The Prediction of Mechanical Properties of Composites and Porous Materials Based on Micro-CT-Scans and 3D Material Models

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Math2Market GmbH

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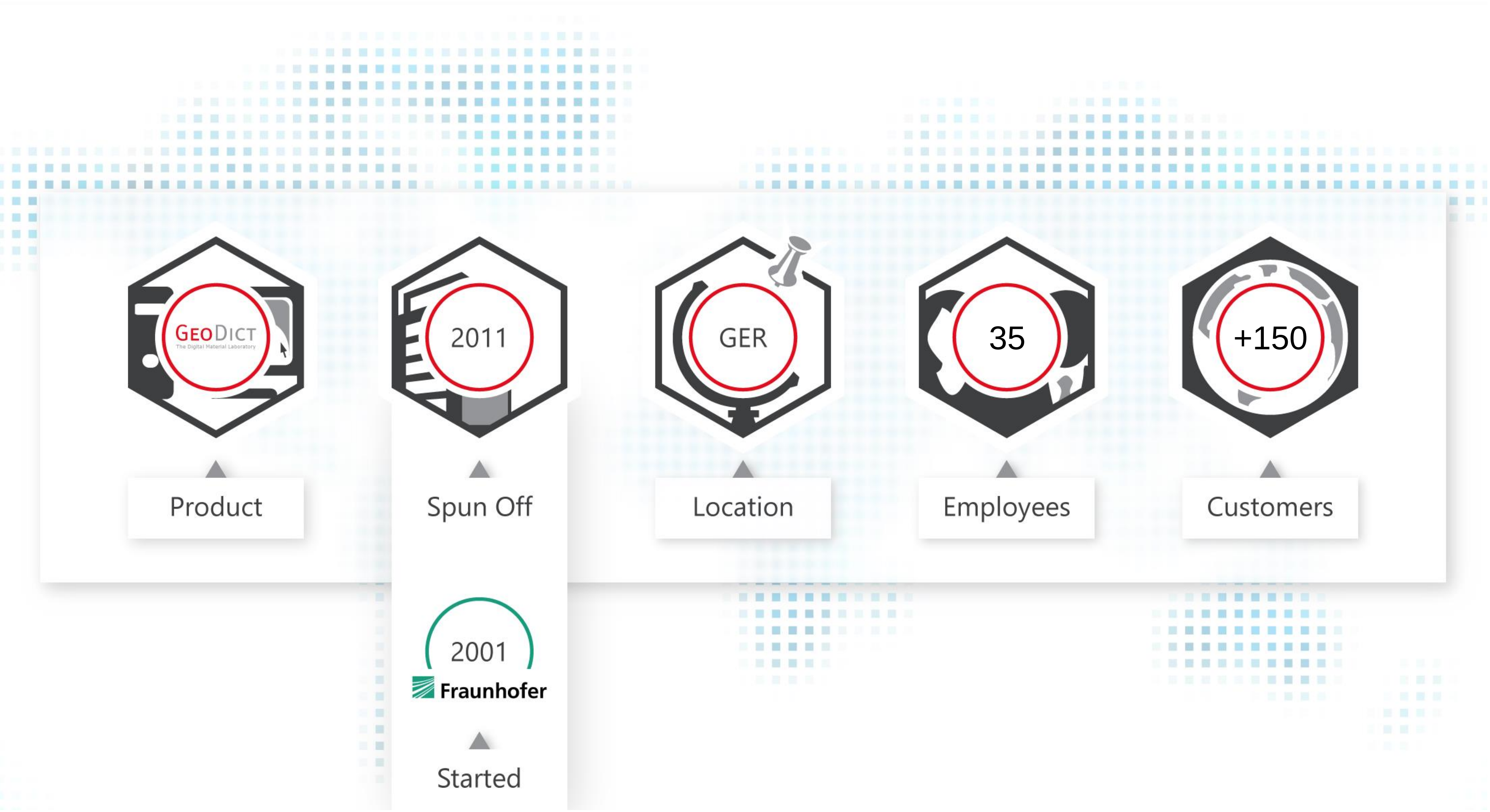
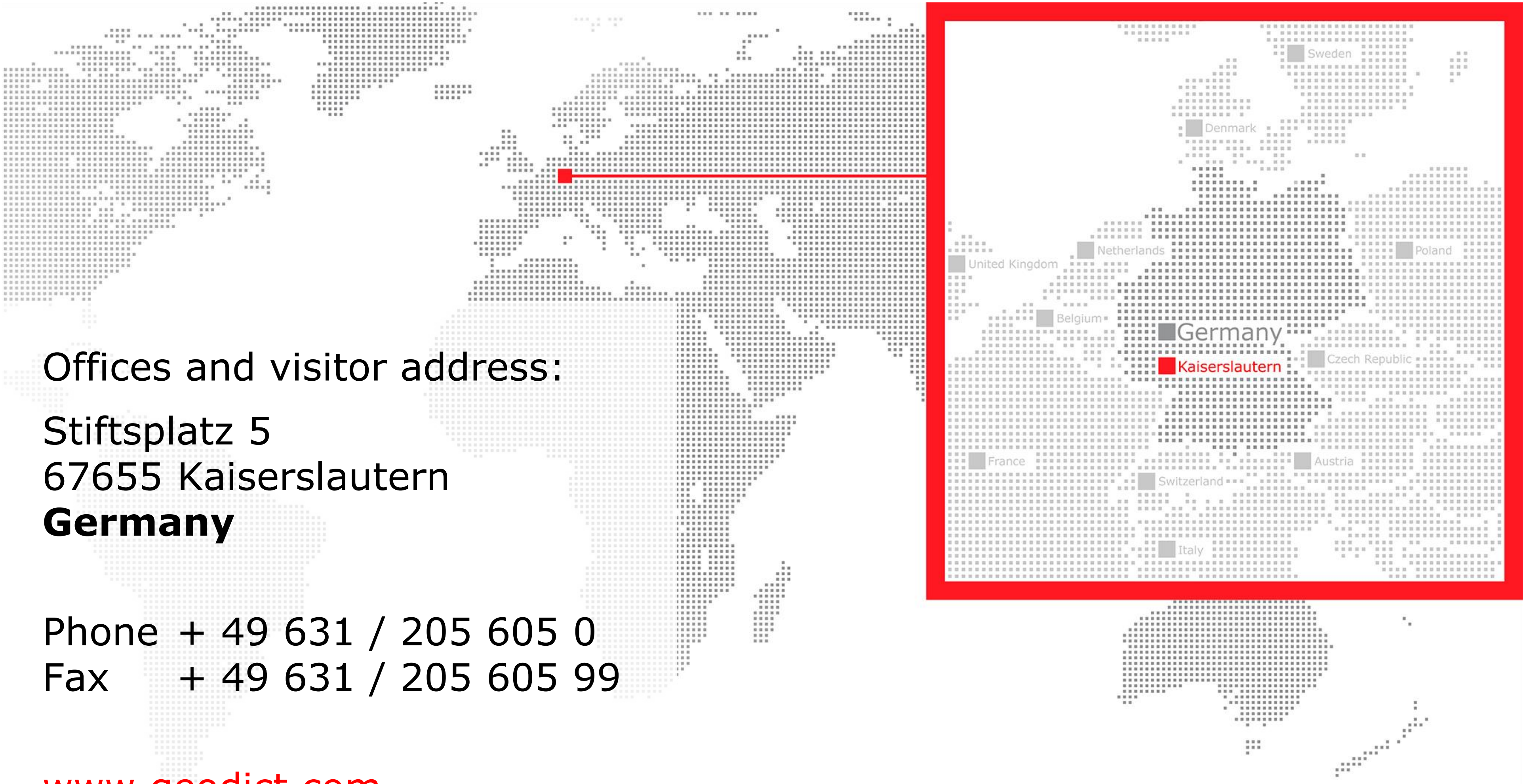
Company Overview

