

# Design and optimization of fibrous filter media using life-time simulations

International Advanced Filtration Technology Congress  
Taipei, Taiwan, May 2-4, 2018

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# Location and Contact

**MATH**  
2 MARKET

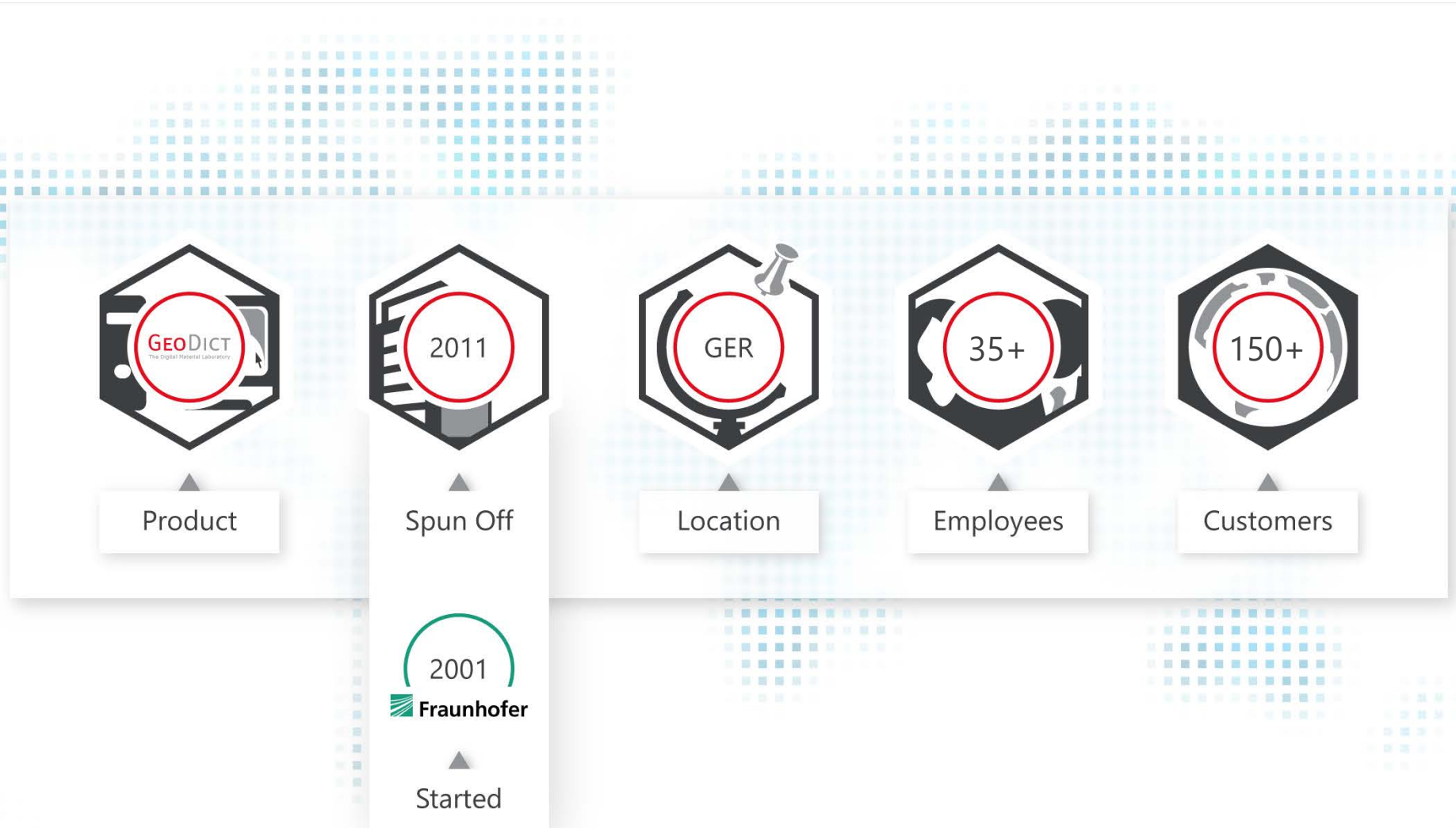
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# SELECTED CLIENTS

# MATH 2 MARKET



Wir leben Autos.



WORLD WIDE WEAVE



**BOSCH**



**HAVER & BOECKER**



Karlsruher Institut für Technologie



**TOYOTA**



**MANN+  
HUMMEL**



**VOLKSWAGEN**  
AKTIENGESELLSCHAFT



FORSCHUNGSZENTRUM



Duale Hochschule  
Baden-Württemberg



EUROPEAN COMMISSION

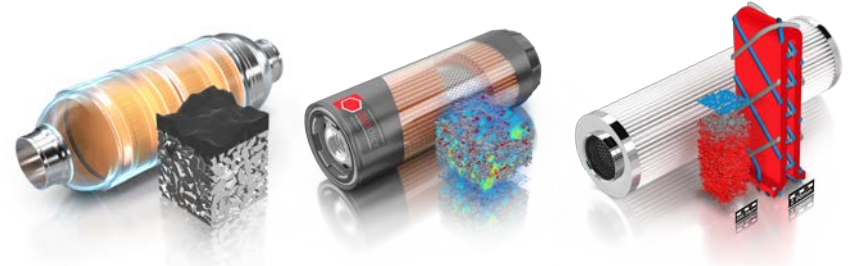


# GeoDict® Solutions for ...

**MATH**  
2 MARKET

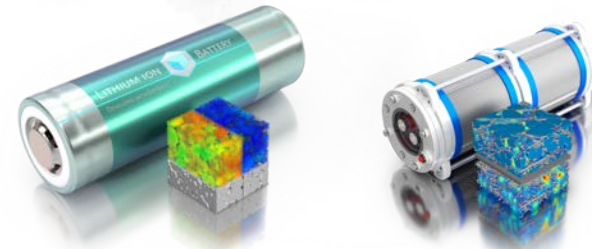
## Filtration

Mostly automotive,  
filter media & filters  
for water, sludge, oil,  
air and fuel



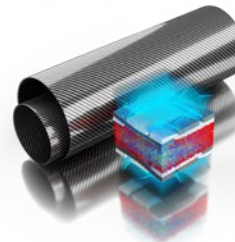
## Electrochemistry

Fuel cell media &  
battery materials,  
catalyst materials



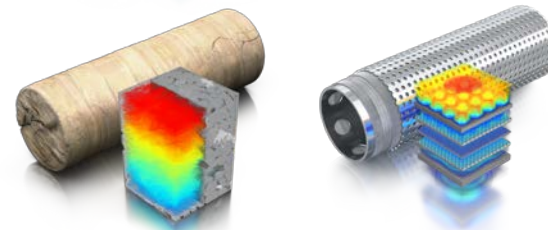
## Composites

CFRP, GFRP, mostly  
automotive,  
lightweight materials

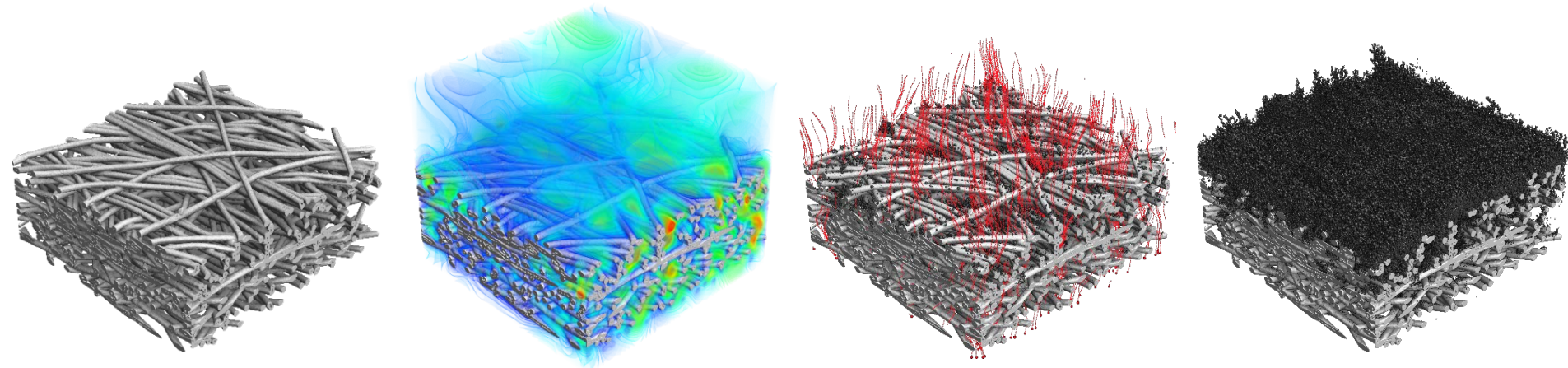


## Digital Rock Physics

Digital rock physics,  
digital sand control

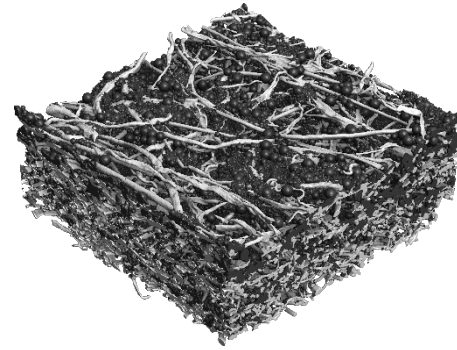
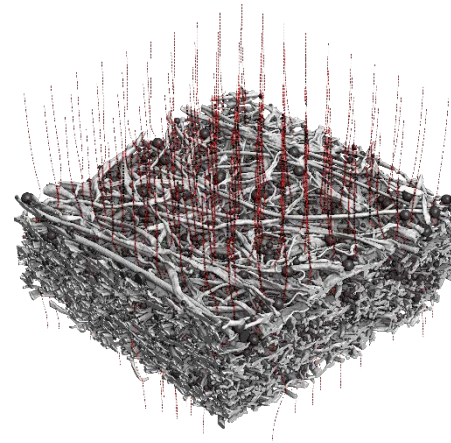
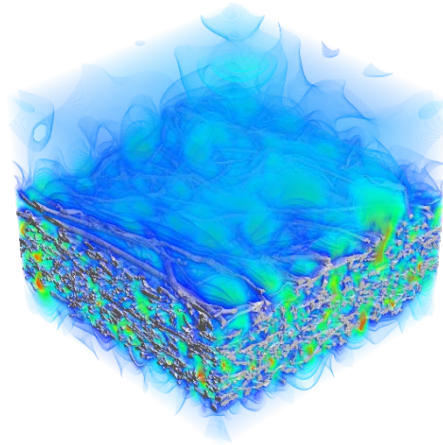
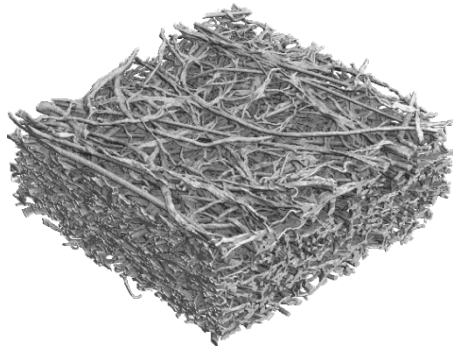


