Mikrostruktursimulation der mechanischen Deformation von Fasermaterialien

Heiko Andrä[1], Andreas Fink[1], Michael Godehardt[2], Matthias Kabel[1], Janis Sliseris[1], Sarah Staub[1], Oliver Wirjadi[2]

[1] Strömungs- und Materialsimulation
[2] Bildverarbeitung
Fraunhofer ITWM, Kaiserslautern

VVD 2015 – Verarbeitungsmaschinen und Verpackungstechnik
12. und 13. März 2015 in Dresden/Radebeul

Fraunhofer ITWM

Outline

- Introduction and Motivation
- Image processing of 3D µCT scans
- Generation of representative volume elements for microstructures
- Microscale simulation and numerical homogenization
- Two-scale simulation

Fraunhofer
ITWM

Computer Aided Material Characterization

Mechanical properties of fibrous materials (paper, paperboard, fiberboard) depend on a variety of microstructural parameters, e.g.:

- Fiber orientation (FO)
- Fiber length, curvature and thickness
- Fiber volume fraction

➔ Measurements are complicated (or even impossible) and need to be done for many samples

A combination of measurements for simple specimens and simulations for varying complex microstructure parameters accelerates the material characterization of fibrous materials.

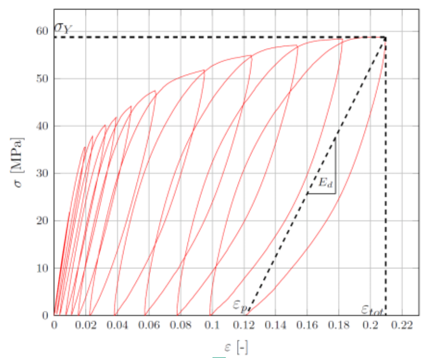
Nonlinear computations on realistic samples are expensive.
➔ Fast microscale solvers necessary

Fraunhofer ITWM

Computer Aided Material Characterization

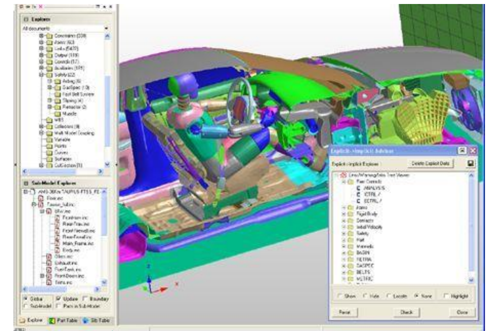
Measurement for specimen

- Isotropic behavior
- Rate dependent



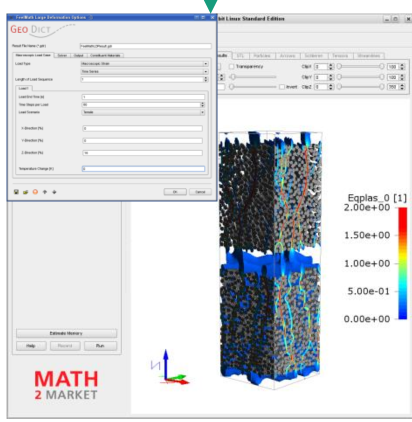
Macro-scale simulation with LS-DYNA or PAMCRASH

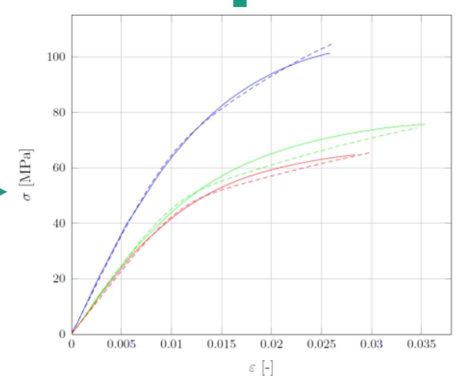
- Arbitrary geometries
- Local mesh refinement



Microscale simulation

- Microstructure can be easily changed
- Effect of defects (pores) can be studied
- Complicated coupon test can be reduced





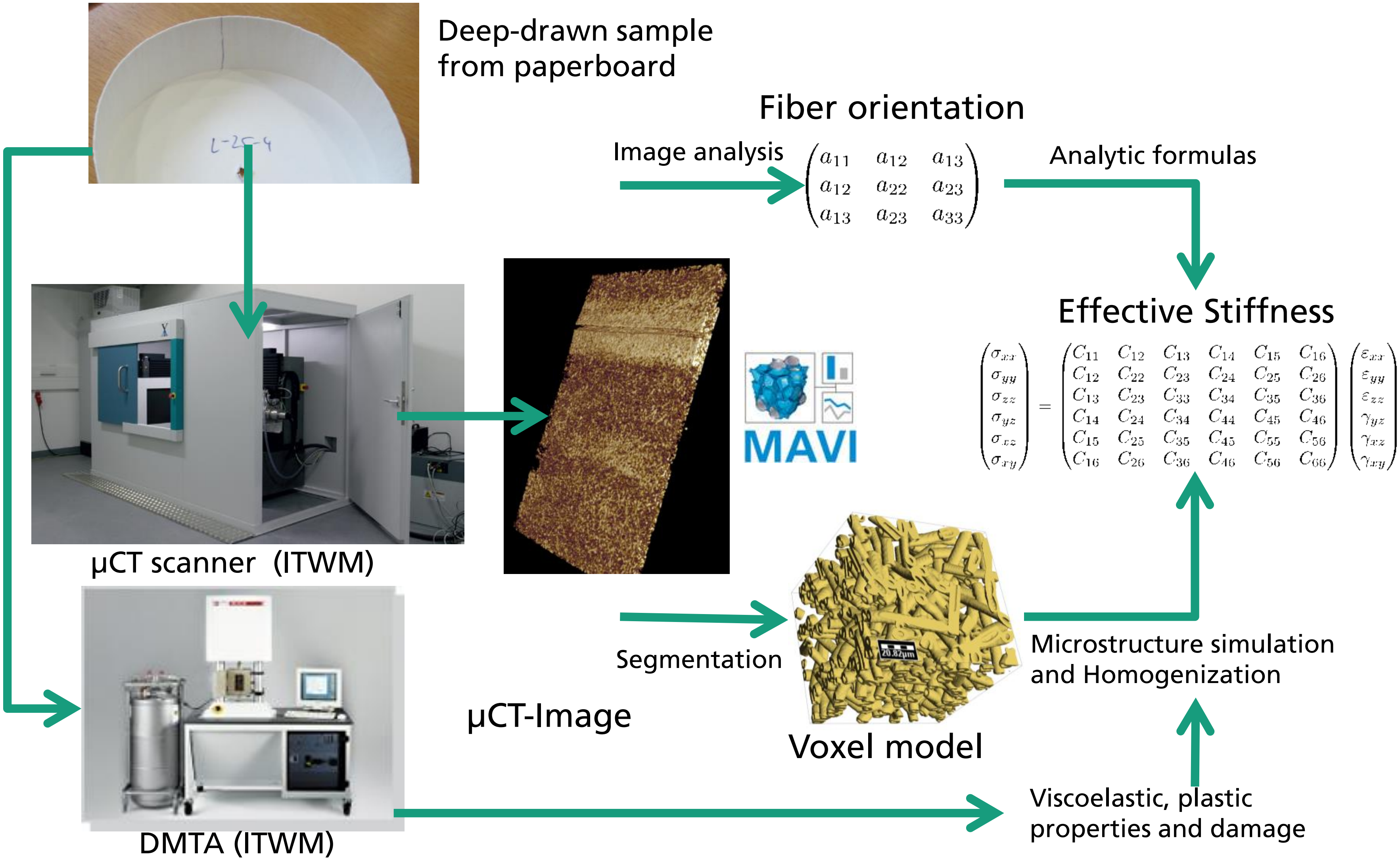
Material cards

- Simulation results are used to derive effective material laws
- Anisotropic behavior
- Rate dependent

Material CAE **Structural CAE**

Fraunhofer ITWM

Material and microstructure characterization



Microstructure simulation technique

Experiments

- -Bending and tensile test
- -µCT scans
- -Measurements of fiber length and thickness

Image processing

- -Second order partial derivatives at Gaussian scale-space
- -Reconstruction of fiber orientation

Generation of database of RVEs

- -Simulation of fiber lay-down process
- -Compression of fiber network
- -Generation of hybrid voxel image