Math2Market GmbH - Company Overview



Company Overview

Math2Market GmbH Company – Location and Contact



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www.geodict.com

Company Overview

Math2Market GmbH Company – our Mission and Goals

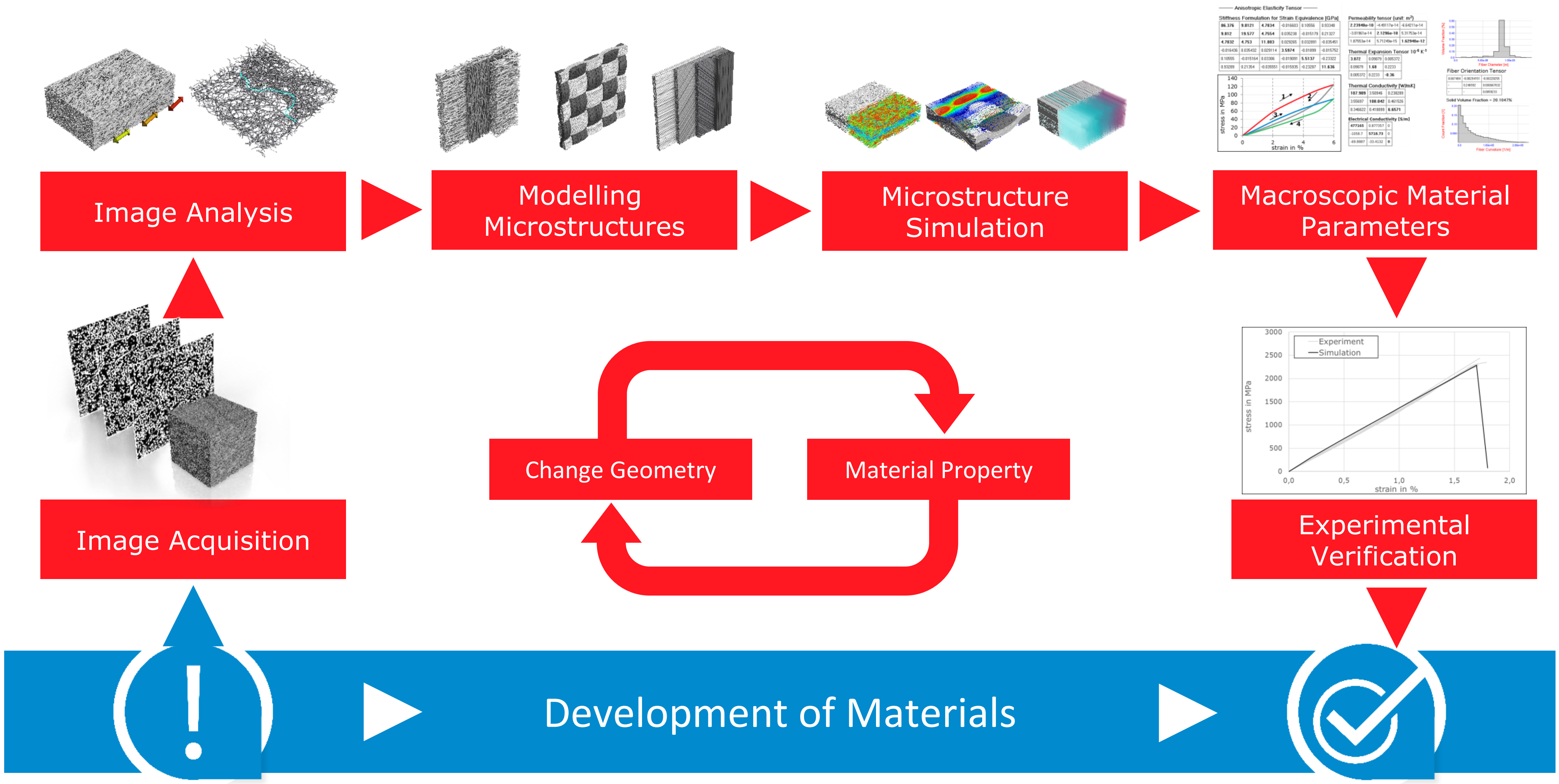
Company Overview

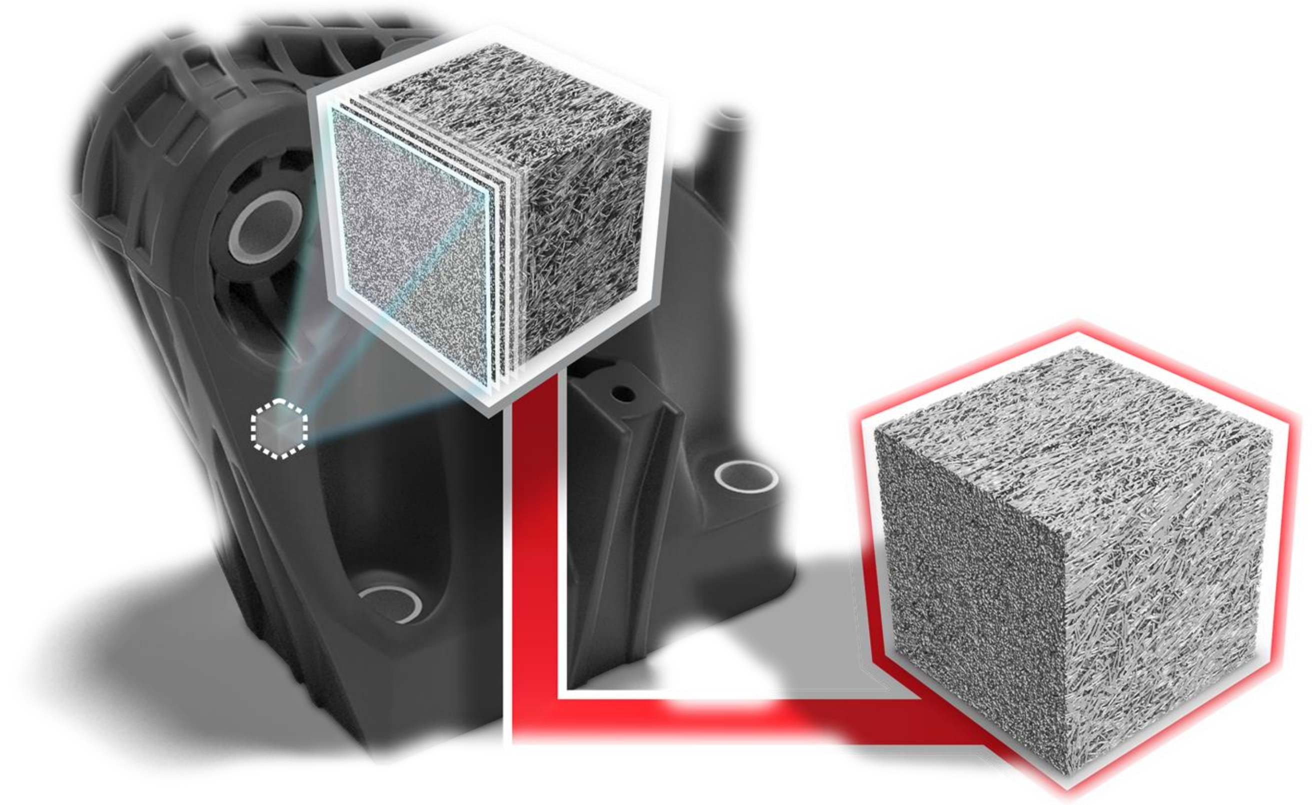
Math2Market GmbH Company – Promoted Industries

Filtration	Mostly automotive, filter media & filters for water, sludge, oil, air and fuel
Electrochemistry	Fuel cell media & battery materials, catalyst materials
Composites	CFRP, GFRP, mostly automotive, lightweight materials
Oil and Gas	Digital rock physics, digital sand control

What is the Digital Material Laboratory GeoDict?