# GeoDict for Filtration: Gas Filtration Portfolio



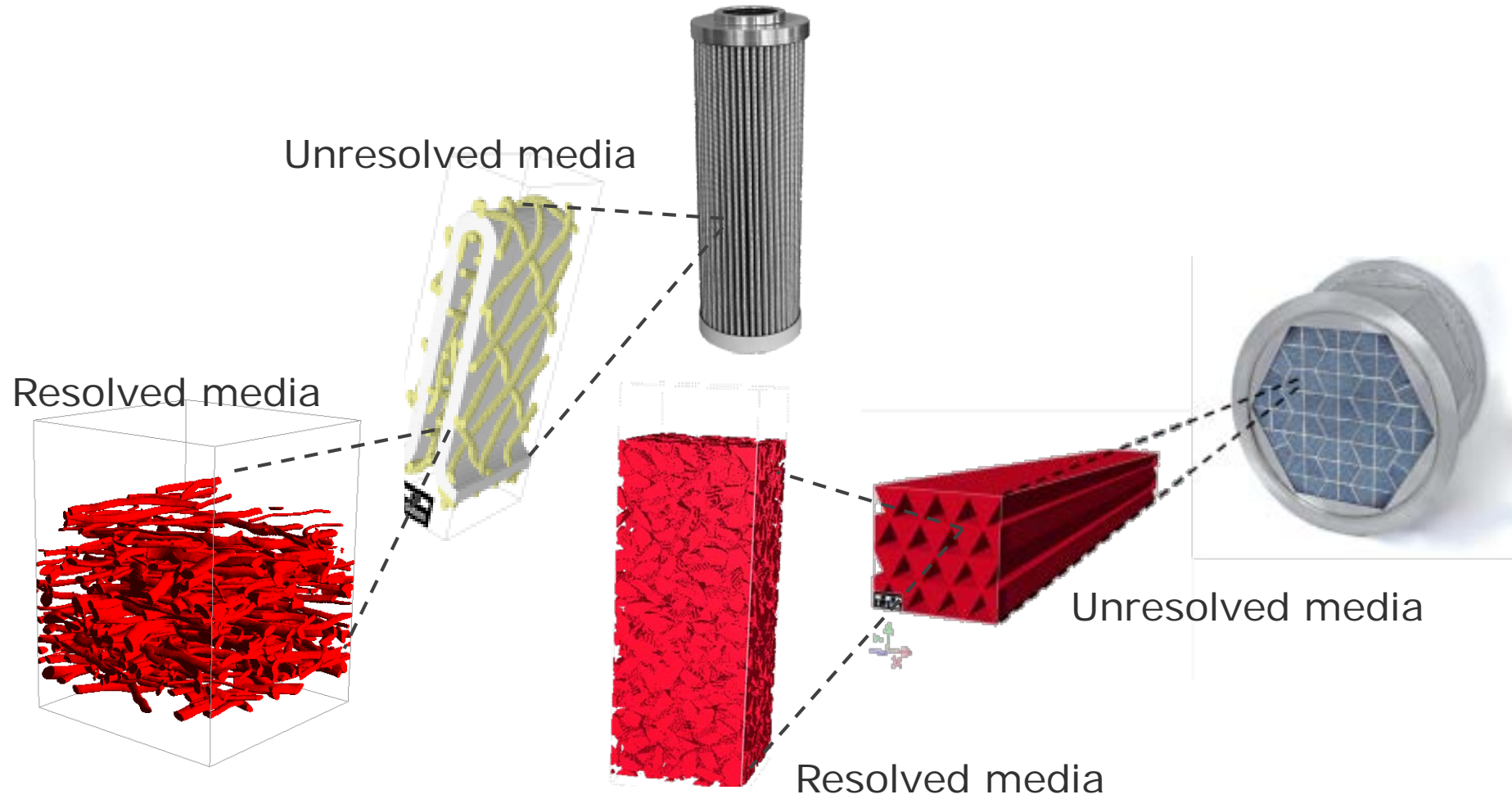
Filter Media	Clean Filter Parameters	Gas Filtration Experiments	Gas Filtration Results
<ul style="list-style-type: none"> <li>■ Nonwoven fabrics</li> <li>■ Woven fabrics</li> <li>■ Foams</li> <li>■ Sintered ceramics</li> <li>■ Pleats and support meshes</li> </ul>	<ul style="list-style-type: none"> <li>■ Media thickness</li> <li>■ Fiber diameters</li> <li>■ Fiber orientation</li> <li>■ Grammage</li> <li>■ Pore size distribution</li> <li>■ Bubble point</li> <li>■ Percolation path</li> </ul>	<ul style="list-style-type: none"> <li>■ Single pass tests</li> <li>■ Diesel soot test dust</li> <li>■ Standard aerosol test dusts</li> </ul>	<ul style="list-style-type: none"> <li>■ Initial pressure drop</li> <li>■ Pressure drop evolution</li> <li>■ Initial filter efficiency</li> <li>■ Fractional efficiencies</li> <li>■ Filter capacity</li> <li>■ Filter class</li> <li>■ Most penetrating particle size</li> </ul>

# GeoDict for Filtration: Liquid Filtration Portfolio



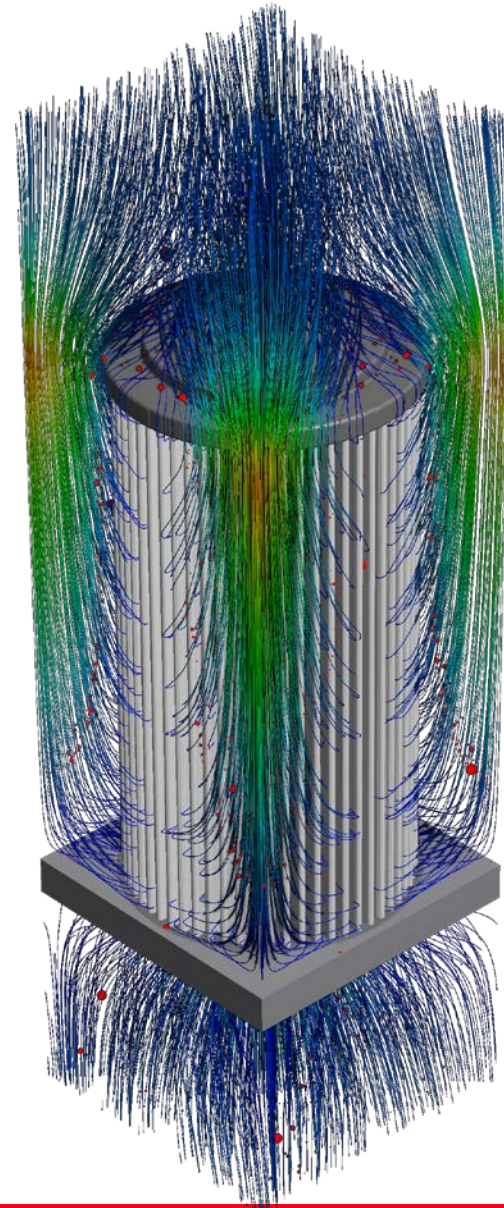
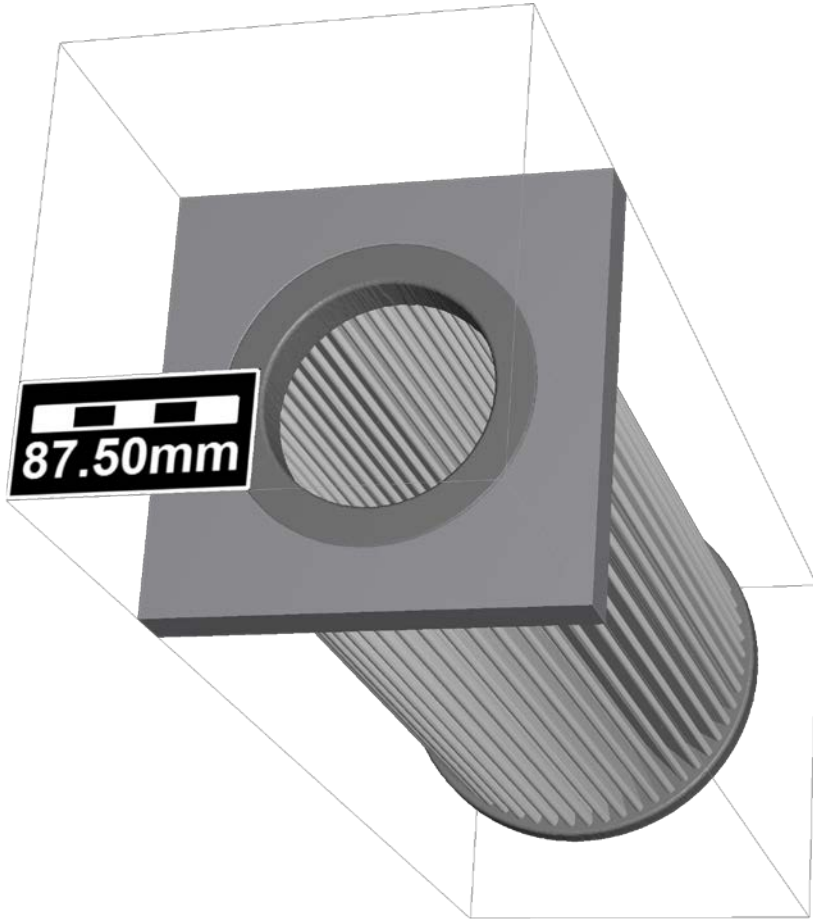
Filter Media	Clean Filter Parameters	Liquid Filtration Experiments	Liquid Filtration Results
<ul style="list-style-type: none"> <li>■ Nonwoven fabrics</li> <li>■ Woven fabrics</li> <li>■ Foams</li> <li>■ Membranes</li> <li>■ Metal wire meshes</li> <li>■ Pleats &amp; support meshes</li> </ul>	<ul style="list-style-type: none"> <li>■ Media thickness</li> <li>■ Fiber diameters</li> <li>■ Fiber orientation</li> <li>■ Grammage</li> <li>■ Pore size distribution</li> <li>■ Bubble point</li> <li>■ Percolation path</li> </ul>	<ul style="list-style-type: none"> <li>■ Multi pass tests</li> <li>■ Standard test dusts</li> </ul>	<ul style="list-style-type: none"> <li>■ Initial pressure drop</li> <li>■ Pressure drop evolution</li> <li>■ Initial filter efficiency</li> <li>■ Fractional efficiencies</li> <li>■ Filter capacity</li> <li>■ Filter class</li> <li>■ Filter clogging behavior</li> </ul>

