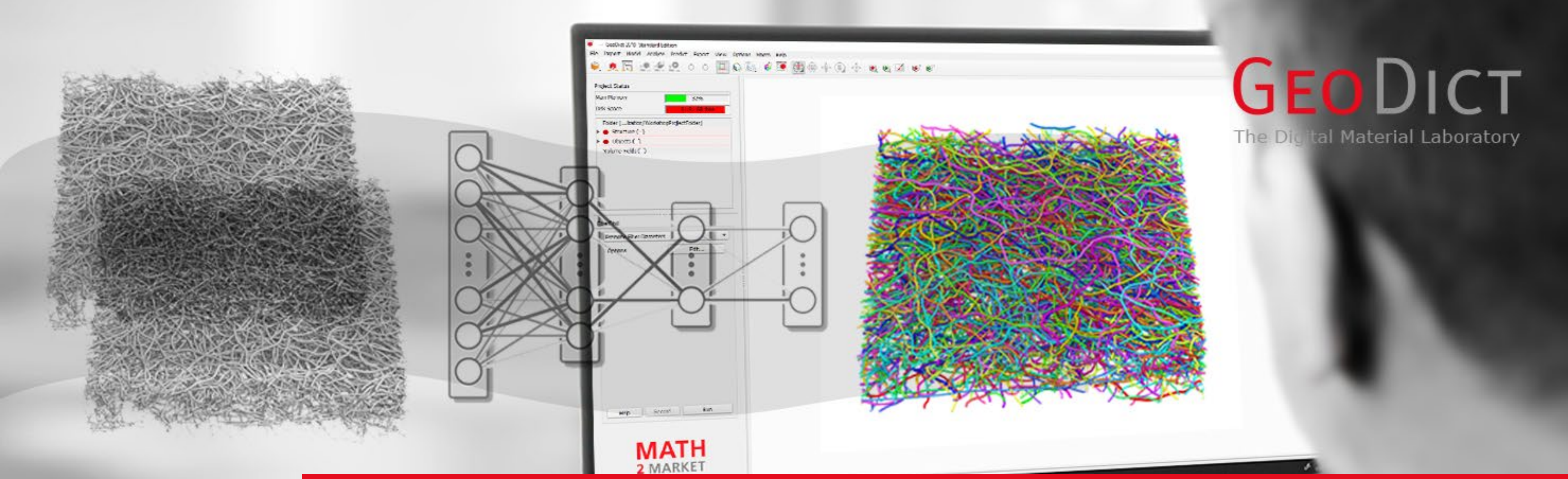


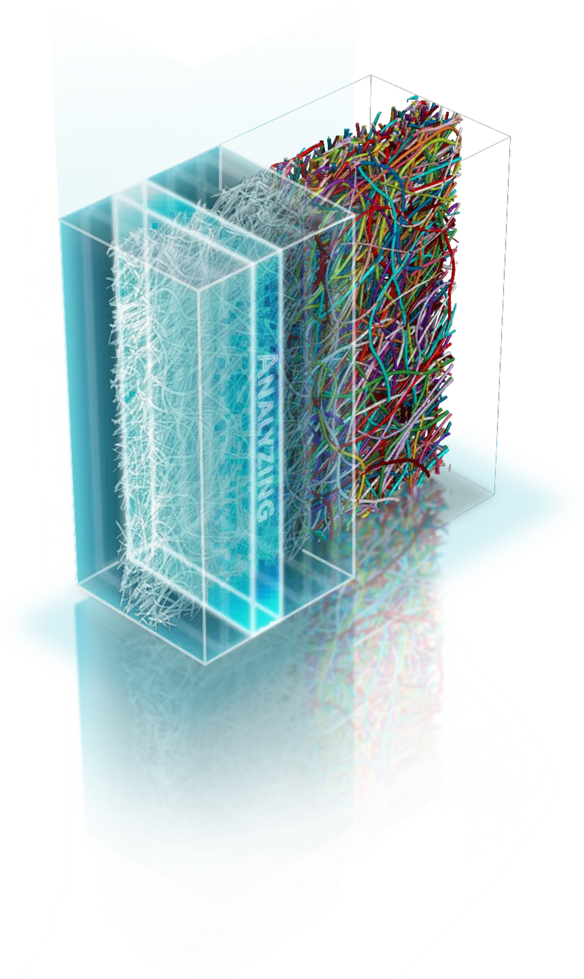
Artificial intelligence (AI) based identification of binder and fiber characteristics with GeoDict

Math2Market GmbH, Kaiserslautern, Germany

MATH
2 MARKET

OVERVIEW

Understanding Nonwovens Using Artificial Intelligence (AI)