GeoDict – Digital Material Laboratory

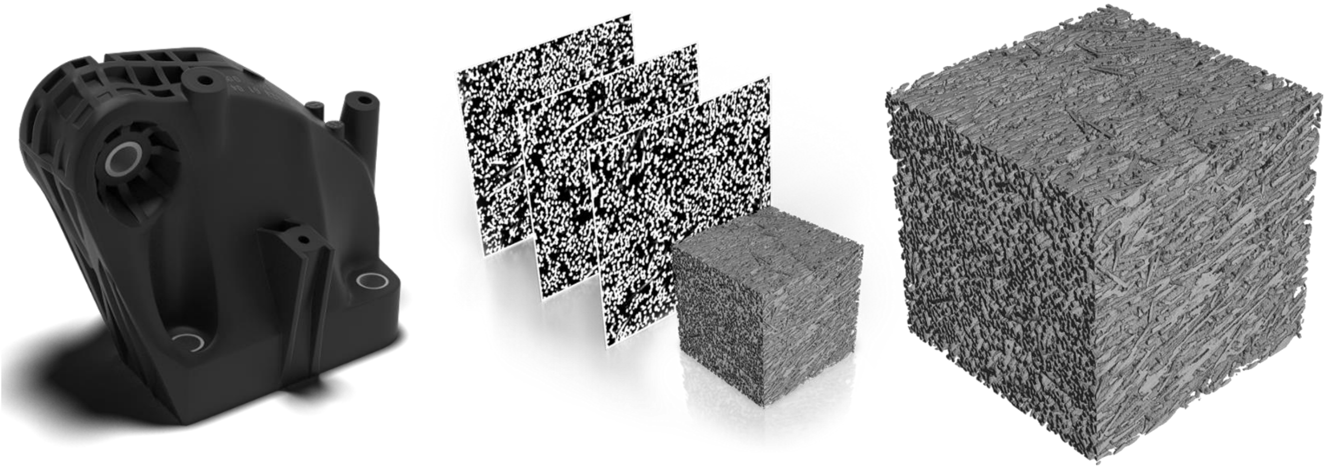




Characterization of a Short Glass Fiber Reinforced Plastic

Short Glass Fiber Reinforced Plastic

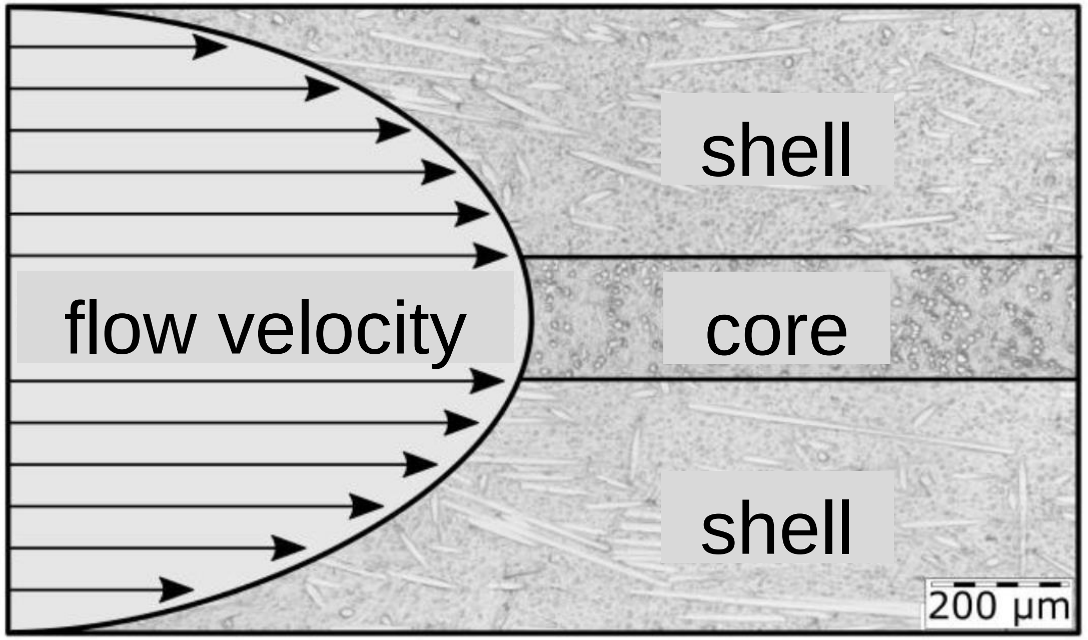
- Material used in an engine bearer
  - produced by injection molding
  - matrix material
    - thermoplastic
    - polyamide 6
  - fiber reinforcement
    - glass fibers
    - percentage: 50 % by weight
    - length: 100 µm – 500 µm