# Simulate filtration at different scales



# Filter Element: ImportGeo, FlowDict, FilterDict

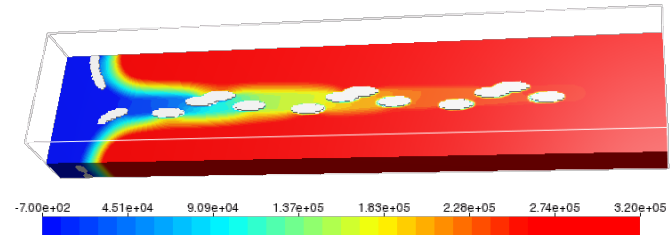
**MATH**  
2 MARKET



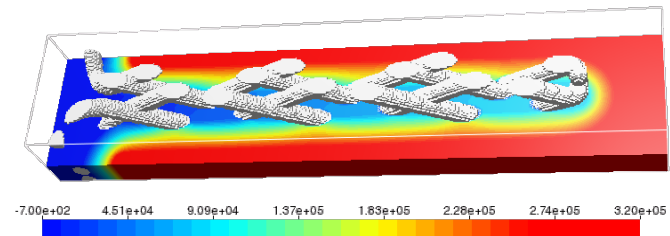
# Meso-scale: Optimized hydraulic filter

- Same pleat count
- Vary channel width by weave pattern & wire diameter

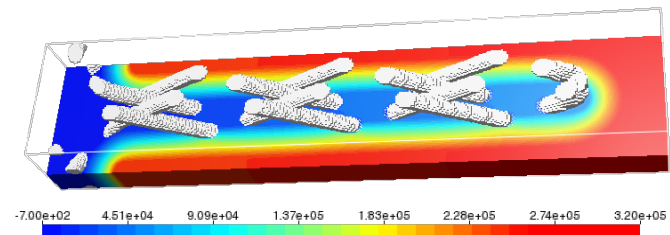
Trying different parameters, the pressure drop could be lowered by more than 35%, by reducing the pressure loss along the outflow channel.



Narrow Channel: 4 bar



Thick Wire: 3.1 bar



Thin Wire: 2.7 bar

# Digital Material Design

**MATH**  
2 MARKET

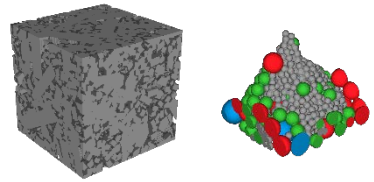
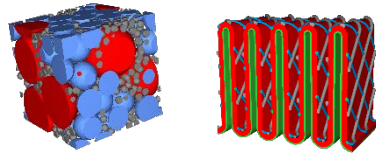
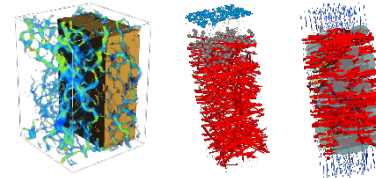


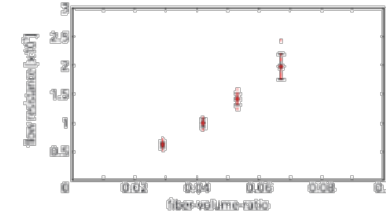
Image analysis



Models of microstructures



Microstructure simulation



Macroscopic material parameters

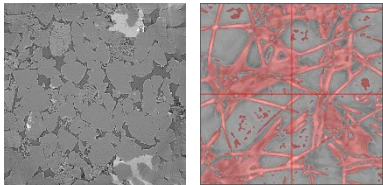
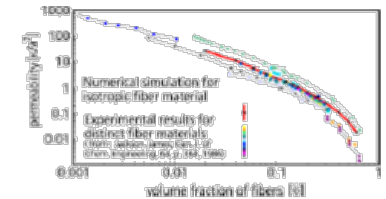


Image acquisition

Change Geometry

Material Property



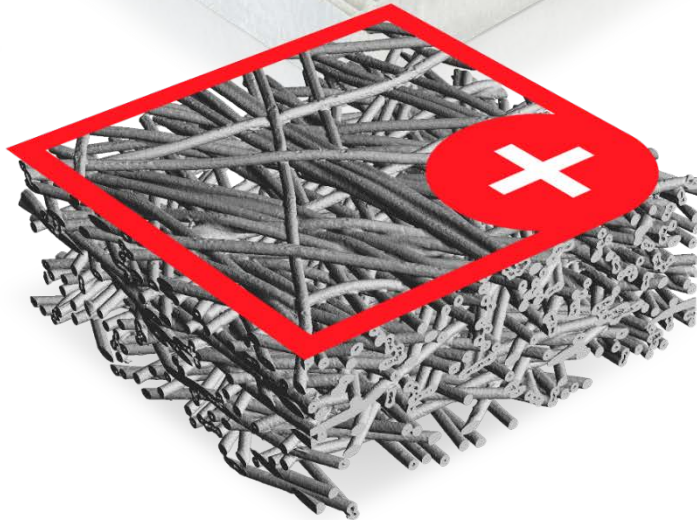
Experimental verification



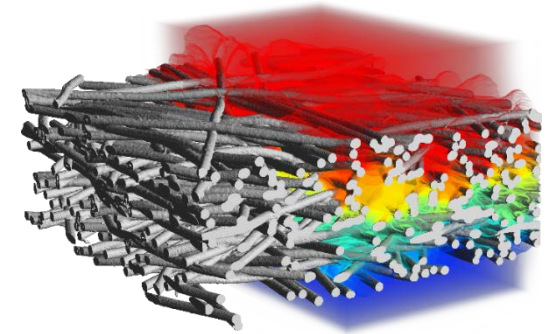
Development of Materials



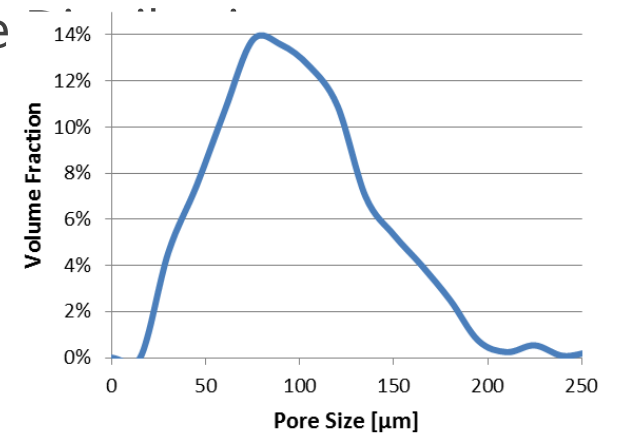
# $\mu$ CT-scan of cabin air filter sample



## ■ Flow and pressure drop

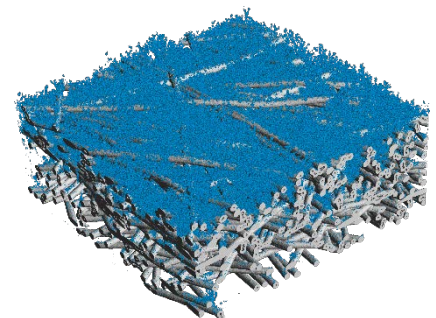
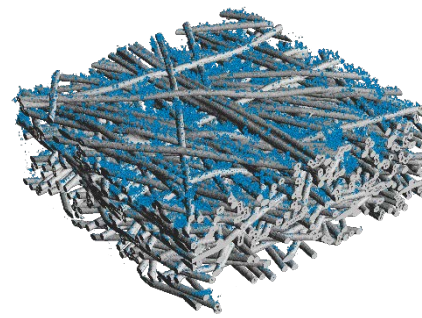
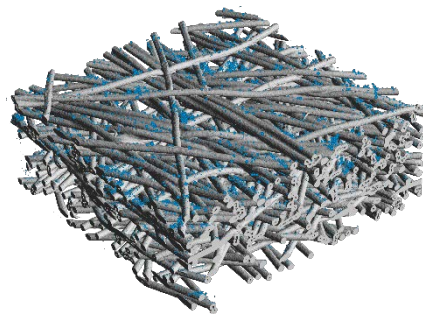
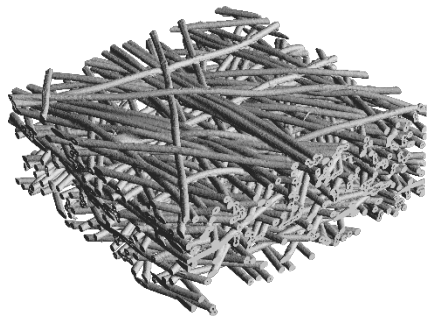
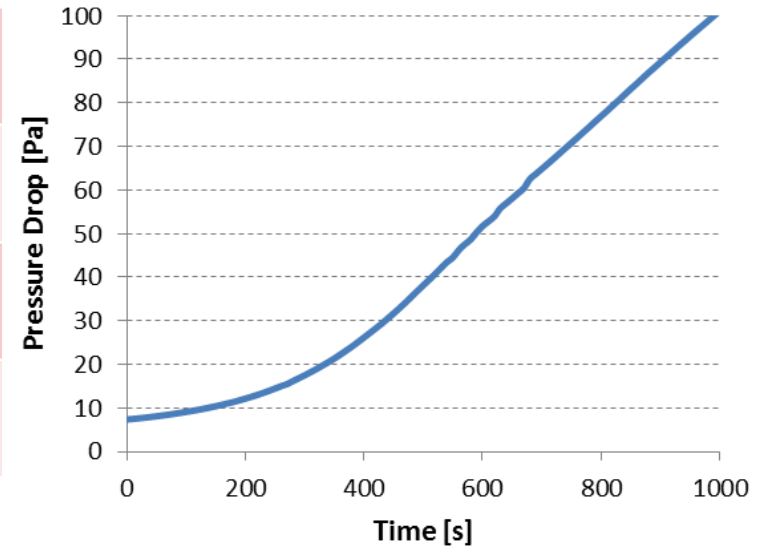