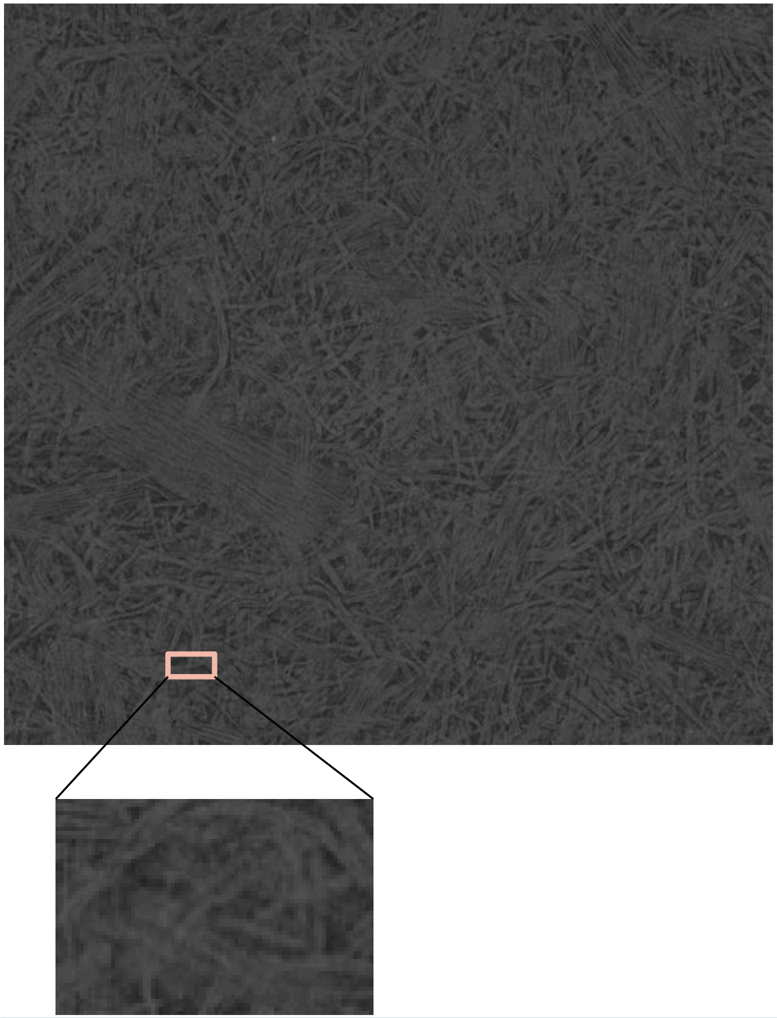
Microscale simulation

- -Simulation of 6 load cases
- -Numerical homogenization
- -Effective stiffness

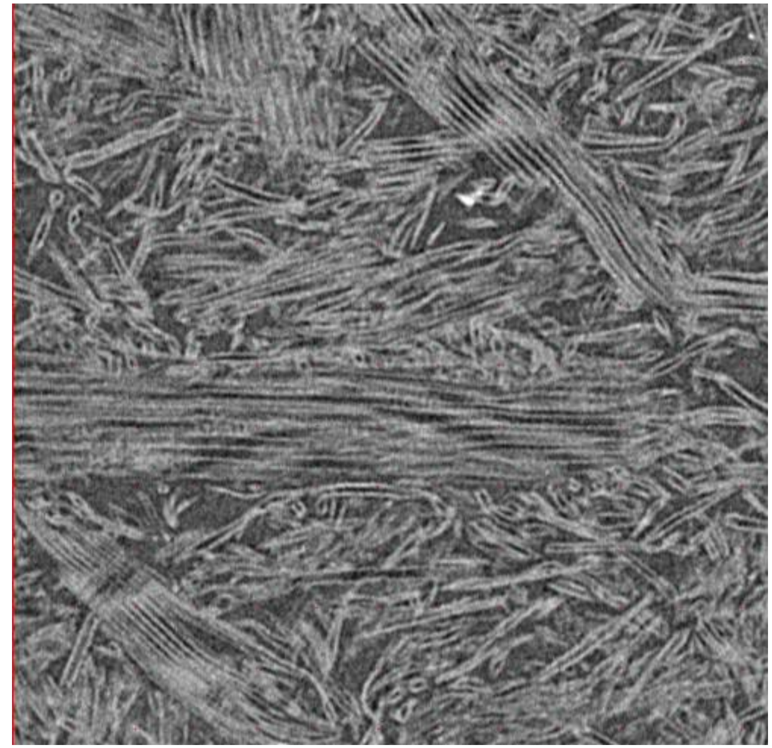
Fraunhofer ITWM

3D Imaging: Fiberboard

µCT with 8 µm voxel length

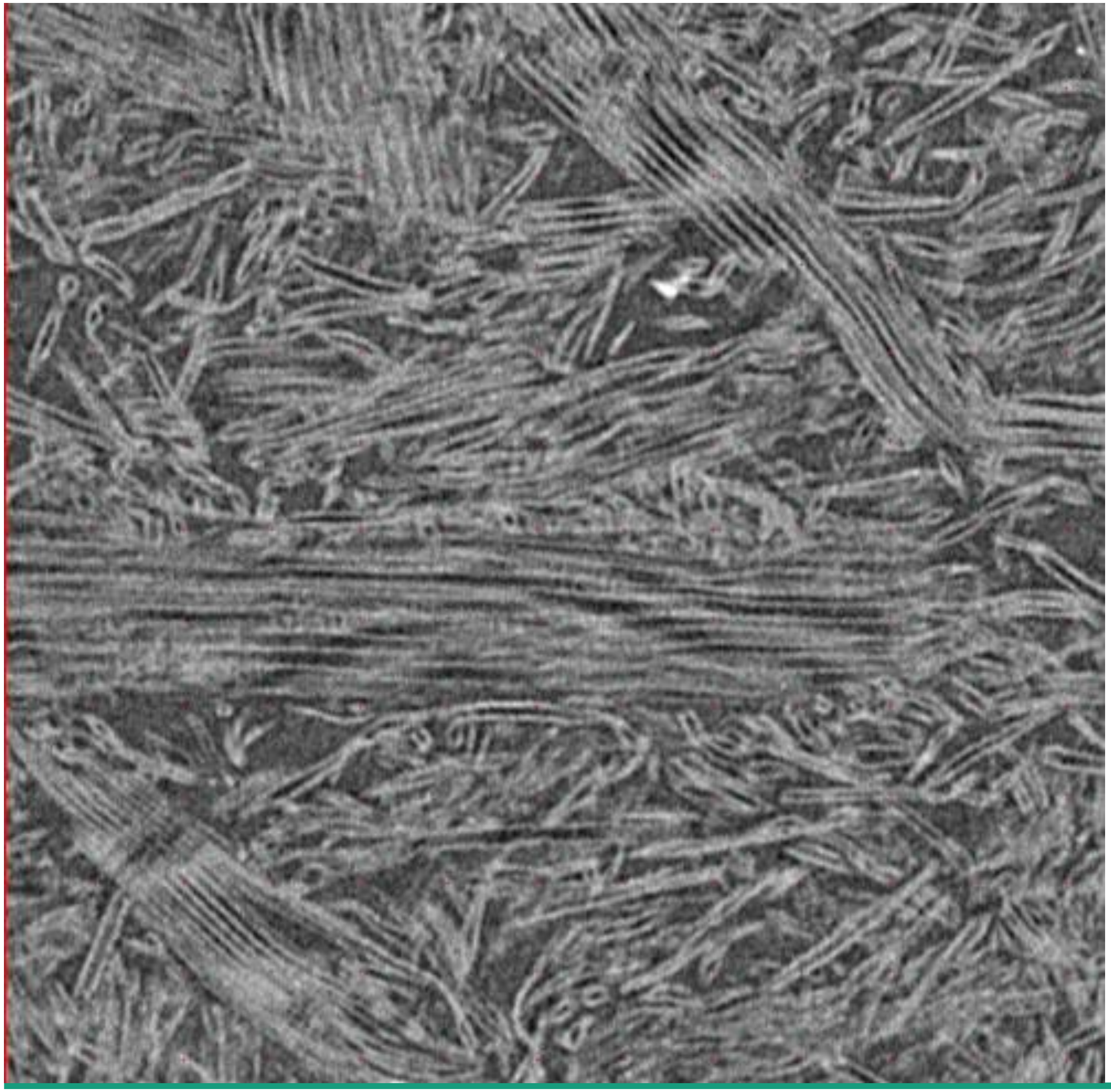


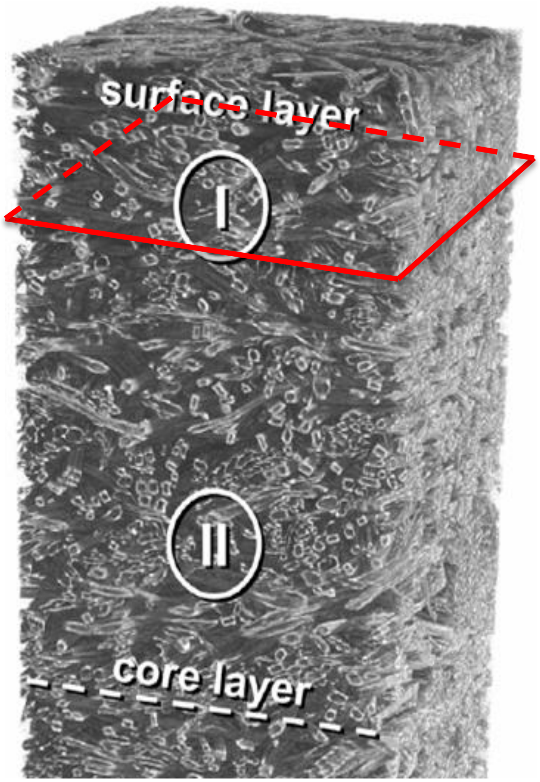
µCT with 4 µm voxel length



µCT image from GE Phoenix X-Ray

3D Imaging: Fiberboard



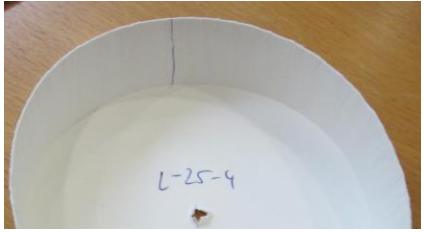


Resolution: 4 µm
Diameter: 8 mm,
Height: 6 mm

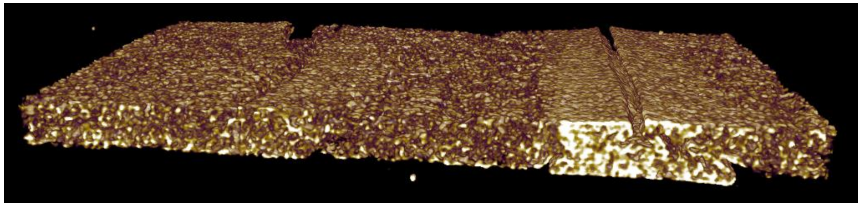
µCT image from GE Phoenix X-Ray

Fraunhofer ITWM

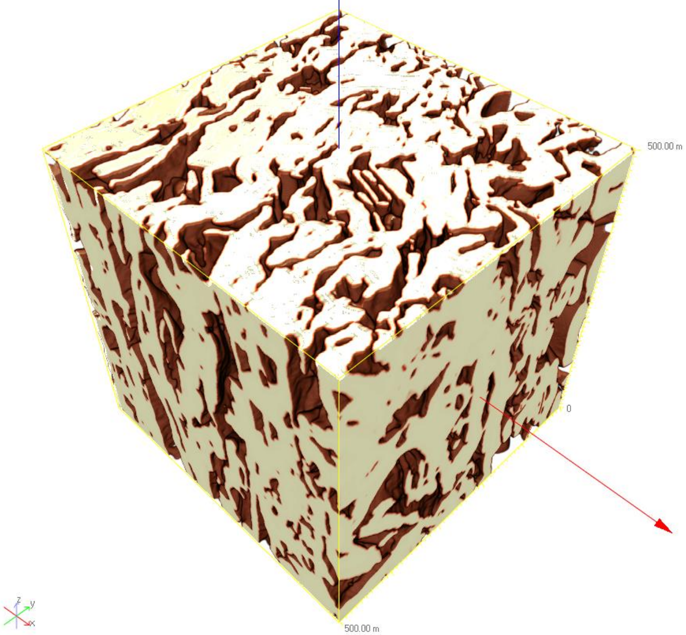
3D Imaging: Deep-drawn sample from paperboard (VM/VAT, TU Dresden)

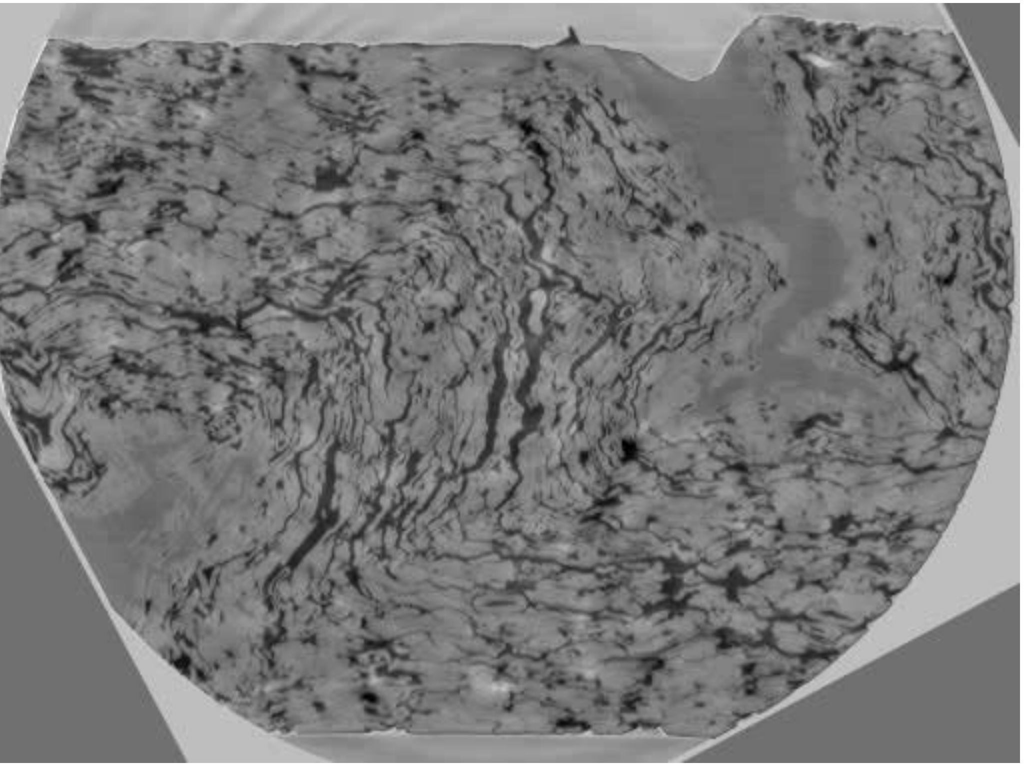