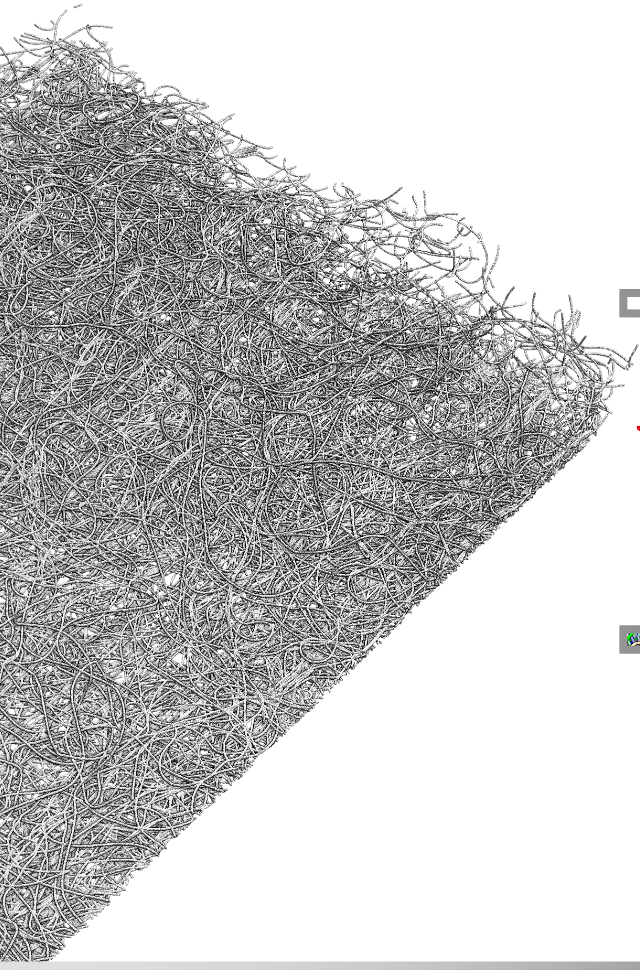
GeoDict 2018: Existing methods define

- fiber diameter distribution (FiberFind)
- fiber orientation (FiberFind)
- pore size distribution (PoroDict)

GeoDict 2019: FiberFind-AI with Deep Learning

- individual fiber information (FiberFind-**AI**)
- individual fiber length (FiberFind-**AI**)
- individual fiber diameters (FiberFind-**AI**)
- individual fiber orientation (FiberFind-**AI**)
- statistics of the above better than in 2018

THE BENEFITS OF FIBERFIND-AI



OVERWHELMING TIME SAVINGS

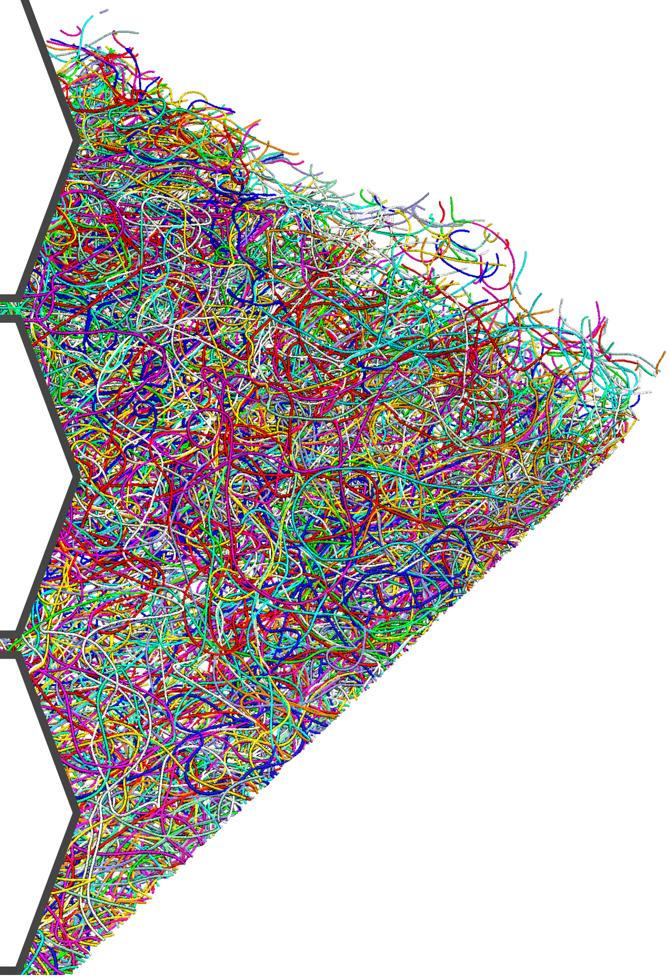
FiberFind reliably, automatically and quickly detects fibers and binder in **3D scans**

TRANSFORMATION OF DATA INTO INFORMATION

The artificial intelligence in FiberFind turns **voxels into fibers**, transforms data into information

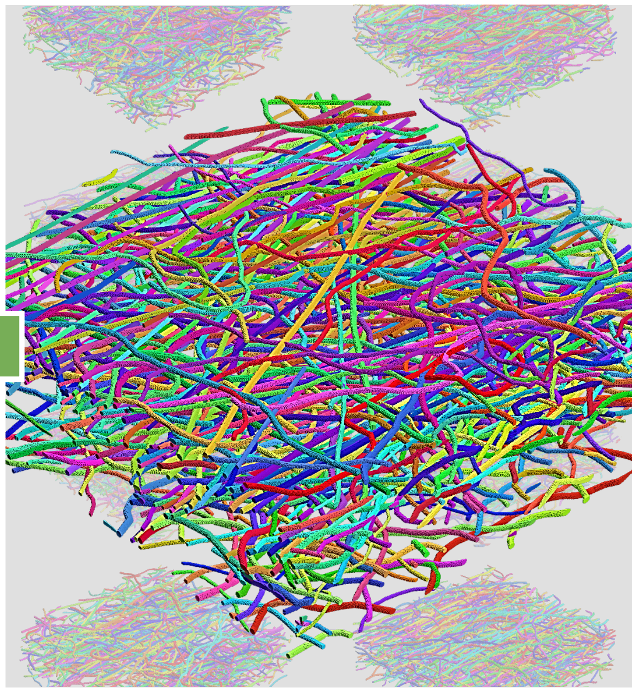
COMPLEX ANALYSES MADE POSSIBLE

Computation of fiber **lengths**, fiber **diameters**, fiber **orientations** becomes straightforward



