenses, 2016:

- ★ industrial (16)
- ★ university (40)



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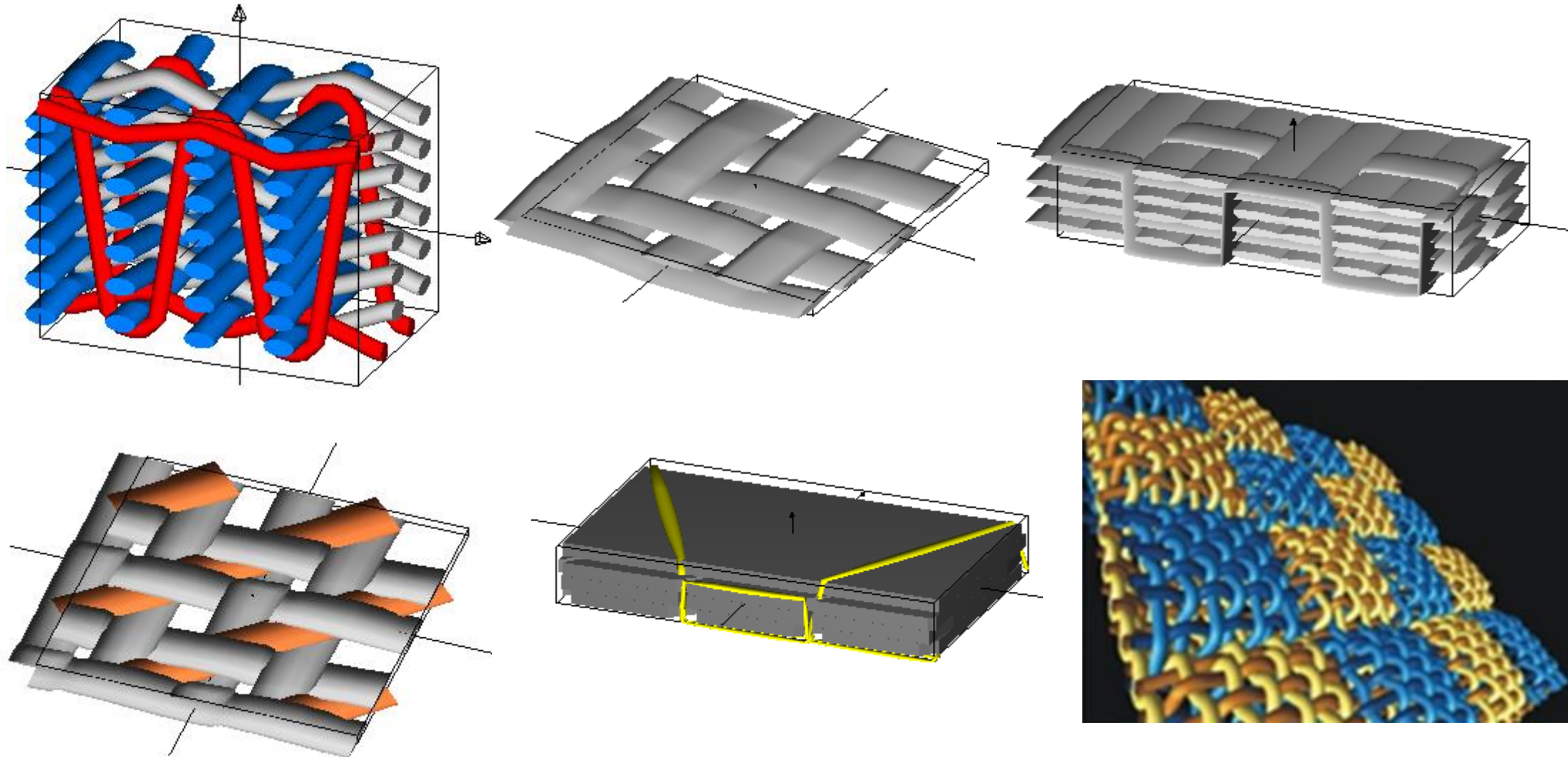


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A gallery of WiseTex models

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WiseTex 3.0:

- open XML input and output formats

New possibilities:

easy integration:

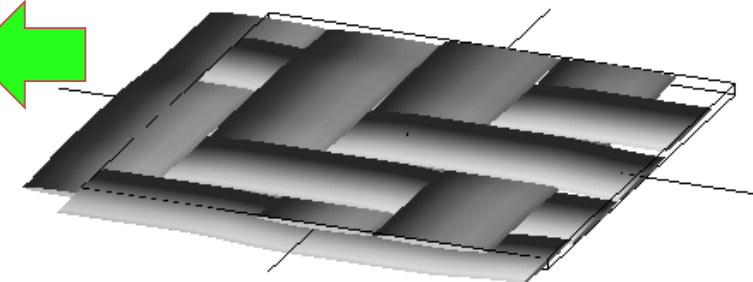
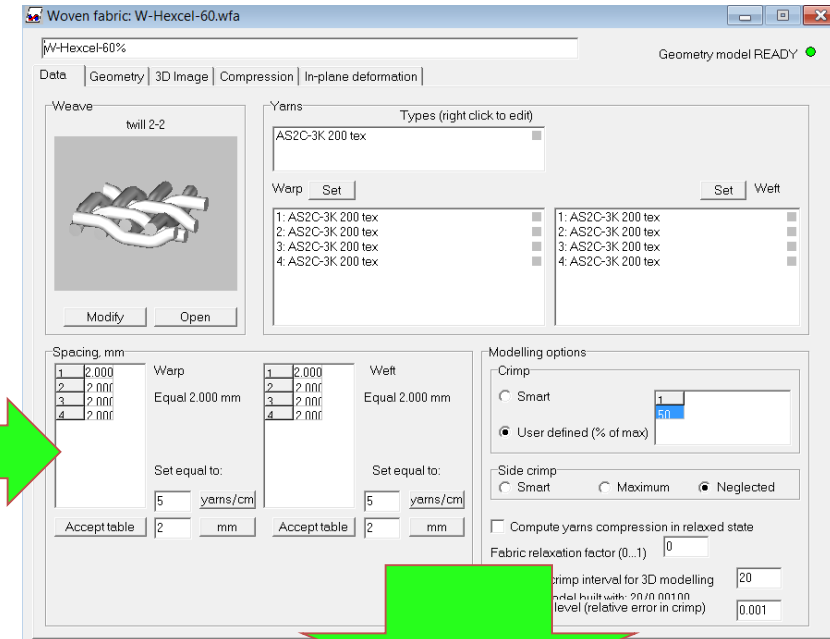
- upstream, with user-defined process models (e.g., braiding process)
- downstream, with user-defined modes of composite (e.g. meso-FE)

WiseTex
or custom
software

XML: textile
data

XML: fabric
geometry

custom
software





WiseTex 3.0+:

- open XML input and output formats
- **“command line” version**

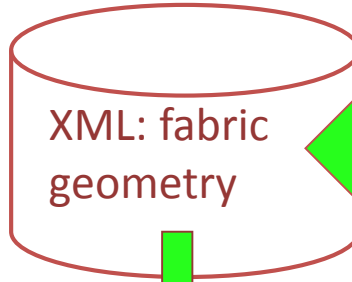
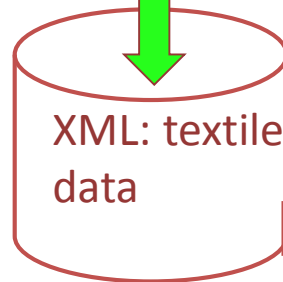
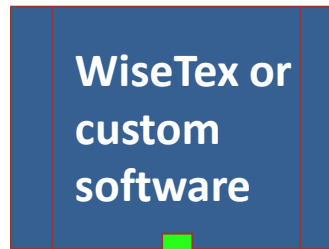
New possibilities:

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)

