GeoDict – the Digital Material Laboratory for Gas and Liquid Filtration

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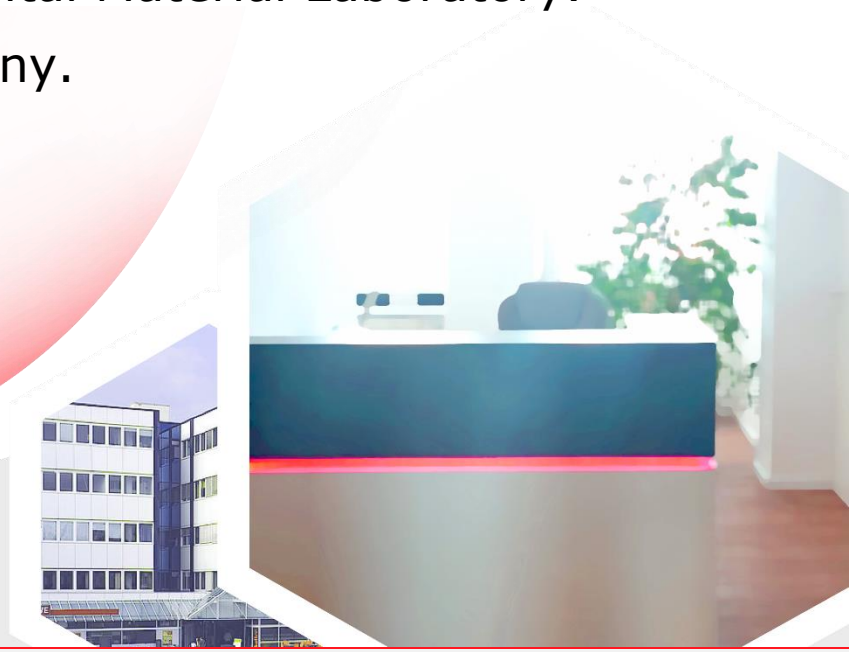
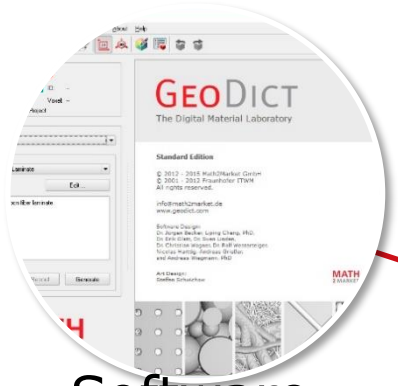
Math2Market GmbH
Some background information

- Math2Market creates and markets software for engineers and scientists that want to analyze and design porous and composite materials based on the material's geometric inhomogeneity.
- The materials can come from µCT, FIB-SEM or models and are represented as 3-dimensional images in the software.
- This software is called GeoDict, the Digital Material Laboratory.
- M2M is based in Kaiserslautern, Germany.
- M2M spun off from Fraunhofer Institute for Industrial Mathematics.



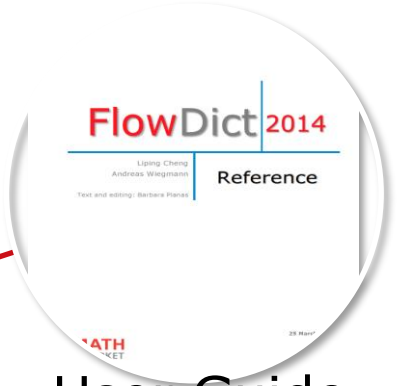
- Visit us at our booth

Math2Market GmbH
Services provided to our clients



Software

Client



User Guide

Support & Training

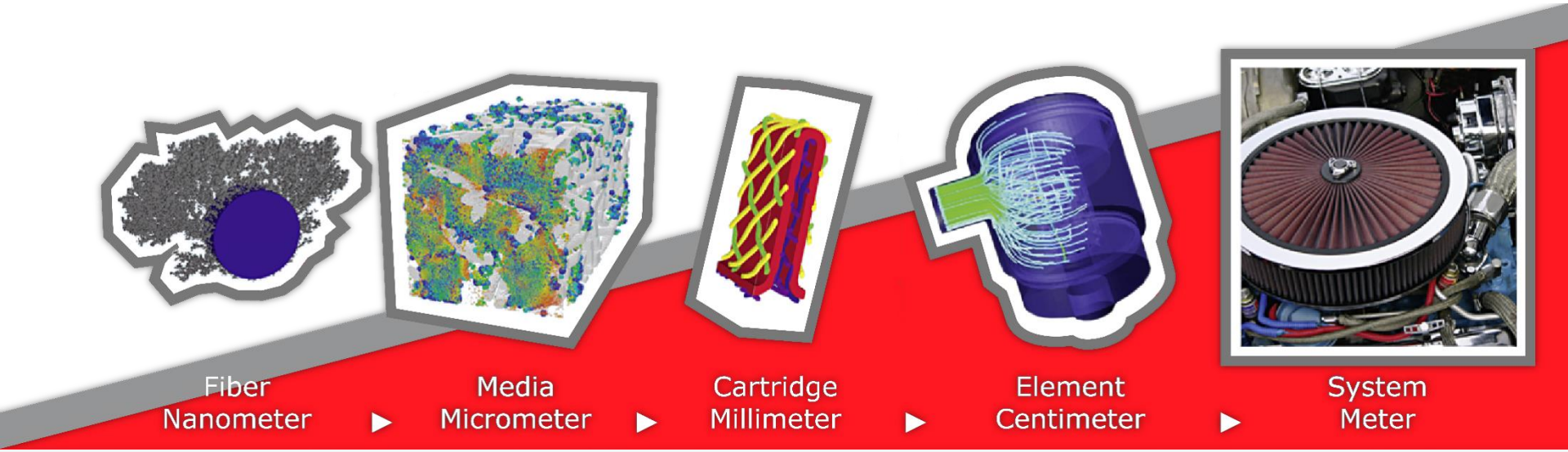
Consulting & Projects

Math2Market GmbH
Cooperation with Fraunhofer ITWM

”The migration of our research and technology into commercial software used to take ten or more years. [Through M2M], this transfer takes now only 2-3 years!“

Dr. Konrad Steiner Fraunhofer ITWM

Head of department “Flow and Material Simulation”



Math2Market GmbH
Industries

Filtration	Mostly automotive, filter media & filters
Personal Care	Wipes, Feminine Care, Baby Care
Electrochemistry	Fuel cell media & battery materials
Weaves and Paper	Paper forming and dewatering, Metal Wire Mesh
Composites	Mostly automotive, lightweight materials
Oil and Gas	Digital rock physics, digital sand control

Math2Market GmbH
GeoDict Material Engineering Workflow

I | Validation

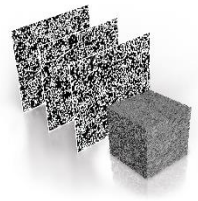
Validation of real world experiment data with the simulated experiment data from GeoDict for the material model design.

Have your material and validate it by

a) import your material to GeoDict as a CT scan

b) compute your material properties based on the CT scan in GeoDict and fit with experiments

c) create a material model and compute its properties to fit with the experiment



Yes

III | Verification

Manufactor your new material

Verify predicted properties of your new material by experiment

How can simulations help to improve a filter?

