MATH 2 MARKET

DIGITAL TWIN - HOW TO GENERATE AND VALIDATE MODELLED MICROSTRUCTURES FROM 2D AND 3D IMAGES

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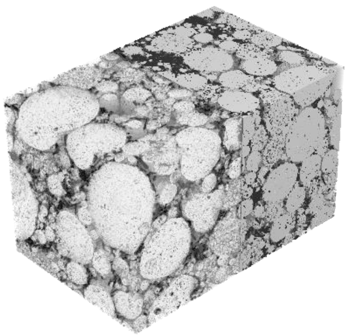
OUTLINE

The Workflow for Digital Material Design with GeoDict®

GeoDict

Import

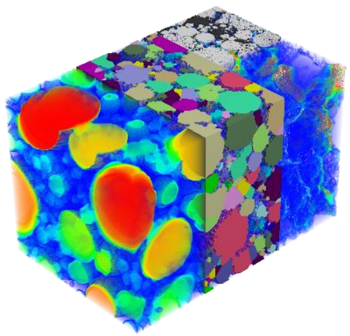


The idea is the beginning.

Design a material from scratch or import images from an existing material to create a digital model.

Digital Material

Analyze

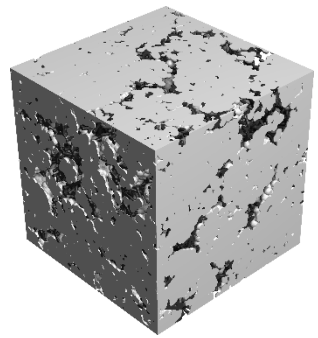


Discover the geometric properties and compute the physical properties of the material.

This is the start of creating a Digital Twin.

Statistical Model

Model

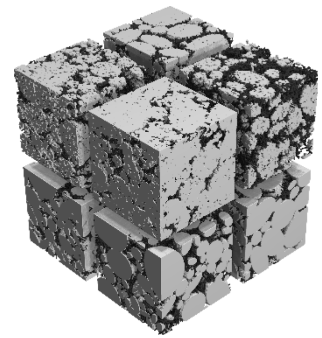


A Digital Twin is the statistical representation of the material in the digital world.

Here begins the design process.

Digital Twin

Design



Digital prototypes are easily and rapidly created.

Simulate and evaluate in a loop to find the material with the desired properties.

Digital Prototypes

Next Generation Material

The materials of the future are within reach and we help you find them faster.

This is innovation through simulation.

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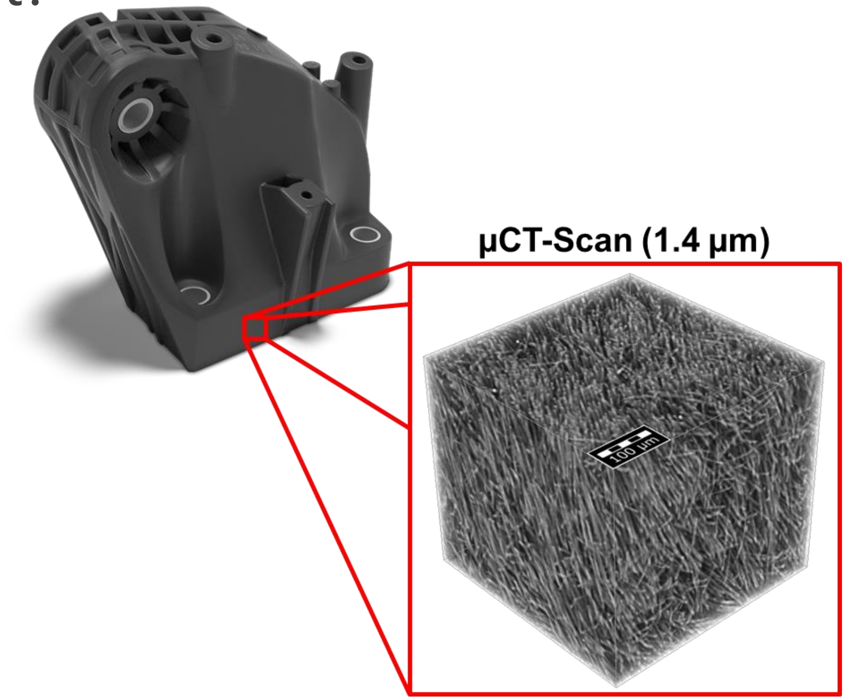
Outline

Digital Twin of a SFRP

- What material are we looking at?
  - PA6GF50
    - Polyamide 6 matrix
    - short glass fiber reinforcement
    - 50 % fibers by weight
  - produced by injection molding
  - used in mass production for structural components (e.g. engine bearer)



Digital Twin of a SFRP

GeoDict

- 6 Steps to the Digital Twin

1. Import, process and segment the µCT-scan
2. Calculate the mechanical properties directly on the µCT-scan
3. Determine the geometrical properties of the material
   (fiber diameter, fiber orientation, fiber length)
4. Model the digital twin
5. Calculate the mechanical properties of the digital twin
6. Comparison of the results

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Digital Twin of a SFRP
Import and Segmentation

GeoDict

- Import a stack of 2d images
- Image processing to improve quality for segmentation n
  - noise reduction, edge sharpening

original

NLM, Patch Radius: 1vx
Window Radius: 3vx
Strength: 0.1

NLM, Patch Radius: 1vx
Window Radius: 3vx
Strength: 0.2

NLM, Patch Radius: 1vx
Window Radius: 3vx
Strength: 0.3

NLM, Patch Radius: 1vx
Window Radius: 3vx
Strength: 0.4

Applying a Non-Local Means Filter for noise reduction

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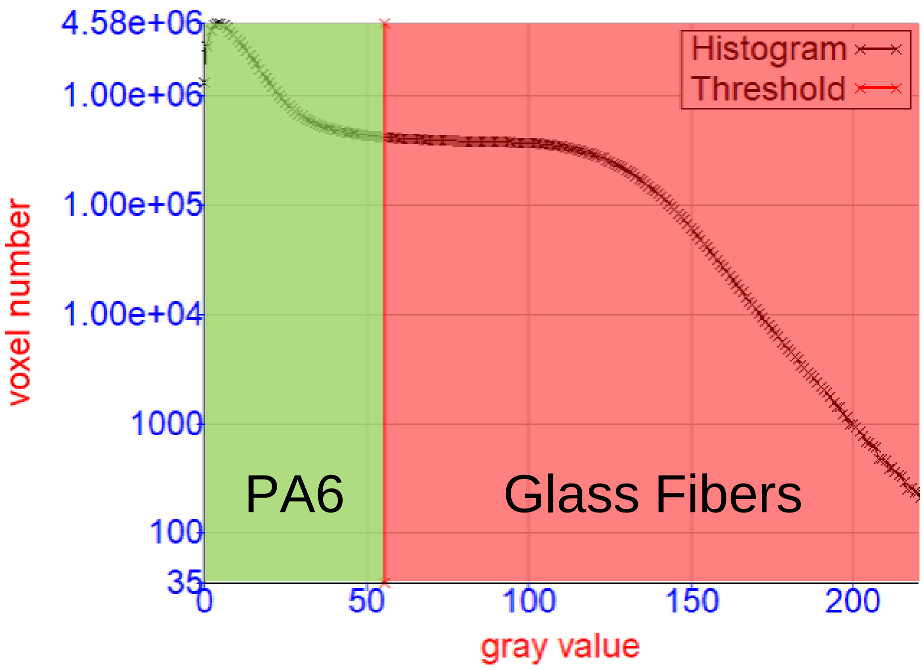
DIGITAL TWIN OF A SFRP
IMPORT AND SEGMENTATION