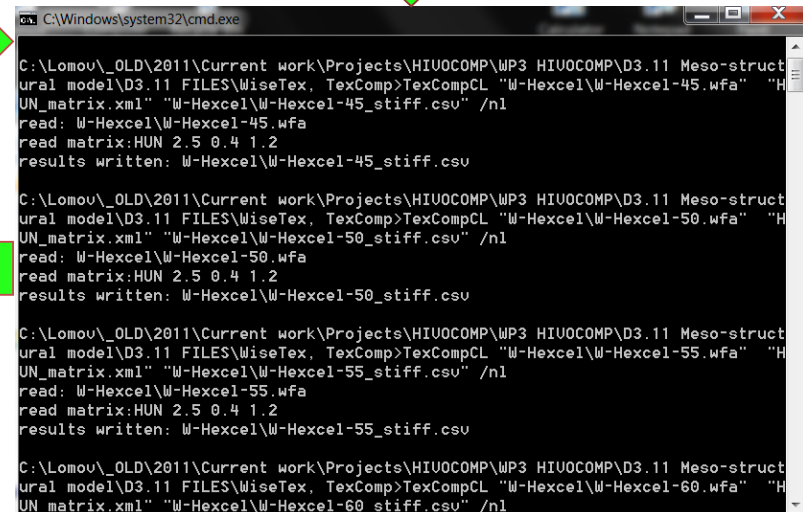


command line script

```

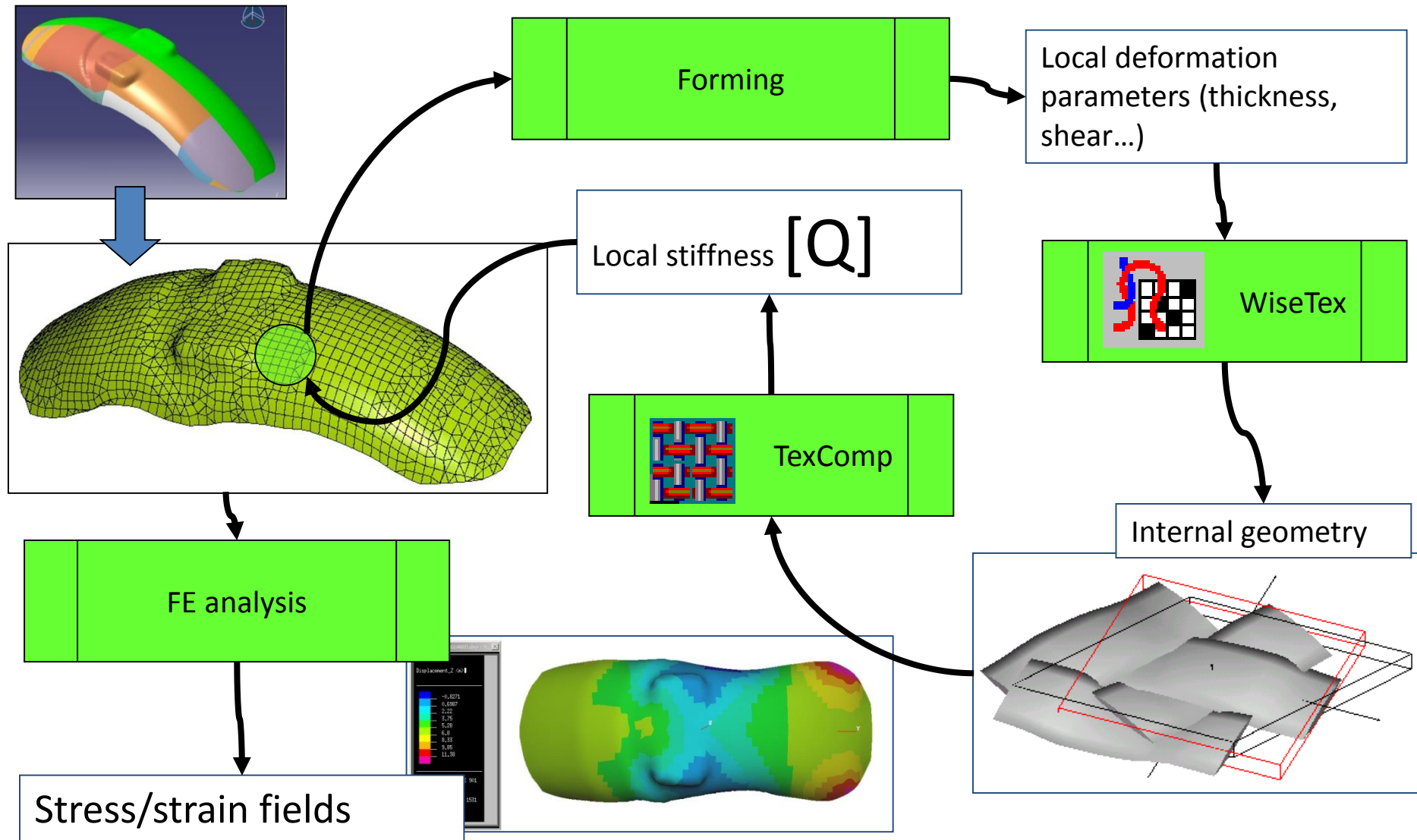
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\W-Hexcel-45_stiff.csv" /n1
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\W-Hexcel-60_stiff.csv" /n1

```





Multi-level analysis





1. Introduction
2. Internal geometry of textile composites: WiseTex software

3. Micro-CT reconstruction of the fibrous microstructure

4. Conclusion

Ilya Straumit
Stepan V. Lomov
Martine Wevers

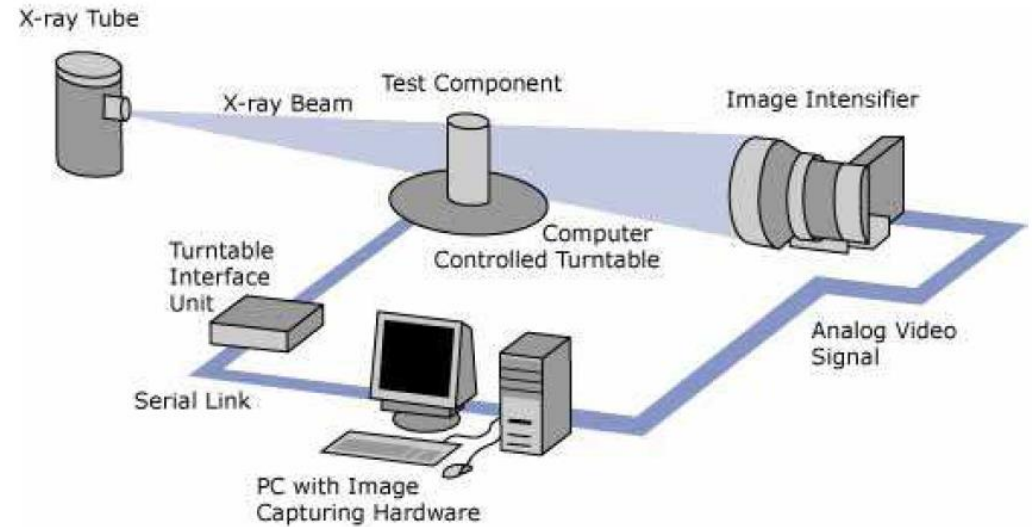
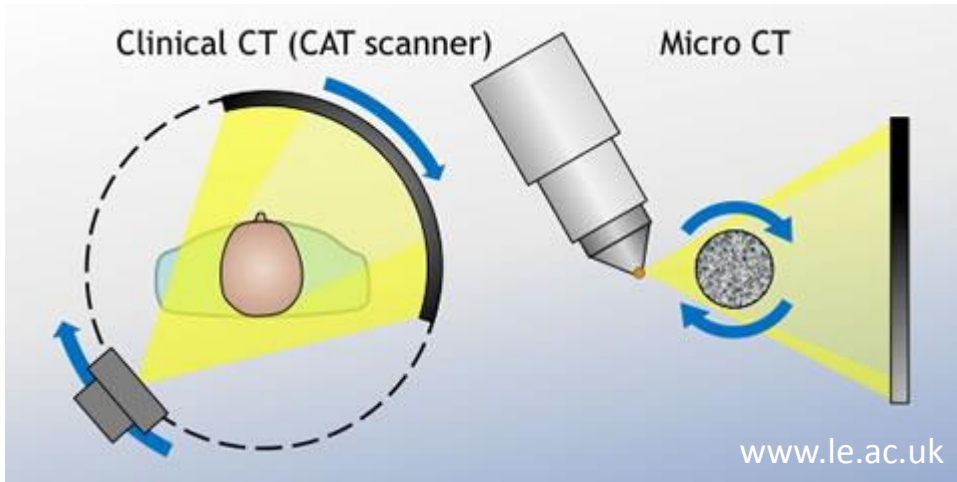