Step 1: Understand the existing filter material

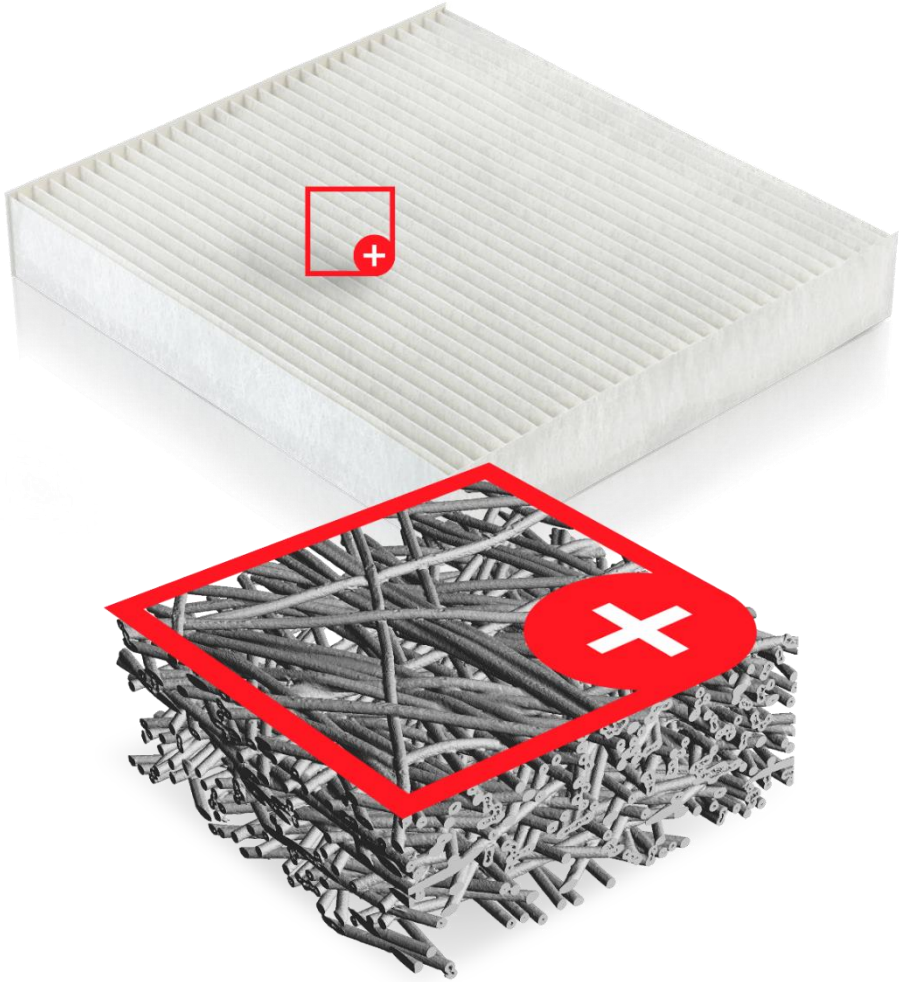
- CT Scan
- Simulations on CT Scan

Step 2: Create a model of the existing material

- Analyze CT Scan
- Create structure model
- Simulations on Structure model

Step 3: Modify the structure model

Sample Structure: Cabin Air Filter

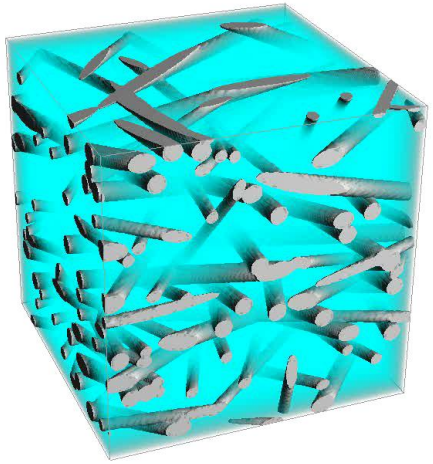


- Commercially available filter
- CT scan by service provider RJL Micro&Analytic

Step 1:

Understand the existing filter material

Characterize Materials



open and close porosity 开孔和闭孔孔隙率

pore size distribution 孔径分布

largest through pore 最大穿透粒径

bubble point 起泡点

surface area 表面积

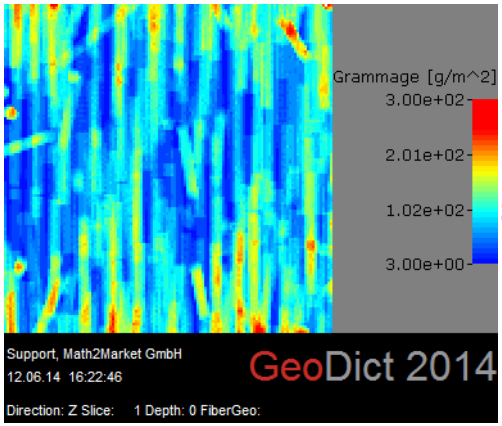
fiber diameter 纤维直径

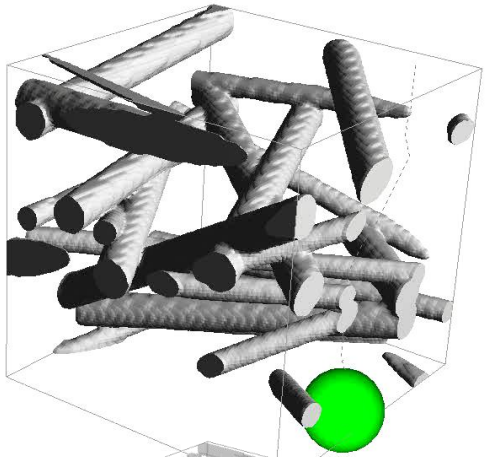
fiber orientation 纤维朝向

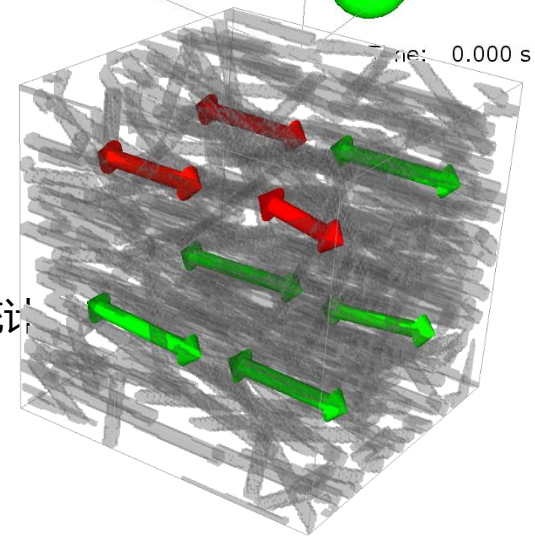
grain size distribution 颗粒尺寸分布

solid volume fraction statistics 固体体积比统计

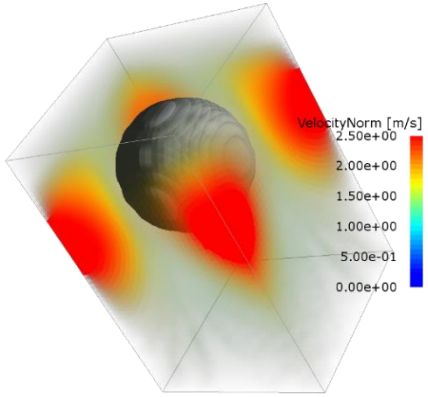
...







Characterize Properties



Permeability 渗透率

flow, pressure loss 流场，压降

acoustic absorption 声音吸收

large deformations 大变形

media scale filtration 过滤介质尺度的过滤

filter scale filtration 过滤器件尺度的过滤

elastic and plastic properties 弹性和塑性特征参数

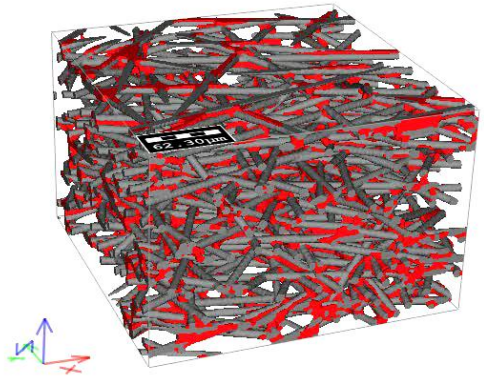
capillary pressure, 2-phase flow 毛细管压力，两相流

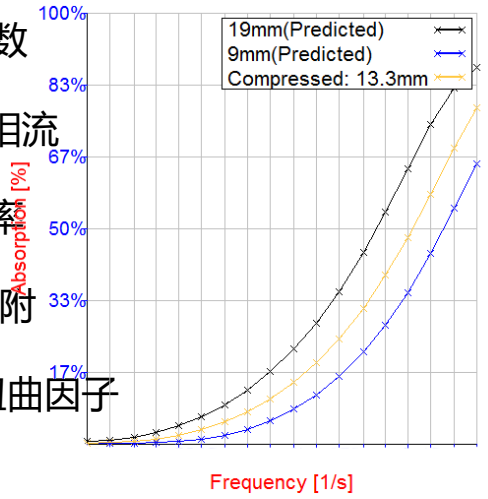
electrical & thermal conductivity 导电率和导热率

advection, diffusion, adsorption 平流、扩散、吸附

effective diffusivity, tortuosity factor 有效扩散率，扭曲因子

...





Determine Flow Rate or Pressure Drop

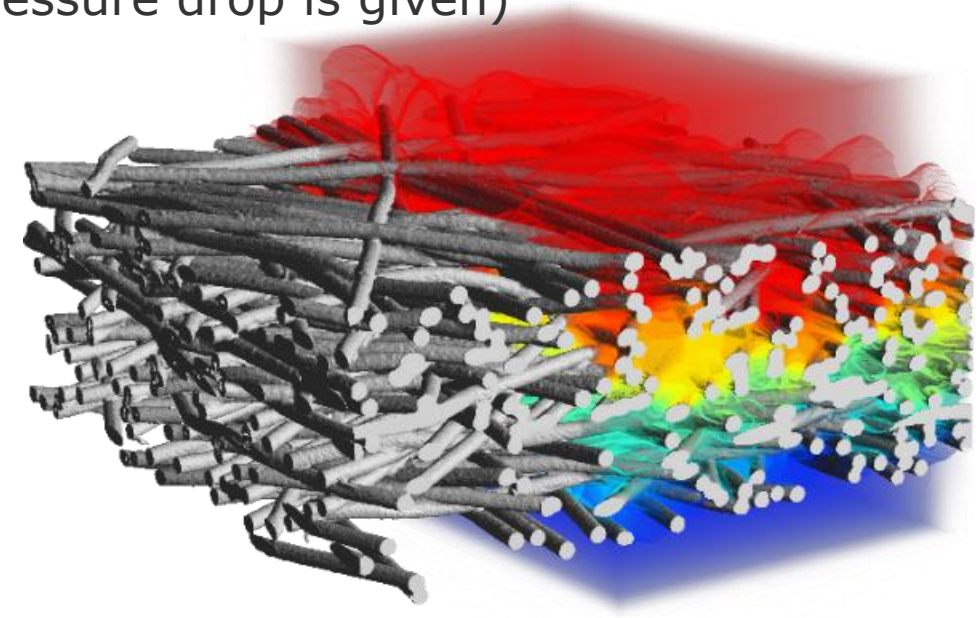
Stationary Navier-Stokes flow:

$-\mu\Delta\vec{u} + \rho(\vec{u}\cdot\nabla)\vec{u} + \nabla p = 0$ (momentum balance)