## ■ Pore Size



# Filter Life Time simulation

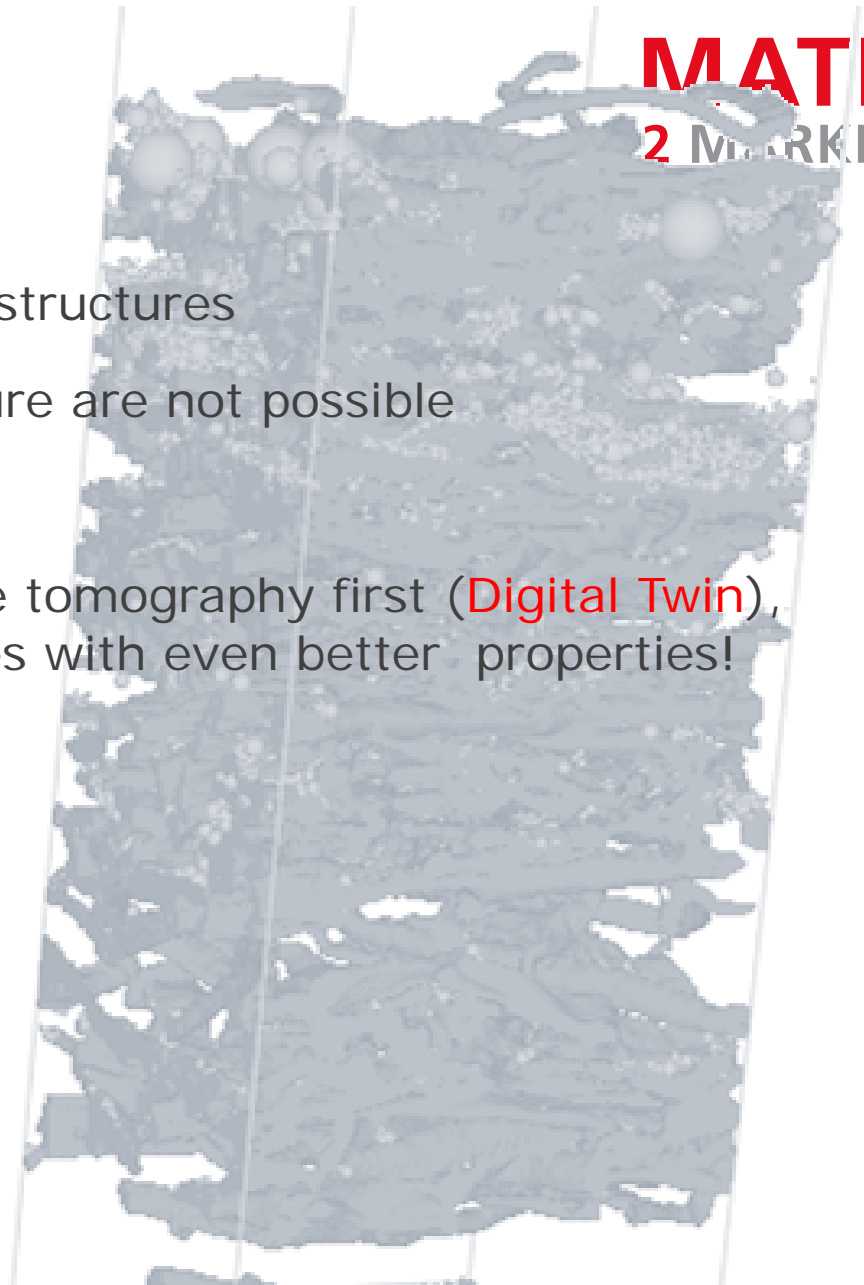
Initial pressure drop	7 Pa
Pressure drop after 1000s	101 Pa
Total deposited dust after 1000s	93 g/m <sup>2</sup>
Total filter efficiency	93% (weight)



# Simulate on $\mu$ CT scans

- (+) Allows simulations on real filter structures
- (-) Modifications of the filter structure are not possible

Aim: create a model that mimics the tomography first (**Digital Twin**), then modify it to find structures with even better properties!



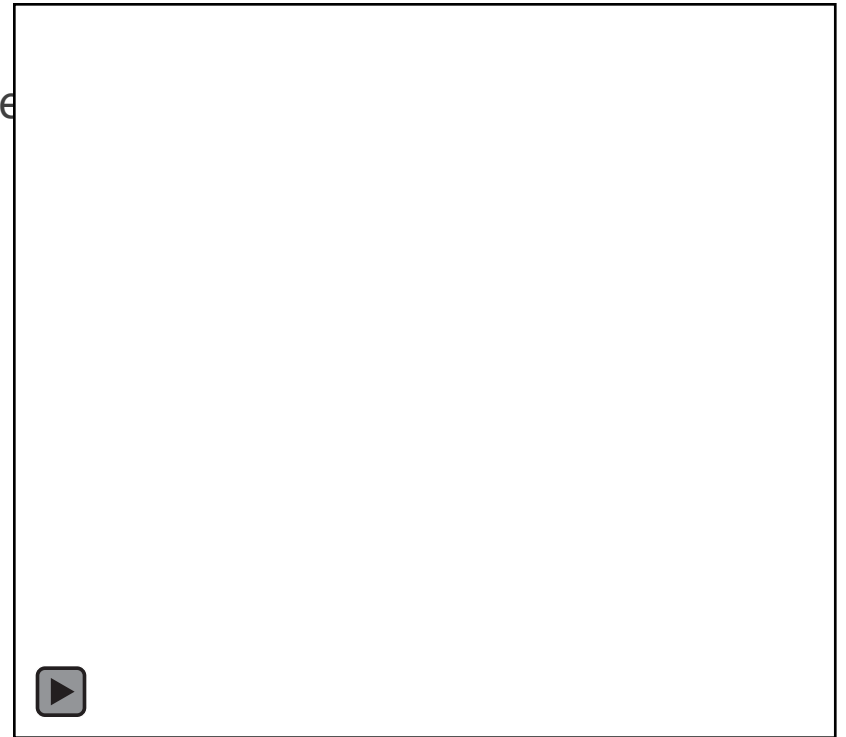
# Create 3D structure models

Input parameters needed (straight fibers):

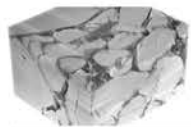
- Porosity
- Fiber type: cross sectional shape, diameter
- Fiber orientation tensor
- Thickness (height) of the filter media

Parameters might be

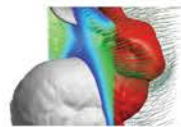
- known from manufacturing process
- measured experimentally
- measured from CT image



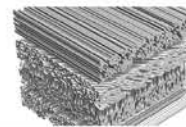
# GeoDict Module Overview



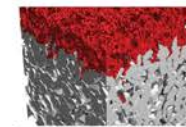
IMPORTGEO



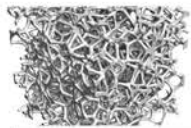
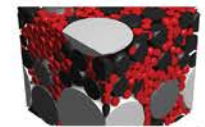
FIBERGEO



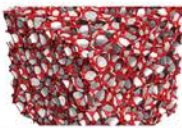
PAPERGEO



GRAINGEO



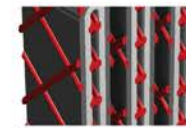
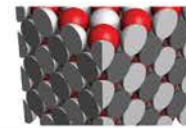
FOAMGEO



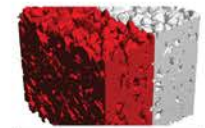
WEAVEGEO



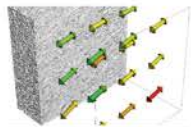
GRIDGEO



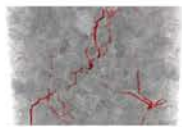
PLEATGEO



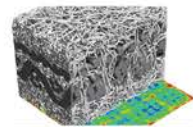
EXPORTGEO



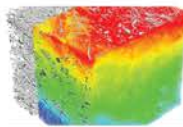
FIBERGUESS



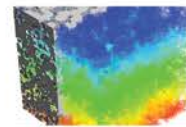
PORODICT



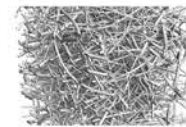
MATDICT



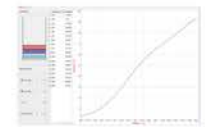
CONDUCTODICT



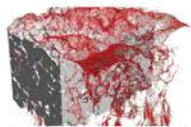
DIFFUDICT



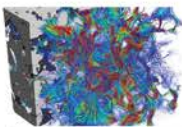
ELASTODICT



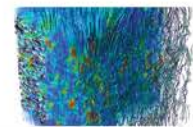
ACOUSTODICT



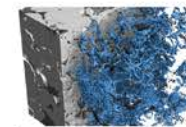
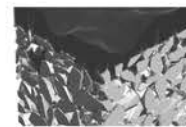
ADDIDICT