GEODICT

- automated thresholding using OTSU[1] algorithm



[1]Nobuyuki Otsu (1979). "A threshold selection method from gray-level histograms". IEEE Trans. Sys., Man., Cyber. 9 (1): 62–66

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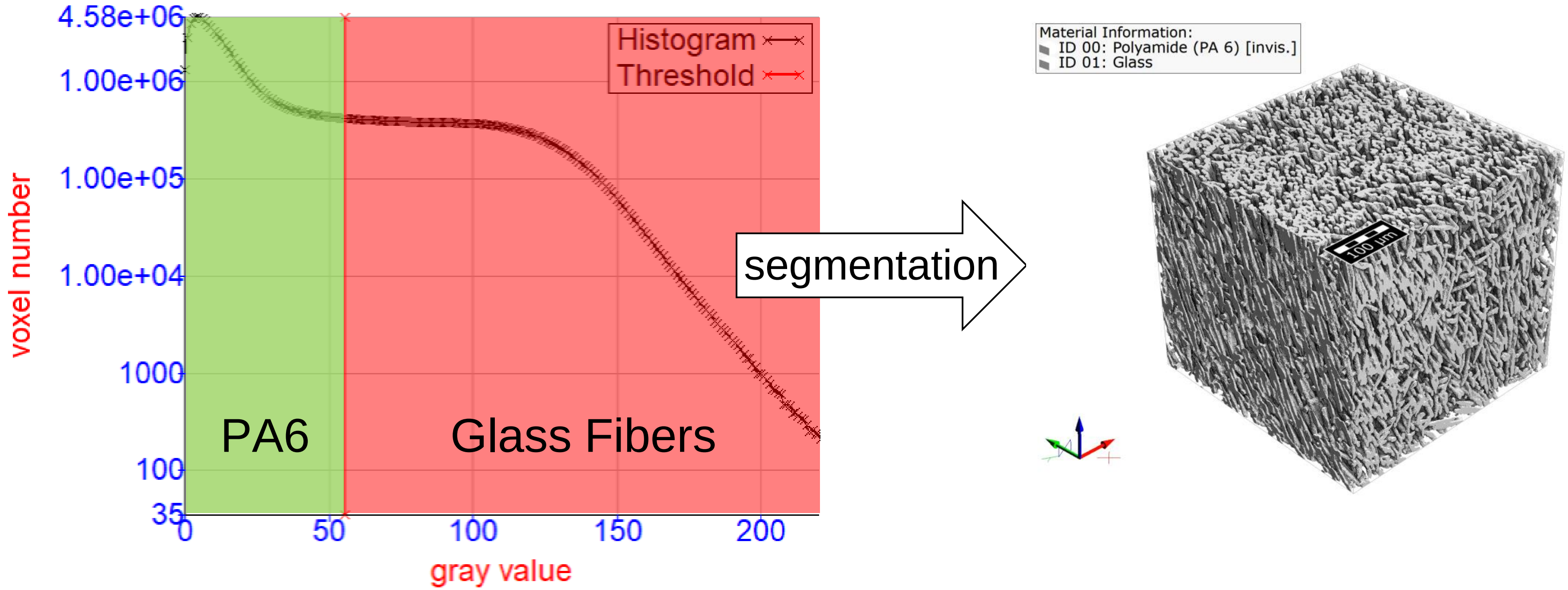
Digital Twin of a SFRP
Import and Segmentation

- automated thresholding using OTSU[1] algorithm



[1]Nobuyuki Otsu (1979). "A threshold selection method from gray-level histograms". IEEE Trans. Sys., Man., Cyber. 9 (1): 62–66

Digital Twin of a SFRP
Mechanical Analysis - CT scan

GeoDict

- linear elastic simulation of 6 different load cases
  - 3 uniaxial experiments
  - 3 shear experiments
- used material properties
  - PA6: E=2.8 GPa / ν=0.39
  - Glass: E=72 GPa / ν=0.22
- computation time: 589 s
  - 4 CPUs
  - 0.5 GB memory

$$C_{\alpha\beta} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} & C_{15} & C_{16} \\ C_{12} & C_{22} & C_{23} & C_{24} & C_{25} & C_{26} \\ C_{13} & C_{23} & C_{33} & C_{34} & C_{35} & C_{36} \\ C_{14} & C_{24} & C_{34} & C_{44} & C_{45} & C_{46} \\ C_{15} & C_{25} & C_{35} & C_{45} & C_{55} & C_{56} \\ C_{16} & C_{26} & C_{36} & C_{46} & C_{56} & C_{66} \end{bmatrix}$$

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Digital Twin of a SFRP
Mechanical Analysis - CT scan

GeoDict

- calculated engineering parameters and stiffness tensor

Orthotropic Approximation

	Strain Equivalence	Energy Equivalence	Mean Value
Young's Modulus E_1 / (GPa)	7.1211	7.1213	7.1212 +- 0.0001
Young's Modulus E_2 / (GPa)	7.9283	7.9285	7.9284 +- 0.0001
Young's Modulus E_3 / (GPa)	11.3851	11.3852	11.3852 +- 0.0000
Poisson Ratio V_{12}	0.3547	0.3547	0.3547 +- 0.0000
Poisson Ratio V_{13}	0.2160	0.2160	0.2160 +- 0.0000
Poisson Ratio V_{23}	0.2517	0.2517	0.2517 +- 0.0000
Poisson Ratio V_{21}	0.3949	0.3949	0.3949 +- 0.0000
Poisson Ratio V_{31}	0.3454	0.3454	0.3454 +- 0.0000
Poisson Ratio V_{32}	0.3614	0.3614	0.3614 +- 0.0000
Shear Modulus G_{12} / (GPa)	2.7558	2.7557	2.7558 +- 0.0001
Shear Modulus G_{13} / (GPa)	3.0113	3.0111	3.0112 +- 0.0001
Shear Modulus G_{23} / (GPa)	3.8636	3.8635	3.8636 +- 0.0001

-------- Anisotropic Elasticity Tensor --------

Stiffness Formulation for Strain Equivalence / (GPa)

10.232	**5.4243**	**5.4948**	0.025524	-0.010267	0.14141
5.4244	**11.597**	**6.0651**	0.80216	-0.08876	0.12121
5.4949	**6.0652**	**15.475**	1.5932	-0.28255	-0.12848
0.025595	0.80212	1.5932	**3.8636**	-0.24775	-0.17071
-0.010275	-0.088766	-0.28258	-0.24774	**3.0113**	0.091551
0.14133	0.12119	-0.12859	-0.17072	0.091522	**2.7558**