Deep-drawn sample



µCT, Resolution 9.7 µm





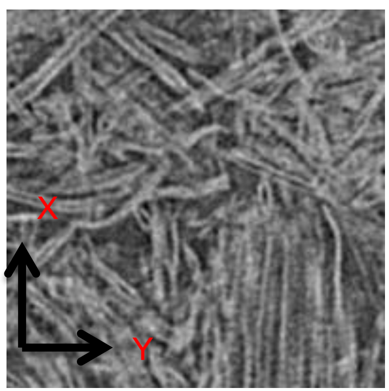
Synchrotron µCT, Resolution: 0.32 µm

M. Hauptmann, A. Lenske

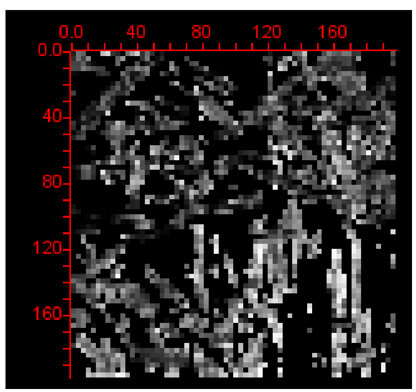
Fraunhofer ITWM

Reconstruction of fiber orientation using direct approach

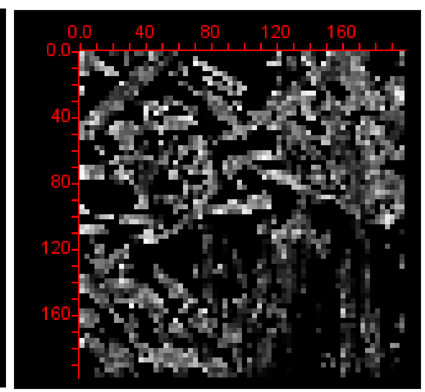
- We estimate the directional distribution by calculating the local fiber direction in each pixel.
- The eigenvector corresponding to smallest eigenvalue of the Hessian matrix is interpreted as local direction. Orientation tensor of fiber is obtained by averaging local directions over small sub-volumes.
- This is done using MAVI software.
- Because of complex fiber geometry and many fiber joints, this method overestimates fibers which are oriented in z direction.