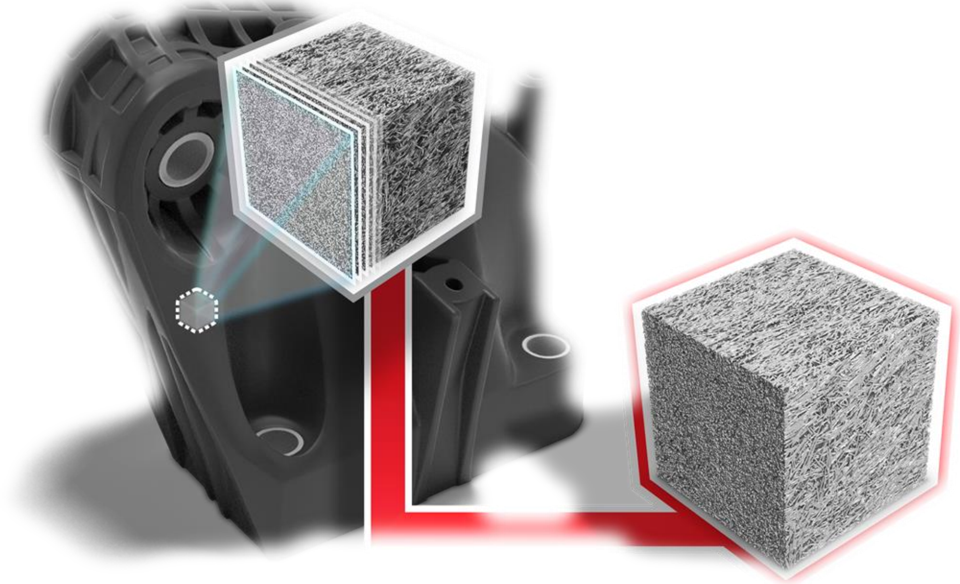


- µCT scan of the material with a resolution of 1.4 µm

Short Glass Fiber Reinforced Plastic

- Fiber orientation in injection molded materials
  - example of molded plate





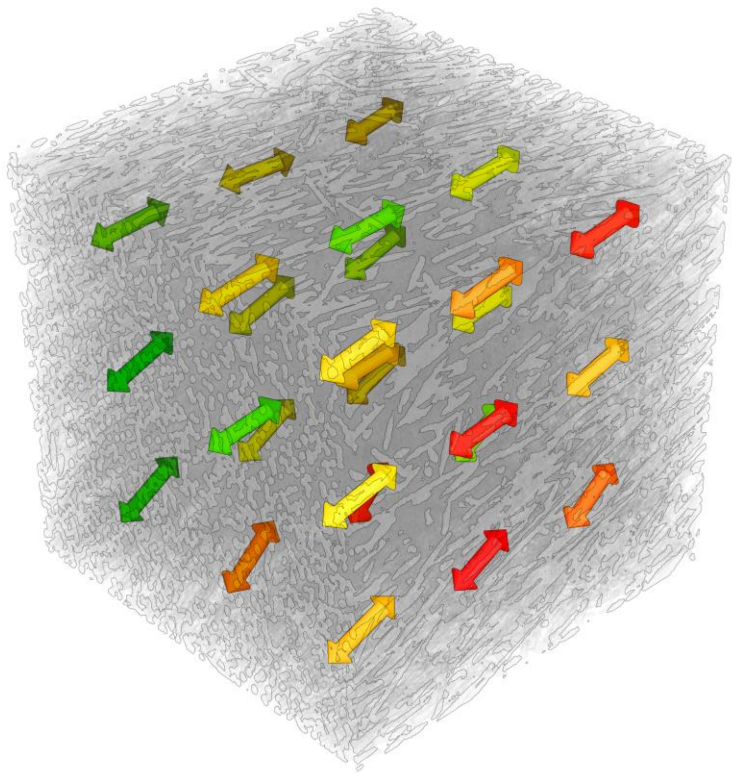
for complex geometries no analytical methods are accurate enough

Short Glass Fiber Reinforced Plastic

- Determination of the fiber orientation using FiberGuess
  - dividing the RVE into user defined blocks
  - PCA: principal component analysis
    - subdivides the domain into windows to eliminate the influence of fiber crossings
    - identifies single fiber fragments and analyzes the direction
  - SLD: star length distribution
    - working on voxel basis
    - analyzes the chord length through the voxel
  - averaging the defined blocks to determine the average orientation tensor

Short Glass Fiber Reinforced Plastic

- Visualization for each block
  - main fiber orientation
  - degree of orientation
  - solid volume fraction

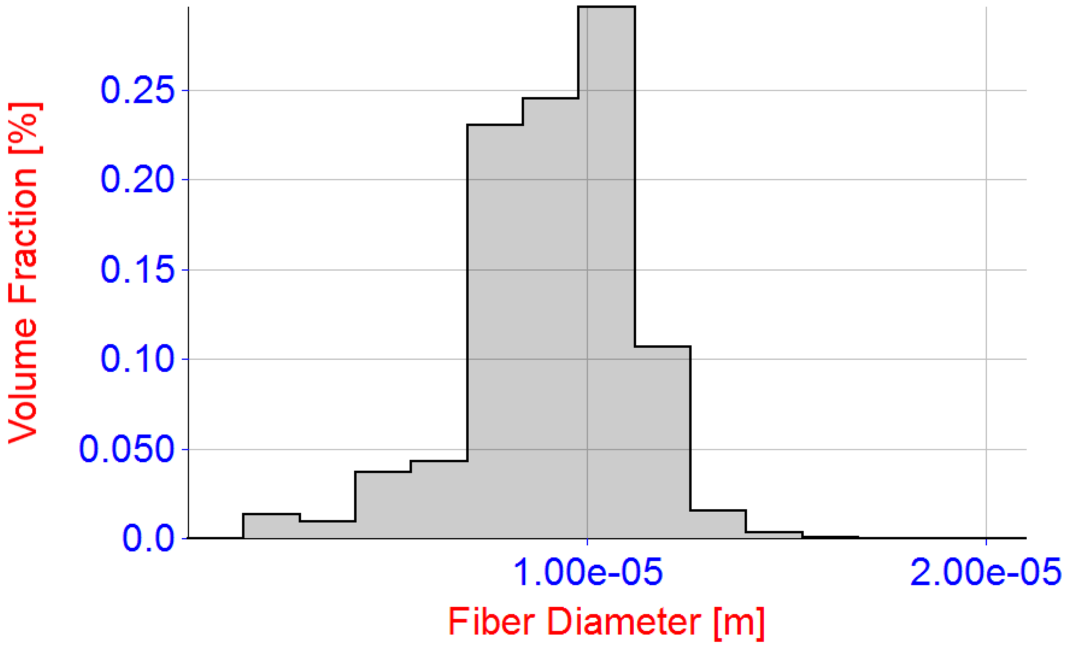


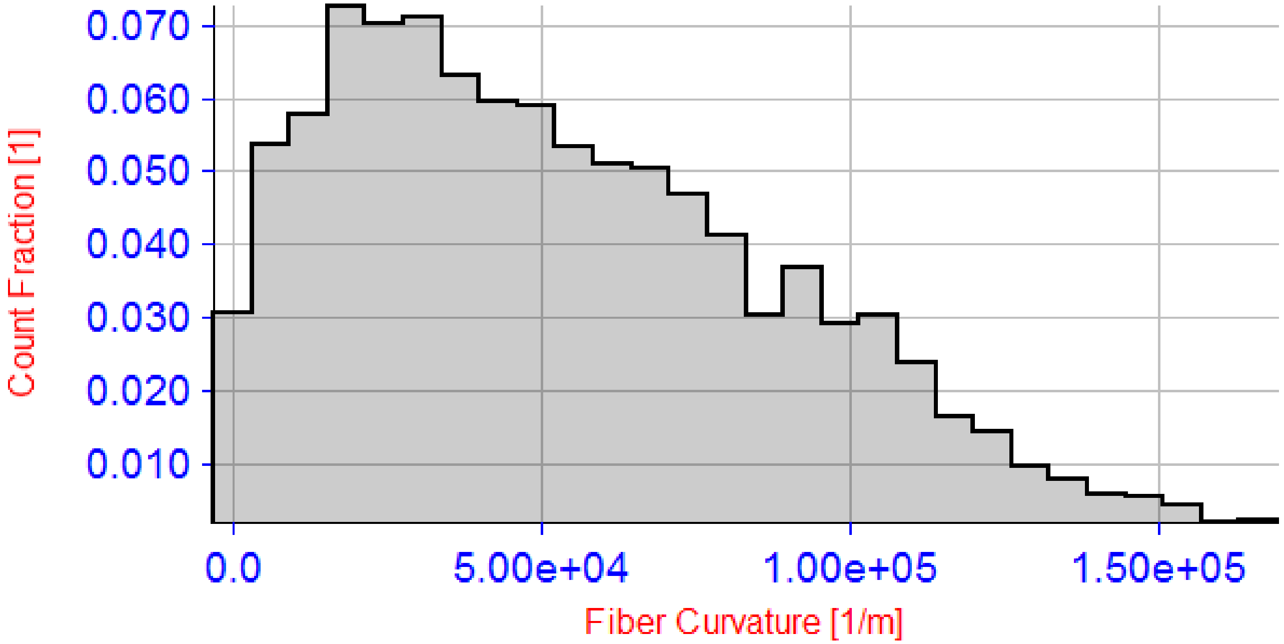
- Results for each block

$$\overline{\boldsymbol{A}_{PCA}} = \begin{bmatrix} 0.545 & -0.034 & 0.023 \\ sym & 0.190 & 0.020 \\ sym & sym & 0.265 \end{bmatrix} \quad \overline{\boldsymbol{A}_{SLD}} = \begin{bmatrix} 0.640 & -0.042 & 0.106 \\ sym & 0.109 & 0.019 \\ sym & sym & 0.251 \end{bmatrix}$$

Short Glass Fiber Reinforced Plastic

- Calculation of other geometric characteristics
  - fiber diameter distribution
  - fiber curviness





Short Glass Fiber Reinforced Plastic

- Input for the mechanical simulation using ElastoDict-VOX
  - model of the microstructure
    - imported and segmented µCT scan
    - generated model (FiberGeo, WeaveGeo, …)
  - material properties of the single constituents
    - from datasheet
    - from measurement