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Micro computed tomography (micro-CT)

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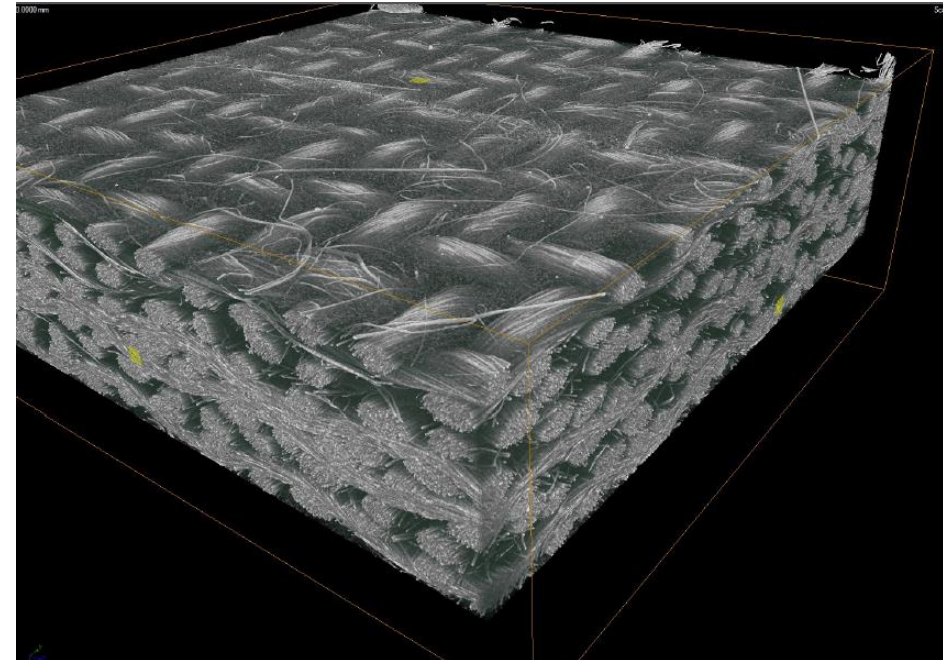