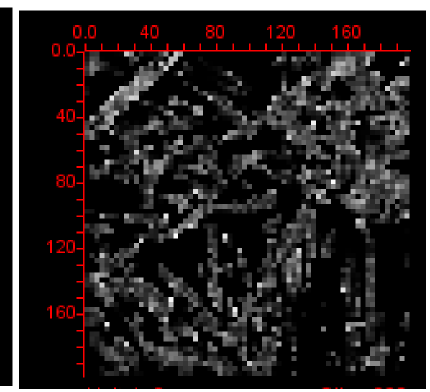
μCT image



Orientation tensor a_{xx}



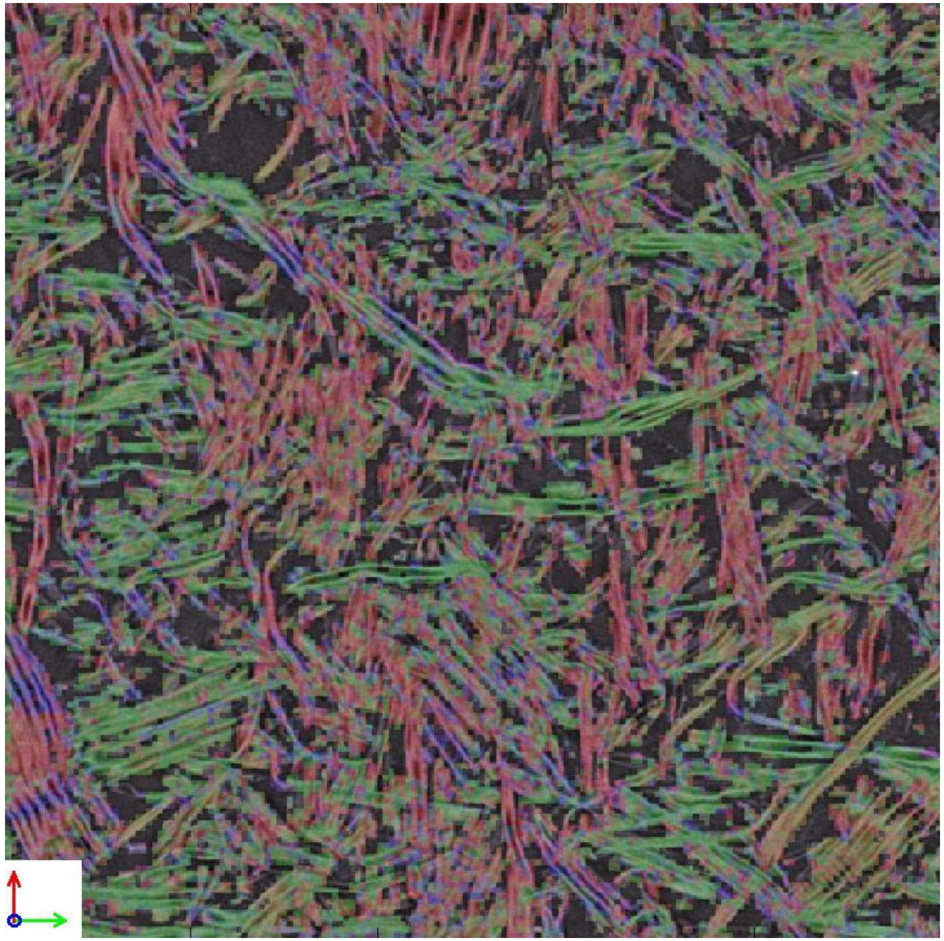
Orientation tensor a_{yy}



Orientation tensor a_{zz}

Lighter color indicates higher value

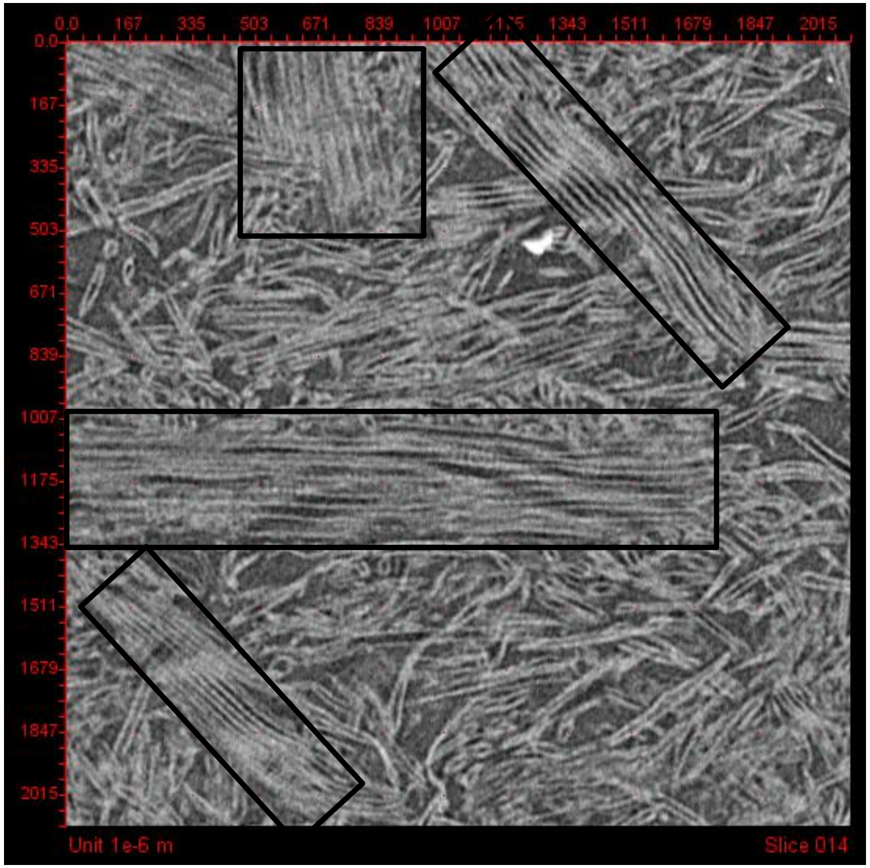
Reconstruction of fiber orientation



Local fiber direction map computed by using Hessian matrix.

Oliver Wirjadi

Analysis of fiber bundles (non-separated fibers)



Non separated fibers (fiber bundles) are analyzed using µCT image.

Fiber bundles are detected by observing that the local fiber orientations are more homogeneous within fiber bundles that elsewhere.

The solid volume fraction of fiber bundles is less than 10 %.

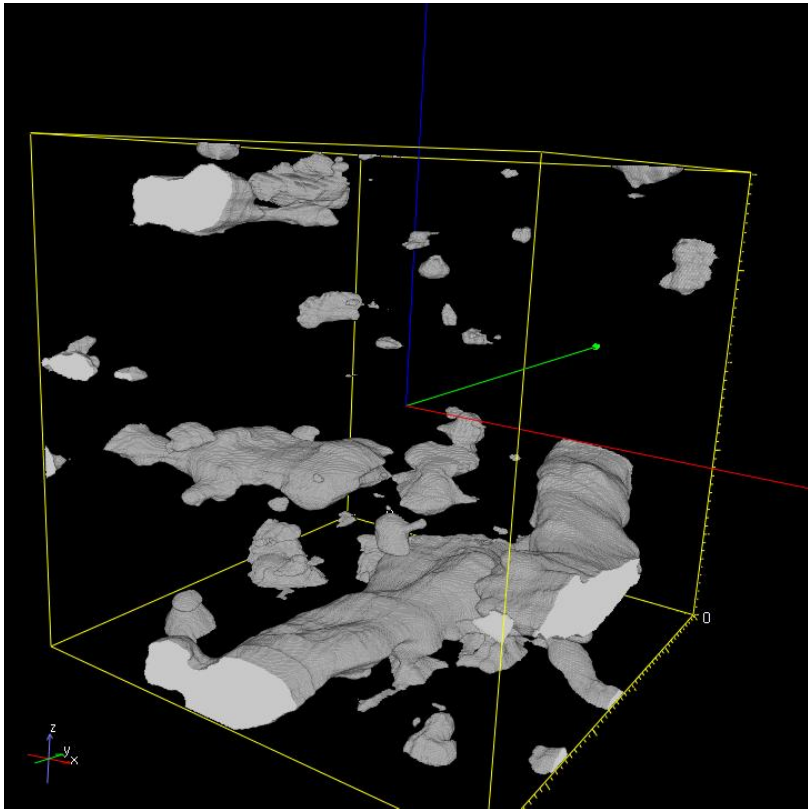
The average orientation of fiber bundles is similar to separated fiber orientation.