Short Glass Fiber Reinforced Plastic

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    - from datasheet
    - from measurement

E_{fiber} = 72 GPa
ν_{fiber} = 0.22

E_{matrix} = 3.3 GPa
ν_{matrix} = 0.39

Short Glass Fiber Reinforced Plastic

- Linear elastic properties of the homogenized material
  - applying small strain/stress increment
  - periodic boundary conditions
  - simulation of six load cases
    - three uniaxial experiments: XX, YY, ZZ
    - three shear experiments: XY, YZ, XZ
  - obtaining the general anisotropic Hooke’s Law to calculate the elasticity tensor

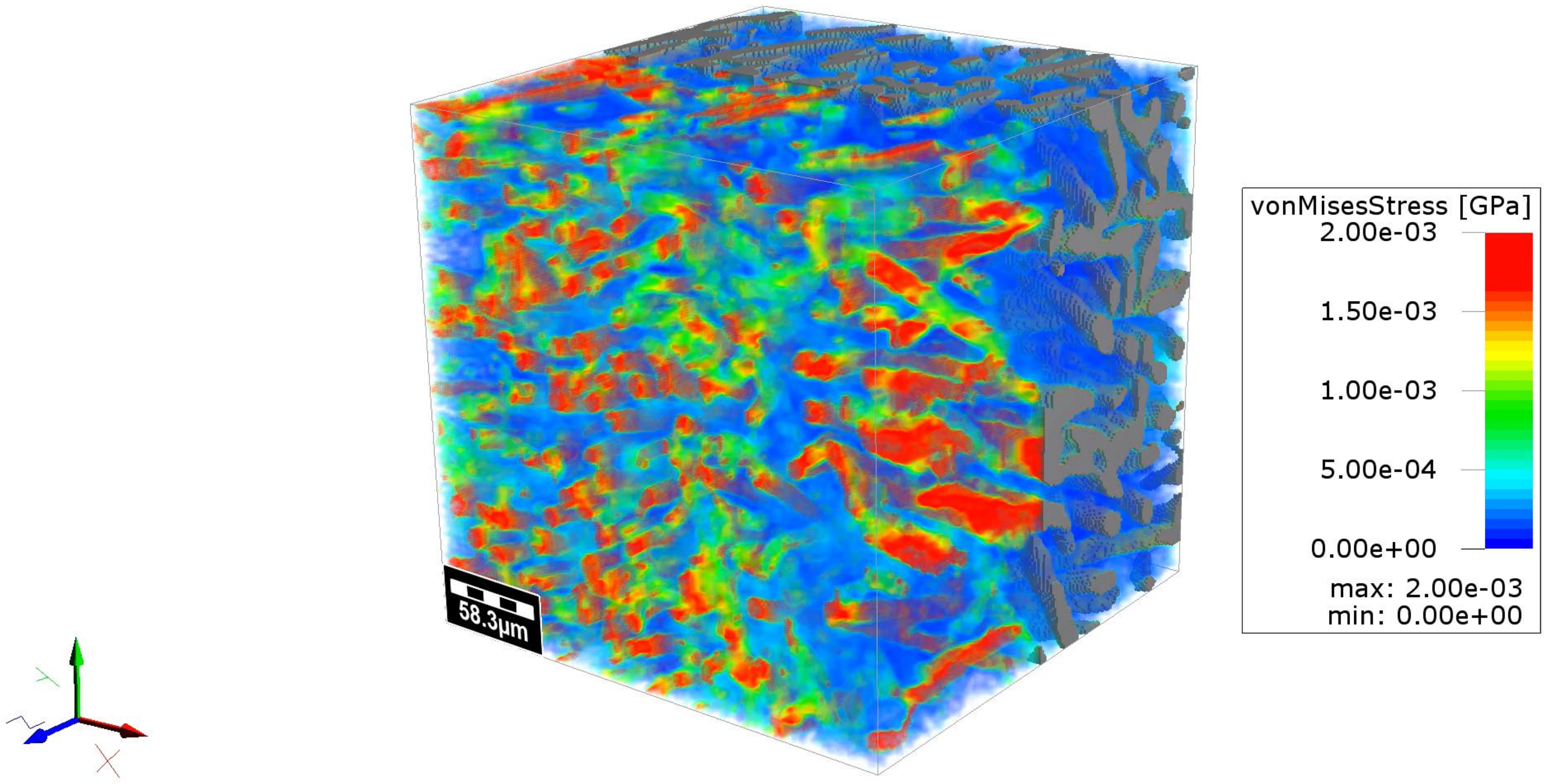
$$\sigma_{ij} = \sum_{r,s=1}^{3} c_{ijrs}\, \epsilon_{rs} \quad , \qquad\qquad i,j \in \{1,2,3\}$$

Short Glass Fiber Reinforced Plastic

- Visualization of the results
  - displacement
  - stress
  - strain
- Homogenized material properties
  - anisotropic elasticity tensor
  - approximation of the engineering constants
    - orthotropic
    - isotropic
  - thermal expansion properties

Short Glass Fiber Reinforced Plastic

- Visualization of the results
  - e.g. von Mises stress



Short Glass Fiber Reinforced Plastic

- Homogenized material properties
  - elasticity tensor
  - engineering constants

Anisotropic Elasticity Tensor

Stiffness Formulation for Strain Equivalence [GPa]

10.016	**5.3594**	**5.4999**	0.045512	-0.094108	0.12392
5.3596	**10.716**	**5.7295**	0.51863	-0.093485	0.082552
5.4998	**5.7296**	**15.377**	1.1905	-0.60699	-0.20454
0.045524	0.51862	1.1905	**3.4158**	-0.34325	-0.21146
-0.094059	-0.09342	-0.60689	-0.34327	**3.0735**	0.083305
0.12388	0.08248	-0.20462	-0.21149	0.08328	**2.6627**

Orthotropic Approximation

	Strain Equivalence	Energy Equivalence	Mean Value
Young's Modulus E_1 [GPa]	6.7722	6.7725	6.7724 +- 0.0001
Young's Modulus E_2 [GPa]	7.2198	7.2201	7.2200 +- 0.0002
Young's Modulus E_3 [GPa]	11.3678	11.3680	11.3679 +- 0.0001
Poisson Ratio ν_{12}	0.3858	0.3857	0.3858 +- 0.0000
Poisson Ratio ν_{13}	0.2139	0.2139	0.2139 +- 0.0000
Poisson Ratio ν_{23}	0.2255	0.2255	0.2255 +- 0.0000
Poisson Ratio ν_{21}	0.4112	0.4112	0.4112 +- 0.0000
Poisson Ratio ν_{31}	0.3591	0.3591	0.3591 +- 0.0000
Poisson Ratio ν_{32}	0.3551	0.3551	0.3551 +- 0.0000
Shear Modulus G_{12} [GPa]	2.6627	2.6625	2.6626 +- 0.0001
Shear Modulus G_{13} [GPa]	3.0735	3.0733	3.0734 +- 0.0001
Shear Modulus G_{23} [GPa]	3.4158	3.4156	3.4157 +- 0.0001