Overview

Training Phase of Neural Network

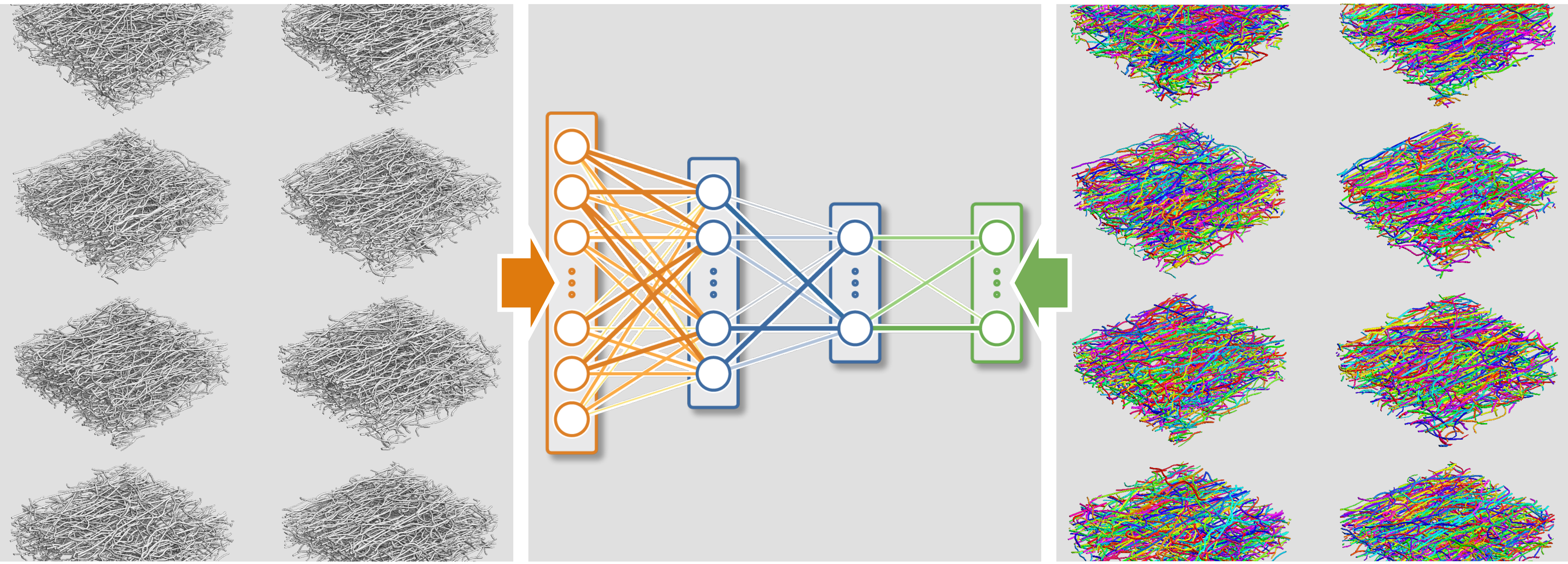


Binarized GeoDict model (as input)

Neural Network learns

Original GeoDict model (as input)

Training Phase of Neural Network

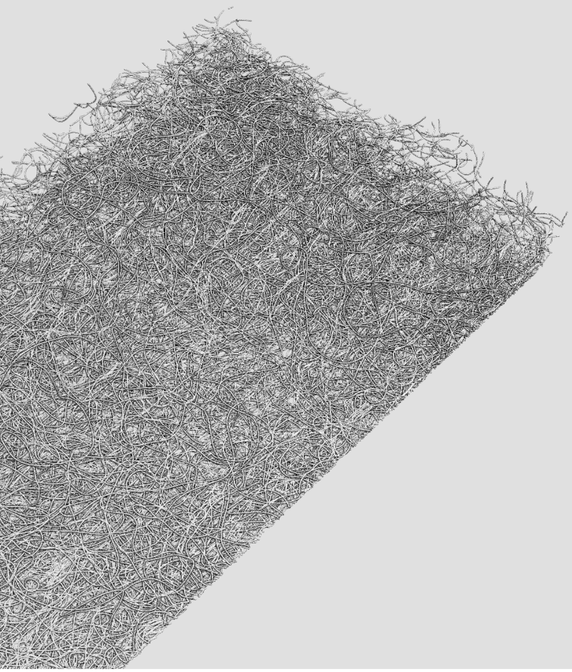


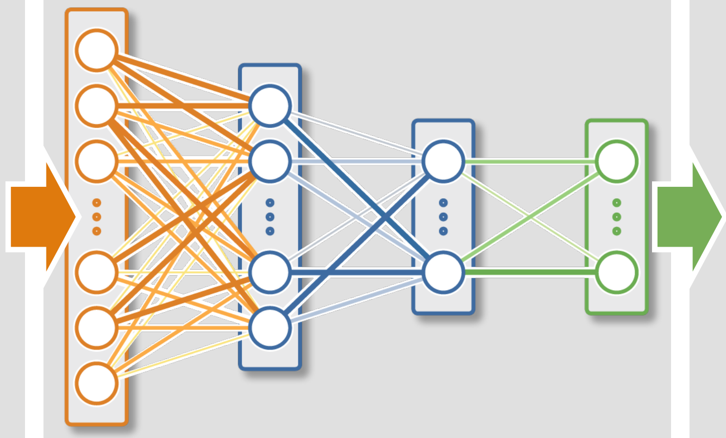
Dozens of Binarized GeoDict models (as input)

Neural Network learns

Dozens of Original GeoDict models (as input)