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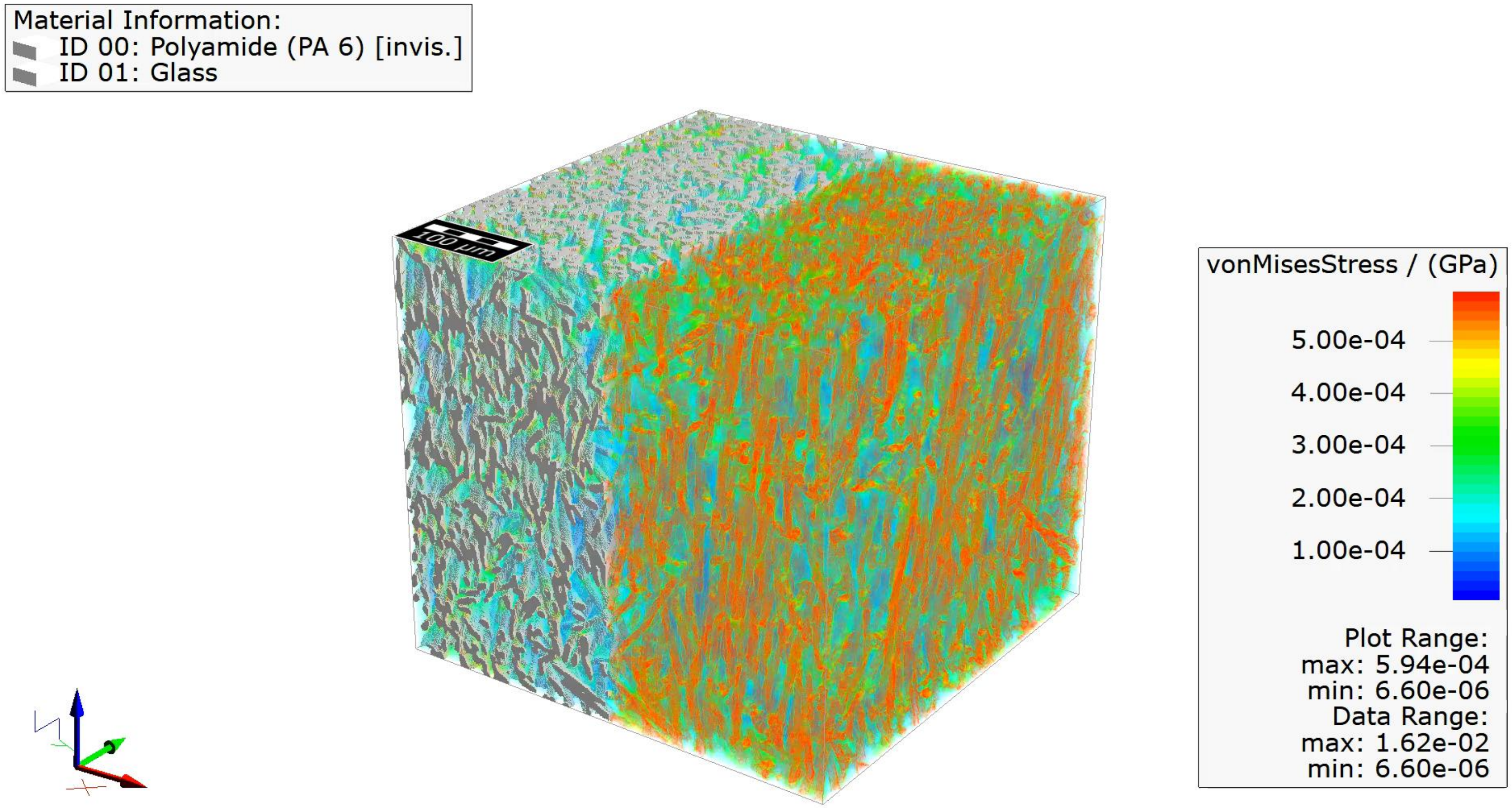
Digital Twin of a SFRP
Mechanical Analysis - CT scan

- visualization of the von-Mises stress

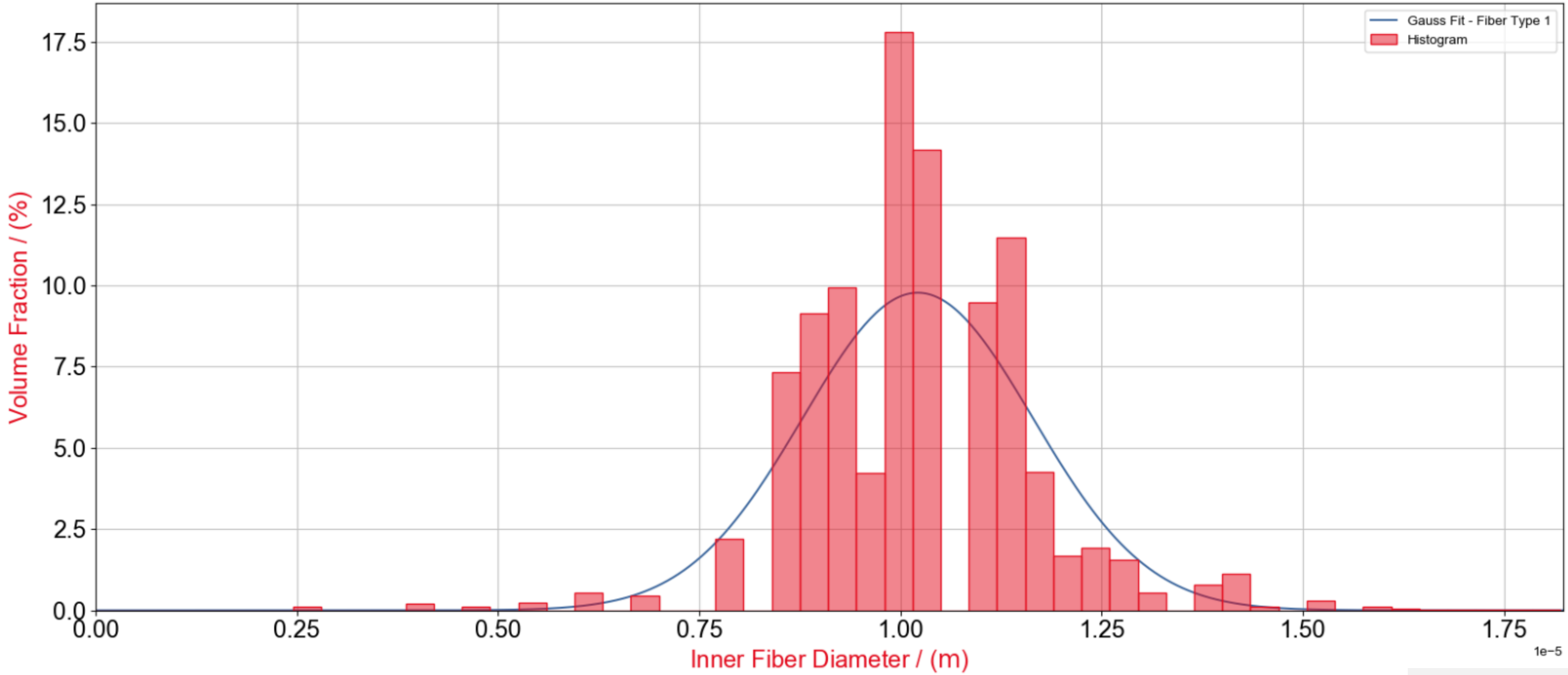


Digital Twin of a SFRP
Geometrical Analysis - CT scan

GeoDict

- fiber diameter distribution

	Average Inner Diameter / (m)	Standard Deviation / (m)	Volume Fraction / (%)
Type 1	1.0216e-5	1.42793e-6	100