Short Glass Fiber Reinforced Plastic

- Homogenized material properties
  - angle dependency of the stiffness

Anisotropic Elasticity Tensor

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10.016	**5.3594**	**5.4999**	0.045512	-0.094108	0.12392
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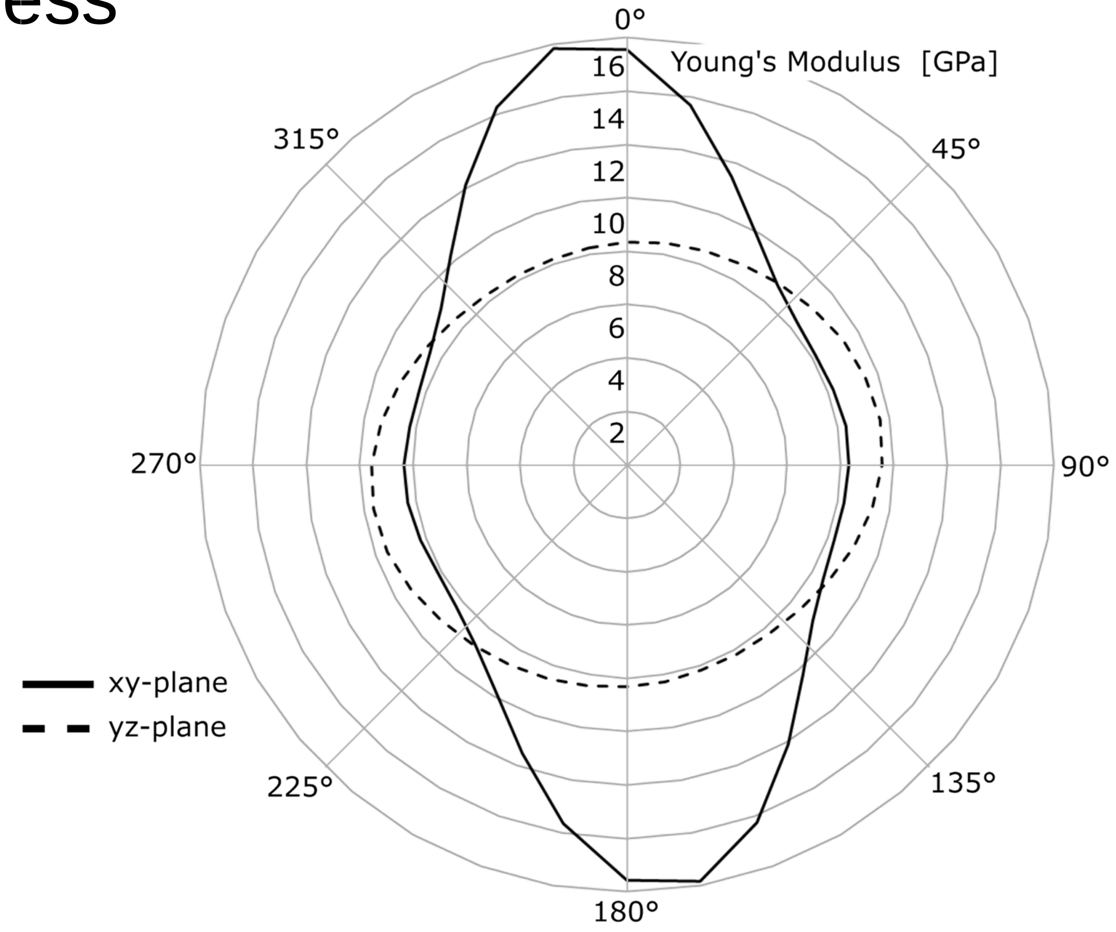


Short Glass Fiber Reinforced Plastic

- Homogenized material properties
  - defining the expansion coefficient of the single constituents
  - calculating the macroscopic expansion properties

Thermal Stress Tensor GPa/K

-0.001047	4.82e-07	9.271e-07
4.82e-07	**-0.001058**	6.252e-07
9.271e-07	6.252e-07	**-0.001056**

Short Glass Fiber Reinforced Plastic

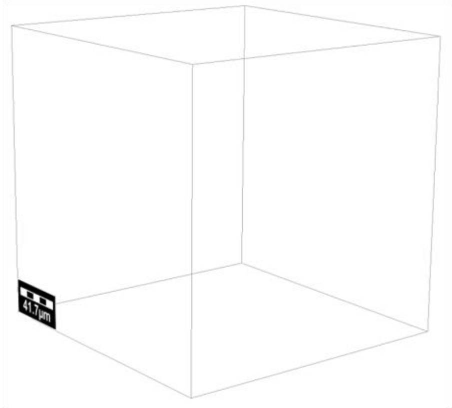
- Parameter studies based on modelled microstructures
  - short fiber structures with different fiber volume fractions
  - constant fiber length: 200 µm
  - constant fiber diameter: 9.2 µm
    (average diameter from the imported µCT structure)
  - definition of the fiber orientation tensor

$$\overline{\boldsymbol{A}_{fiber}} = \begin{bmatrix} 0.8 & 0 & 0 \\ sym & 0.1 & 0 \\ sym & sym & 0.1 \end{bmatrix}$$

  - automated study using the Python-Interface GeoPython

Short Glass Fiber Reinforced Plastic

- Influence of the fiber volume fraction on the Young’s modulus



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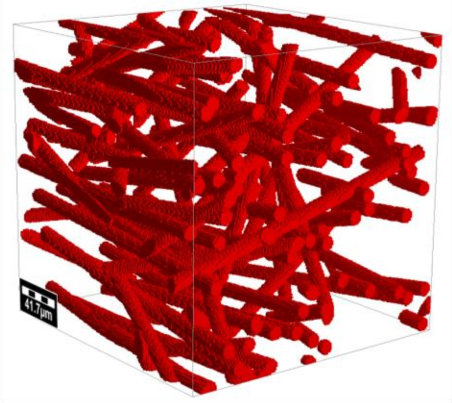

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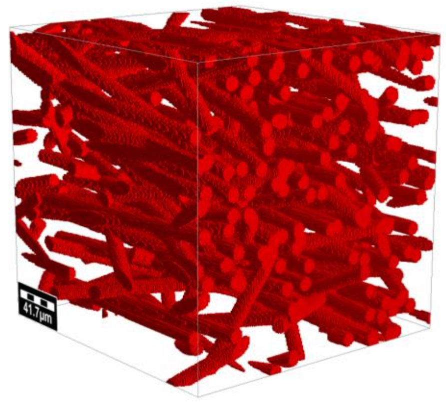

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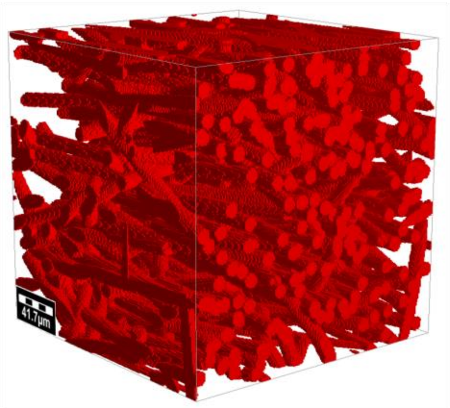