Resolution: 4 µm
Diameter: 8 mm, height: 6 mm

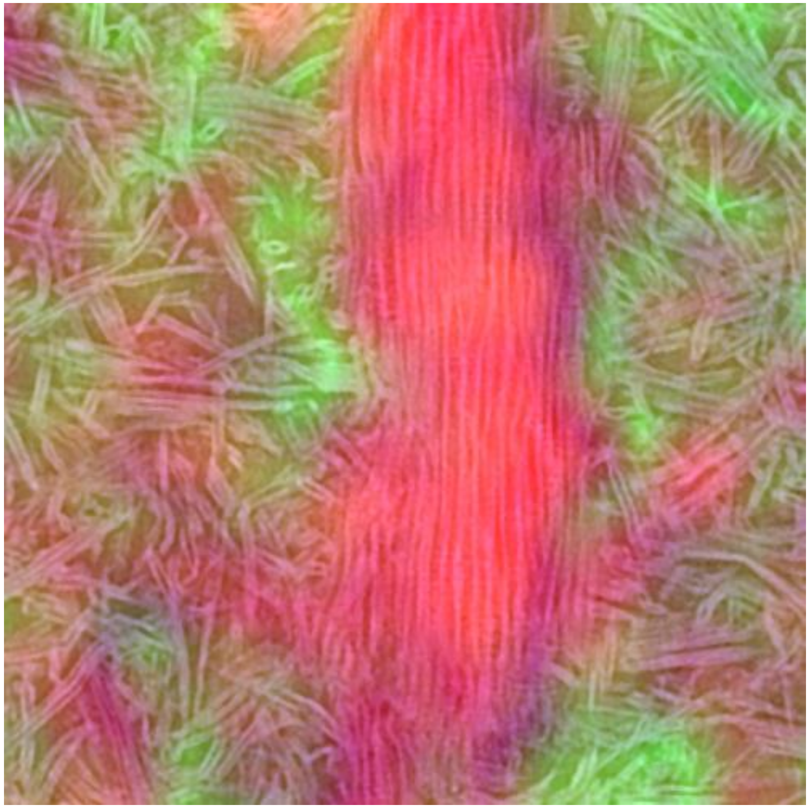
Oliver Wirjadi

µCT image from GE Phoenix X-Ray

Segmentation of fiber bundles



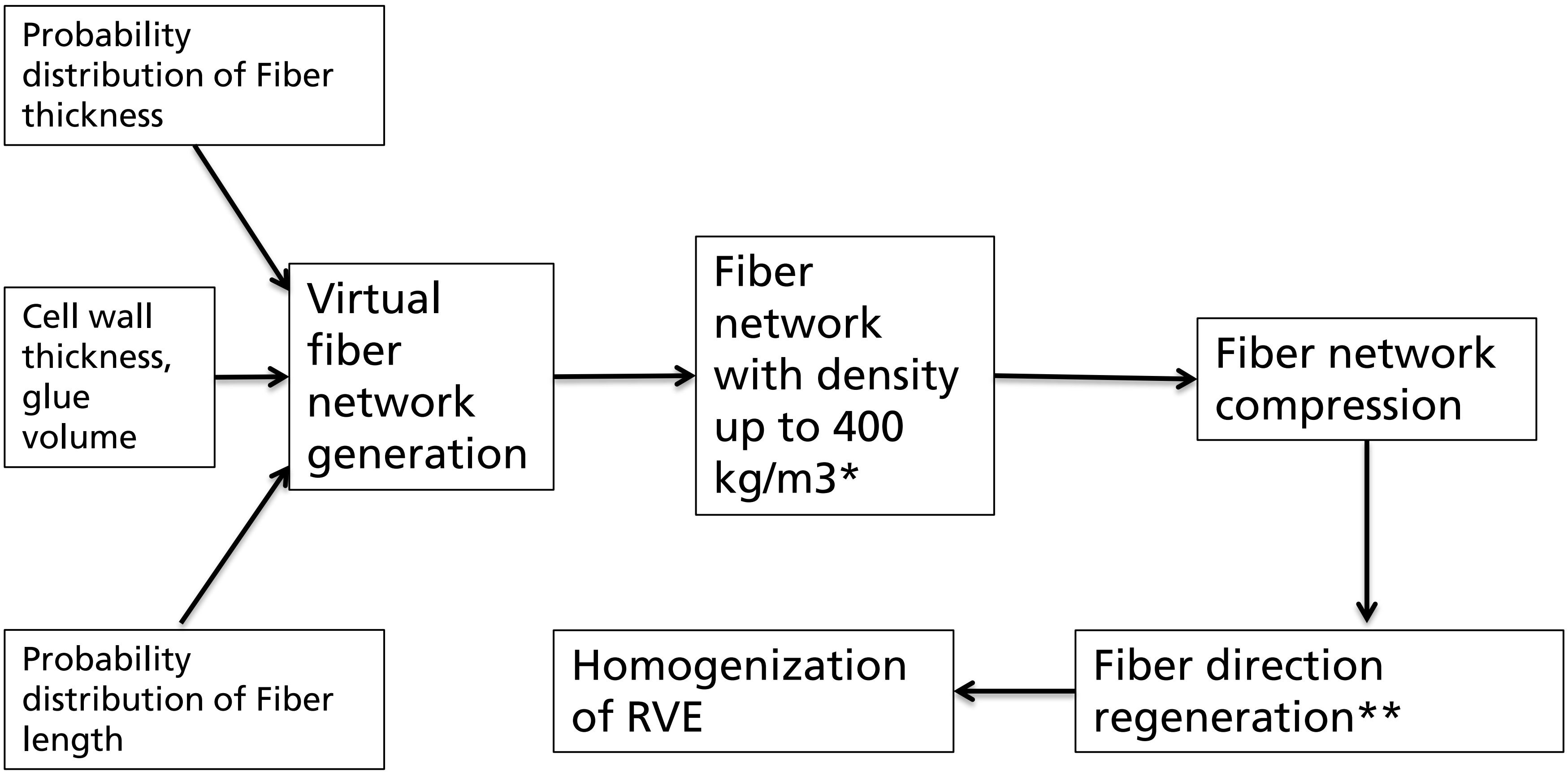
Fiber bundles in gray color


Fiber bundles in red color

Oliver Wirjadi

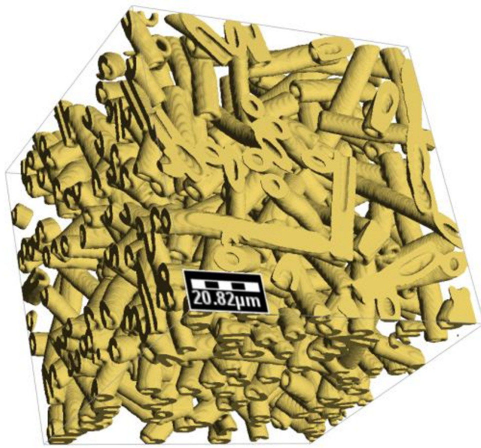
MAVI Fraunhofer ITWM

Construction of representative volume elements (RVEs)

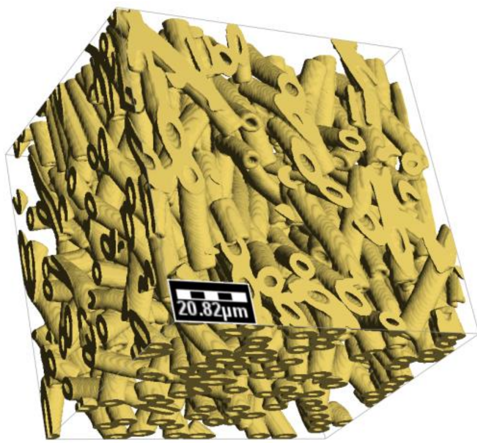


*Fiber overlapping is not allowed,
**We assume that wood fibers are transversal isotropic

Construction of representative volume elements (RVEs)



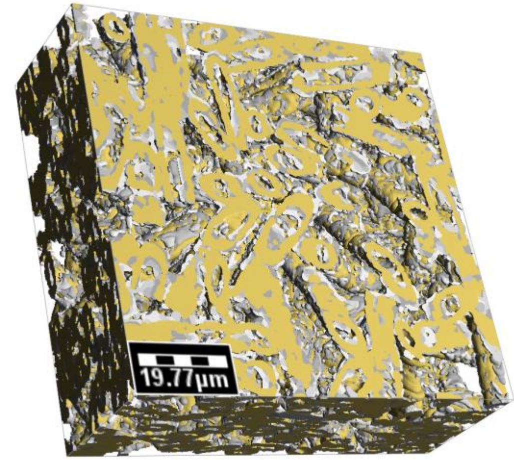
In-plane isotropic FO



In-plane anisotropic FO

Simulation of mechanical compression

FeelMath



In-plane isotropic FO

In-plane anisotropic FO

GeoDict

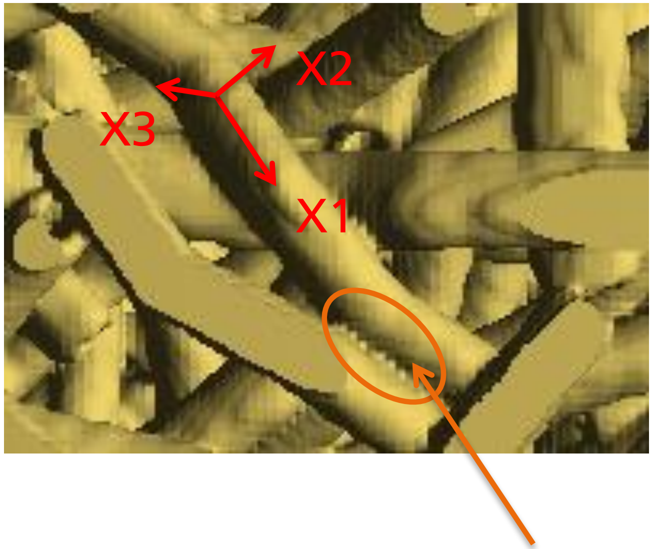
Fraunhofer ITWM

Failure criteria of wood fiber cell wall and glue

1. Axial strength criteria

2. Transversal strength criteria

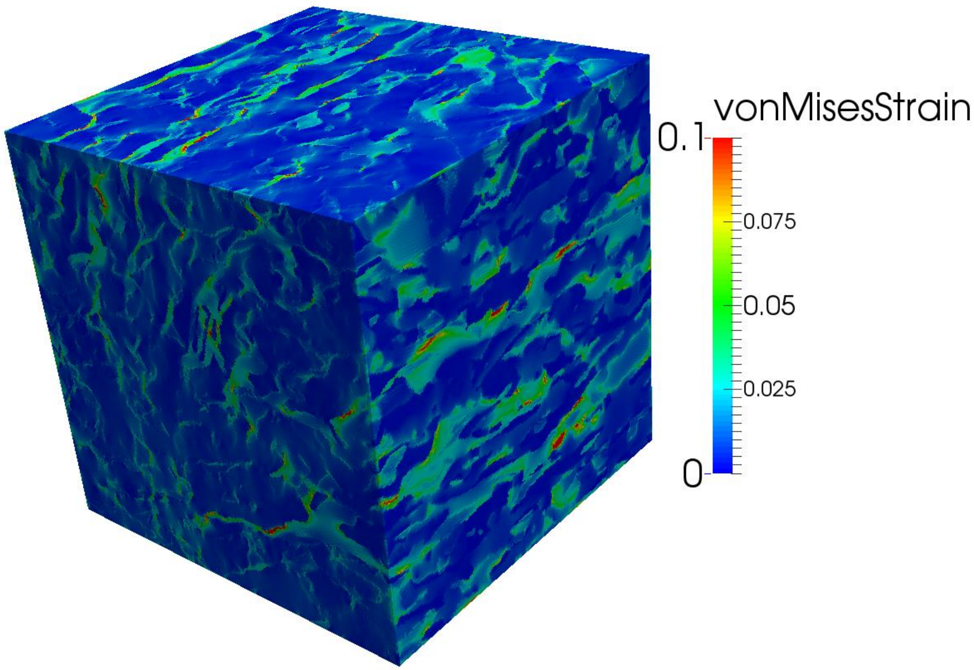
3. Shear strength criteria

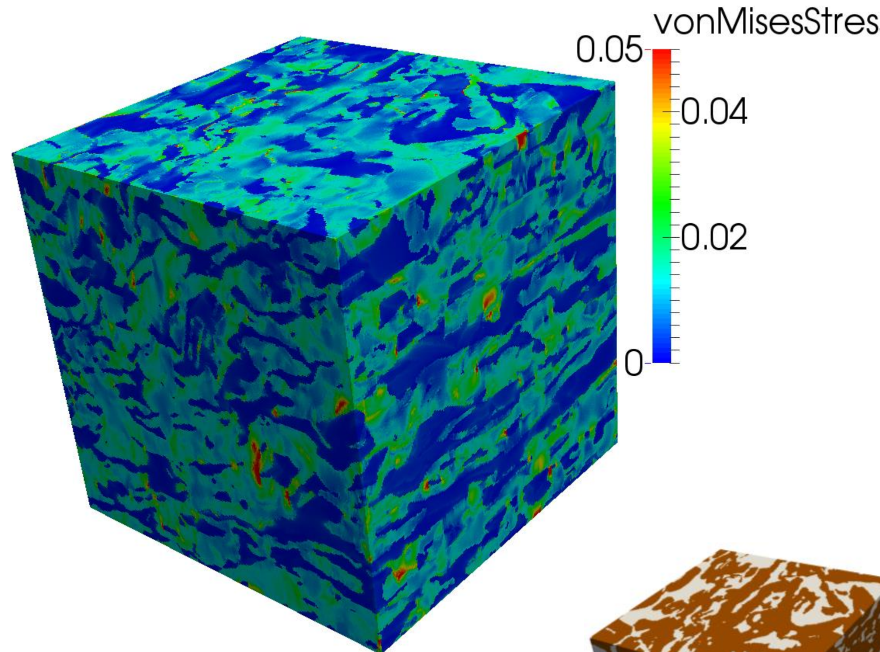


Fiber joint

If the strength criteria is not satisfied, then damage variables are computed and the stiffness is reduced using damage variables.