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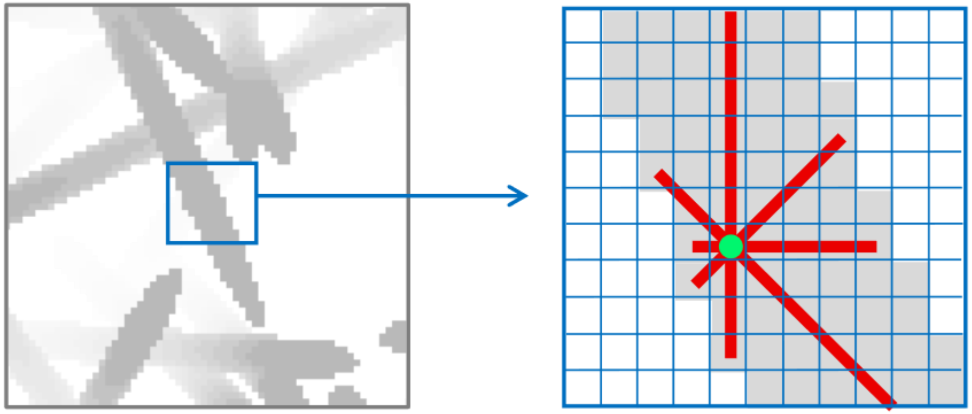
Digital Twin of a SFRP
Geometrical Analysis - CT scan

GeoDict

- fiber orientation analysis
  - using Star Length Distribution Algorithm
  - works on a per-voxel basis
  - analyzes the chord lengths through the voxel for a pre-defined set of directions
  - the relative length of the cords gives the per-voxel orientation tensor
  - tensors are averaged



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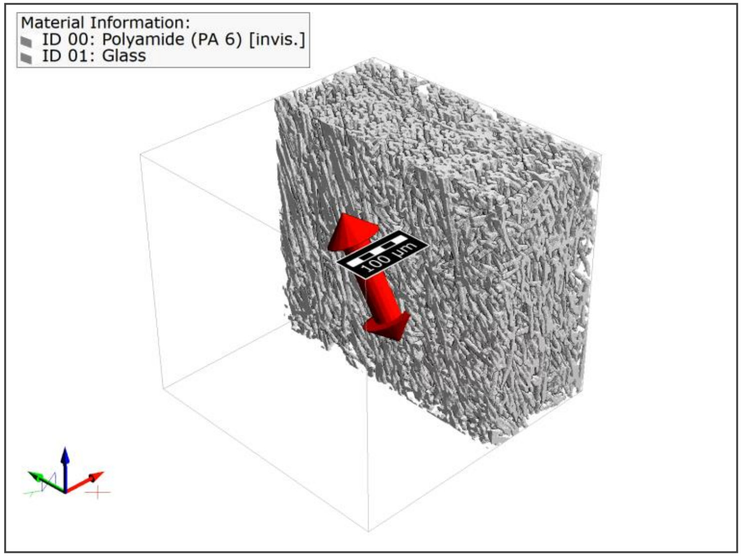
Digital Twin of a SFRP
Geometrical Analysis - CT scan

- fiber orientation analysis
  - homogenized orientation tensor for the entire scan
  - visualization of the main orientation
- calculation of the fiber volume fraction

Block 0,0,0: Solid Volume Fraction = 31.6262%

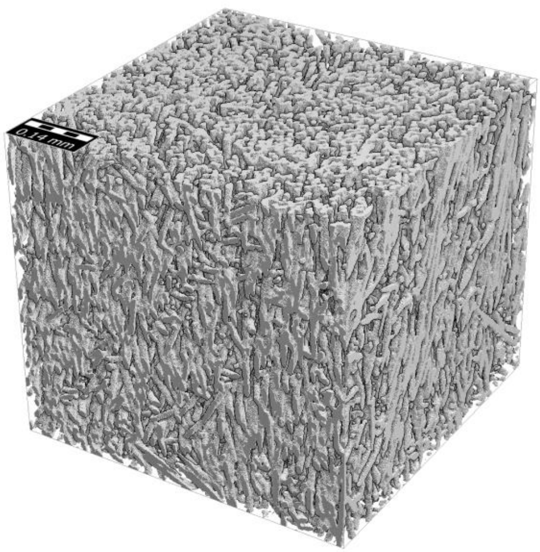
0.166223	-0.0163009	-0.0522386
-	0.28979	0.154429
-	-	0.543987



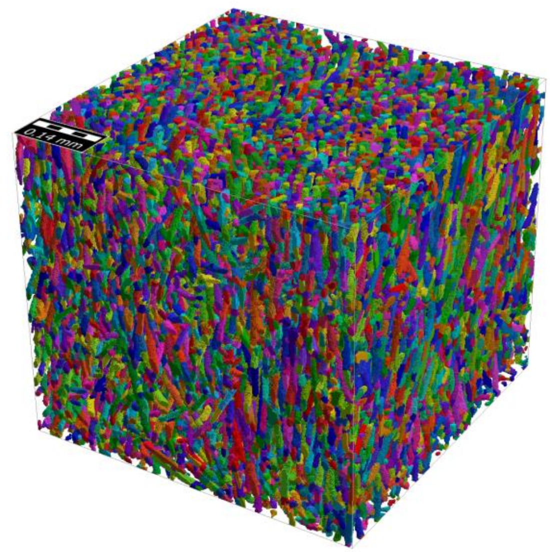
DIGITAL TWIN OF A SFRP GEOMETRICAL ANALYSIS - CT SCAN