Usage Phase of Neural Network



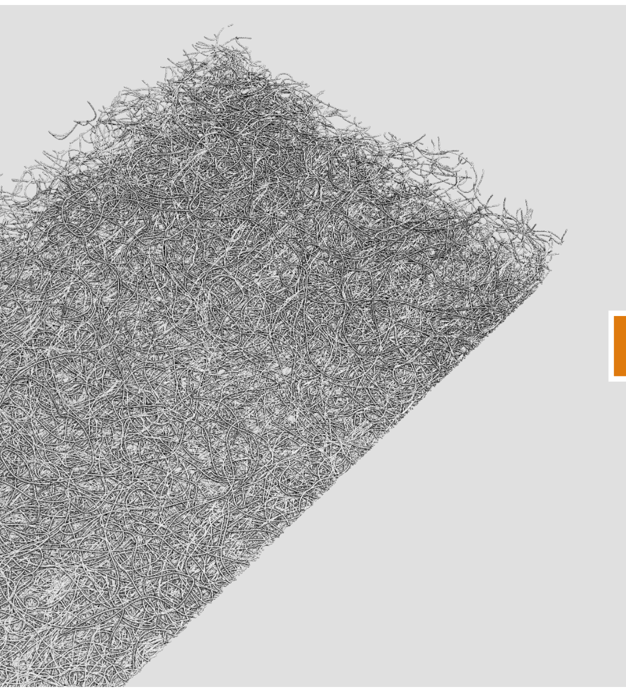


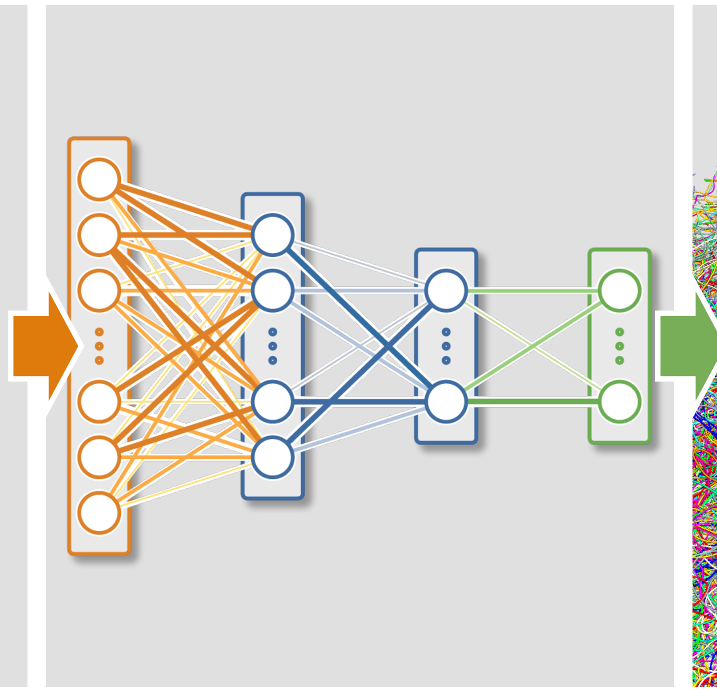
Segmented 3D scan (as input)

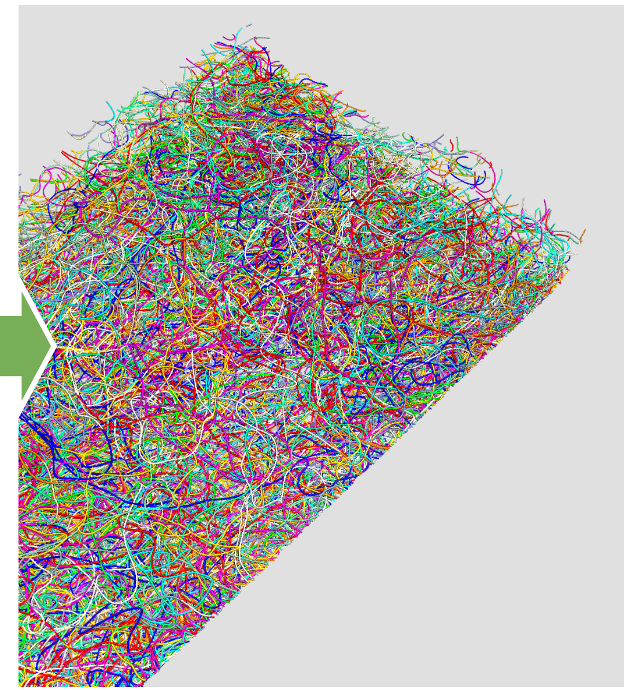
Neural Network

Labeled fibers for 3D scan (as output)

Usage Phase of Neural Network





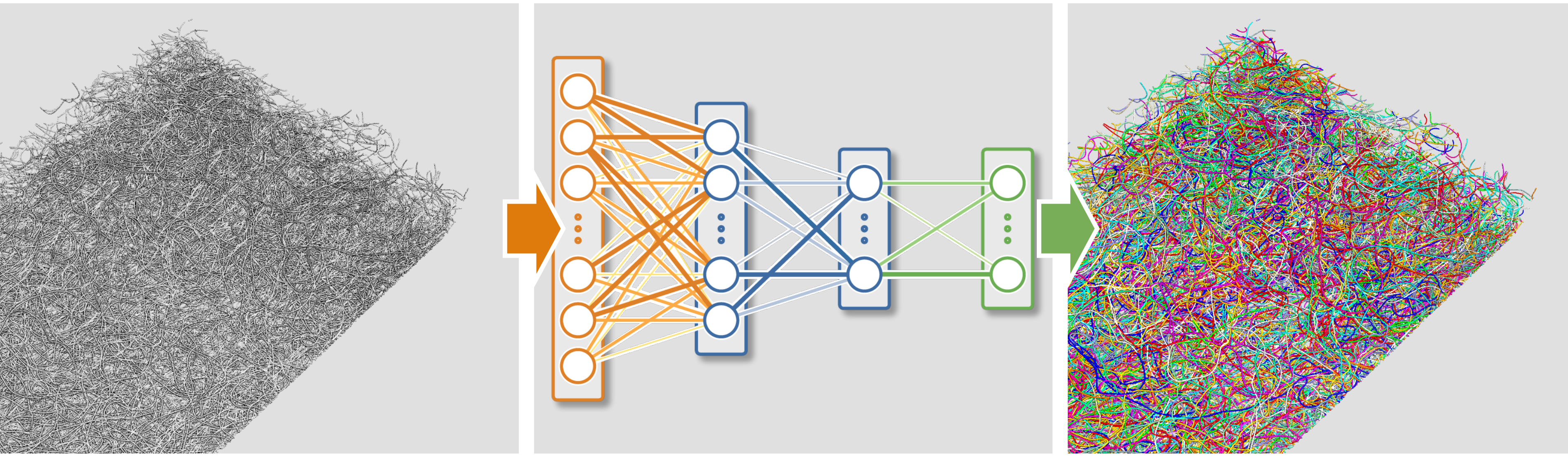


Segmented 3D scan (as input)