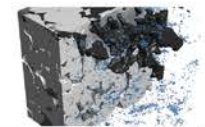
FLOWDICT



FILTERDICT MEDIA & ELEMENT



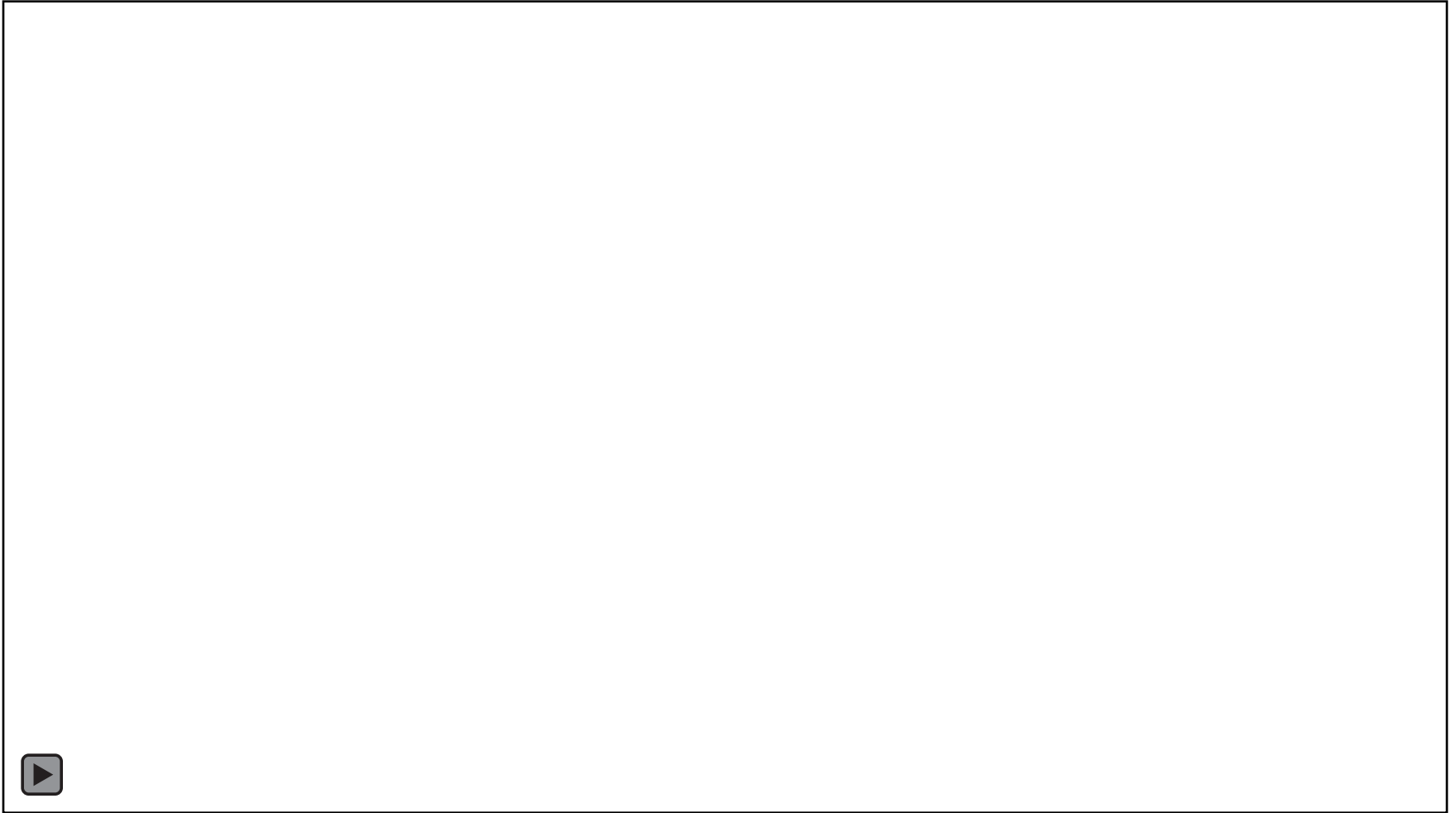
SATUDICT



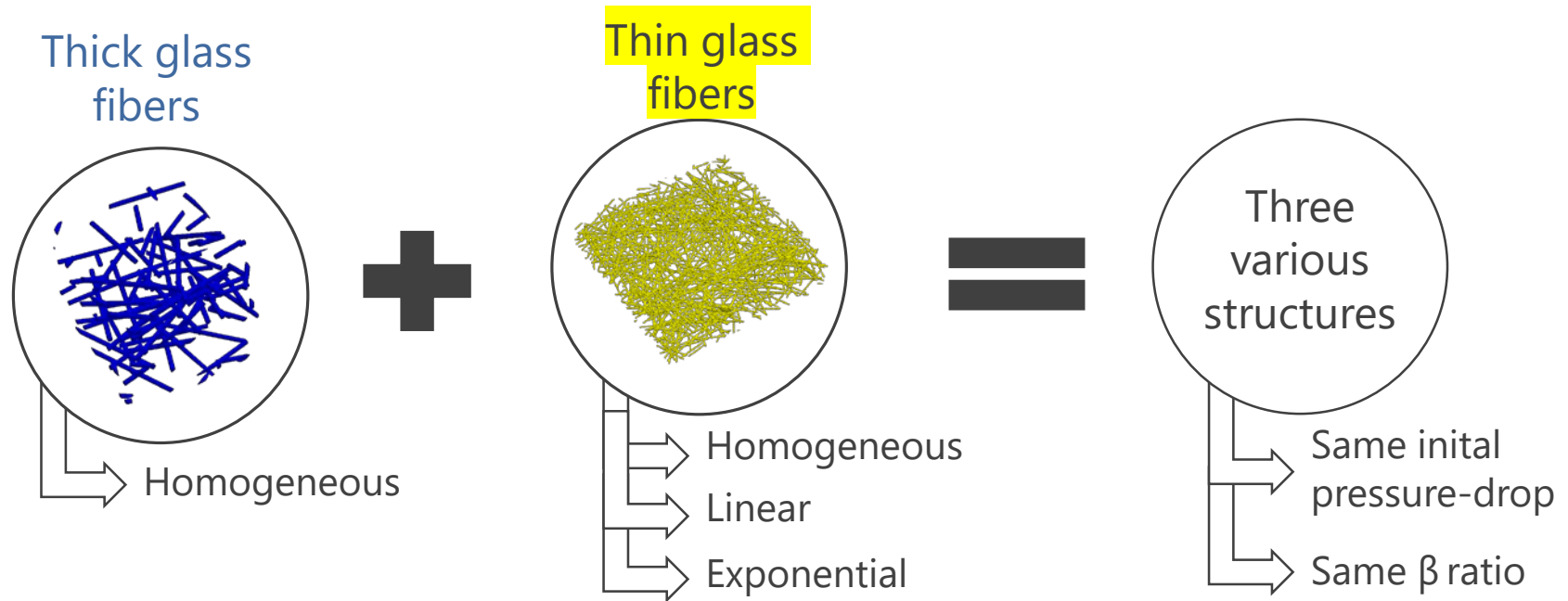
# Filter life-time simulations



# Filter Capacity and Life Time



# Modeling of coarse/fine mixed media filter



## Thick fibers (blue):

Diameter: 20  $\mu\text{m}$

Orientation: Anisotropic 8/1

Material: Glass

Vol. ratio: 60%

## Thin fibers (Yellow):

Diameter: 4  $\mu\text{m}$

Orientation: Anisotropic 8/1

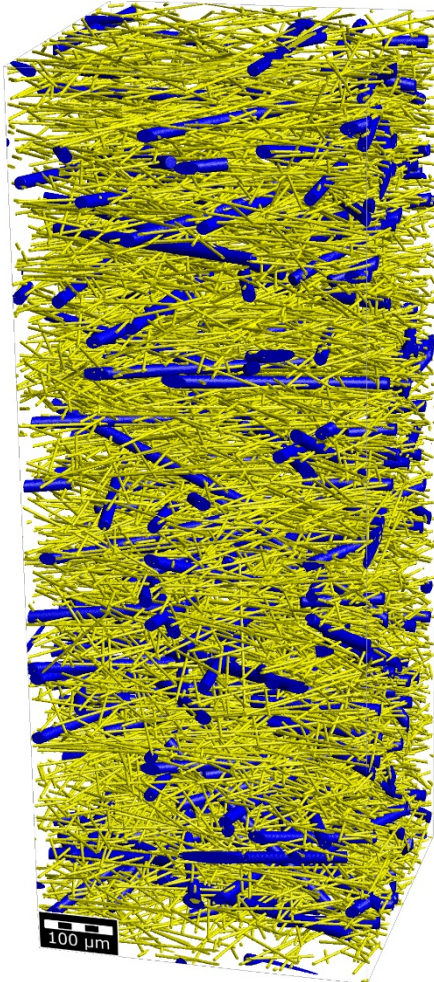
Material: Glass

Vol. ratio: 40%

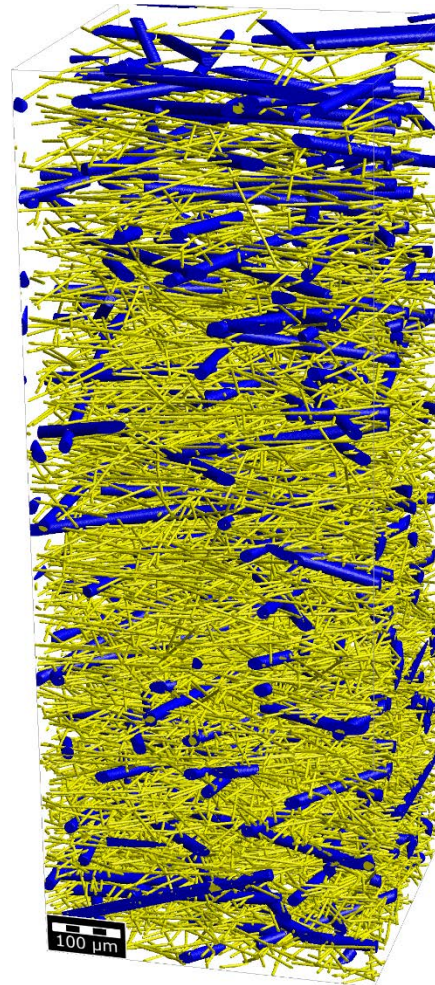
$$\beta_d = \frac{n_{d,U}}{n_{d,D}} = \frac{100}{100 - e}$$