GEODICT

- fiber length analysis using **A**rtificial **I**ntelligence



µCT-Scan



identified fibers

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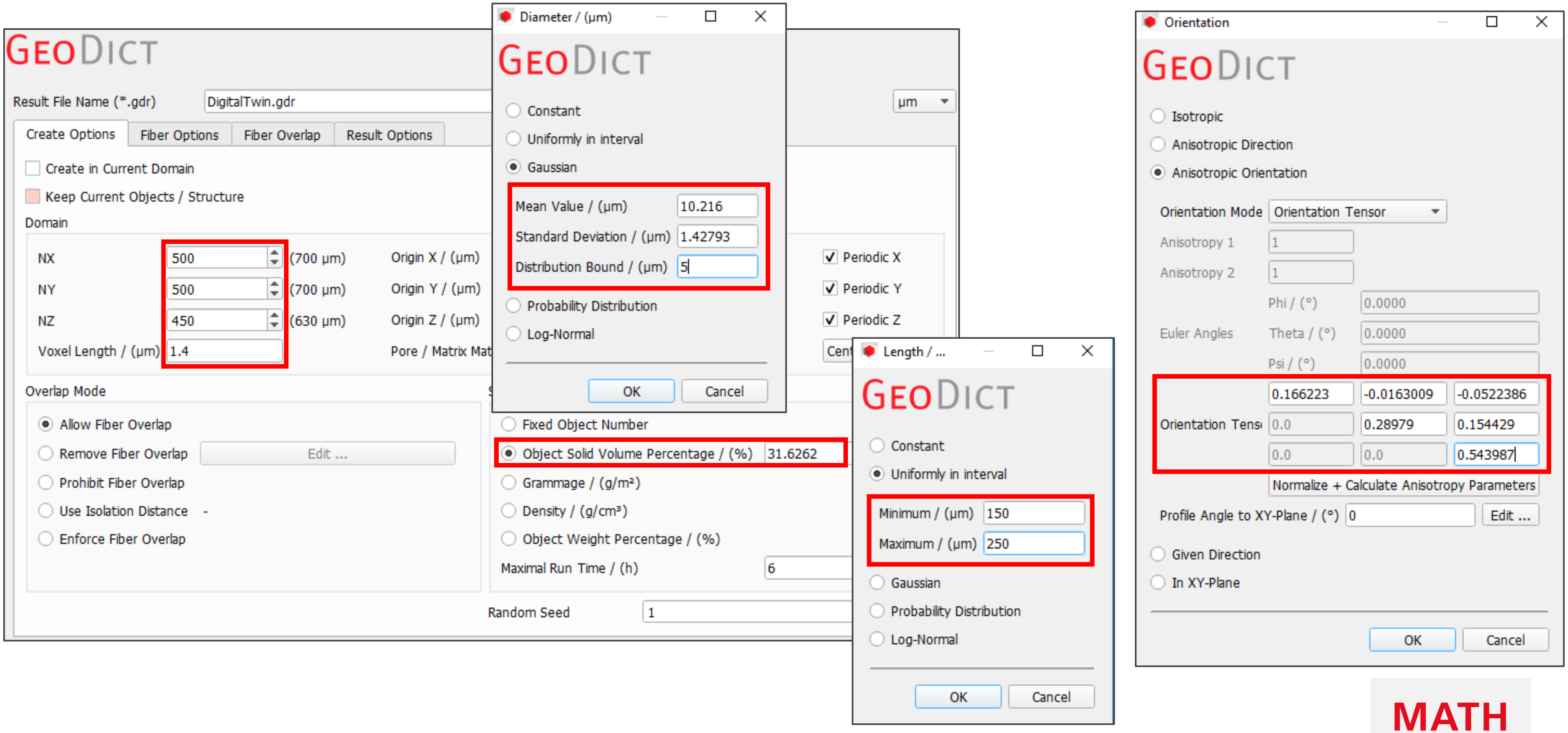
Digital Twin of a SFRP Modeling

- use all collected geometrical properties of the material for modelling the digital twin in FiberGeo



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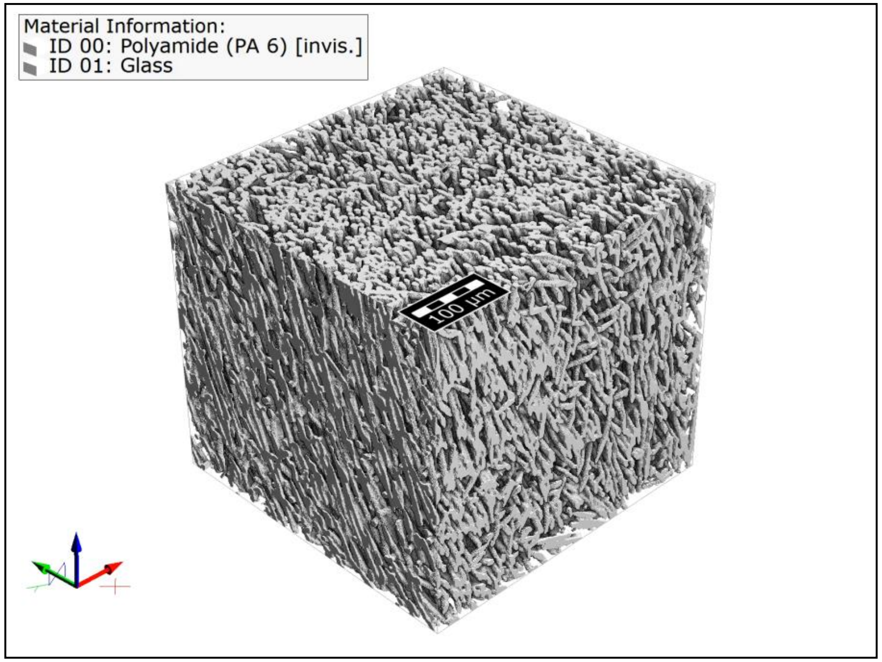
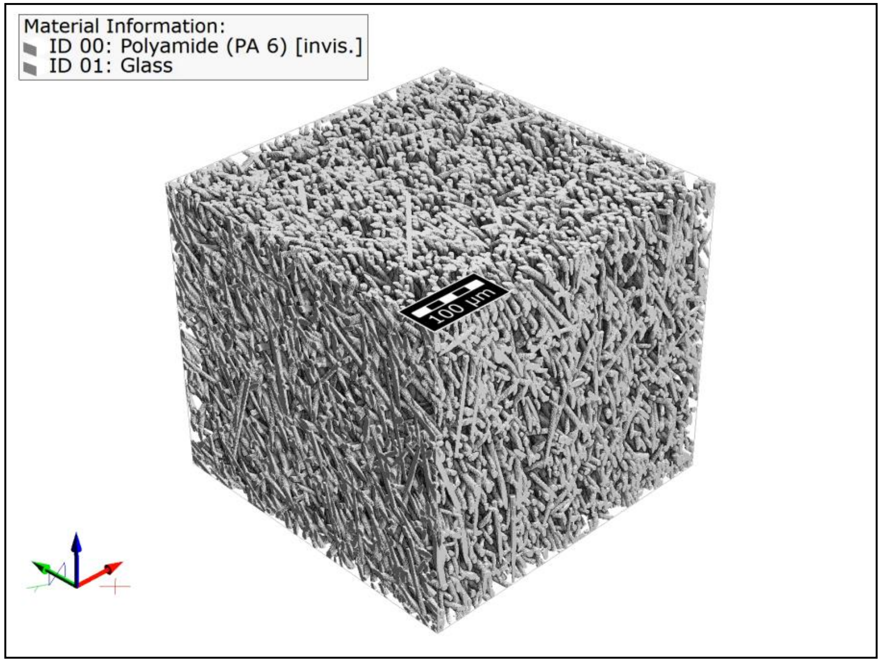
Digital Twin of a SFRP Modeling

- visual comparison of the twin and the µCT-scan



µCT-Scan



Digital Twin

Digital Twin of a SFRP
Mechanical Analysis

- comparison of the stiffness tensor

-------- **Anisotropic Elasticity Tensor** --------

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0.14133	0.12119	-0.12859	-0.17072	0.091522	**2.7558**

µCT-Scan

-------- **Anisotropic Elasticity Tensor** --------

Stiffness Formulation for Strain Equivalence / (GPa)