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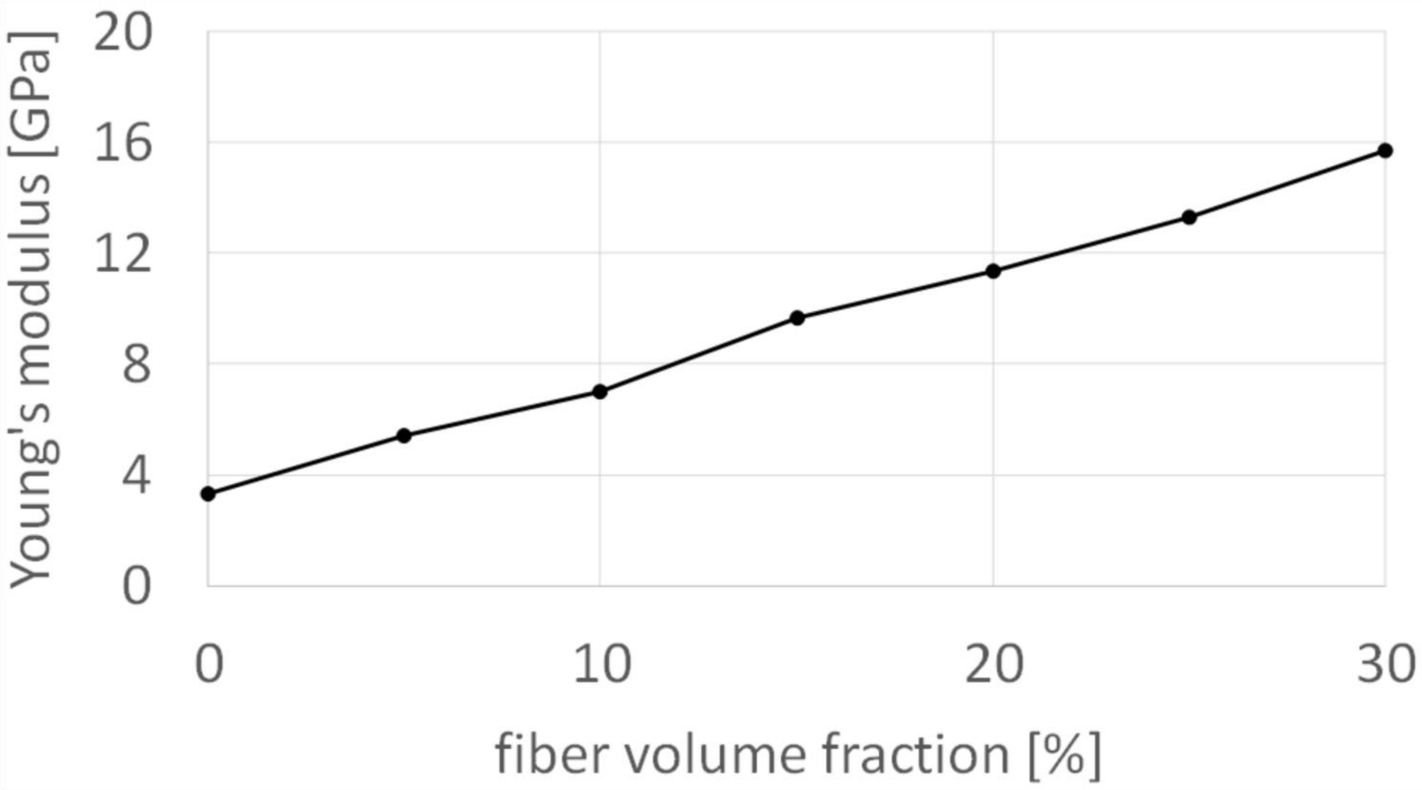
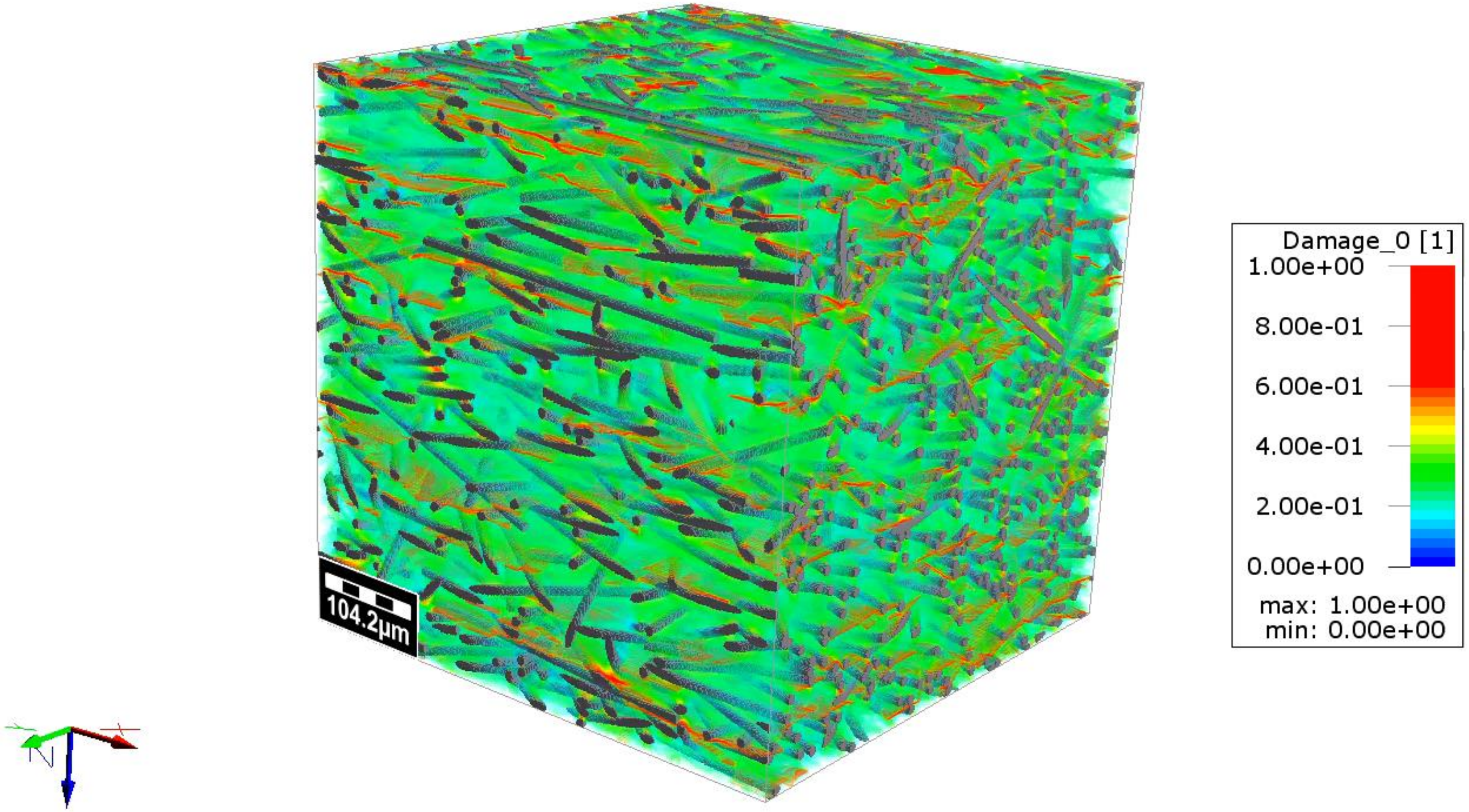


Short Glass Fiber Reinforced Plastic

- Simulation of matrix damage using ElastoDict-LD
  - nonlinear material models available, e.g.:
    - Neo-Hookean
    - Mooney-Rivlin
    - plastic deformation
  - user defined materials (UMAT interface)
  - nonlinear geometry option
  - different loading types
    - uniaxial/shear
    - complex (free definition of the deformation gradient)
  - free or confined boundary conditions