Nanotom – GE
0.5 μm



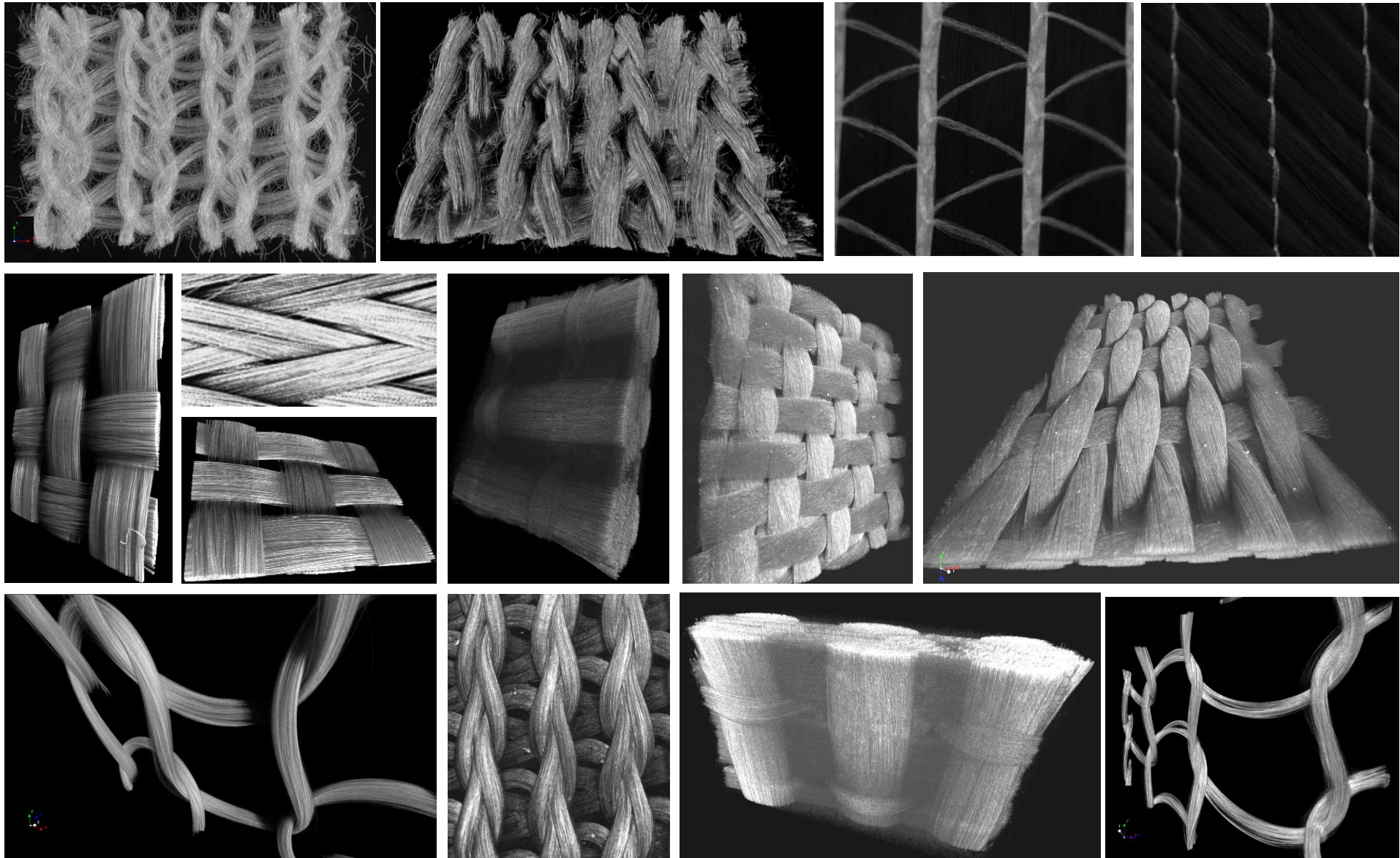
SkyScan, 1 μm

S.V. Lomov



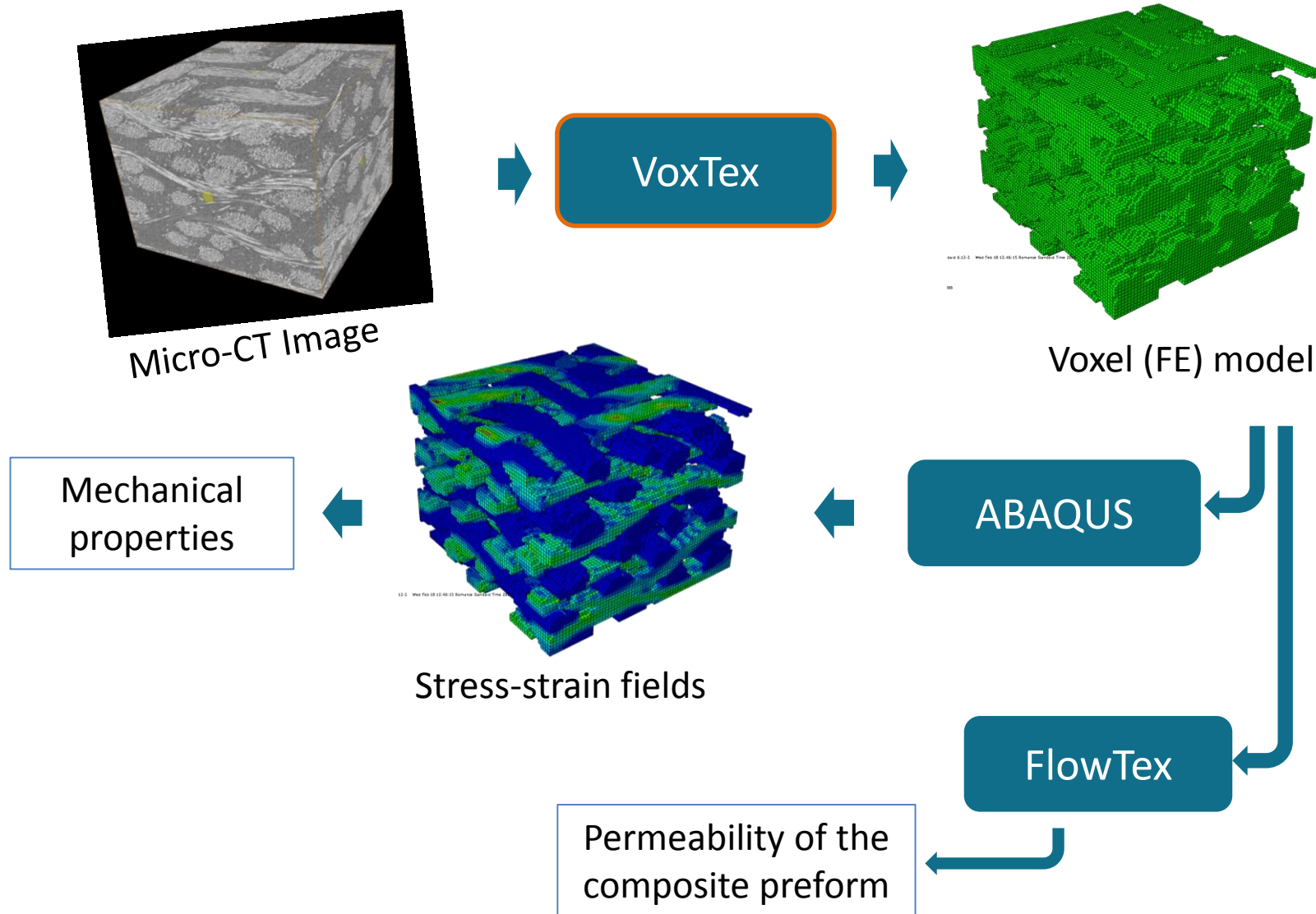


Different textiles





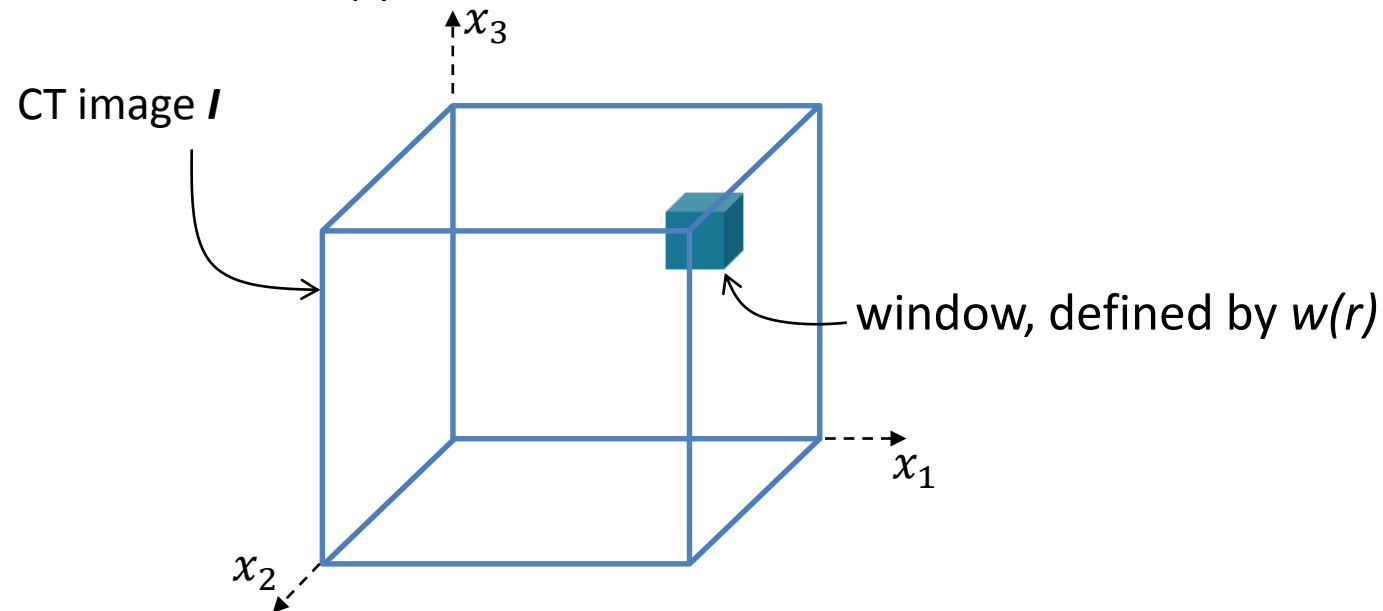
Modelling workflow

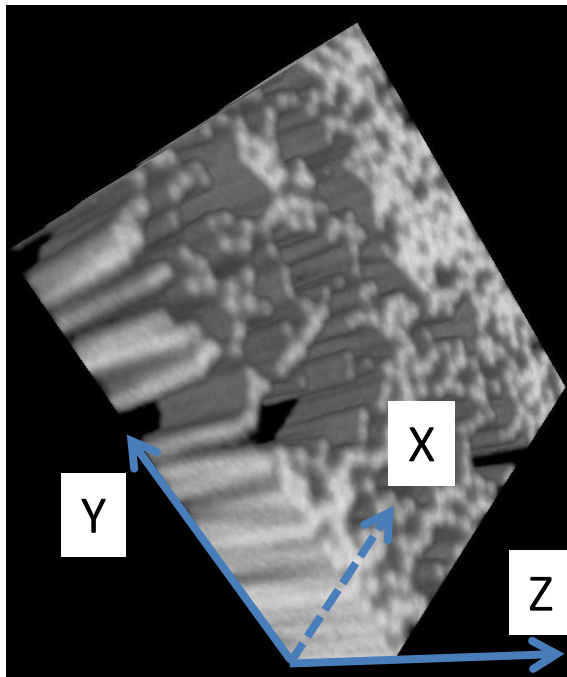




$$S(\mathbf{p}) = \int_{w(\mathbf{p})} S'(\mathbf{r}) d\mathbf{r} \quad S'(x_1, x_2, x_3) = \begin{bmatrix} \left(\frac{\partial I}{\partial x_1}\right)^2 & \frac{\partial I}{\partial x_1} \frac{\partial I}{\partial x_2} & \frac{\partial I}{\partial x_1} \frac{\partial I}{\partial x_3} \\ & \left(\frac{\partial I}{\partial x_2}\right)^2 & \frac{\partial I}{\partial x_2} \frac{\partial I}{\partial x_3} \\ \text{sym} & & \left(\frac{\partial I}{\partial x_3}\right)^2 \end{bmatrix}$$

I – image as three-dimensional function,
 Ω – image domain, and $w(r)$ – window function.





Micro-CT image of unidirectional steel fiber reinforced composite. Z is the direction of fibers.