$\nabla\cdot\vec{u} = 0$ (mass conservation)

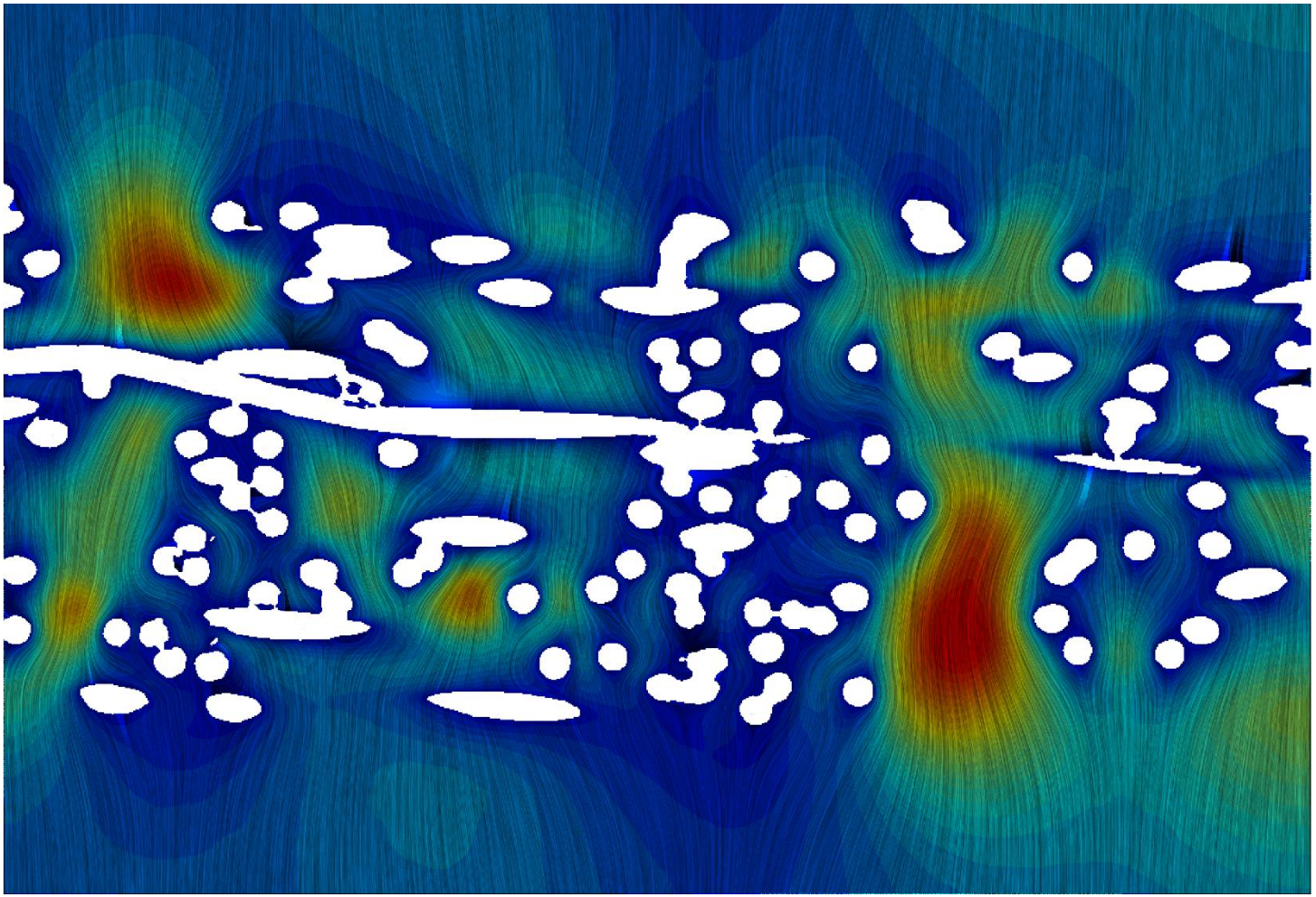
$\vec{u} = 0$ on Γ (no-slip on surface)

$P_{in} = P_{out} + const$ (pressure drop is given)



$\vec{u}$: velocity
p: pressure
μ: dynamic viscosity
ρ: fluid density

Result for Clean Cabin Air Filter Media (Flat Sheet): Pressure drop of 7.35 Pa at 0.1 m/s mean velocity



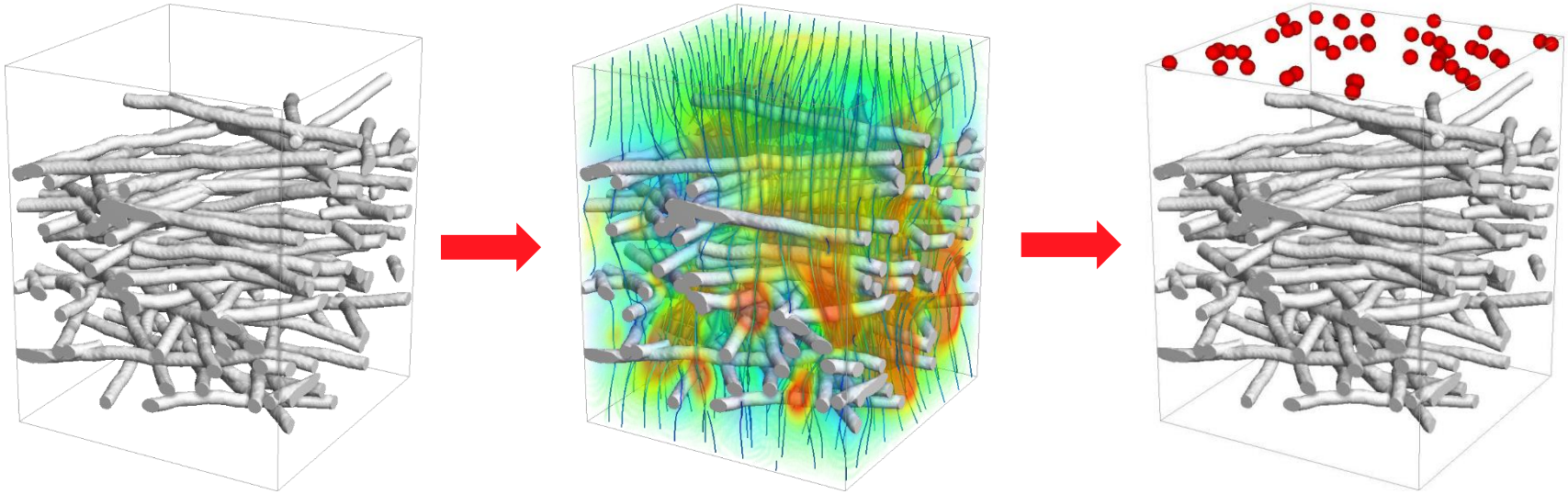
Filter Efficiency Simulations

Basic idea:

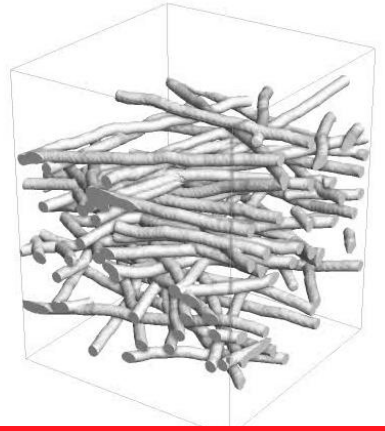
1. Filter media model
2. Determine flow field
3. Track particles (filtered or not?)

Result:

- Percentage of filtered particles



Filter Life Time simulations



1. Filter model

2. Flow field

3. Track particles

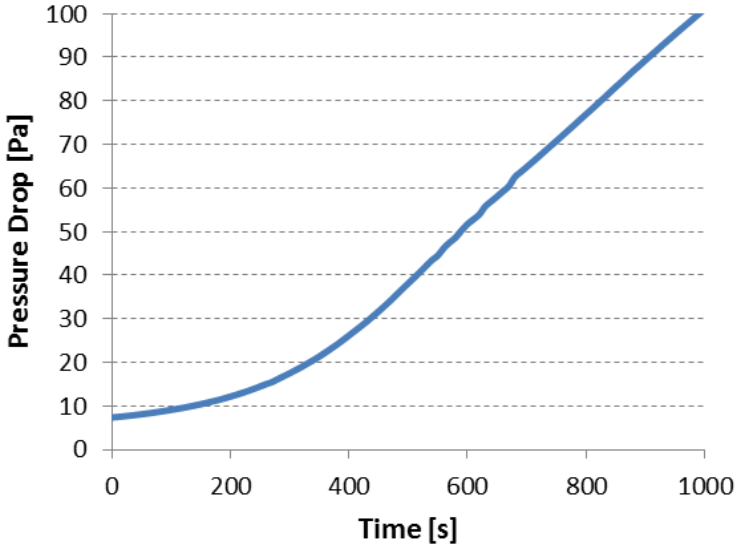
4. Deposit particles

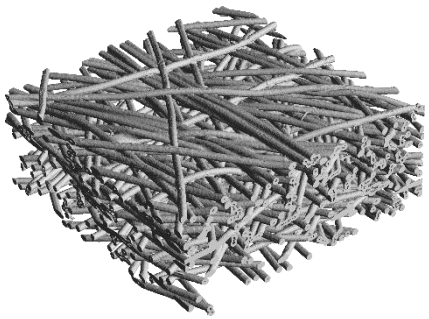
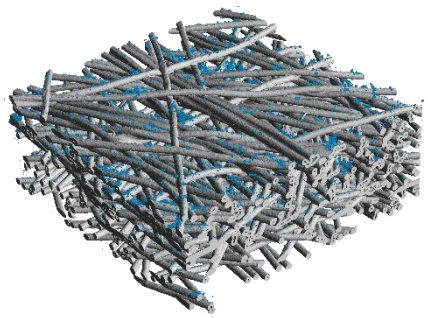
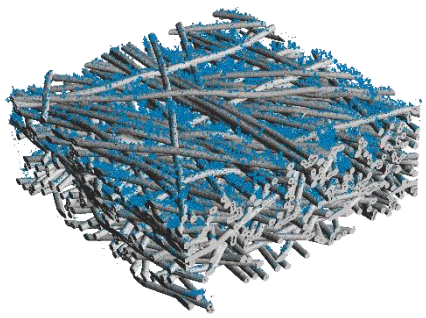
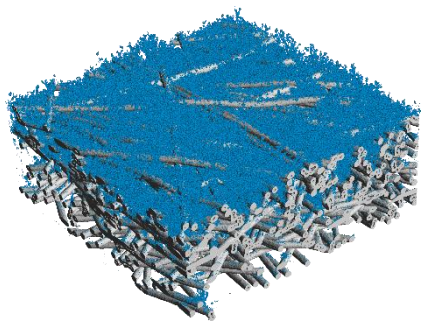
5. Flow field

6. Repeat ...

Cabin Air Filter - Life Time Simulation

Initial pressure drop	7 Pa
Pressure drop after 1000s	101 Pa
Total deposited dust after 1000s	93 g/m²
Total filter efficiency	93% (weigth)



Step 2:

Create a model of the existing material

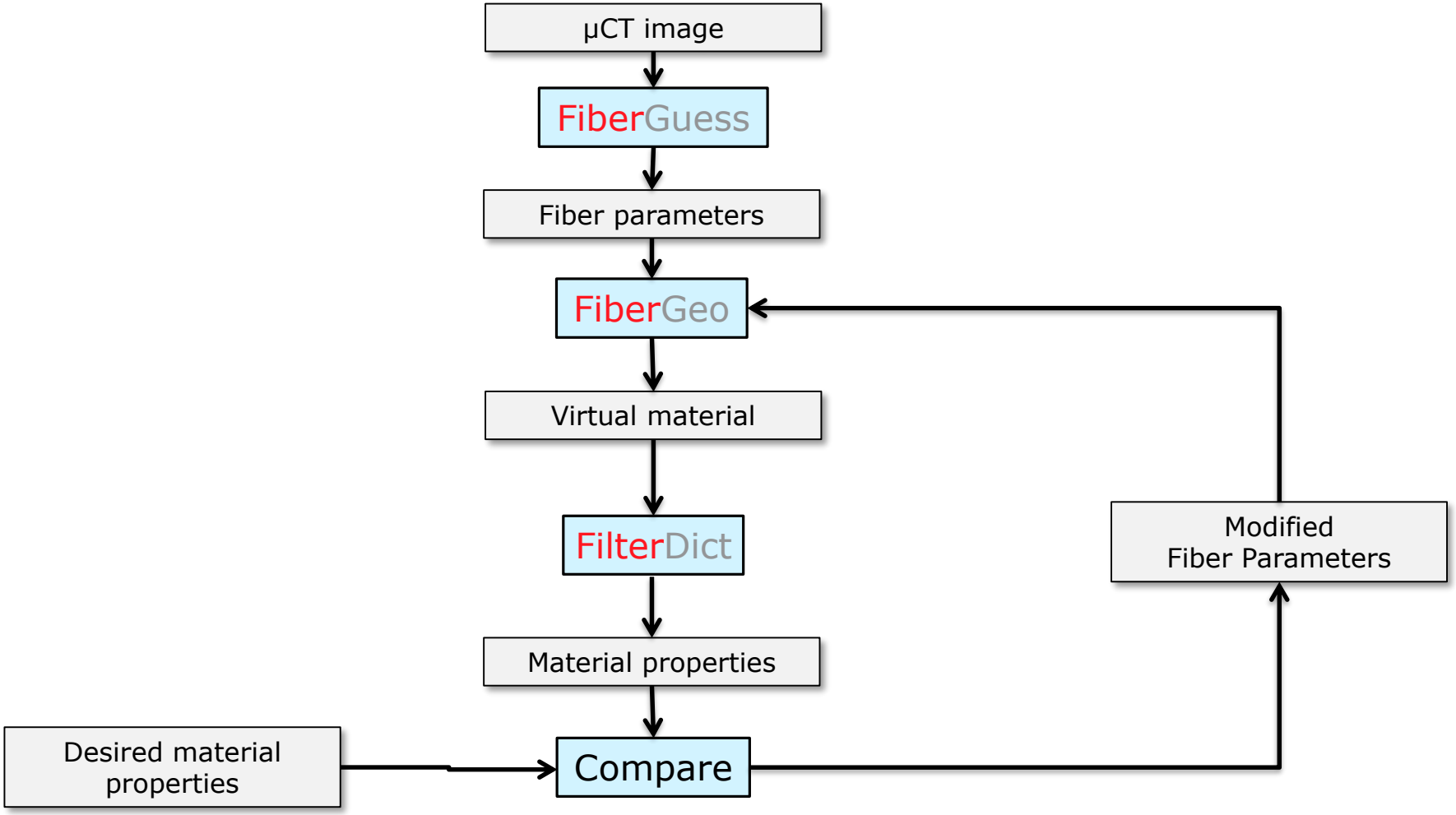
Creating a filter model

Why create a filter model?

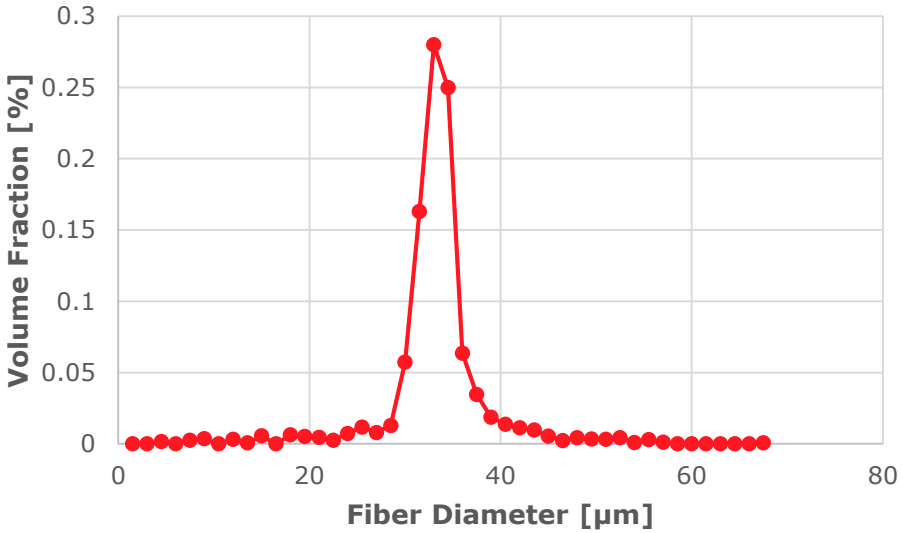
- A CT scan is an image!
  - It can only be changed voxel-by-voxel.
  - It is not possible to remove a fiber
  - It is not possible to change diameters or shape

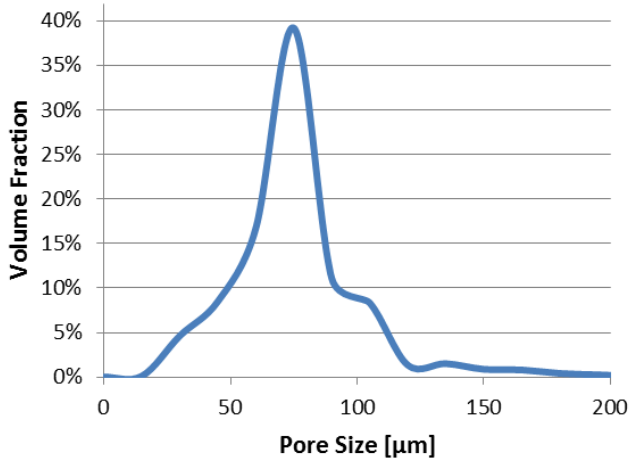
=> We need to “understand” the image!