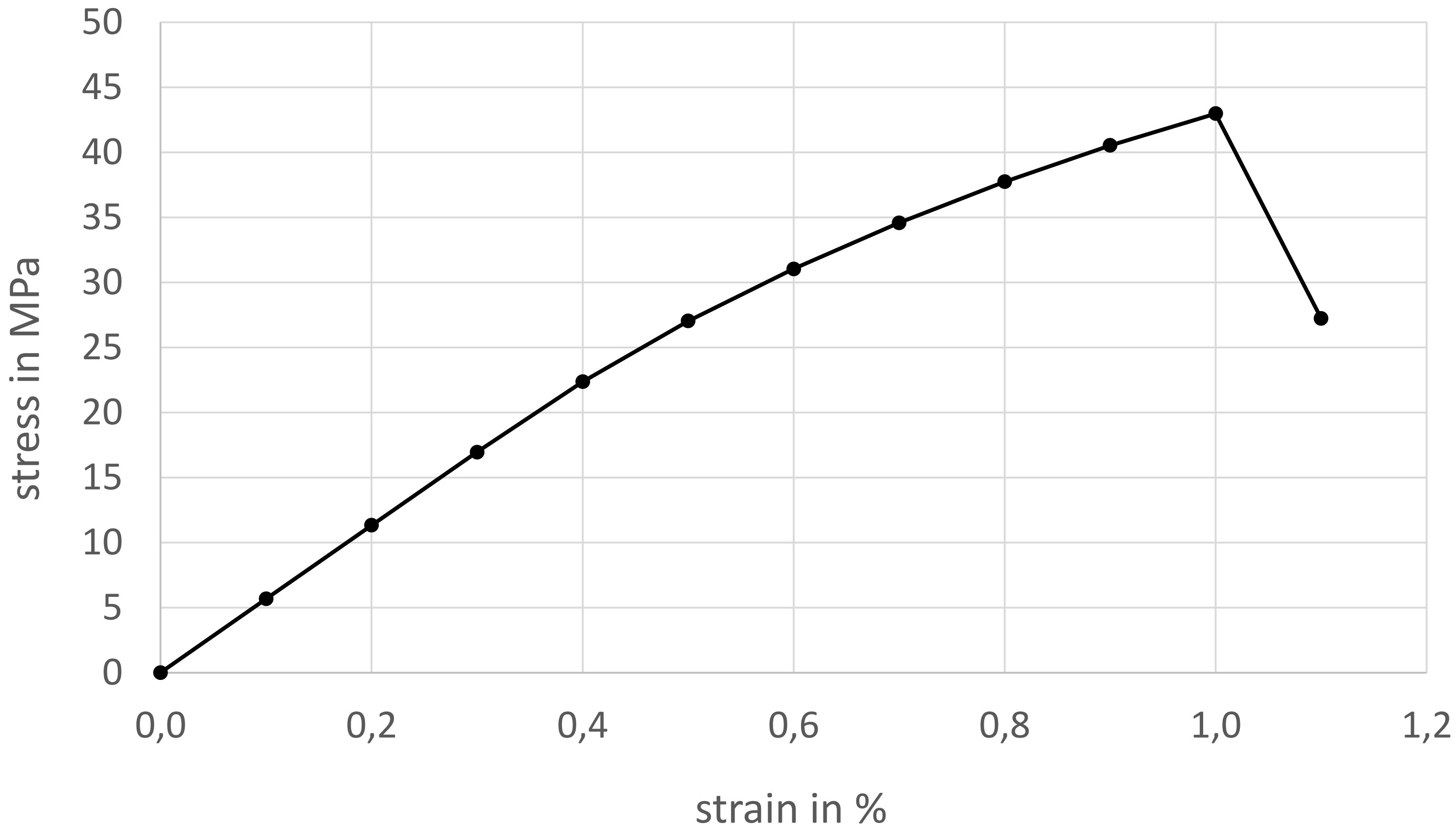
Short Glass Fiber Reinforced Plastic

- Simulation of matrix damage using ElastoDict-LD
  - visualization of UMAT-state variables (e.g. damage)



Short Glass Fiber Reinforced Plastic

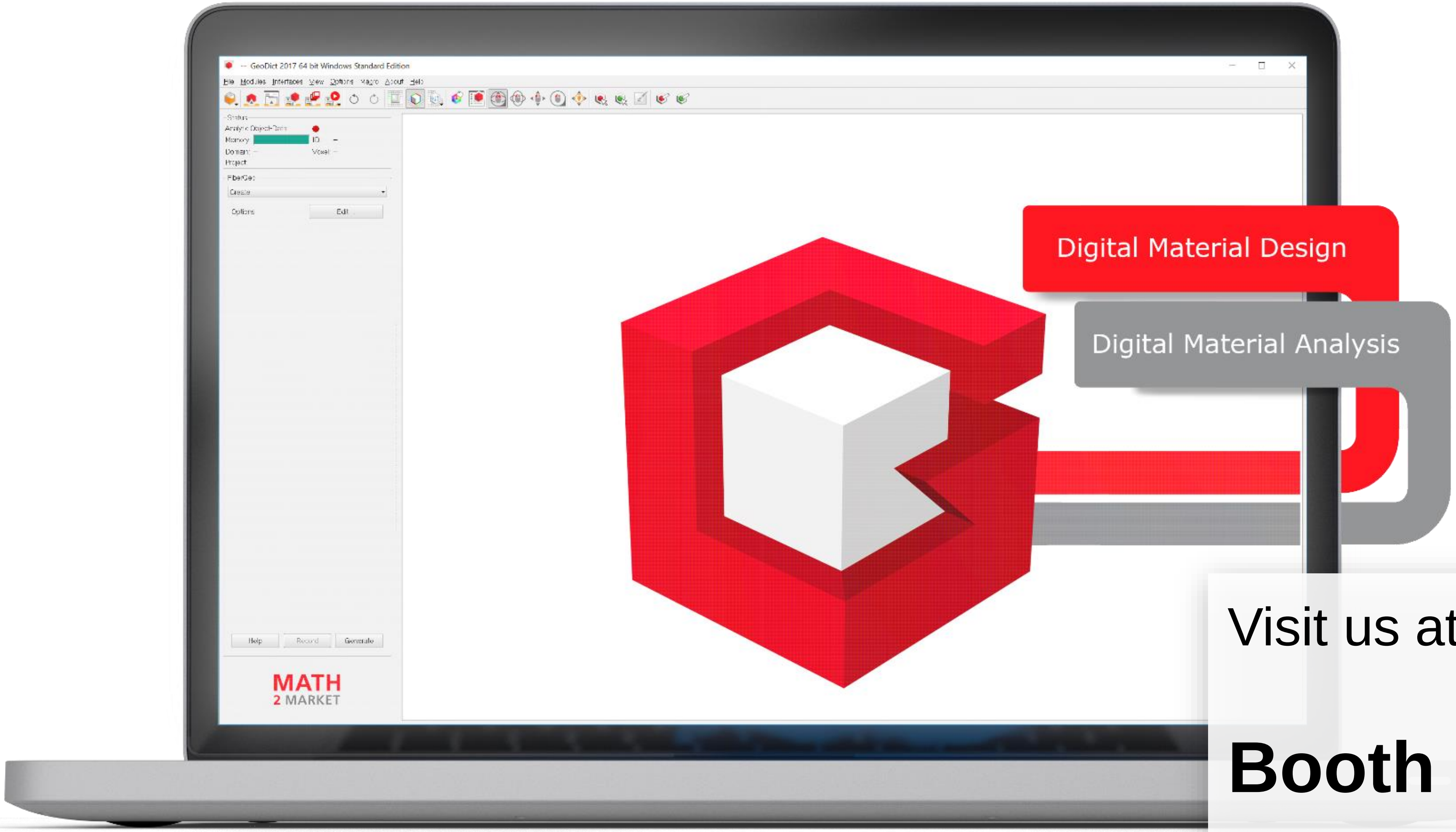
- Simulation of matrix damage using ElastoDict-LD
  - macroscopic stress strain curve



Conclusion

- Micromechanical model
  - import your µCT scan and segment the single constituents
  - generate your microstructure using FiberGeo, FoamGeo, …
- Geometric analysis
  - Fiber orientation analysis
  - Fiber diameter and curvature distribution
- Mechanical simulation
  - elasticity tensor of the homogenized material
  - thermal stress tensor
  - nonlinear material properties

Thank you!



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