10.757	**5.4859**	**5.5878**	0.053966	0.06989	0.16679
5.4859	**11.688**	**6.0427**	0.78271	-0.070062	0.16912
5.5879	**6.0427**	**14.307**	1.1605	-0.031768	-0.05373
0.054045	0.78275	1.1605	**3.6667**	-0.15612	-0.11499
0.069986	-0.069923	-0.031719	-0.15614	**3.1619**	0.081569
0.16684	0.16916	-0.053757	-0.11499	0.081581	**2.9358**

Digital Twin

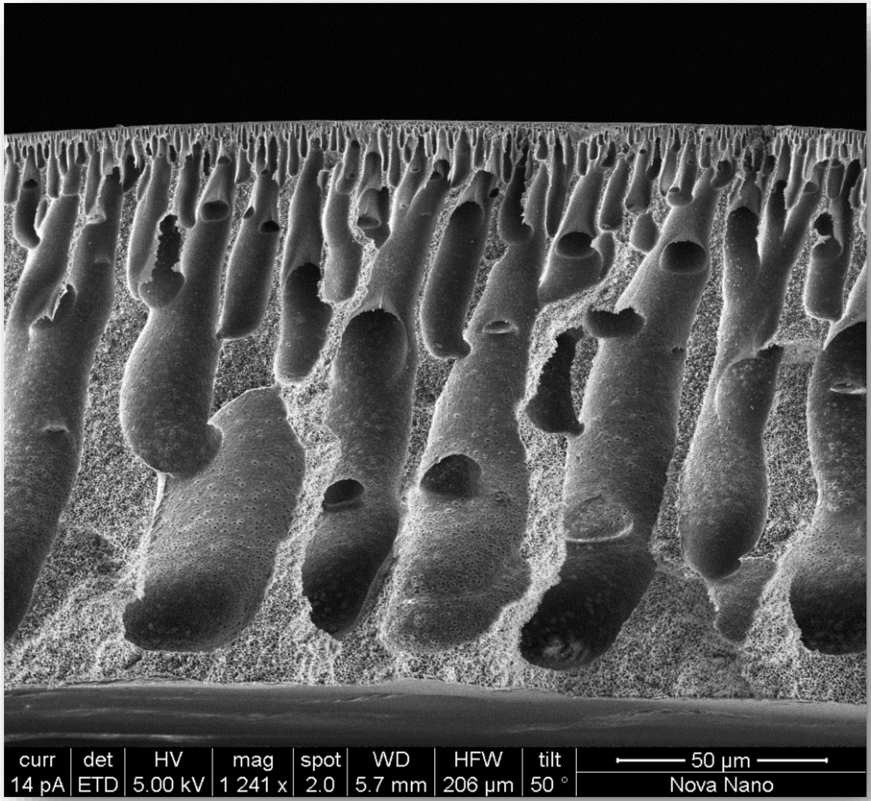
⇨ **very good agreement between µCT-scan and digital twin**

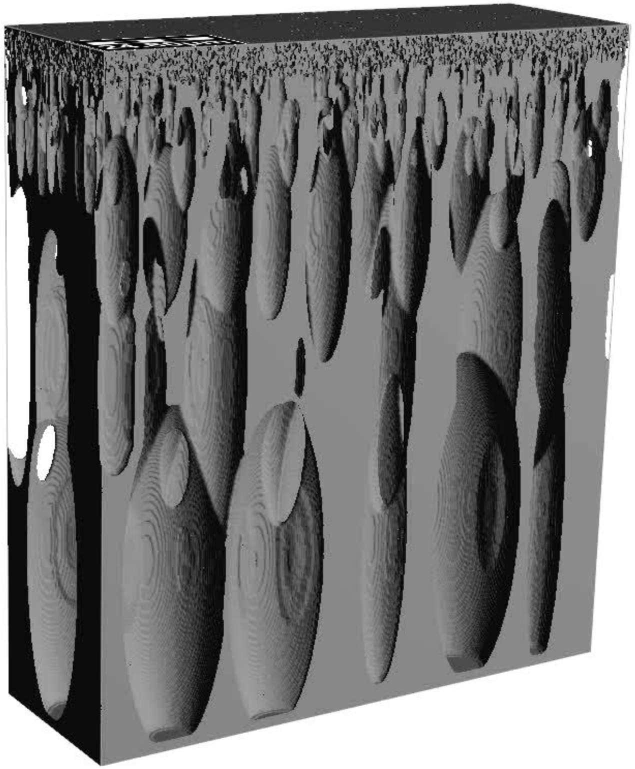
OUTLINE

Other Examples of Digital Twins
Polysulfone Micromembrane

GeoDict

- used for seawater desalination





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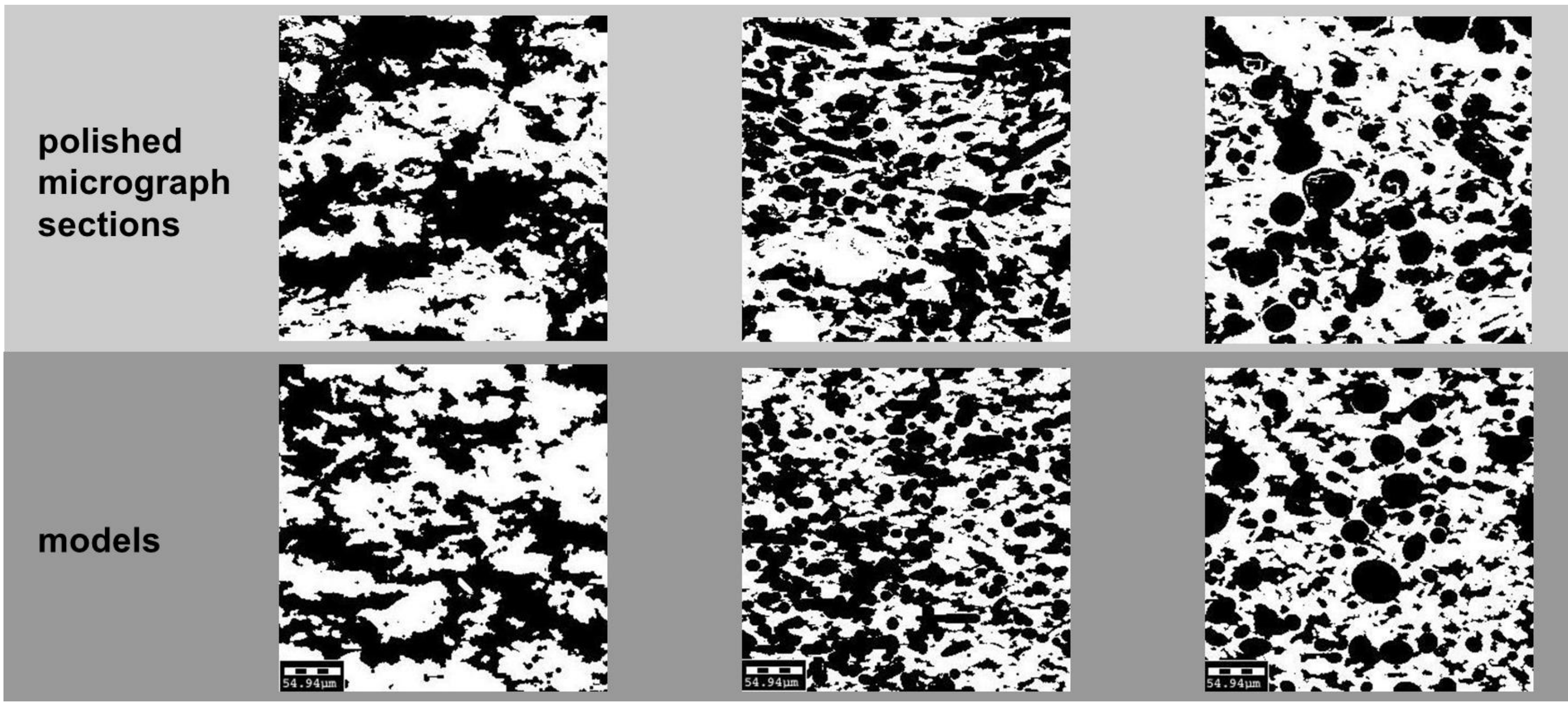
Other Examples of Digital Twins
Sintered Ceramic