Components of the structure tensor:

$$S_{ij} = \begin{bmatrix} 16.8 & 3.6 & 1.1 \\ 3.6 & 7.6 & 0.7 \\ 1.1 & 0.7 & 2.8 \end{bmatrix}$$

Eigenvalues:

$$\lambda = \{2.7 \quad 6.4 \quad 18.1\}$$

First eigenvector:

$$v_0 = \begin{pmatrix} -0.048 \\ -0.107 \\ 0.993 \end{pmatrix}$$

Degree of anisotropy:

$$\beta = 0.85$$

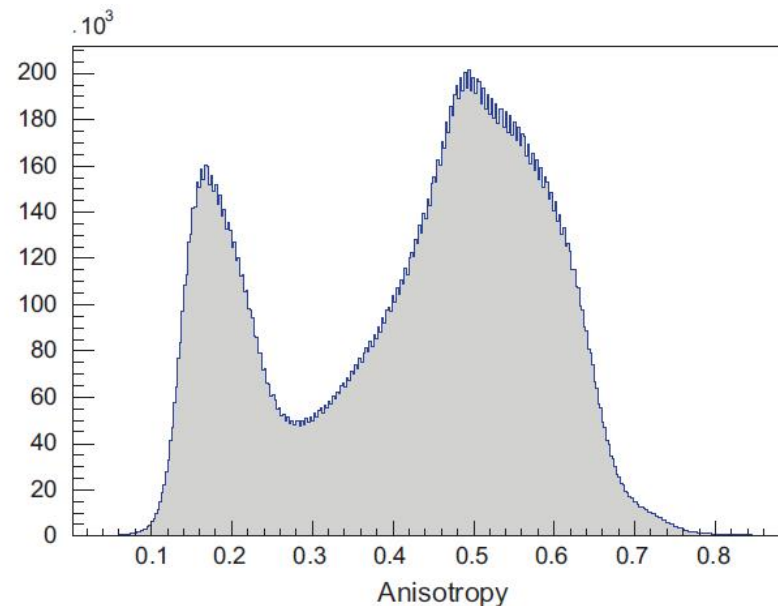
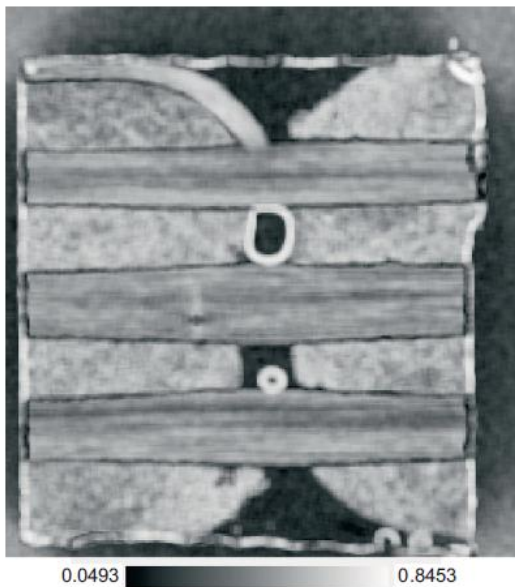


Degree of anisotropy

The ratio of eigenvalues:

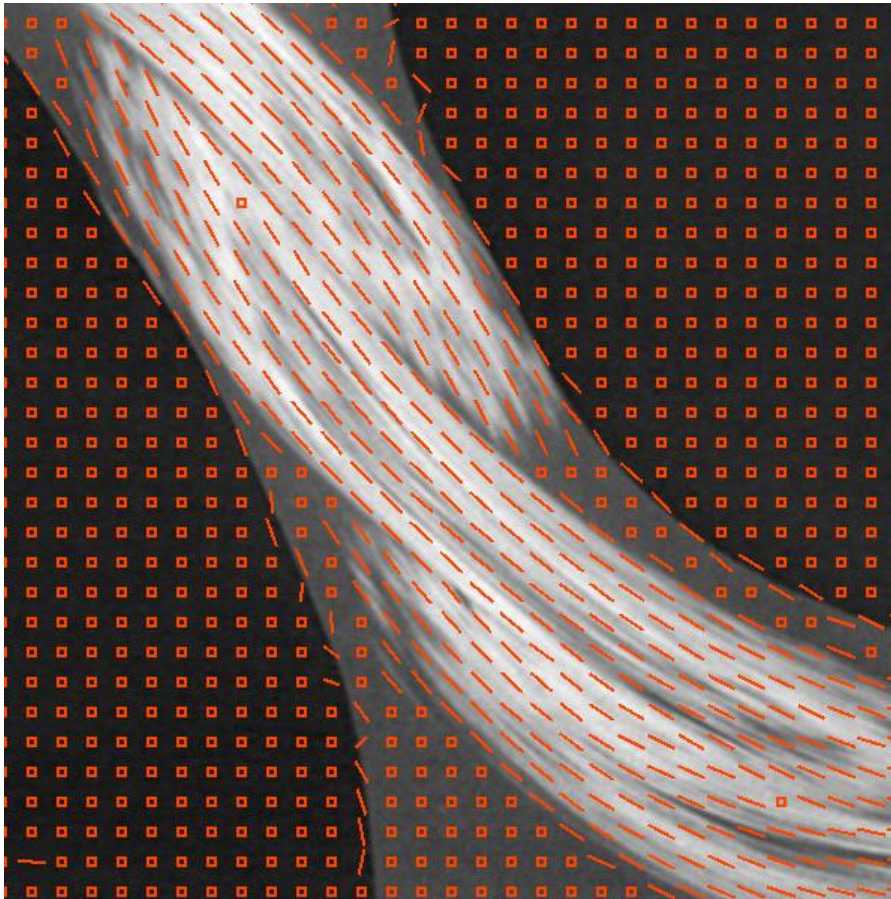
$$\beta = \begin{cases} 1 - \frac{\lambda_1}{\lambda_3} & \text{if } \lambda_3 > 0, \\ 0 & \text{if } \lambda_3 = 0. \end{cases}$$

where λ_1 and λ_3 are lowest and highest eigenvalues of the structure tensor respectively.





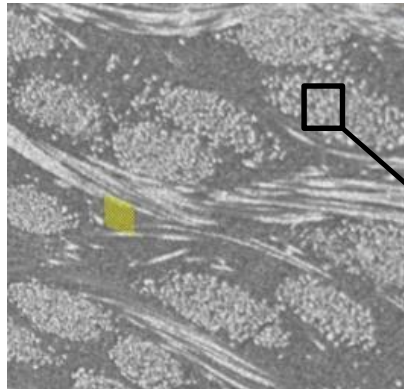
anisotropic
 $\beta \rightarrow 1$

isotropic
 $\beta \rightarrow 0$



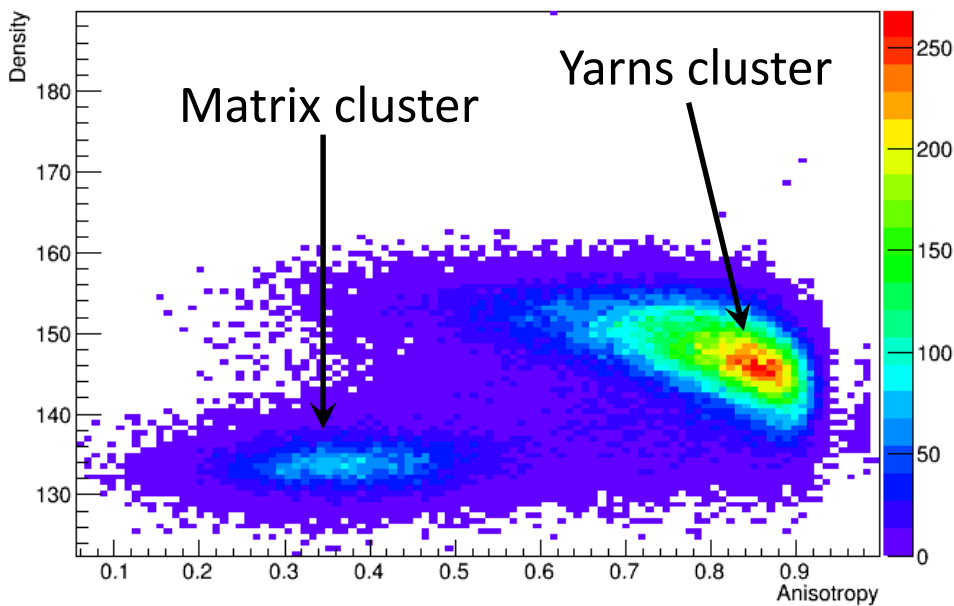
Knitted glass fiber composite
Resolution: 4 μm
Computed orientation fields

-  anisotropic (orientation)
-  isotropic



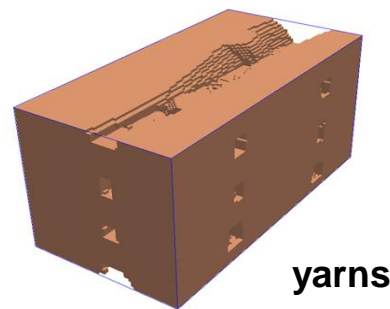
The variables, extracted from the image, reflect physical properties of the material:

- grey value – material attenuation
- structural anisotropy – material microstructure type