# Modeling of three filter media structures

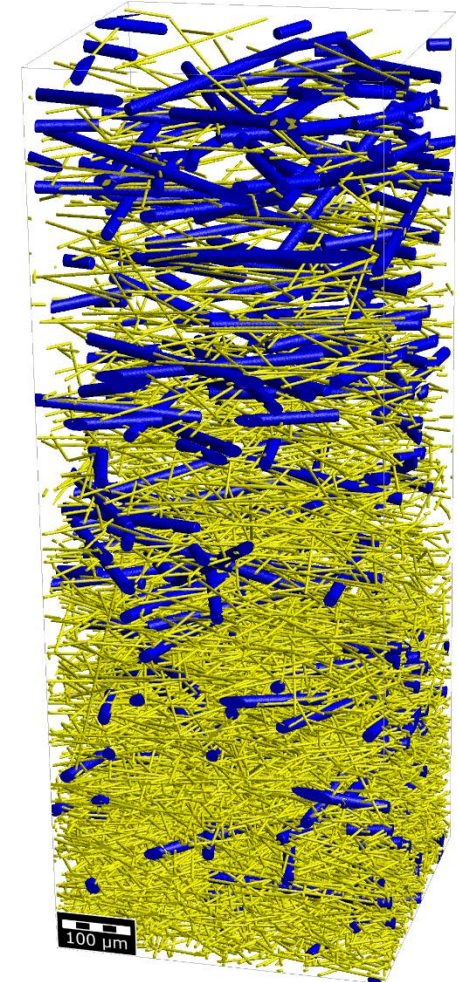
Homogeneous



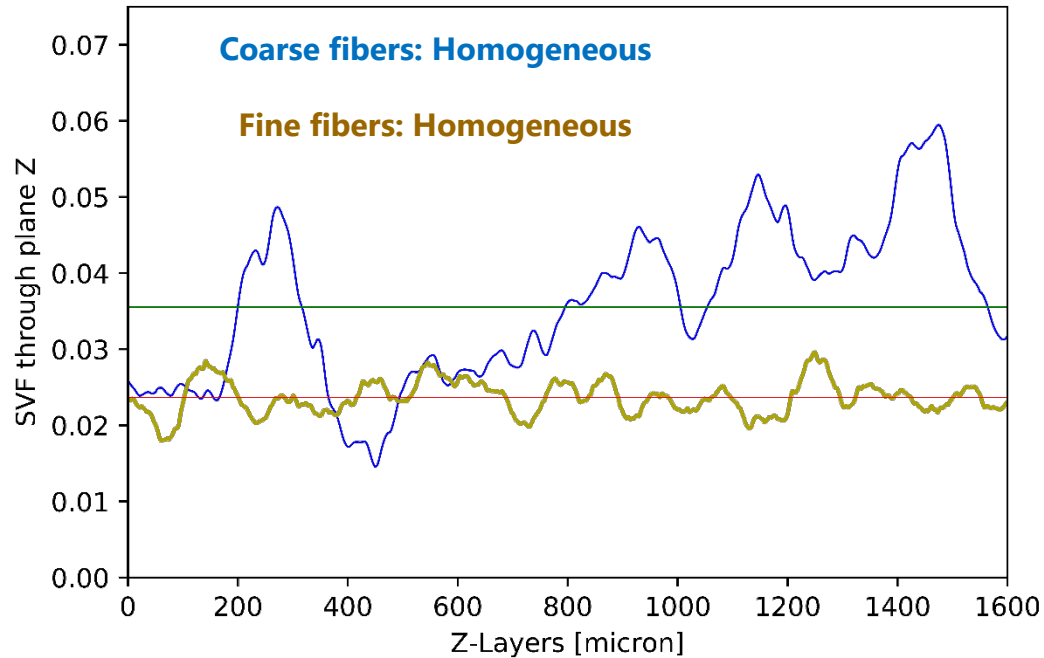
Linear



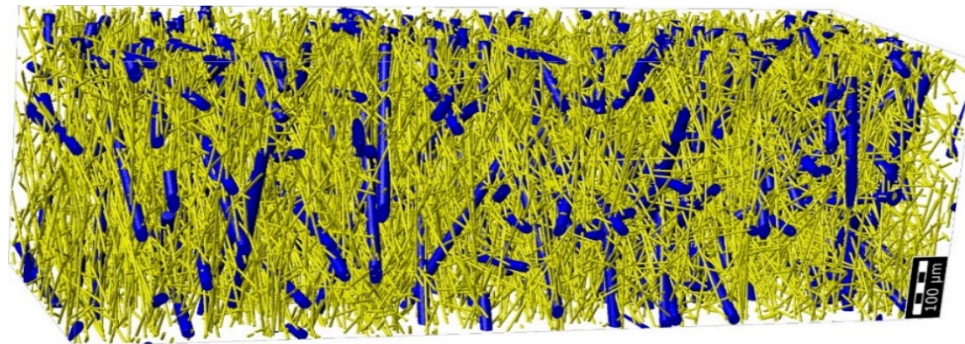
Exponential



# Homogeneous medium

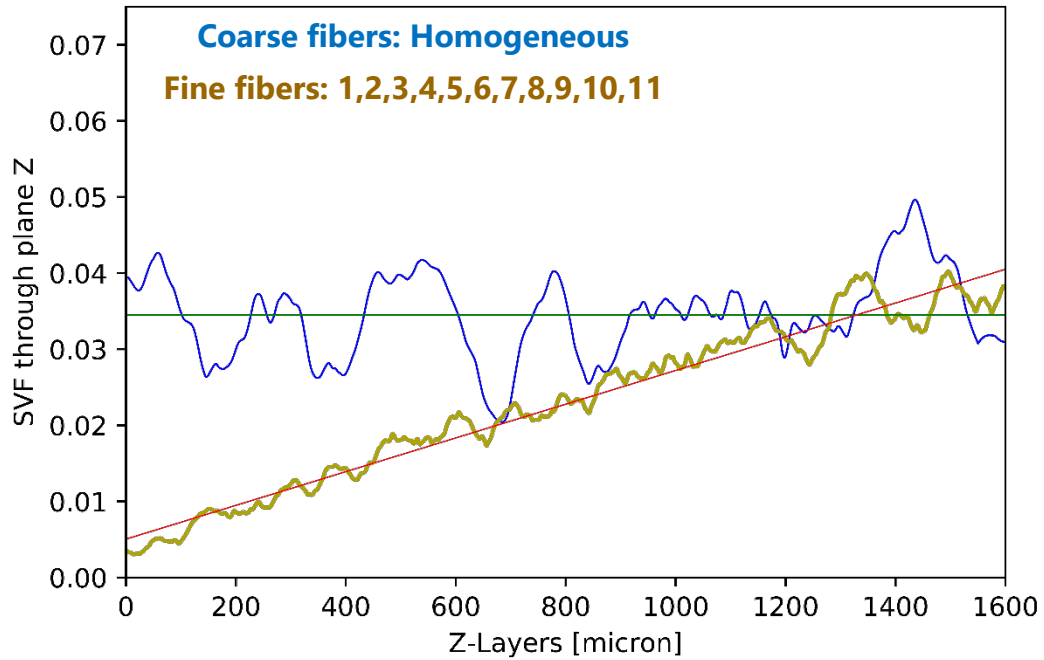


Flow direction

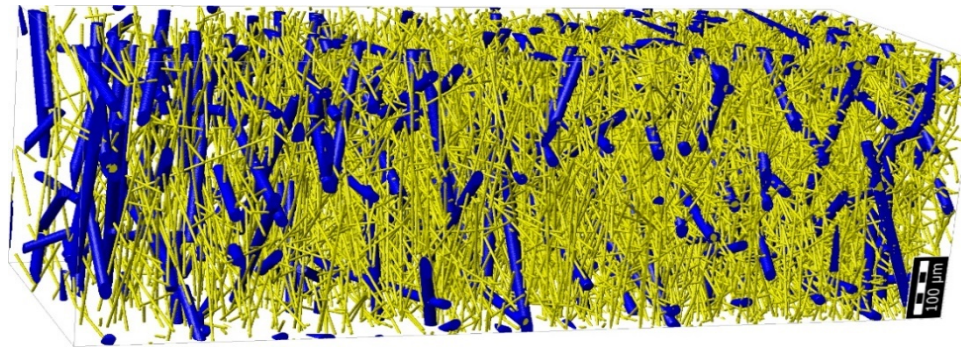


Domain  
600x600x1600  $\mu\text{m}$

# Linear medium

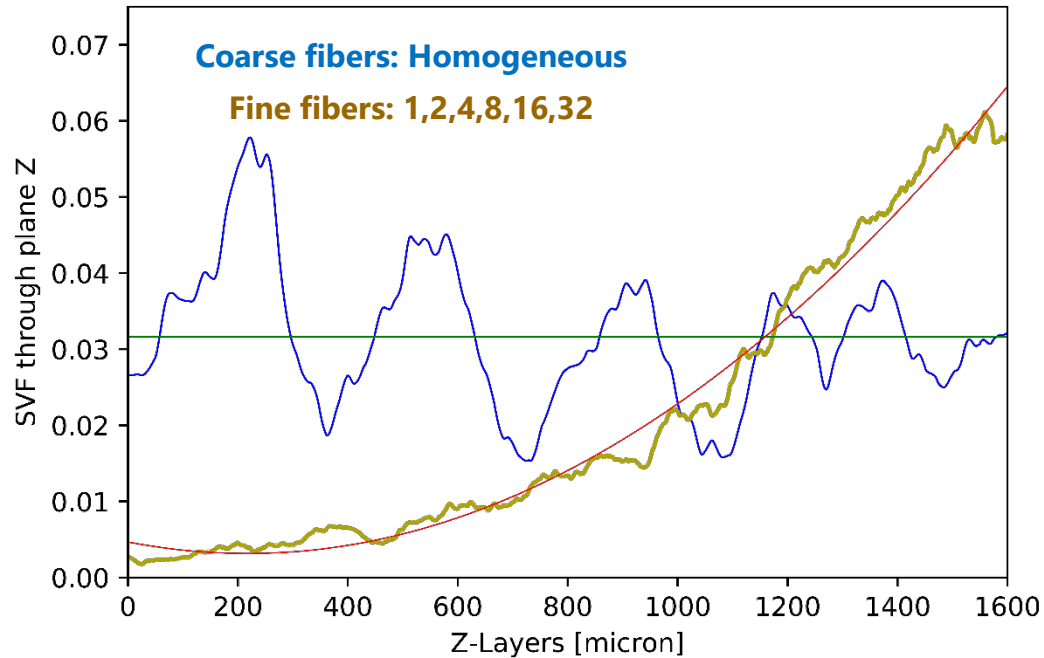


Flow direction

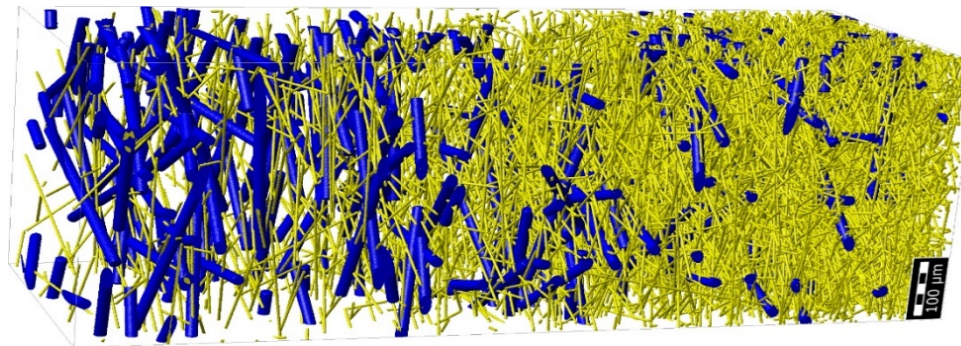


Domain  
600x600x1600  $\mu\text{m}$

# Exponential medium



Flow direction



Domain  
600x600x1600  $\mu\text{m}$

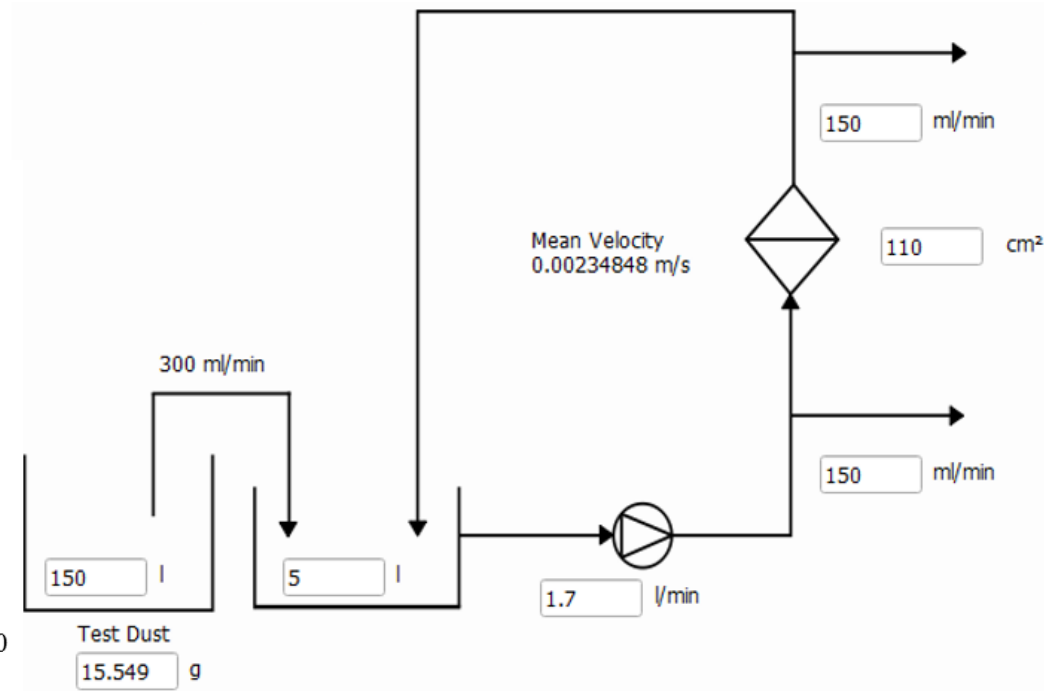
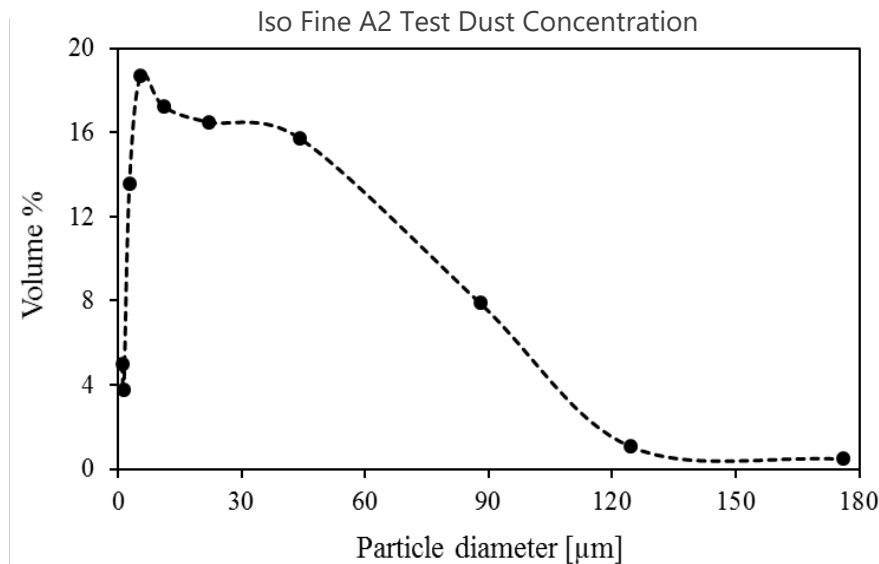
# Structural comparison

Structure	Homogeneous	Linear	Exponential
Size [ $\mu\text{m}$ ]	600x600x1600	600x600x1600	600x600x1600
Distribution of coarse fiber / fine fiber	Uniform / Uniform	Uniform / Linear(1,2,3,4,5,6,.....)	Uniform / Exponential(1,2,4,8,16,.....)