- used for soot particle filters



[Schmidt and Becker, Generating Validated 3D Models of Microporous Ceramics, 2013, Advanced Engineering Materials]

Other Examples of Digital Twins
Sintered Ceramic

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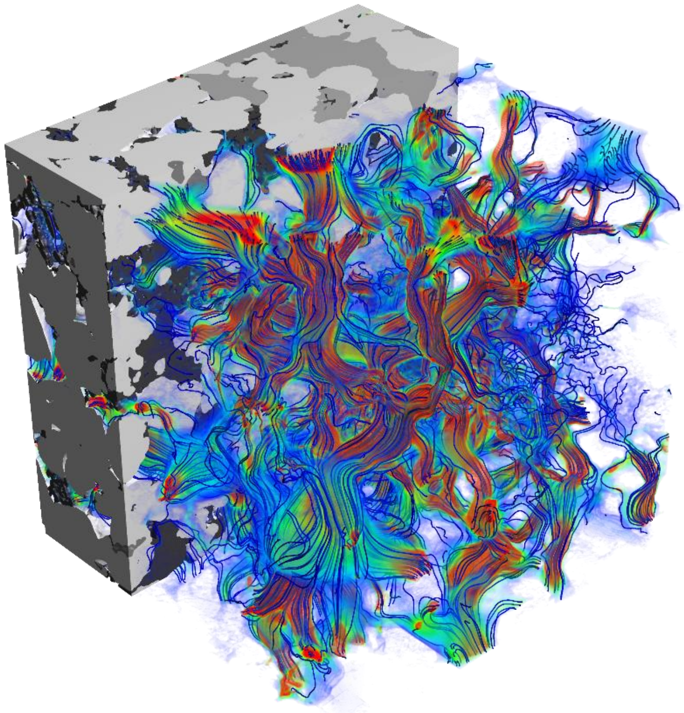
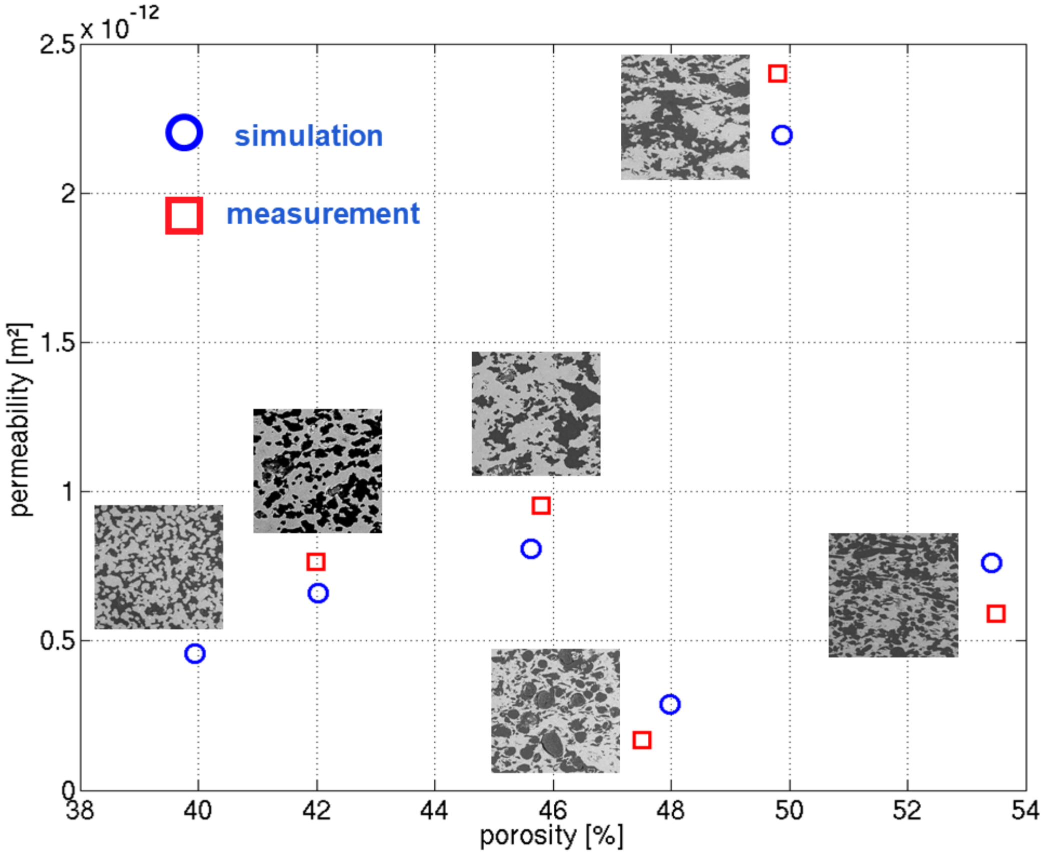
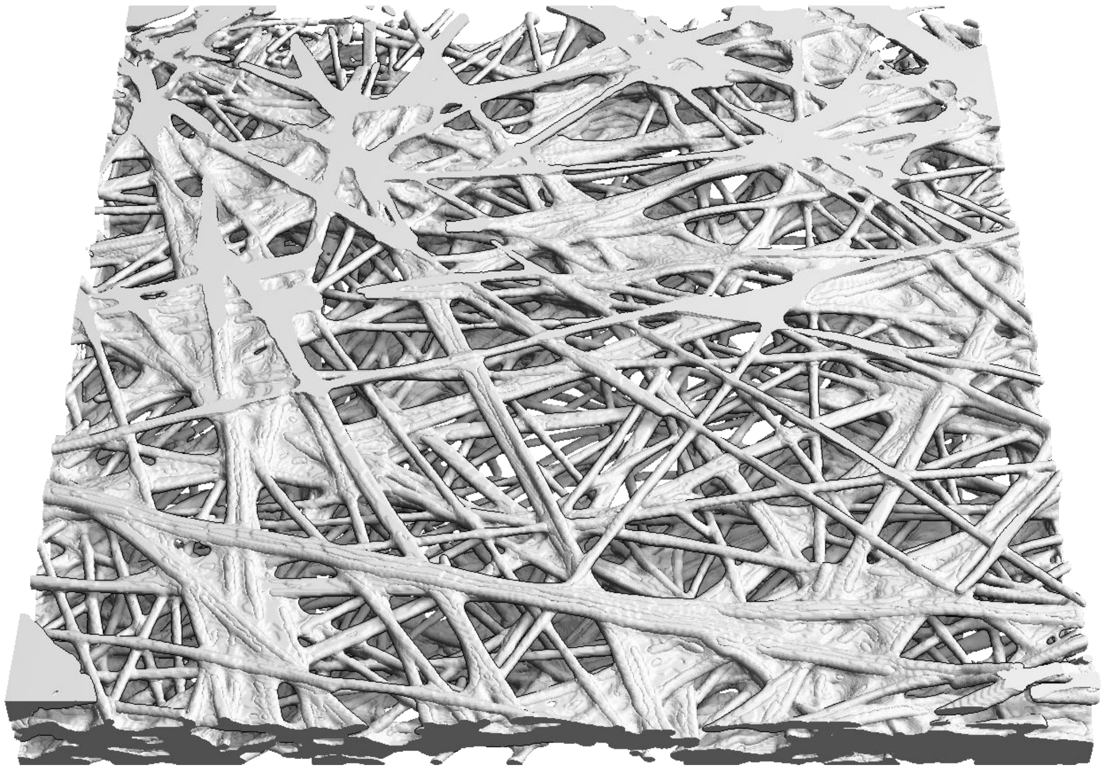