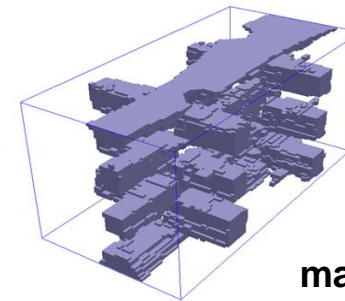


Methods of segmentation:

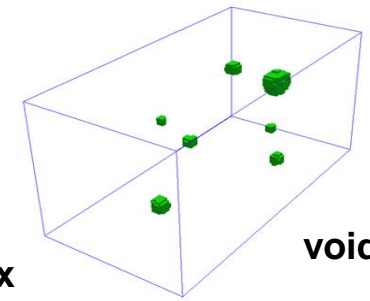
- Unsupervised (k-means)
- Supervised (Gaussian mixture model)



yarns



matrix

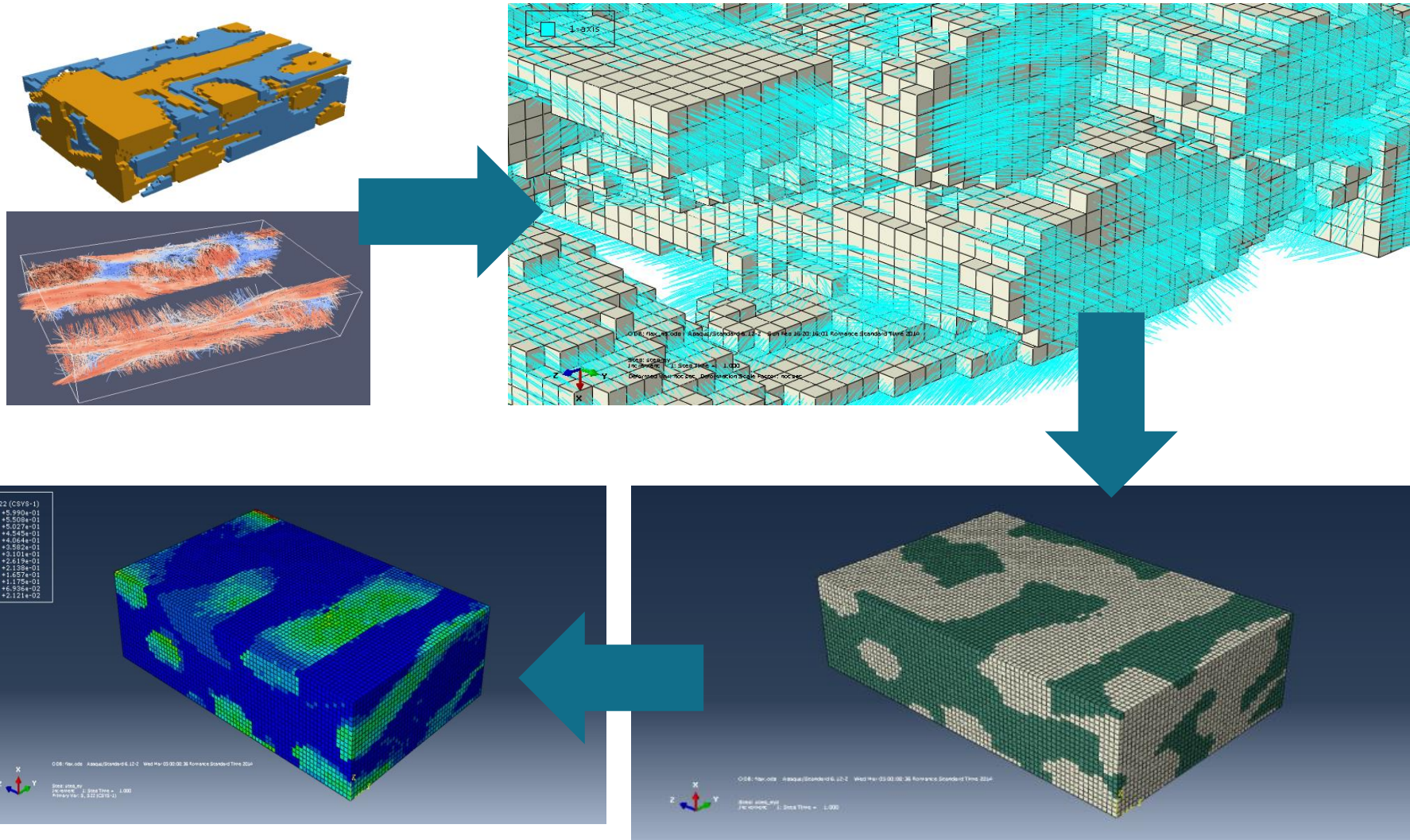


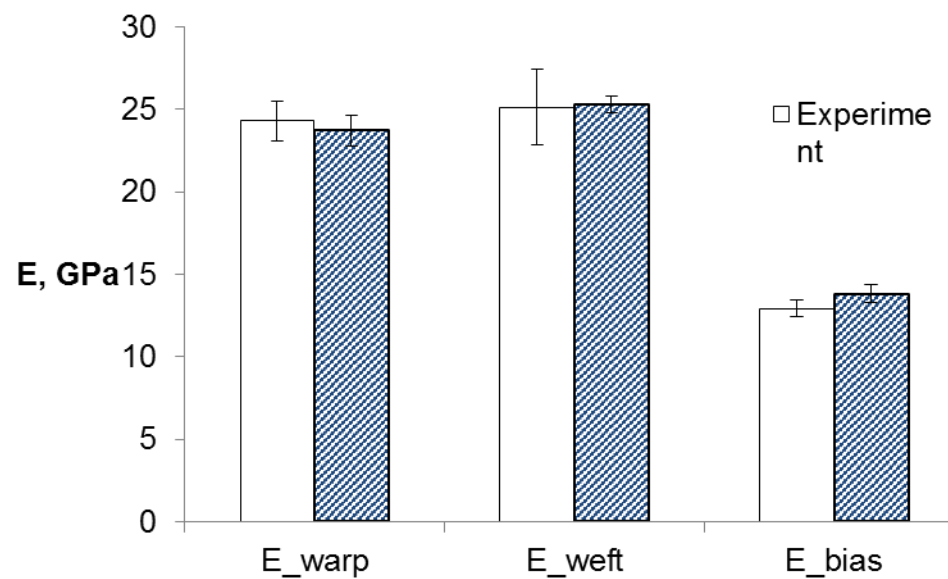
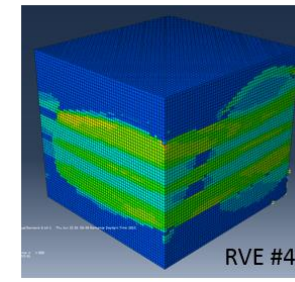
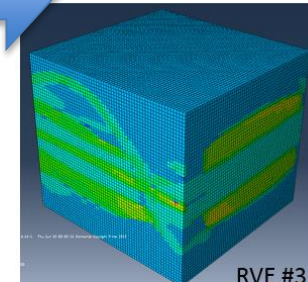
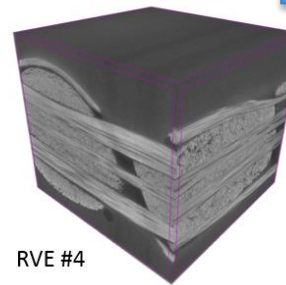