Neural Network

Labeled fibers for 3D scan (as output)

Fiber Identification by Neural Network (NN)
Summary



<u>Training</u>: NN learns from input and output

- input: GeoDict model: binarized version
- output (provided as input): GeoDict model: labeled fibers

<u>Usage</u>: NN predicts labeled output from input using weights

- input: Synchrotron / µCT data: binarized version
- output: Synchrotron / µCT data: labeled fibers

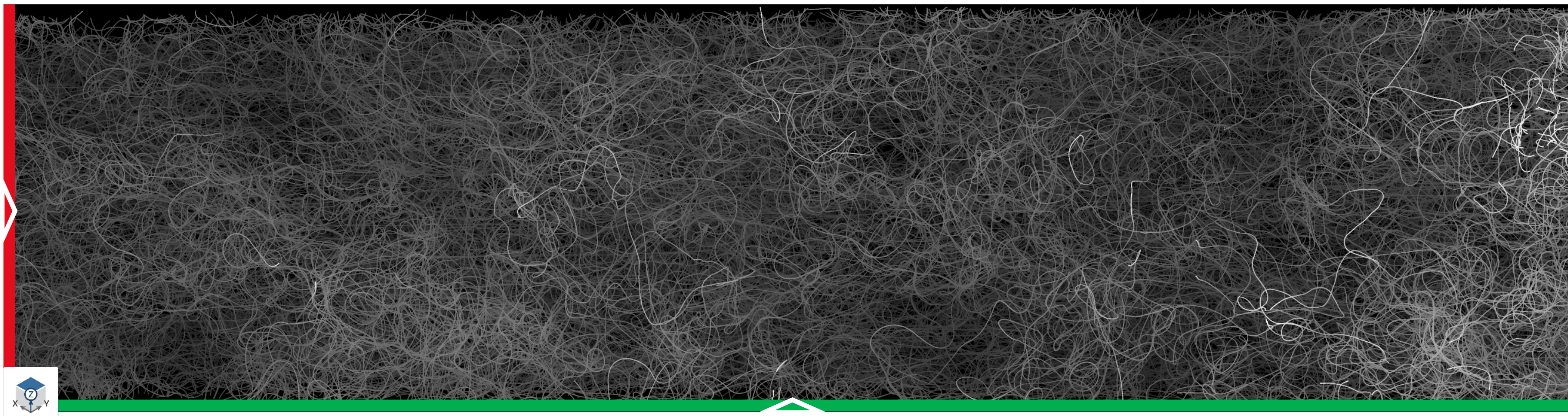
Overview

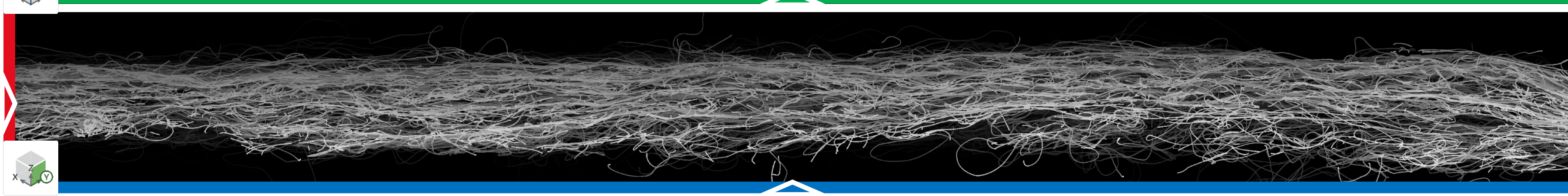
Overview of sample structure

Sample name	Resolution	Physical dimensions	Voxel dimensions
B	2.7 [µm]	42.2 x 10.9 x 4.8 [mm^3]	15619 x 4032 x 1796

- Carded nonwoven samples
- Scanned and stitched together by Bruker µCT
- Analyzed by Math2Market using GeoDict