GeoDict Workflow

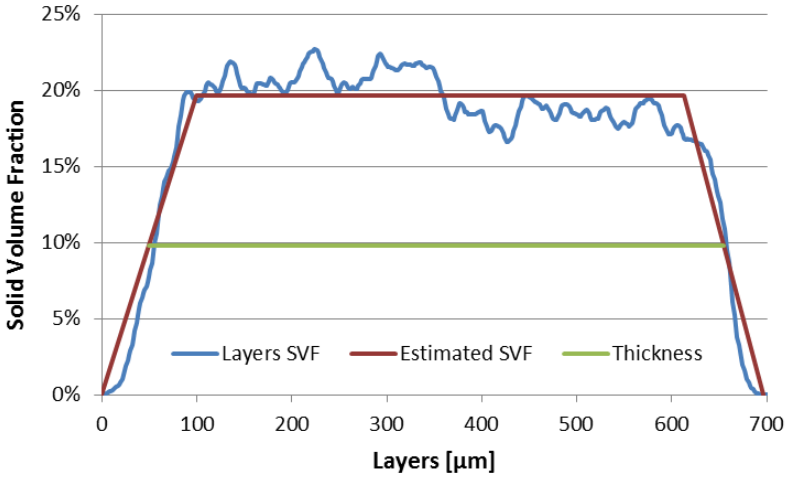


Geometric Analysis I:
Media Thickness, Porosity, Pore Sizes, Fiber Diameter



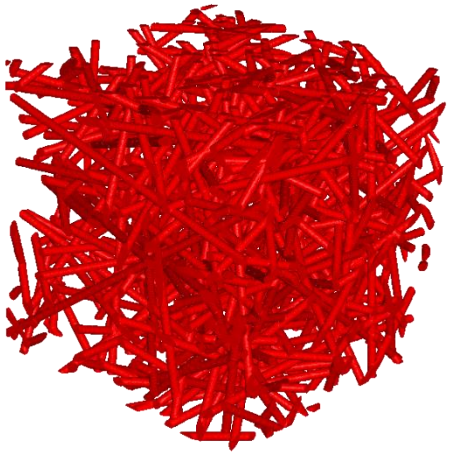


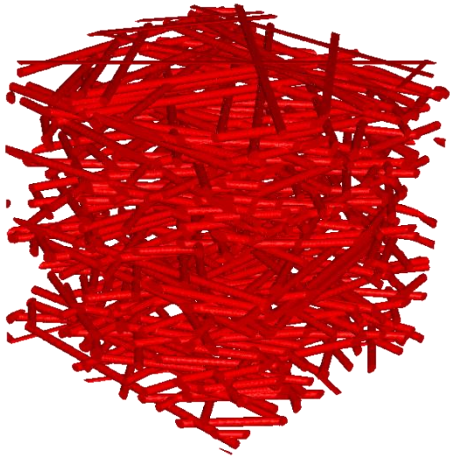
Average fiber diameter: 33.6 µm
Porosity: 80.4 %
Thickness: 605 µm



Geometric Analysis II: Fiber Orientation

How is fiber orientation measured?





0.33	0	0
0	0.33	0
0	0	0.33

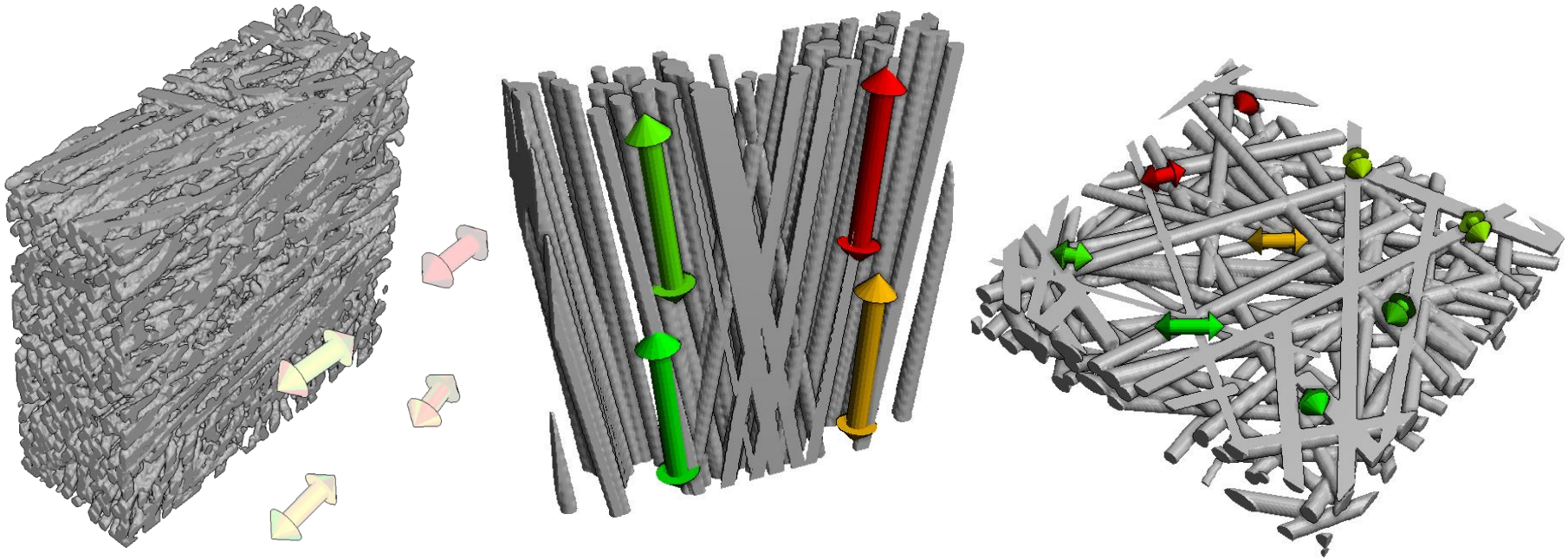
0.5	0	0
0	0.5	0
0	0	0

0.9	0	0
0	0.05	0
0	0	0.05

Orientation tensor describes probability of direction component.

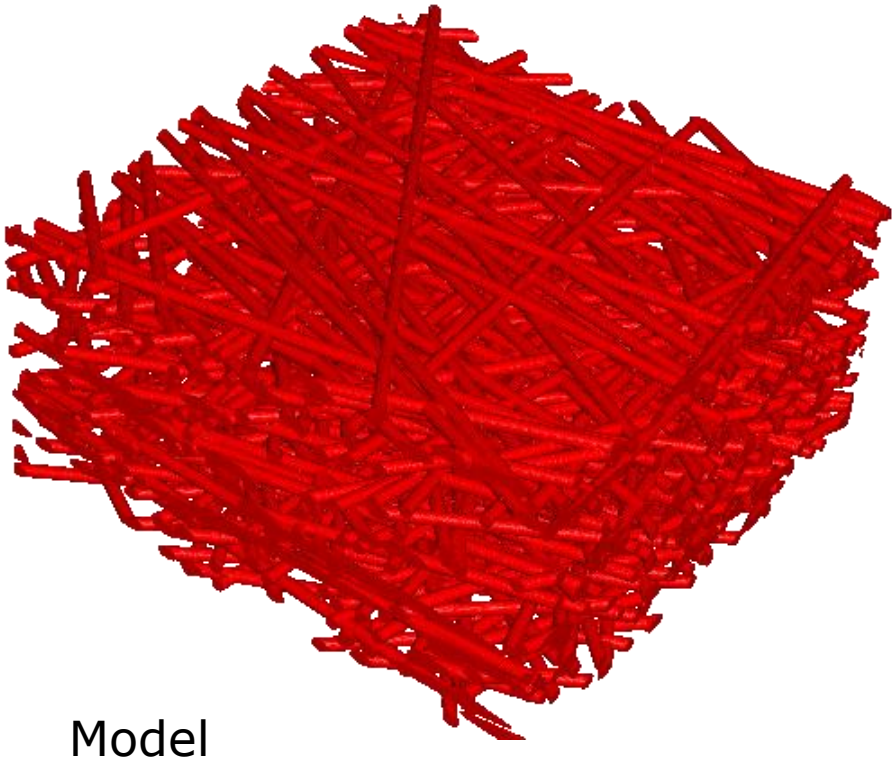
Orientation analysis - Visualization

- Arrows indicate the main fiber orientation for each block
  - Long arrows correspond to strong preference in orientation
  - Compare homogeny material (left) with material with two main fiber directions (middle) and isotropic in plane (right)