Computation of local stress and strain fields



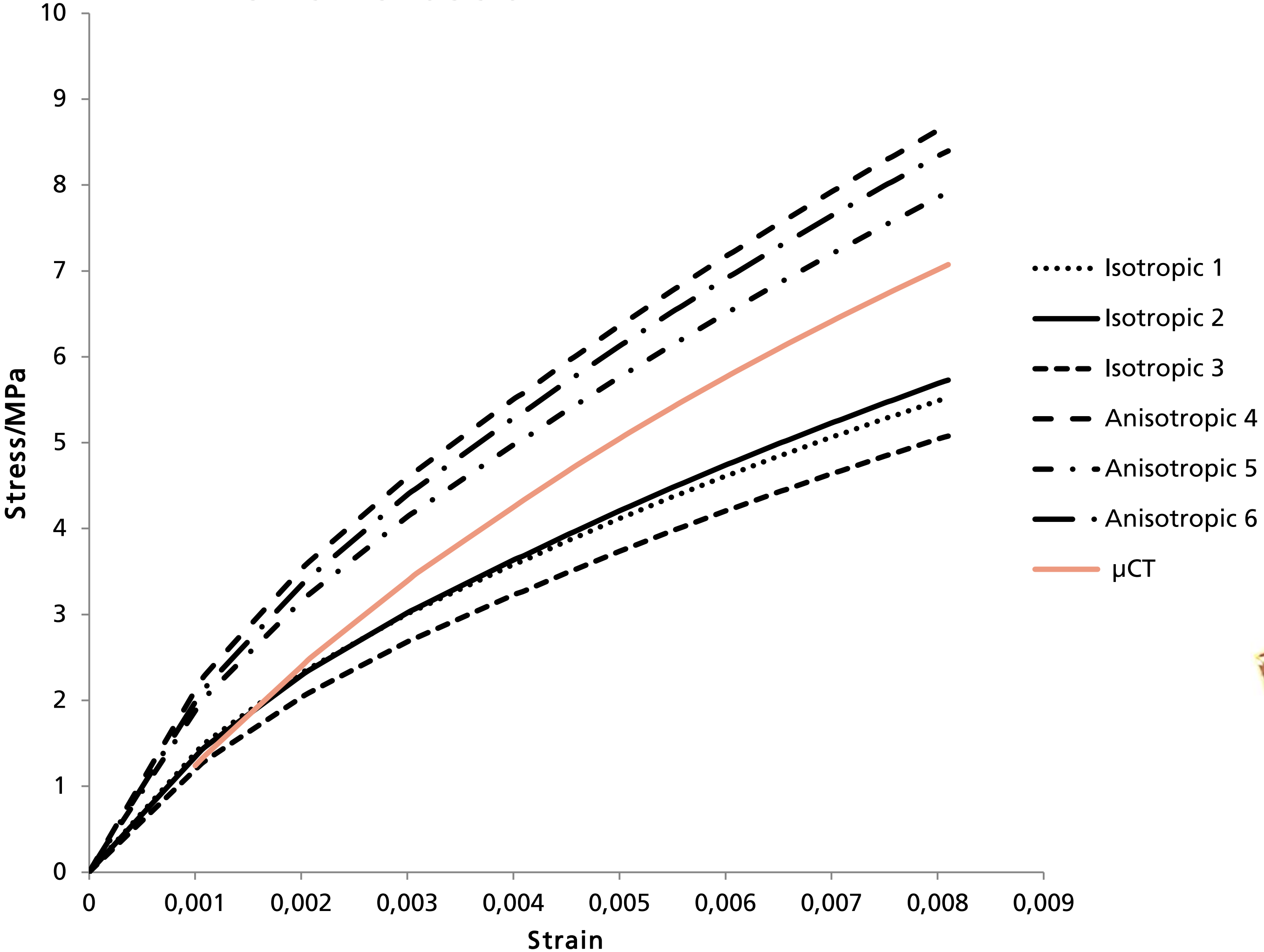


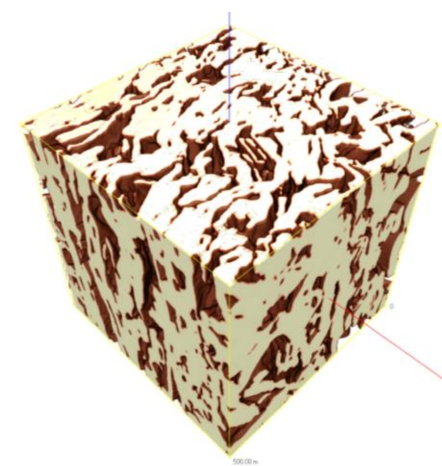
Fast numerical micro computation on voxel images using FFT

- No matrix assembling and storage
- No mesh generation
- PDE is reformulated as volume integral equation of Lippmann-Schwinger type

⇒ Efficient computation of large microstructures (512 x 512 x 512 voxels)

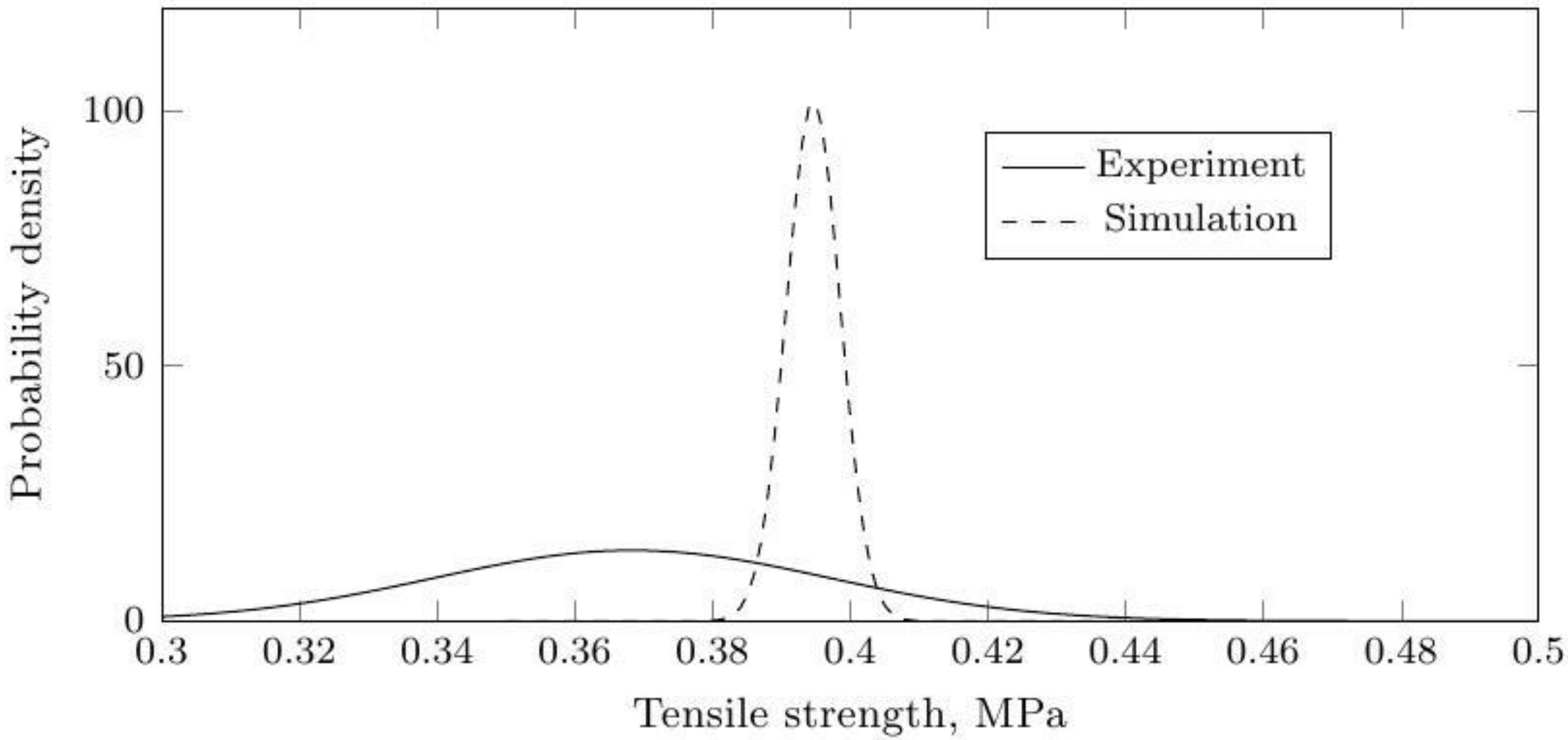
Results of numerical homogenization: Tensile test