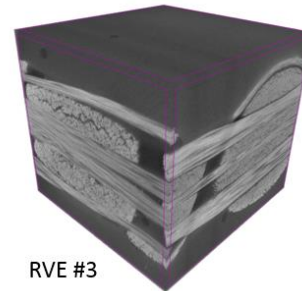
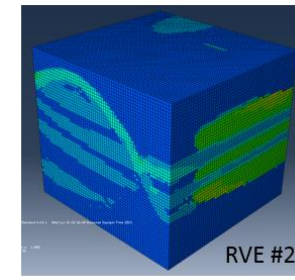
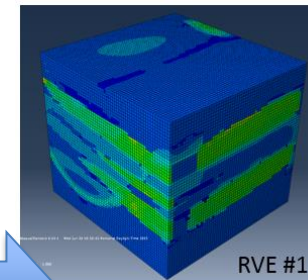
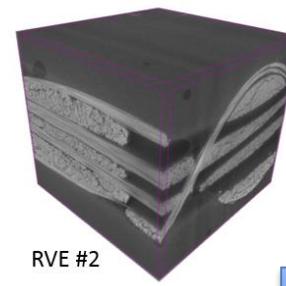
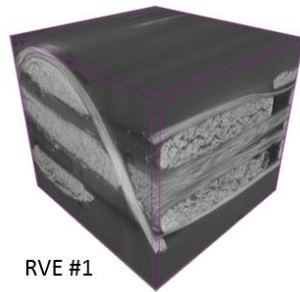
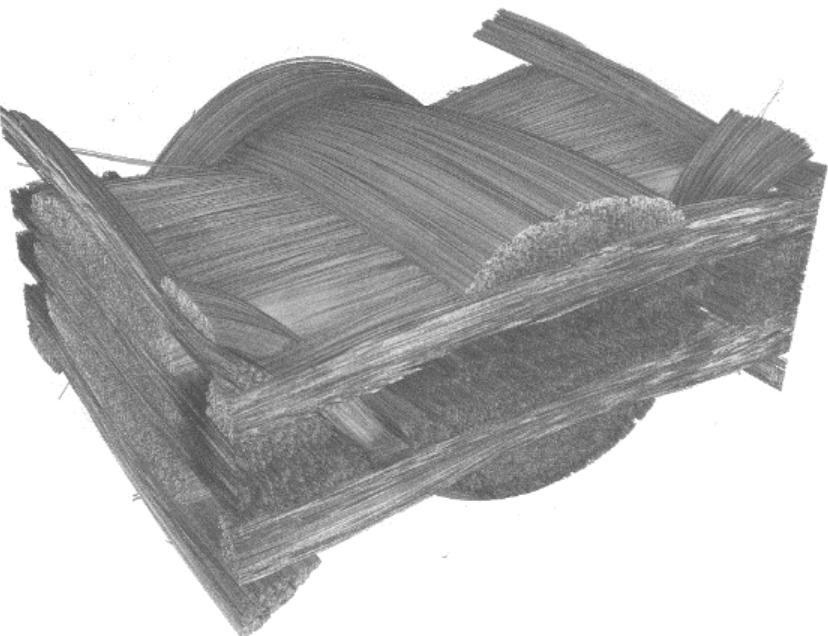
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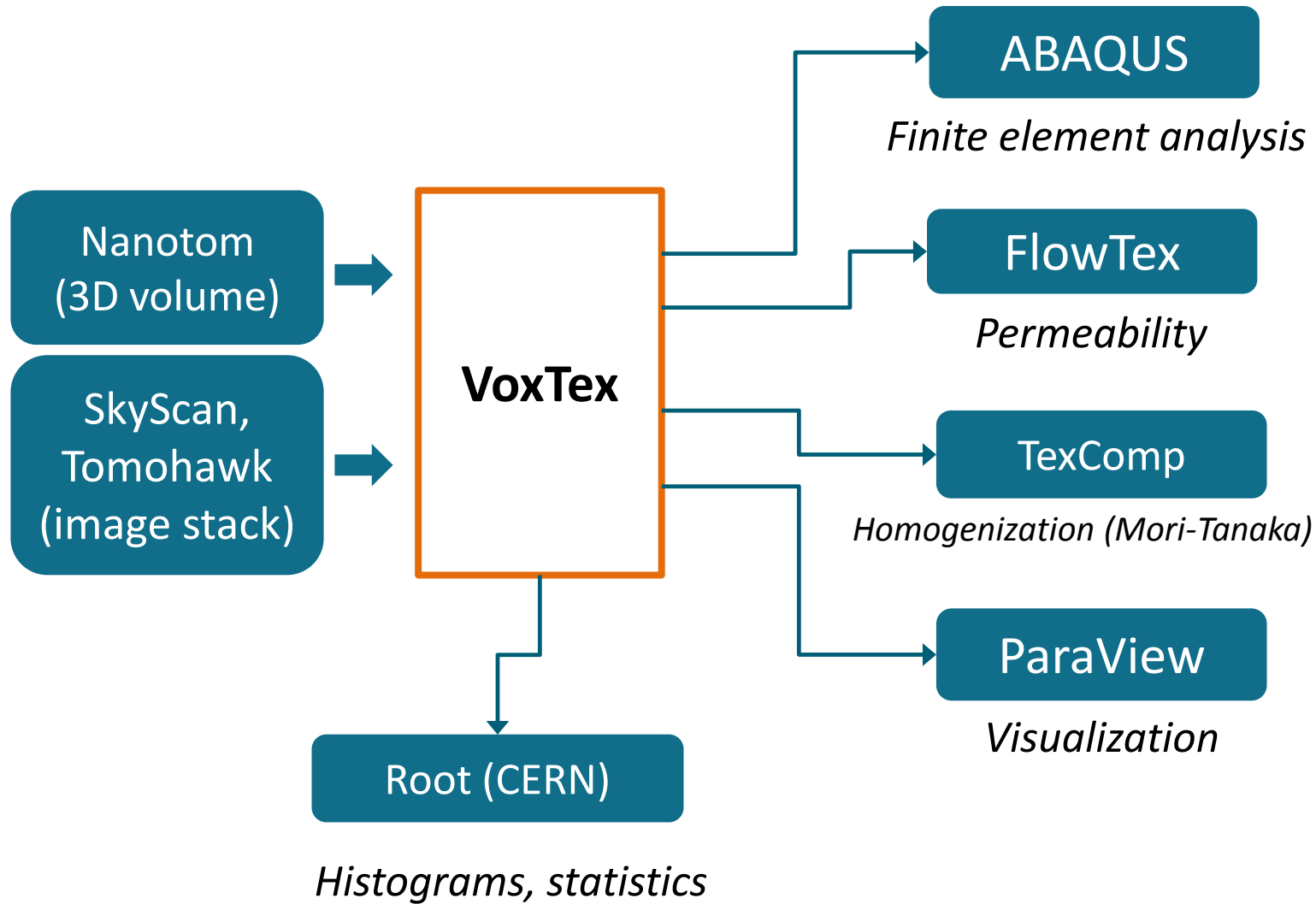
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Micro-Ct based Abaqus model