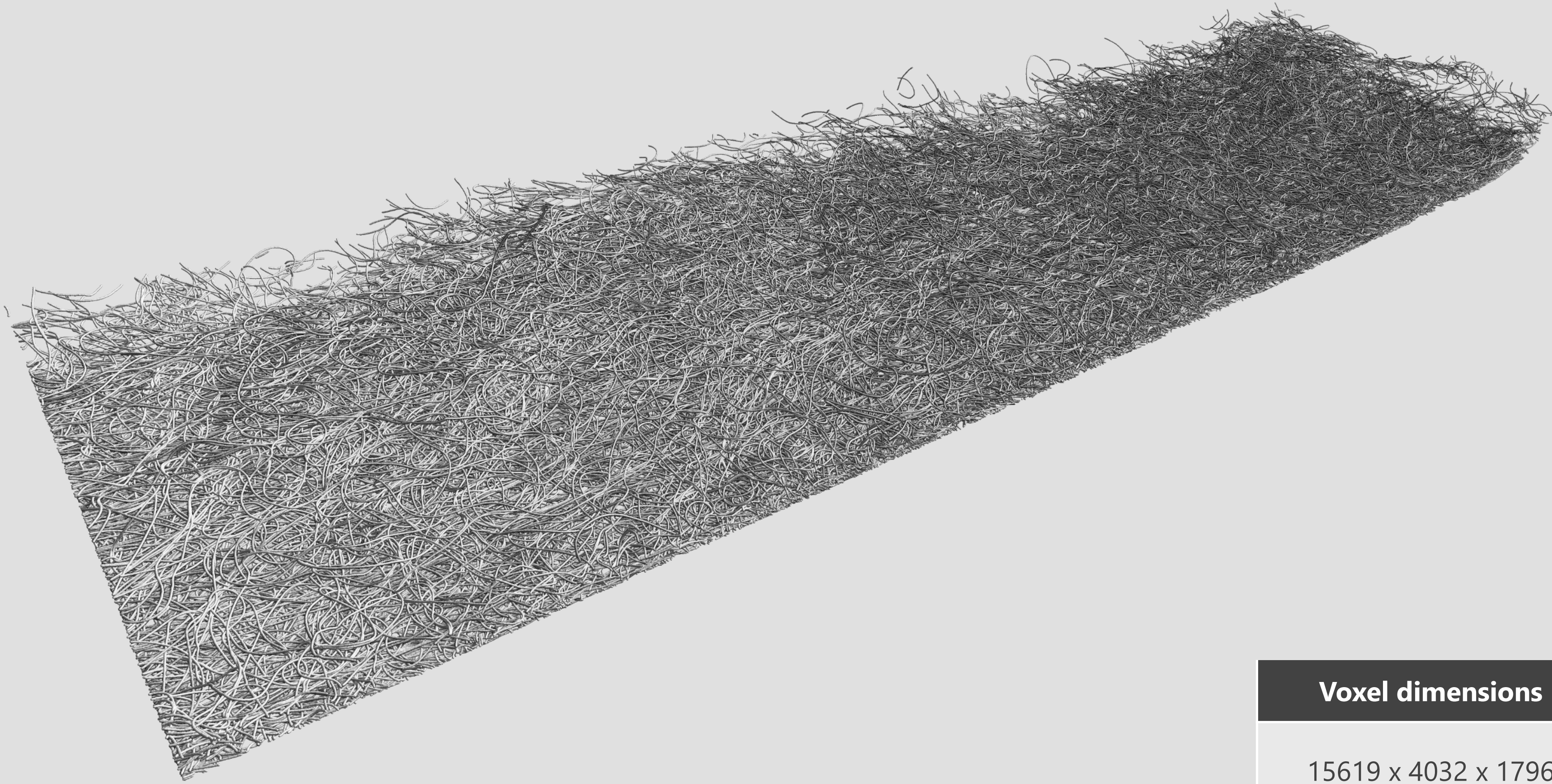
Sample B – SEM View





Resolution	Physical dimensions	Voxel dimensions
2.7 [µm]	42.2 x 10.9 x 4.8 [mm^3]	15619 x 4032 x 1796