Permeability [ $\text{m}^2$ ]	5.47E-11	5.48E-11	5.53E-11
$\beta_{22\mu\text{m}}$	200	200	200
Object solid volume percentage in domain (porosity in %)	6.11 (93.89 %)	5.9 (94.1 %)	5.43 (94.57 %)
Volume coarse fiber / Volume fine fiber	60/40	60/40	60/40

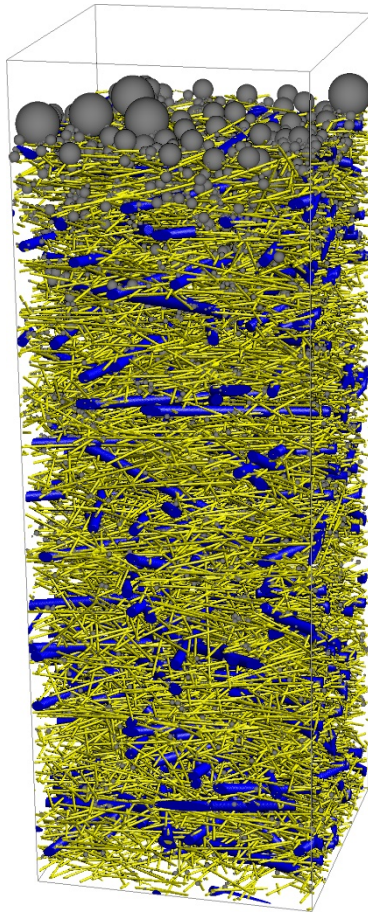
# Experimental setup

Used Fluid: Oil  
Temperature: 20 °C  
Used Particles: ISO Fine A2 test dust  
Particle Density: 2560 kg/m<sup>3</sup>  
Particle Collision Model: Sieving  
Flow regime: Laminar

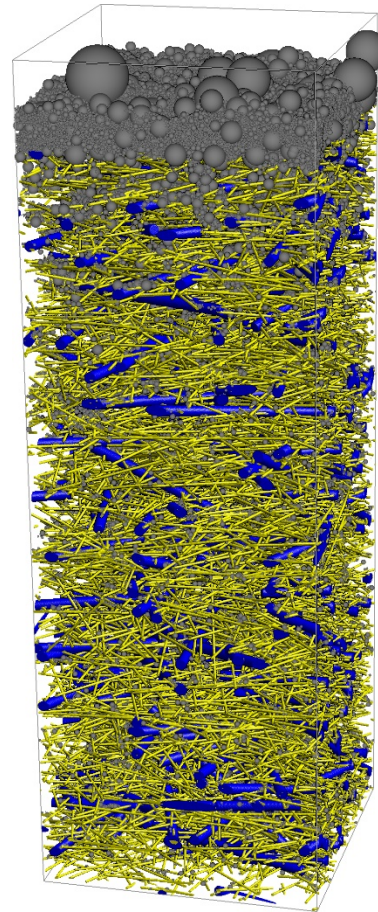
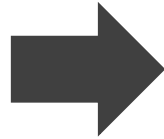
Multi-pass filter test schematic based on ISO 4548-12



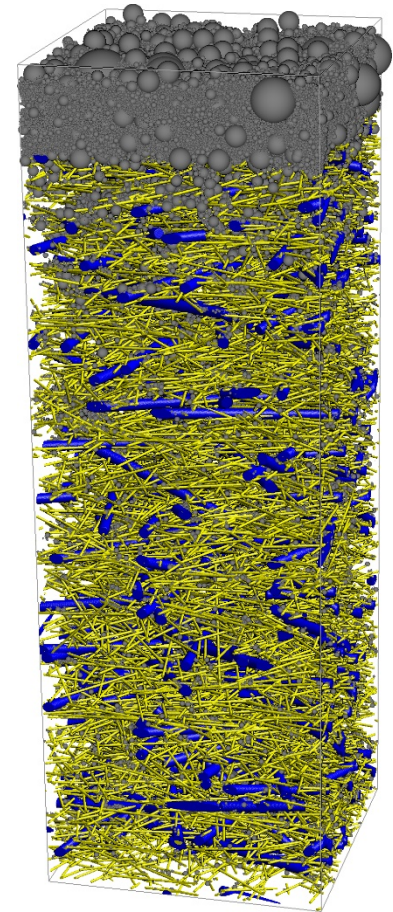
# Transient filtration simulation (Homogeneous structure)



45 min

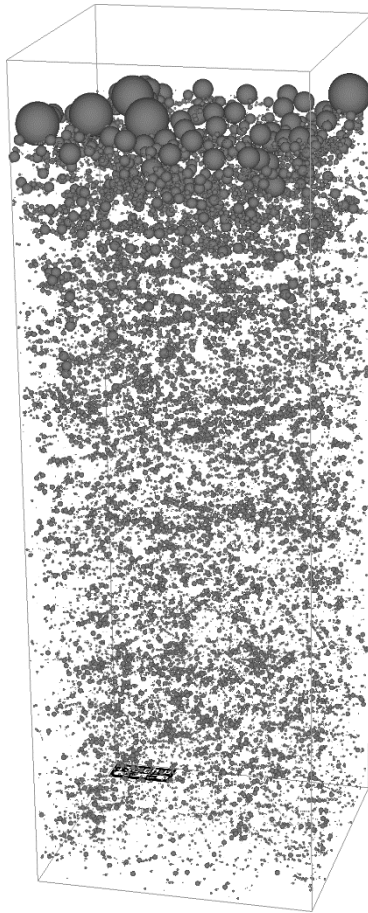


2 hr 25 min

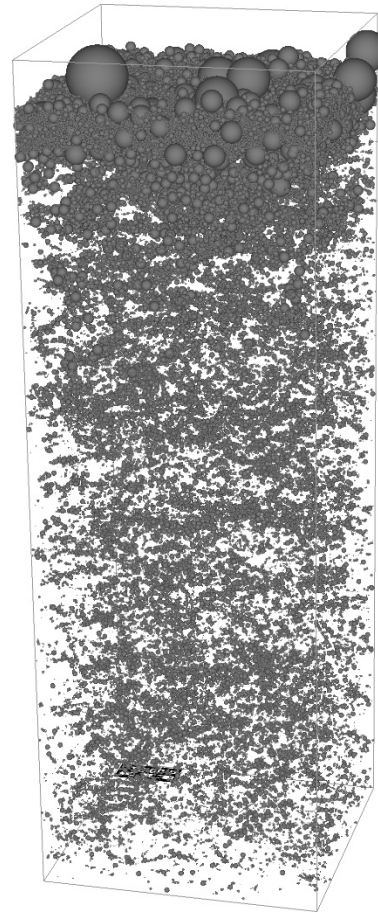
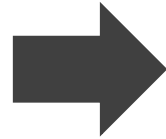