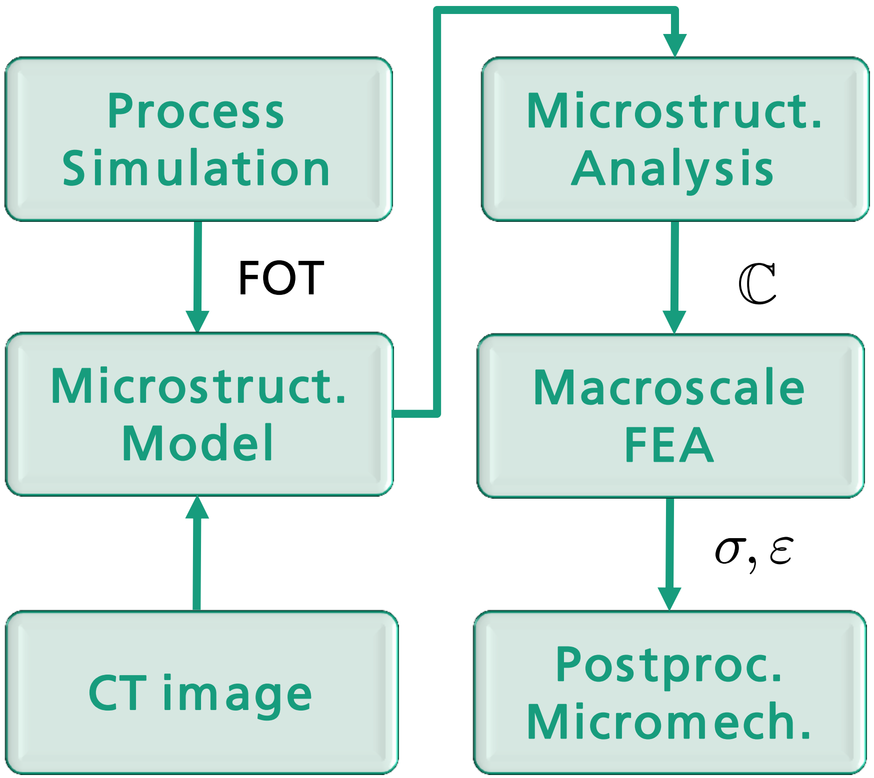
Fraunhofer ITWM

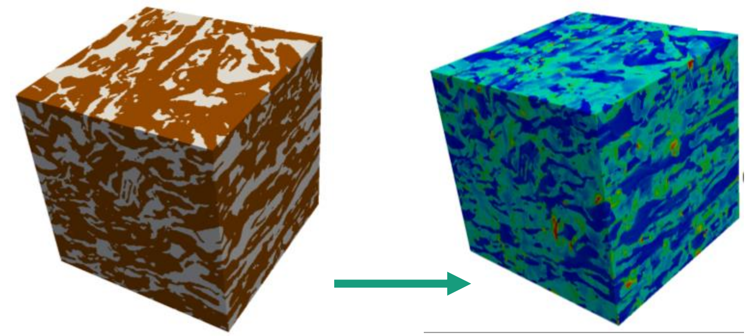
Comparison of numerical and experimental results of tensile test (fiberboard)



Difference between average computed tensile strength and experimentally measured is less than 5%, however the standard deviations varies much more.

Two-scale simulation



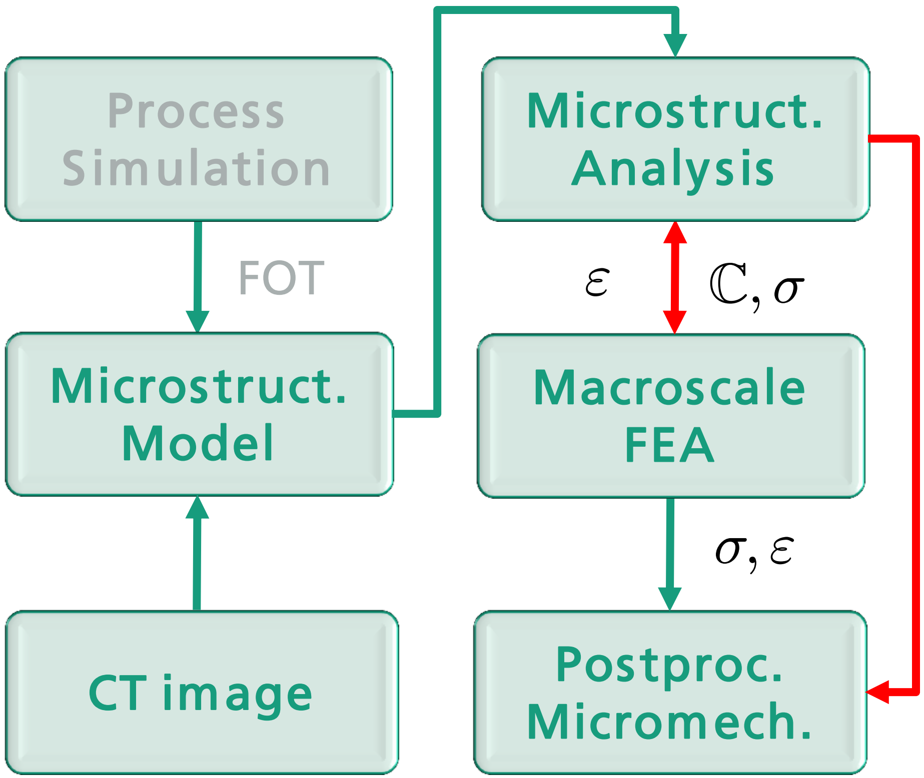


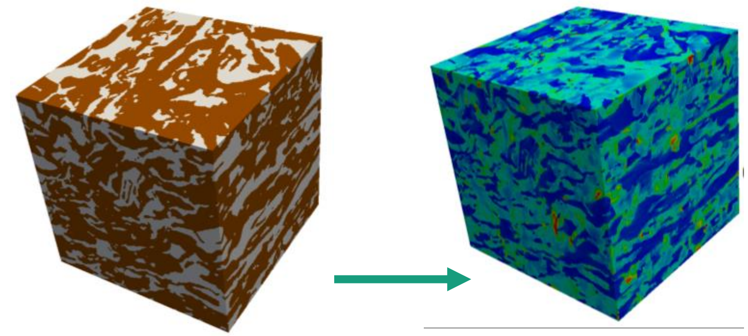
- micro. analysis in advance
- for arbitrary microstructures
- varying elasticity coefficients
- matrix damage, fiber fraction
- interface debonding
- no load history
- proportional loading

- Analytical or discrete geometrical model of the microstructure
- Analytical or numerical microstructural analysis (linear or nonlinear)

Fraunhofer ITWM

Coupled two-scale simulation





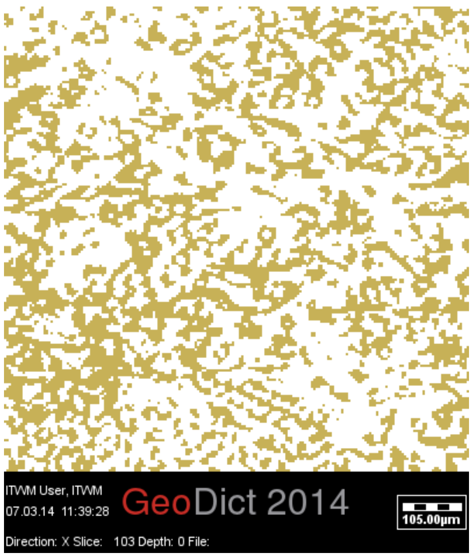
- for arbitrary microstructures
- varying elasticity coefficients
- arbitrary loading
- progressive damage

- Multiscale simulations are very expensive and therefore almost not accepted.
- → Fast "micro solvers" are needed.

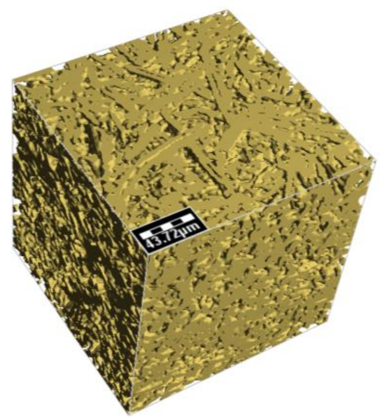
Fraunhofer ITWM

Two scale simulation of three point bending test (fiberboard)

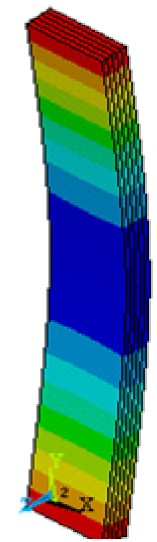
Density profile, fiber orientation according to µCT scans



Micromechanical model (GeoDict, FeelMath)