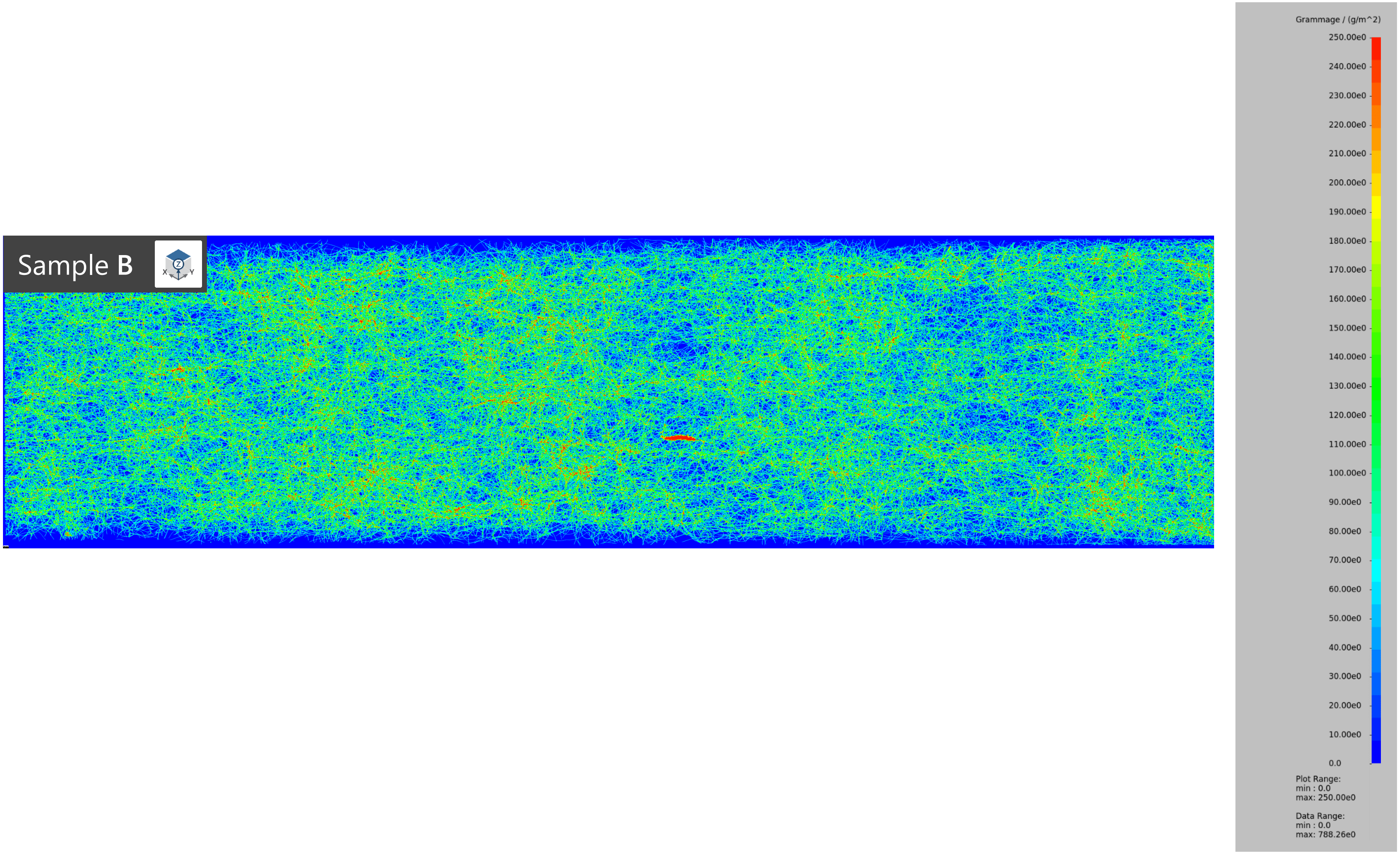
Sample B – 3D View



Voxel dimensions
15619 x 4032 x 1796

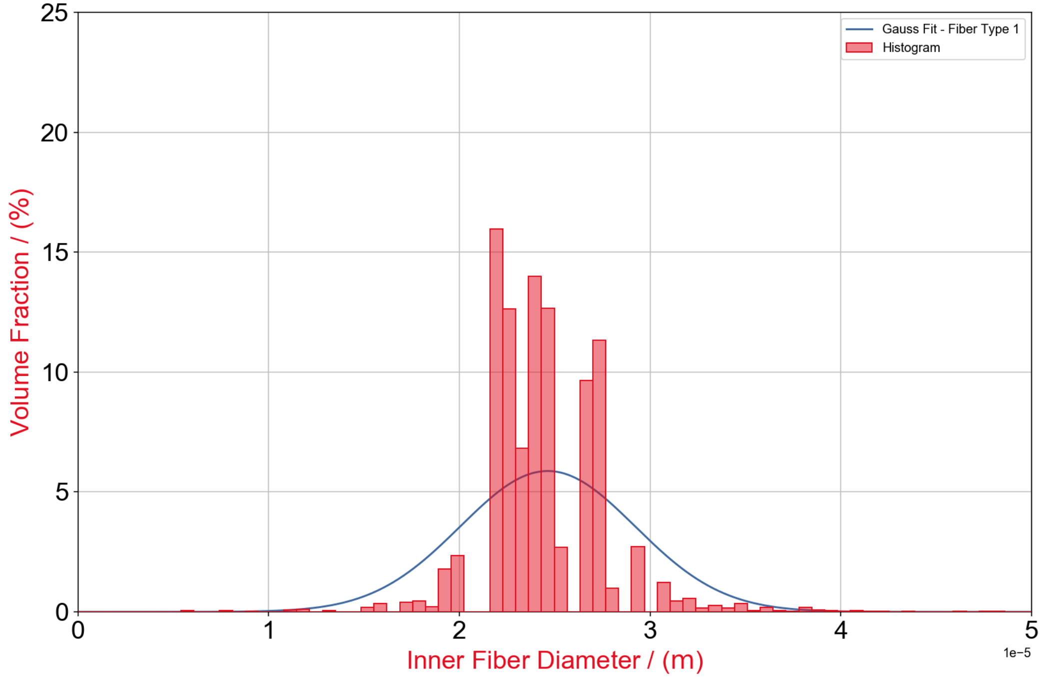
Sample B – Video

Density Map (Cloudiness)