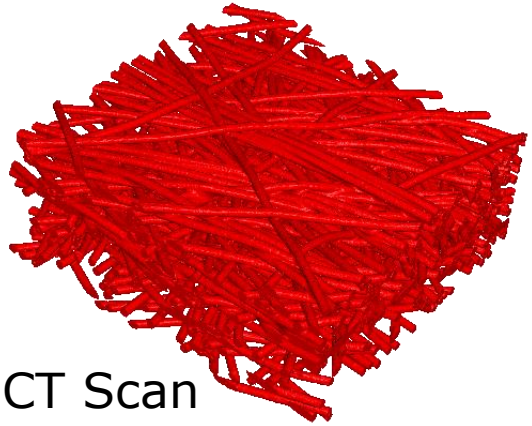
Comparison of CT Scan and Model

CT Scan

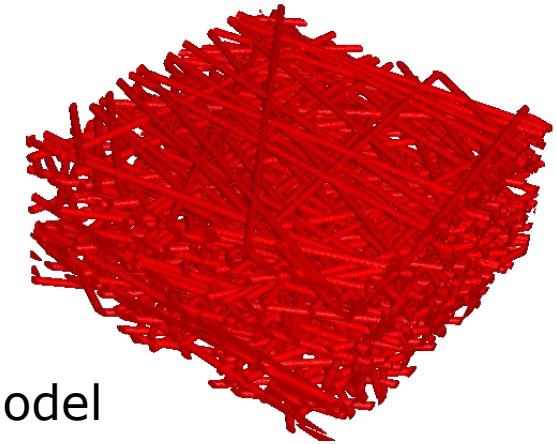


Model

Comparison of CT Scan and Model



CT Scan



Model

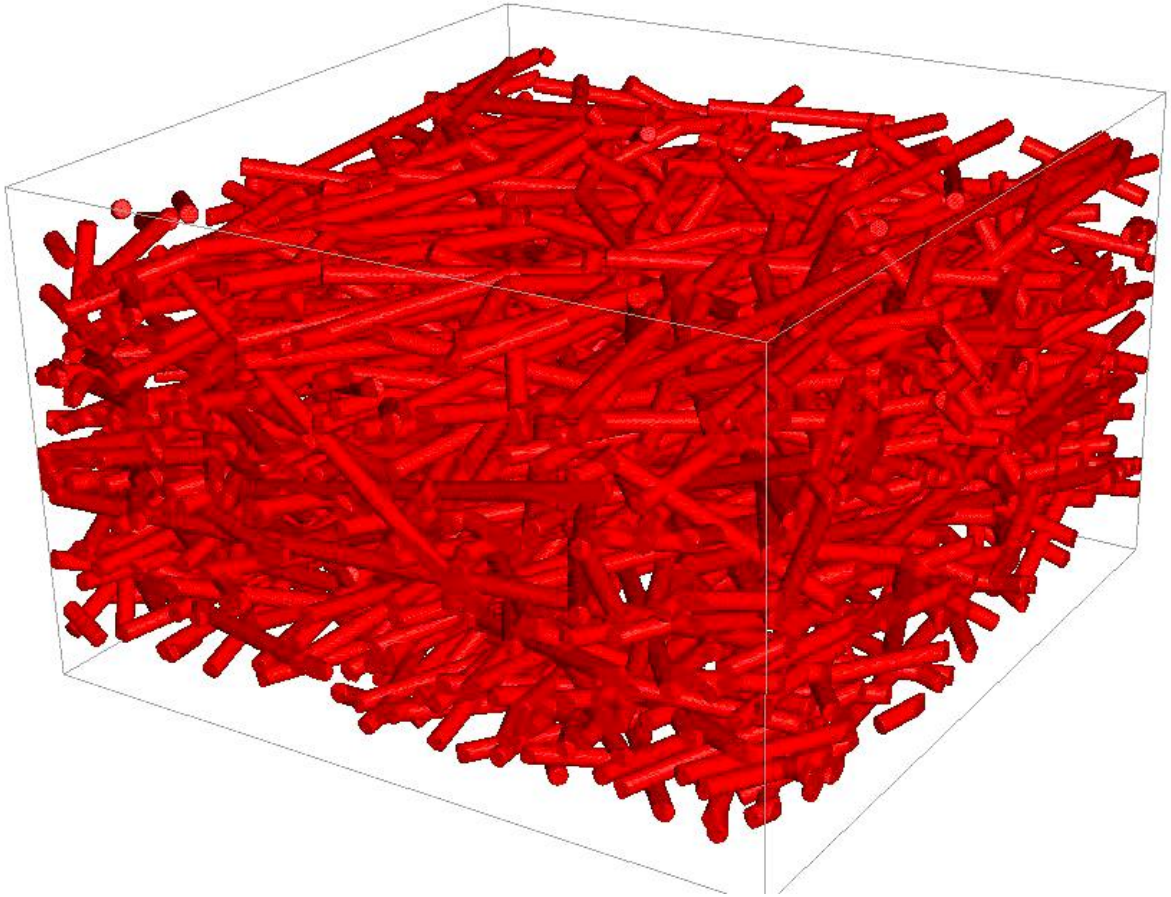
Input parameters found by CT-Scan analysis:

- media thickness
- porosity
- fiber diameter
- in-plane anisotropy

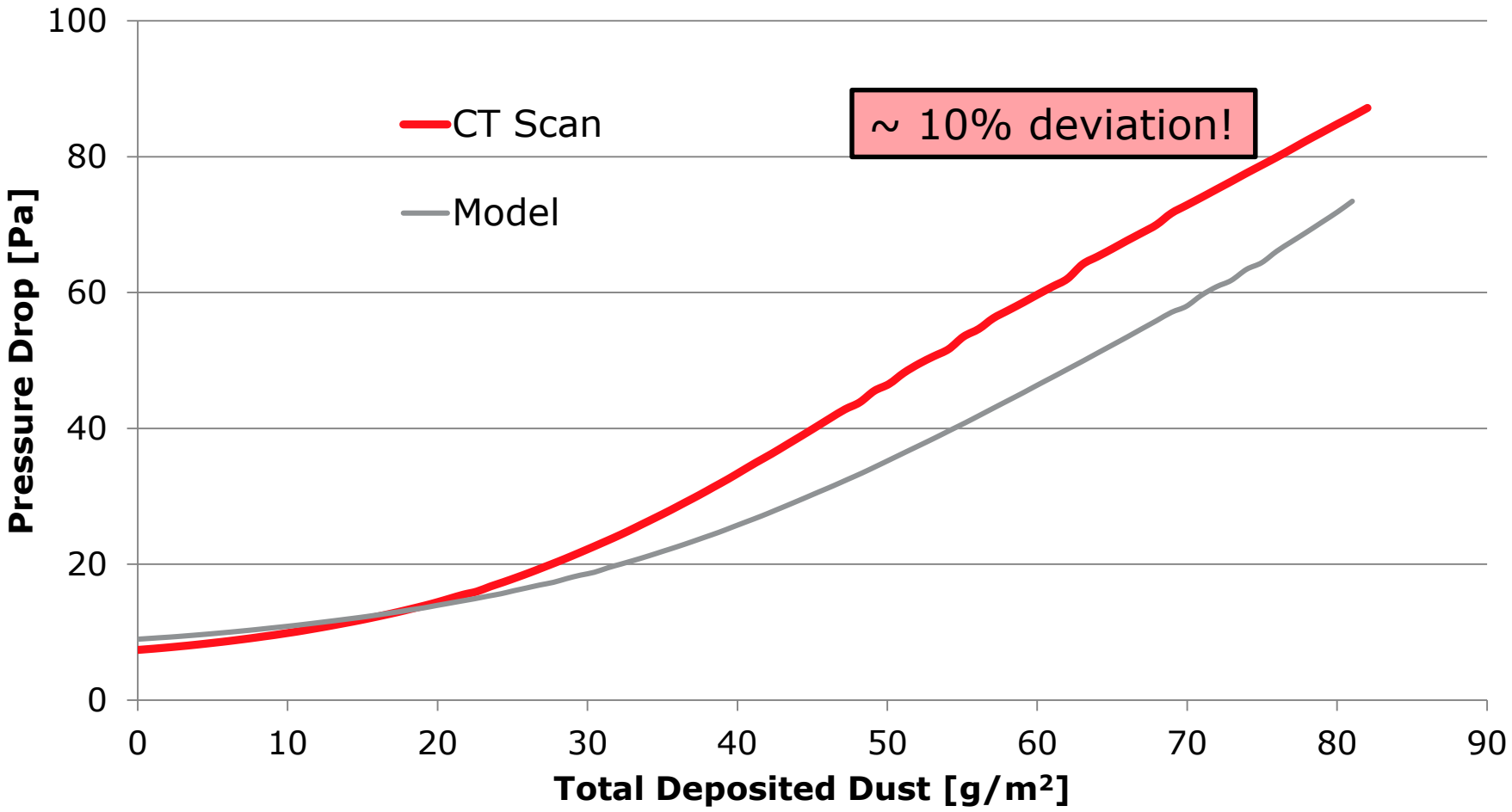
Input parameters taken from assumptions:

- straight fibers
- fibers oriented in-plane
- homogeneous distribution
- circular cross section