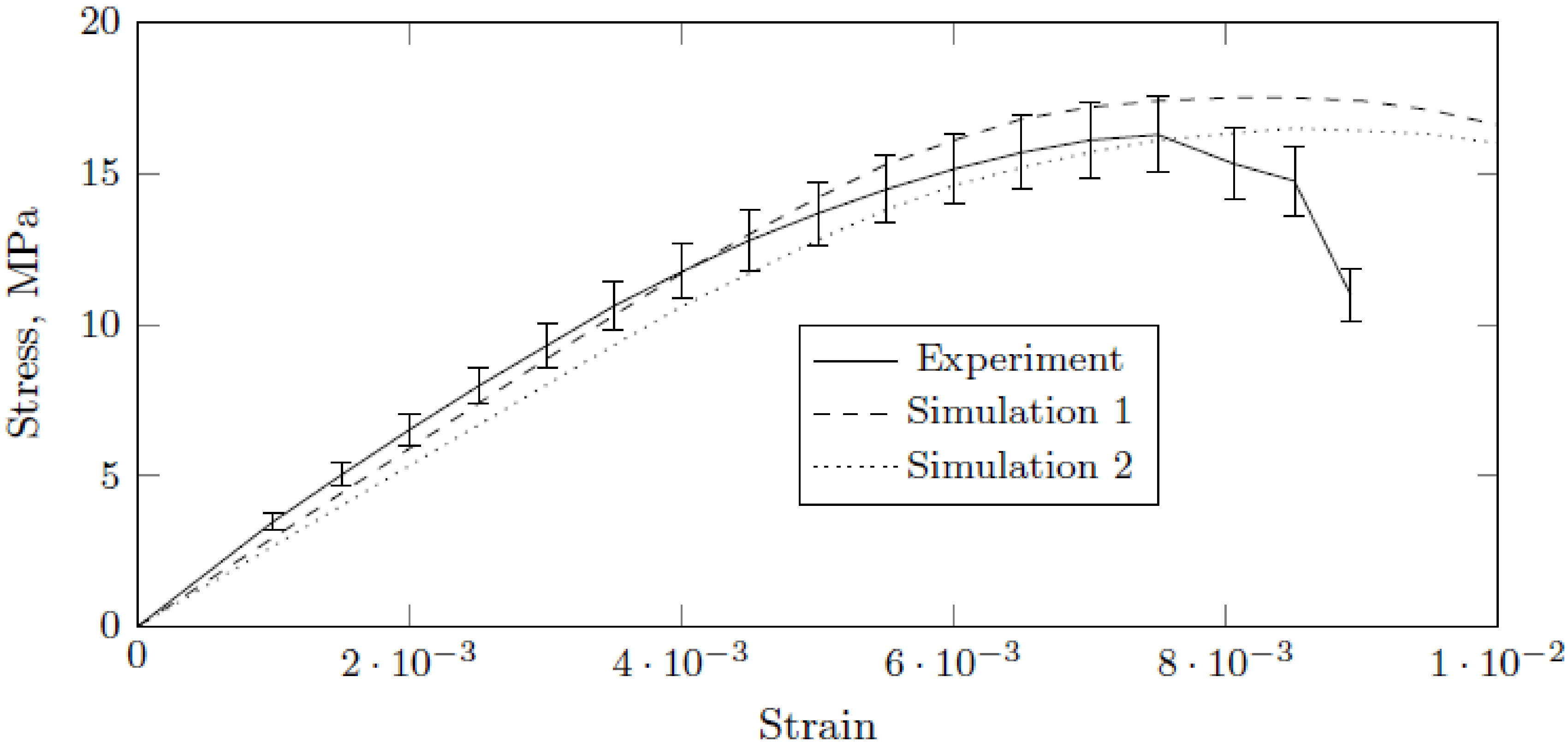
Macromechanical model



Database of stiffness tensor depending on strain tensor

GeoDict FeelMath Fraunhofer ITWM

Two scale simulation of three point bending test (fiberboard)



Fraunhofer ITWM

Applications of FeelMath

- Porous materials
  - Filter media (Oil and water filter)
  - Metallic knitted fabrics
  - Sanitary products
  - Packaging
  - Medium density fiberboards (MDF)
  - Rocks
  - Polymer foams
- Composites
  - Short and long fiber reinforced plastics (CFRP + GFRP)
  - Metallic alloys (AlSi, MMC)
  - Steel reinforced concrete
- Nonlinear material behavior
  - Plasticity
  - Damage
  - Plasticity + Damage
  - Thermal expansion and shrinkage
  - Residual stresses
  - Creep
  - UMAT-Interface

FeelMath Fraunhofer ITWM

The End

Sliseris J, Andrä H, Kabel M, Dix B, Plinke B, Wirjadi O, Frolovs G: Numerical prediction of the stiffness and strength of medium density fiberboards, Mechanics of Materials **79** (2014) 73-84

Thank you very much for your attention.

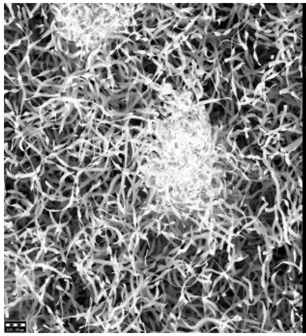
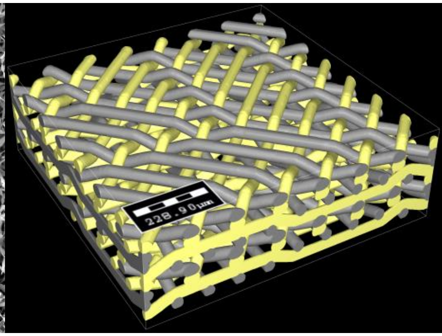
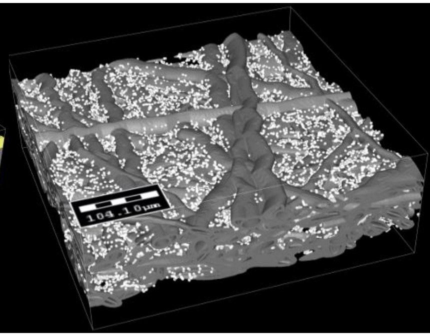
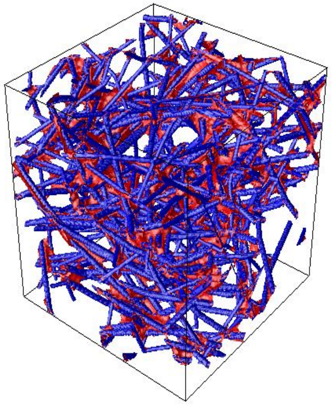
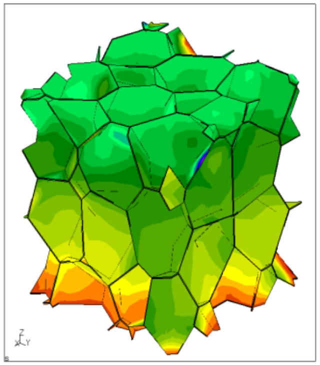
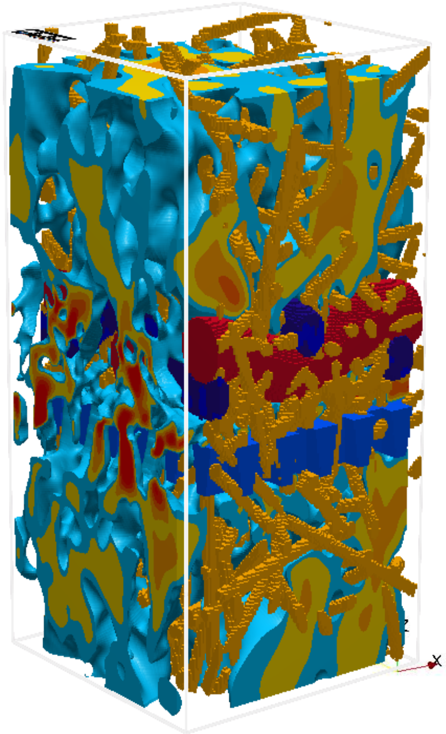
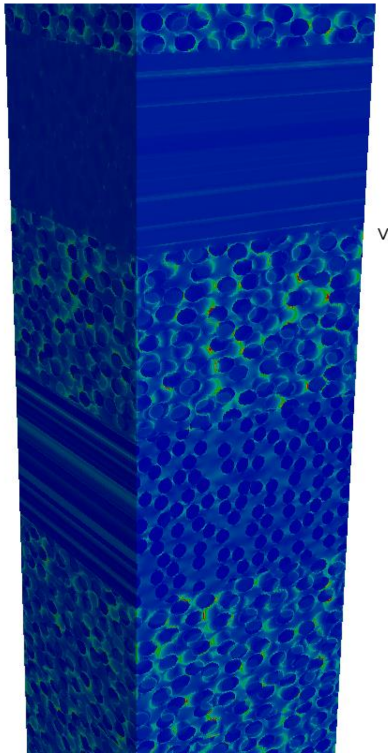
Visit us at

www.itwm.fraunhofer.de

Generation of microstructures

Porous and Composite Material design

- Paper, cellulose material: permeability, capillarity
- Non-wovens (textiles): filter efficiency
- Weaves: flow resistance
- Foam: Heat or acoustic insulation material
- Sinter material: ceramics, MMC
  thermo-mech. behaviour
- Fibre reinforced composites: visco-elastic behavior, creep, fatigue, damage

Virtual Material Laboratory
Modules of the GeoDict Software

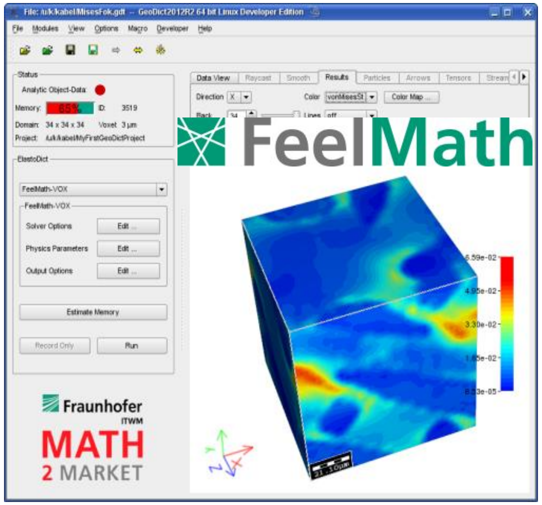
Material Models

- FiberGeo
- SinterGeo
- PaperGeo
- WeaveGeo
- GridGeo
- PackGeo
- PleatGeo
- PaperGeo
- LayerGeo
- FoamGeo
- GadGeo

Property Computation:

- FlowDict (single phase flow properties)
- AddiDict (particle transport)
- ElastoDict (effective elastic properties)
- ConductoDict (effective conductivity)
- DiffuDict (effective diffusivity)
- FilterDict (pressure drop, efficiency, life time)
- SatuDict (two phase flow properties)
- PoroDict (pore size measures)
- AcoustoDict (acoustic absorption)

Demoversion & Information:
www.geodict.com



GEO DICT is the product of MATH 2 MARKET

Math2Market (M2M) is a spin-off company from Fraunhofer ITWM

GEO DICT Fraunhofer ITWM