3 hr 10 min

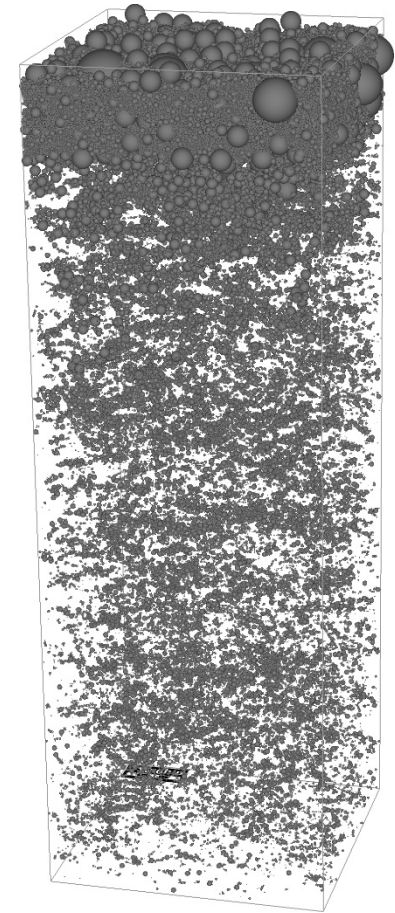
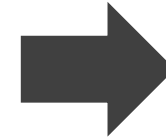
# Transient filtration simulation (Homogeneous structure)



45 min



2 hr 25 min



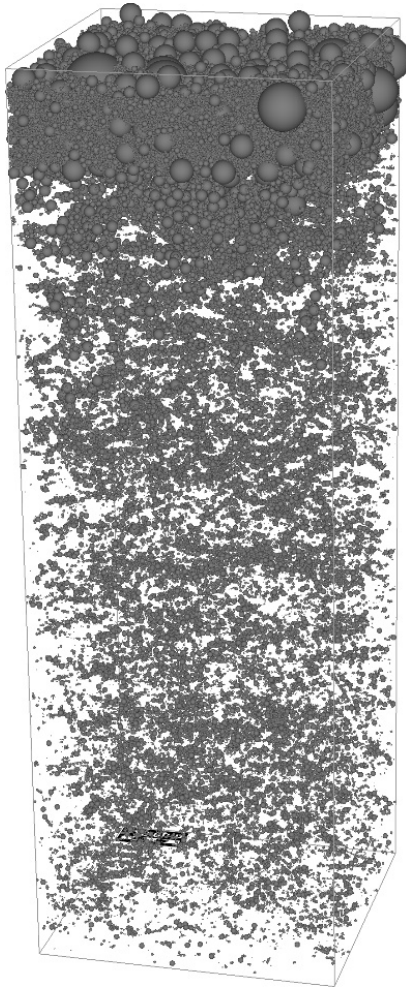
3 hr 10 min

# Animation of the filtration simulation (Linear structure)

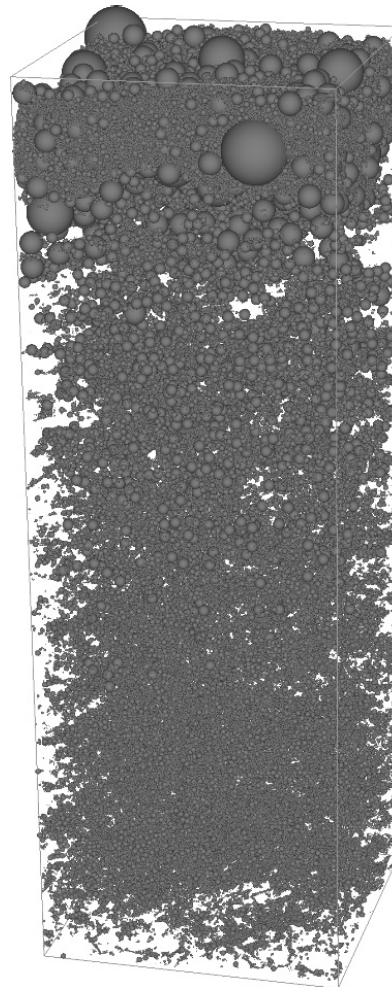


# Comparison of particle depositions

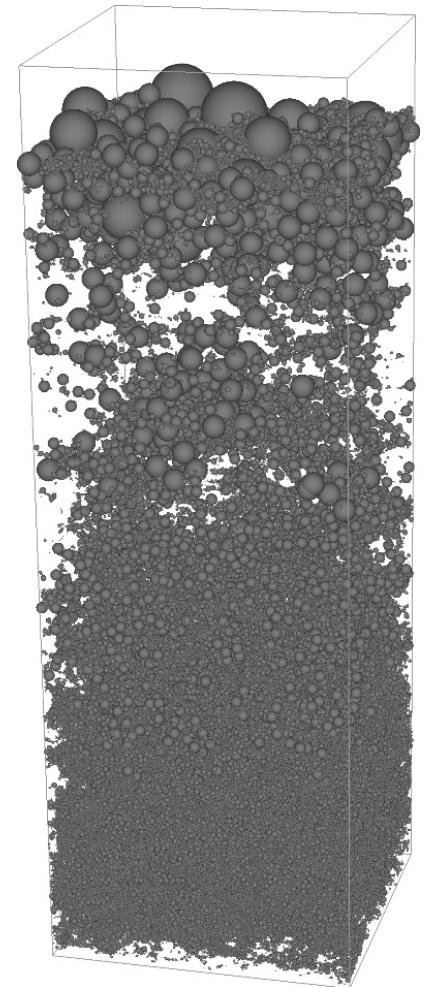
**Homogeneous**



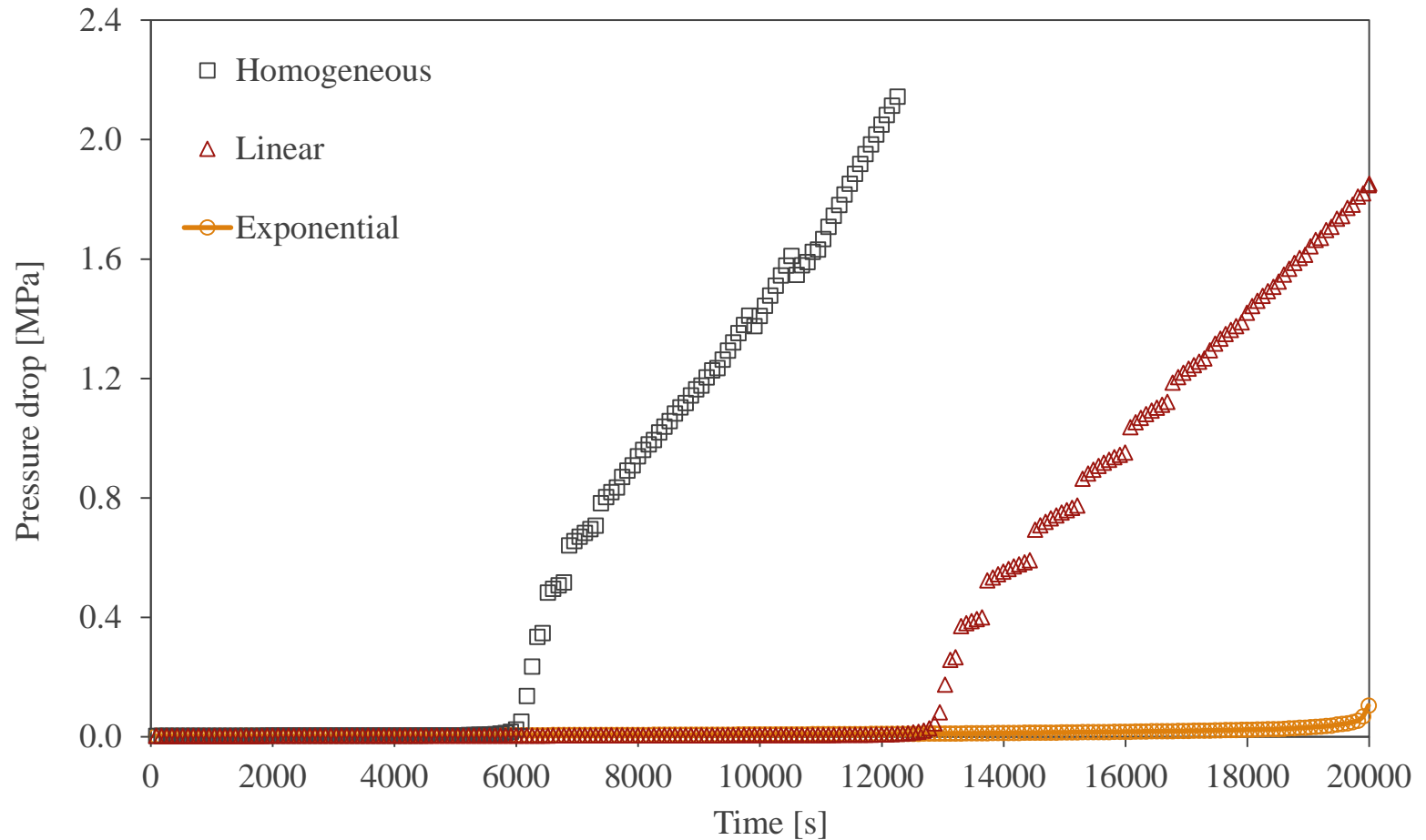
**Linear**



**Exponential**



# Multipass simulation results: Pressure-drop over time



➤ The exponentially increasing media shows the lowest pressure-drop increase through the life-time simulations.

# Conclusions

- ✓ The simulations of filter and filtration can be done at different scales.
- ✓ The macroscopic properties of filter media can be optimized by modifying the micro-structure.
- ✓ The gradient distribution of fibers through the media thickness can improve the filtration characteristics.
- ✓ The exponential media shows the lowest pressure-drop increase & the highest DHC through the life-time simulations.
- ✓ Computer simulations help to find the best performing filter media without having to be physically produced.

Thank you for your attention.

**MATH**  
2 MARKET