[Schmidt and Becker, Generating Validated 3D Models of Microporous Ceramics, 2013, Advanced Engineering Materials]

Other Examples of Digital Twins Gas Diffusion Layer

- used in fuel cells



µCT-Scan

Other Examples of Digital Twins
Gas Diffusion Layer

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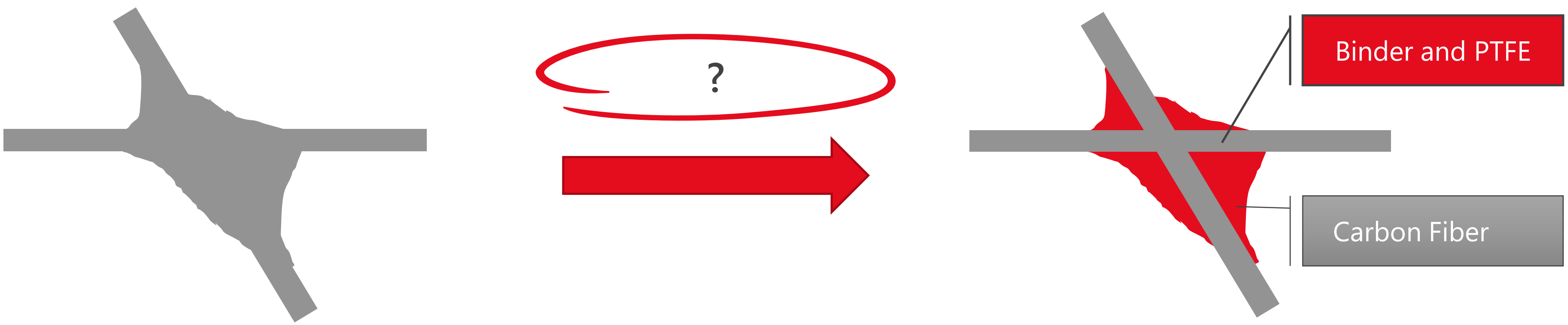
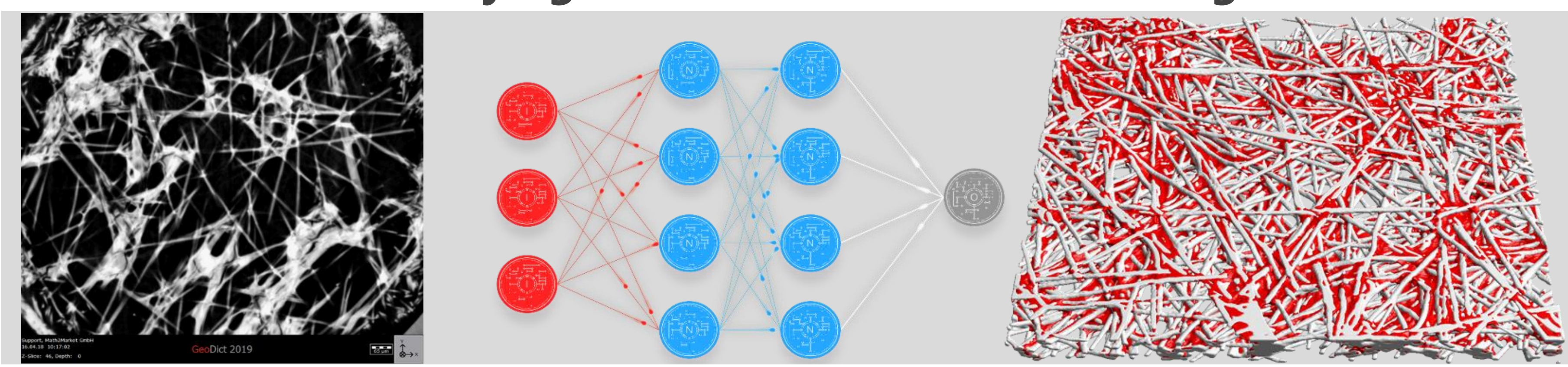


Identifying binder with Machine Learning



Other Examples of Digital Twins
Gas Diffusion Layer

GeoDict

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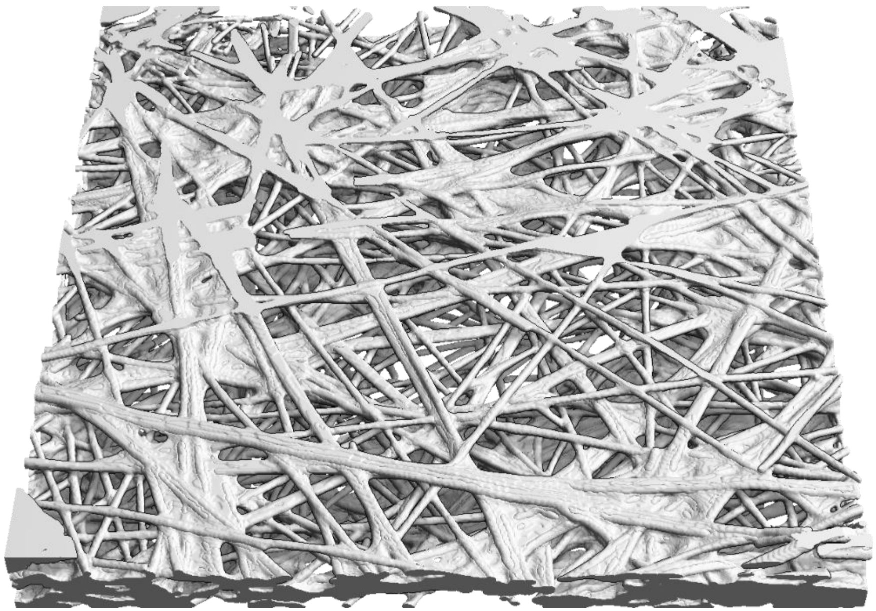

µCT-Scan

segmented image

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Thank you for your Attention!

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