calculated elastic properties



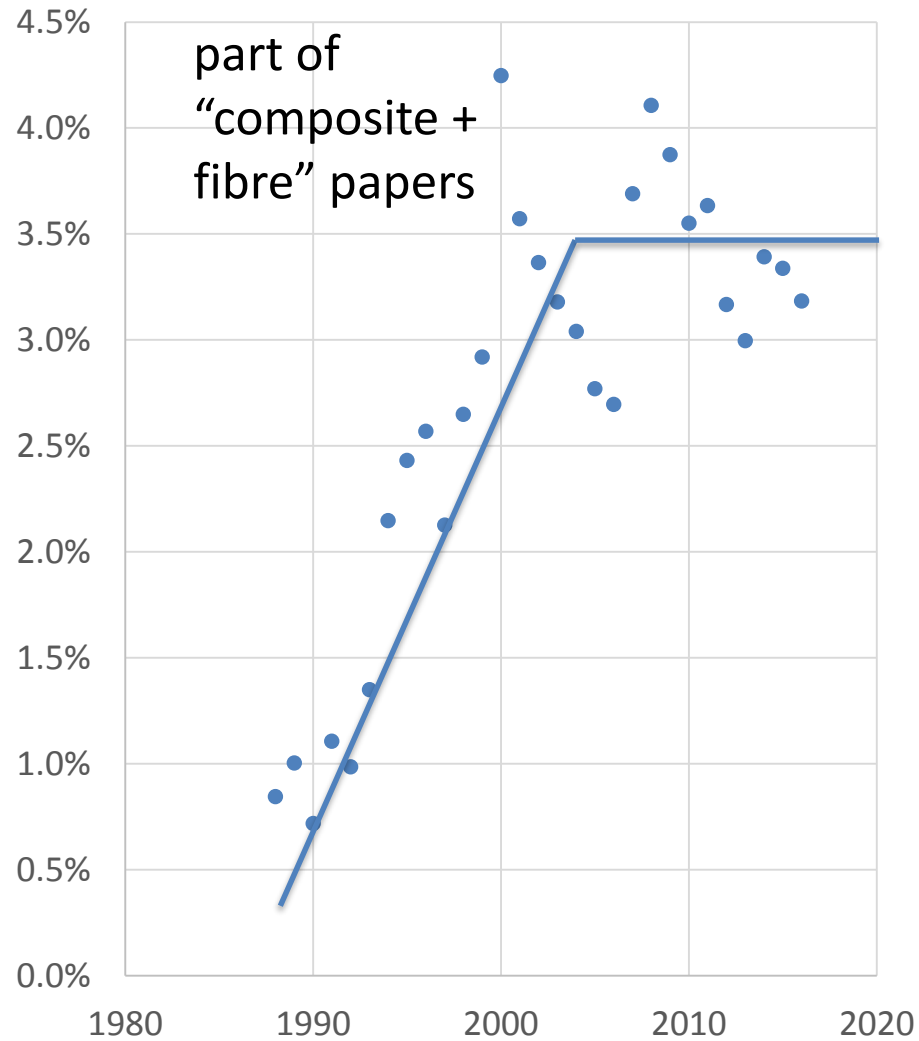
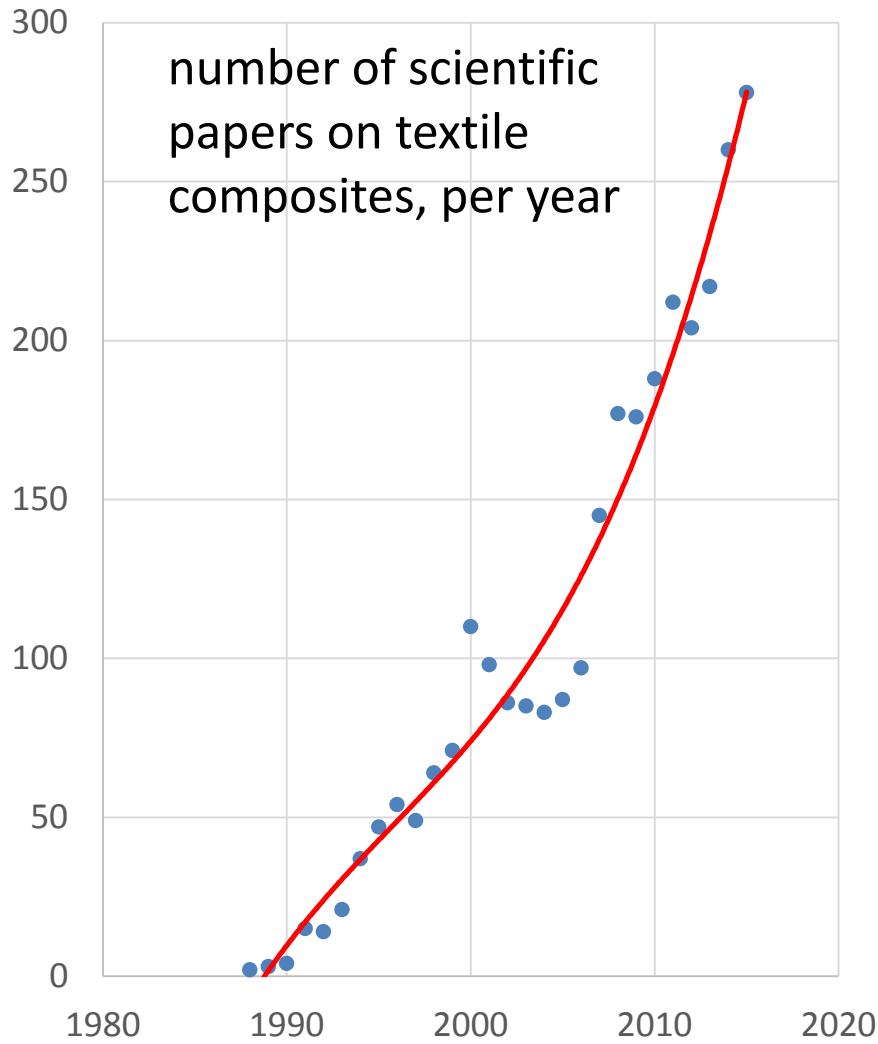


1. Introduction
2. Internal geometry of textile composites: WiseTex software
3. Micro-CT reconstruction of the fibrous microstructure

4. Conclusion



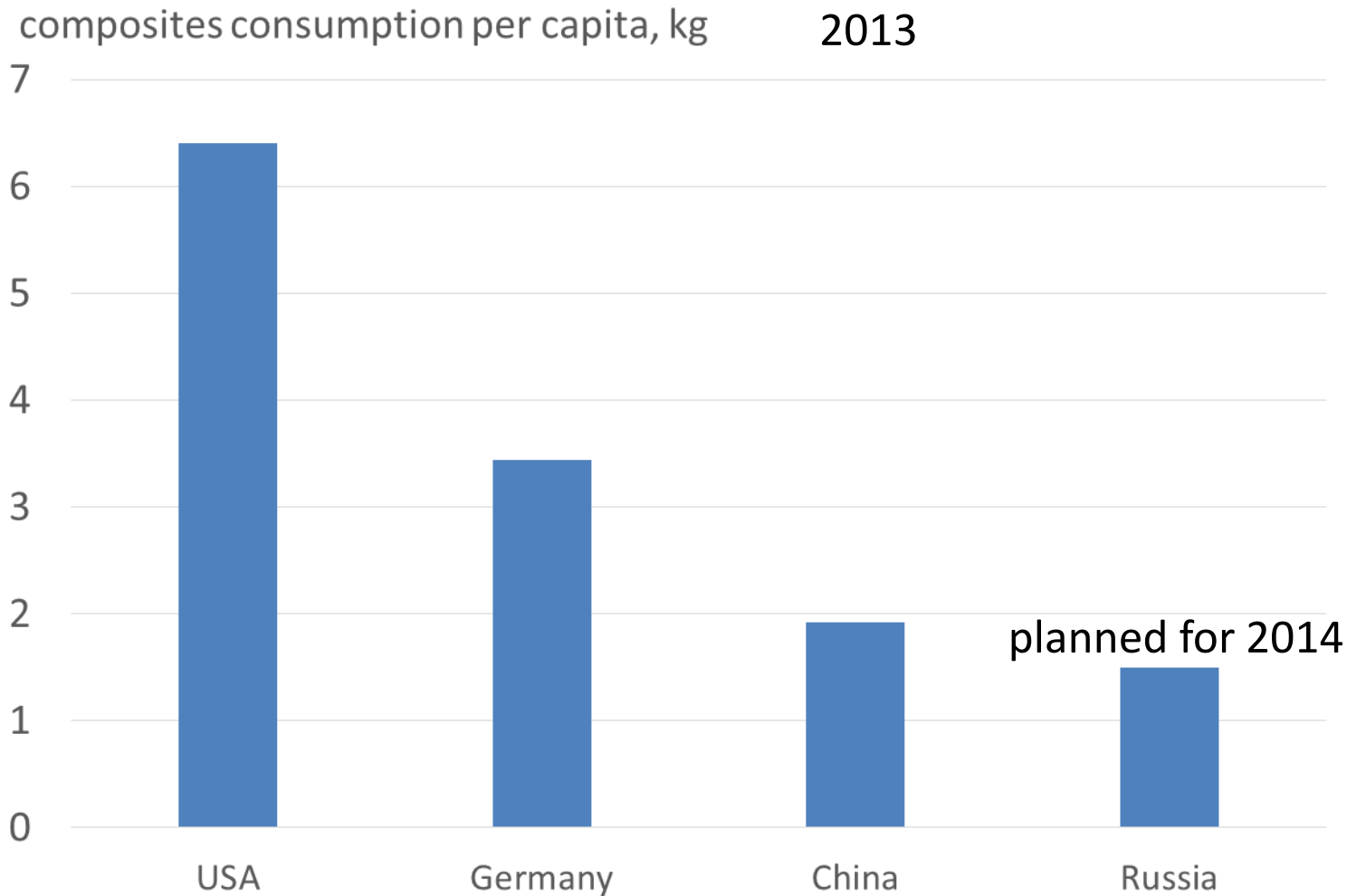
Growing field, steady interest



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