Filter Life Time

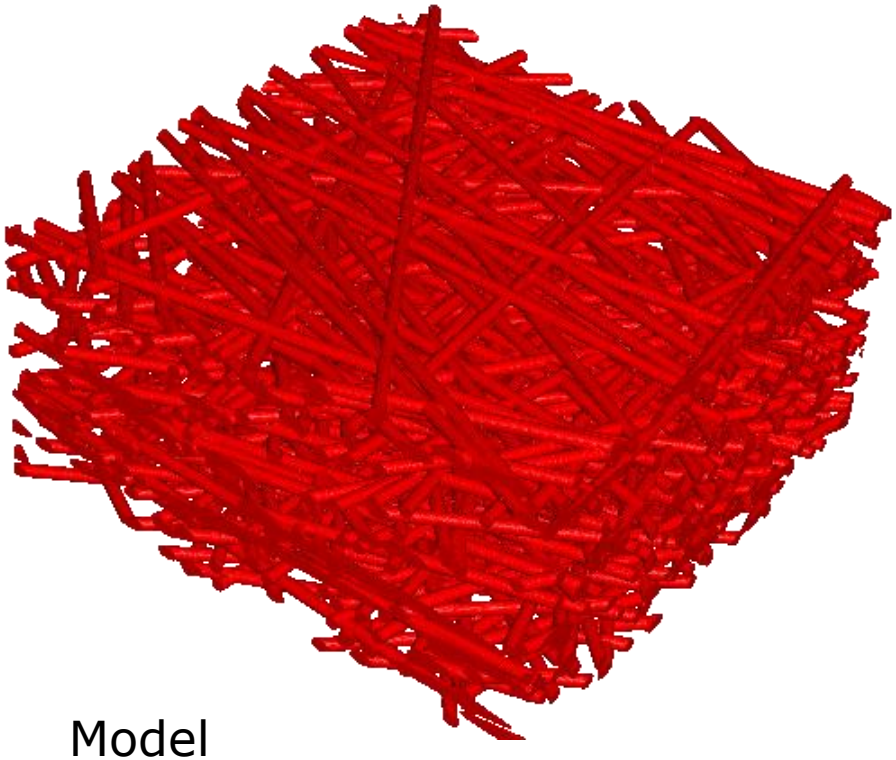


Filter Life Time Simulation
Comparison CT Scan vs Model



Comparison of CT Scan and Model

CT Scan



Model

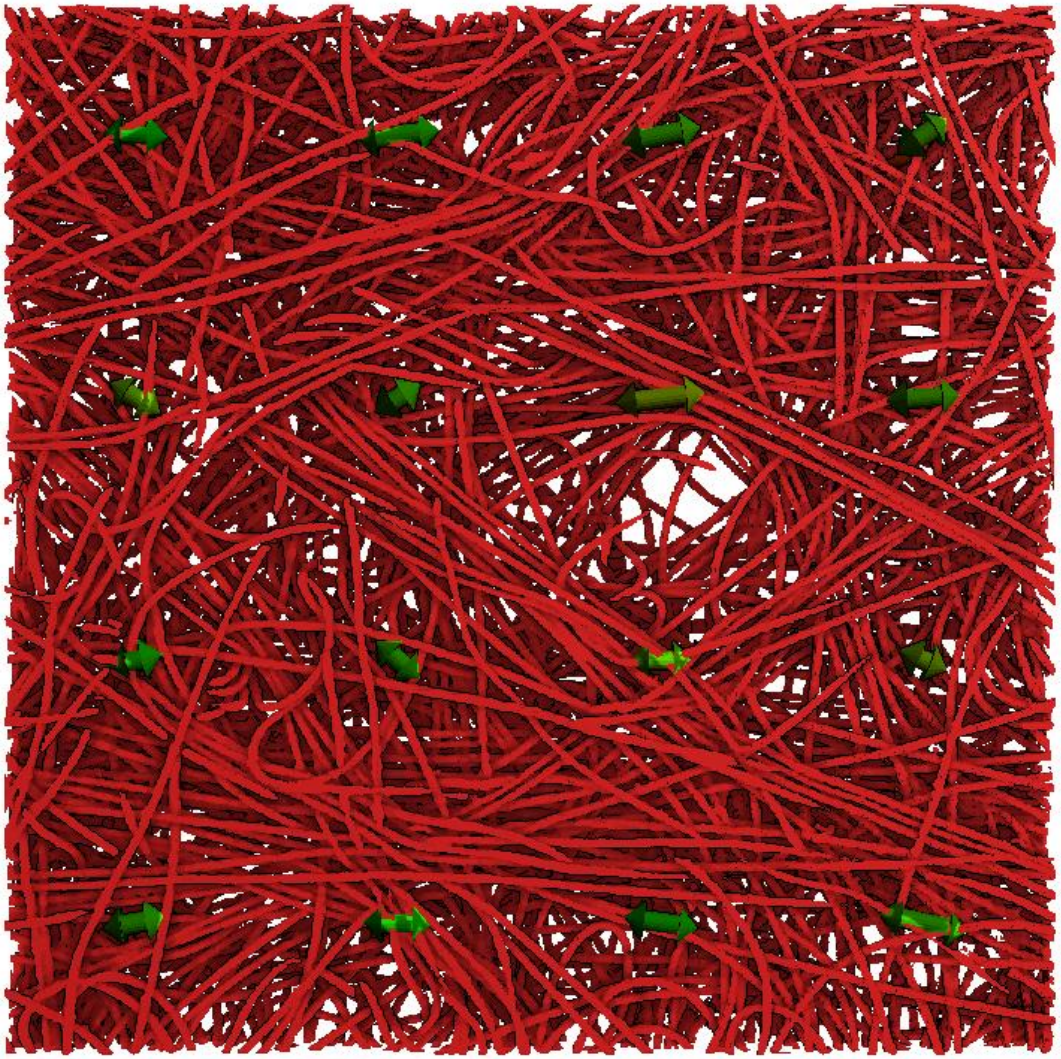
Fiber Curvature and Curliness

In many applications, materials consist of curved fibers

- Nonwoven
- GDL (fuel cells)
- Insulation

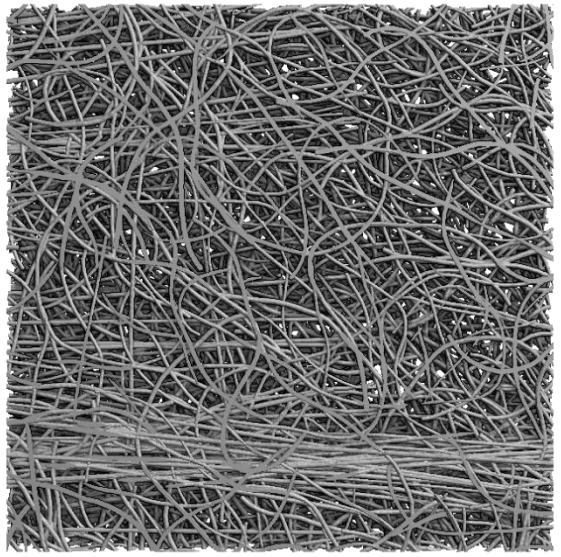
To create an accurate model from a CT scan, one needs curvature and curliness parameters

Curvature and Curliness - example

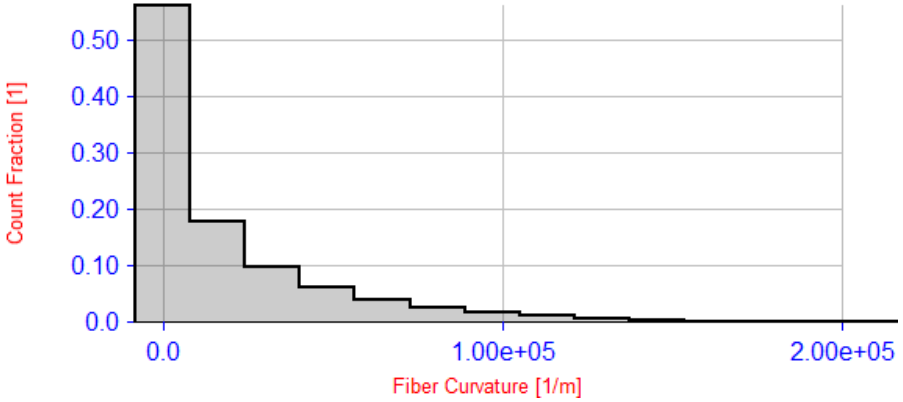


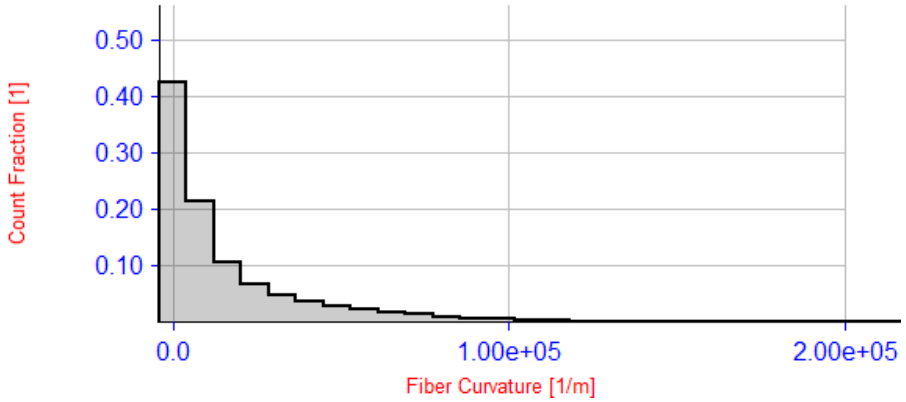
Using estimated parameters to generate a Structure

Original Structure



Generated Structure



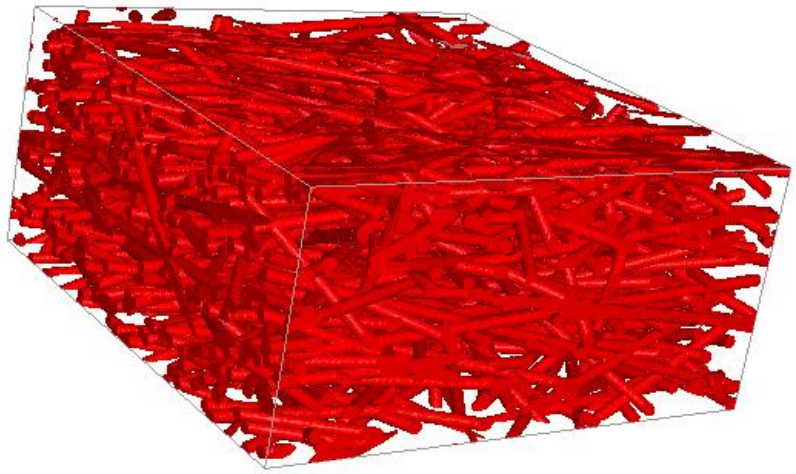


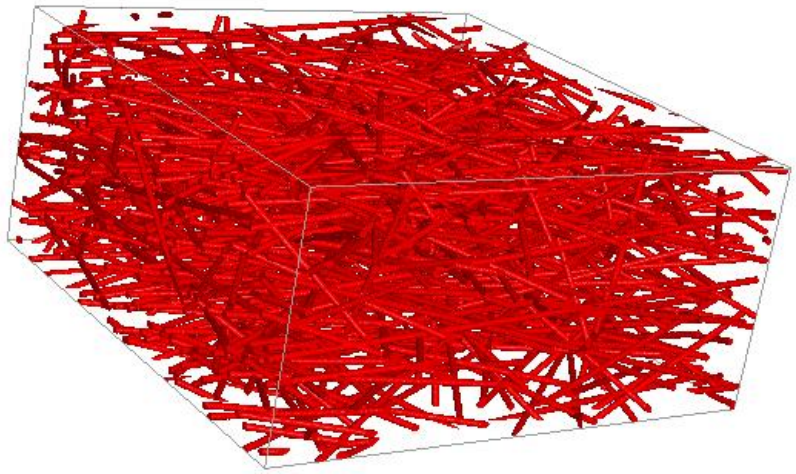
Step 3:

Modify the structure model

Possibilities in GeoDict to Vary the Structure Model

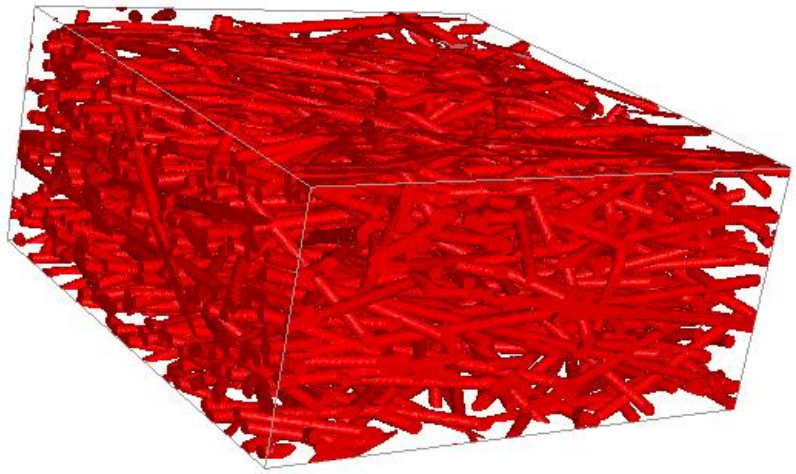
1. Fiber diameter

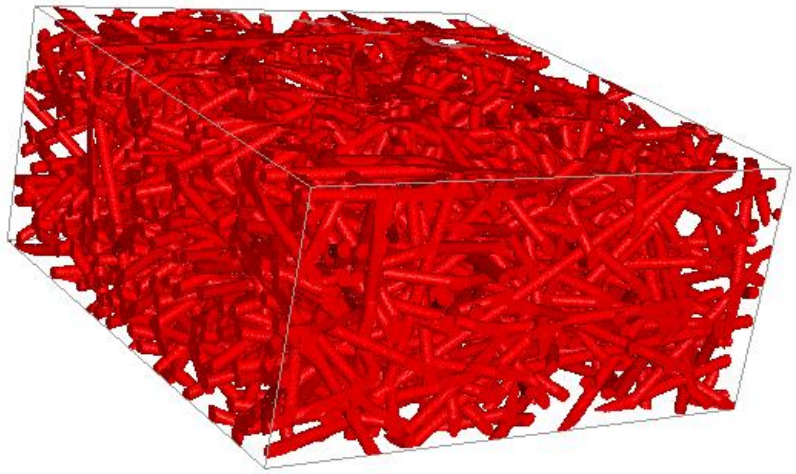




Possibilities in GeoDict to Vary the Structure Model

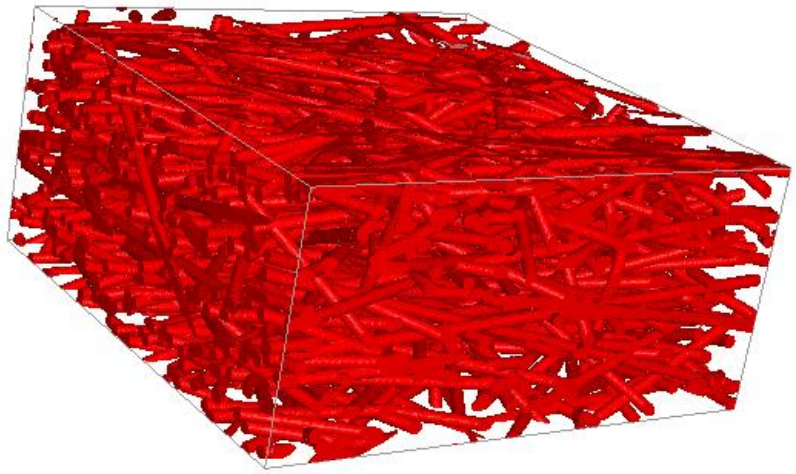
2. Fiber orientation

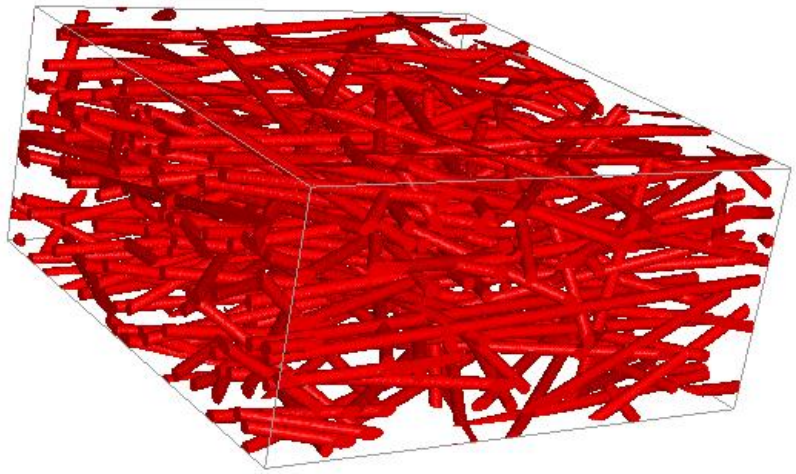




Possibilities in GeoDict to Vary the Structure Model

3. Porosity

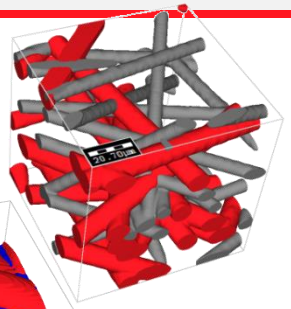


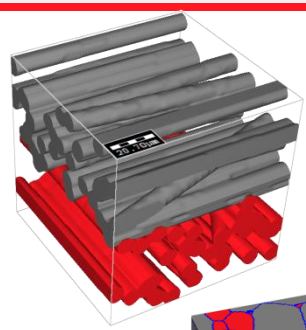


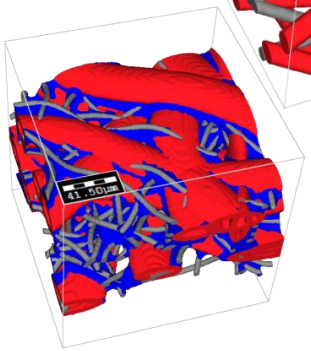
Possibilities in GeoDict to Vary the Structure Model

4. Fiber cross sectional shape
5. Curved fibers instead of straight fibers
6. Density gradient in through-plane direction
7. Media thickness
8. ……

Porous Media Models







Nonwovens 非织造结构

fiber reinforced composites 纤维加强的复合材料

papers 纸张

ceramic materials 陶瓷材料

Rocks 岩石

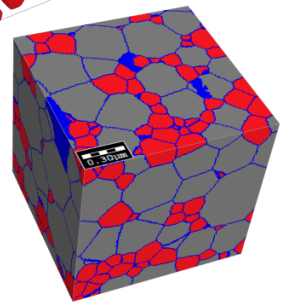
dense (sphere) packing 球状填充

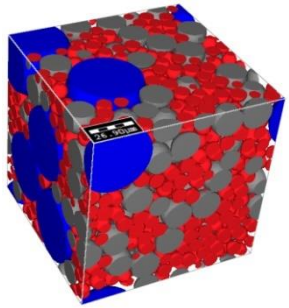
woven materials 织造材料

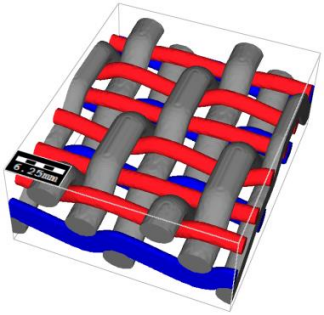
Foams 泡沫

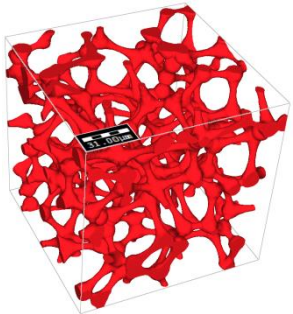
Sponges 海绵

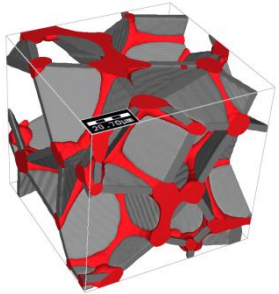
regular materials 规则材料











Summary

- GeoDict is the complete software solution for multi-scale 3D image processing, visualization, simulation-driven property characterization, material development, and process optimization.
- The workflow of new material design cycle with GeoDict is introduced, aiming at modeling structure automatically from CT-scan.
- The function works for straight fibers with circular cross section, and still on progress for curved fibers with circular cross section.

Thank you!

GeoDict

The Digital Material Laboratory

Standard Edition

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