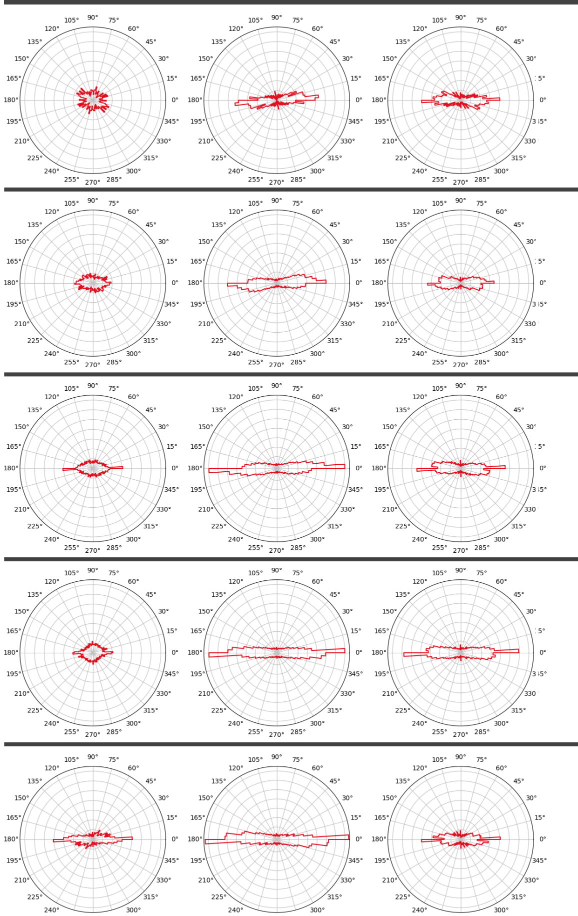
Fiber Diameter Distribution

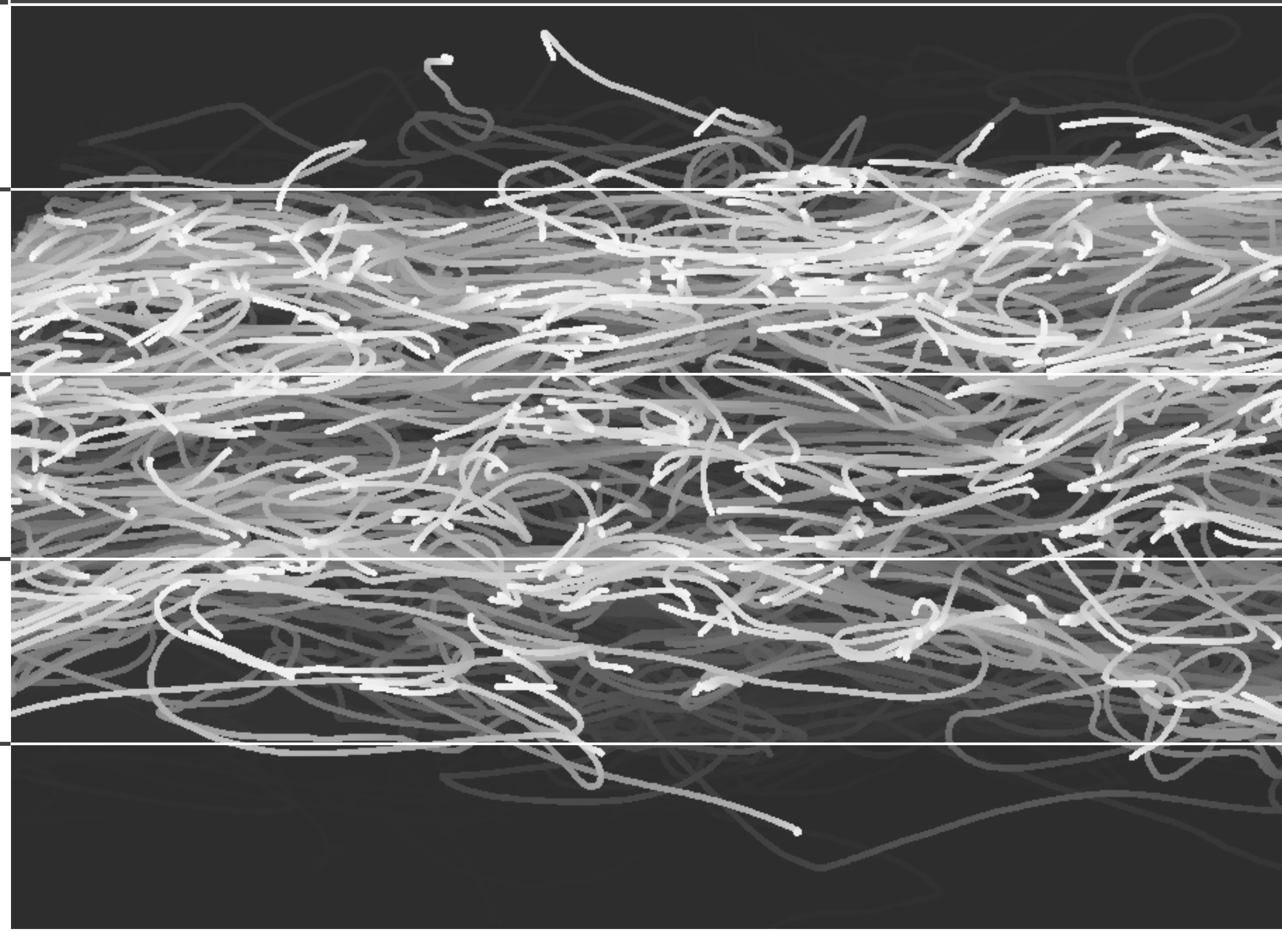
Sample B	
Average fiber diameter	24.6 µm
Standard deviation	4.6 µm



FIBER ORIENTATIONS – SAMPLE B

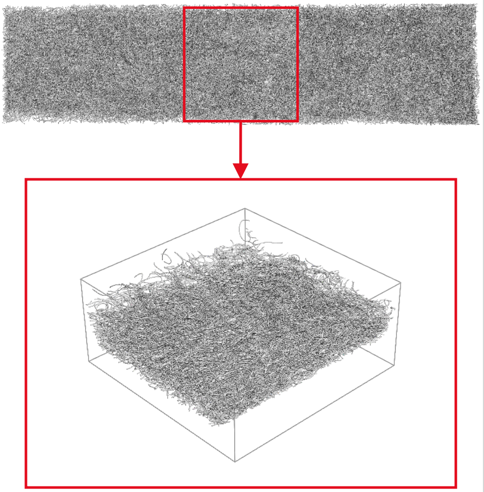
XY	XZ	YZ	View of a section of the surface in the direction of the X axis.

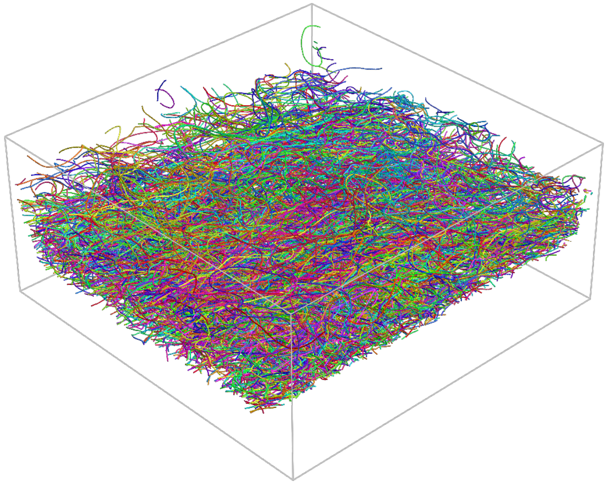


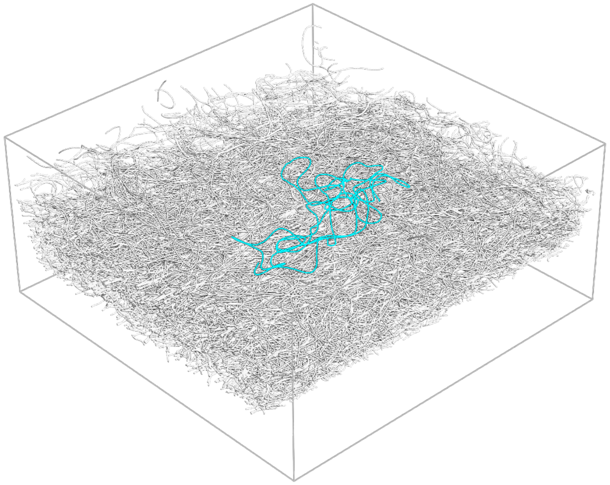


Fiber Identification on Sample B

Sample B	Labeling of fibers	Data becomes information
FiberFind was used on the complete sample. Process is explained on a smaller cutout	The AI separates the solid voxels in the image data into individual fibers. Each fiber becomes an independent, modifiable object which can be treated independently.	Geometric information, such as fiber length, fiber segment orientation & fiber diameter, can be read directly from the object.

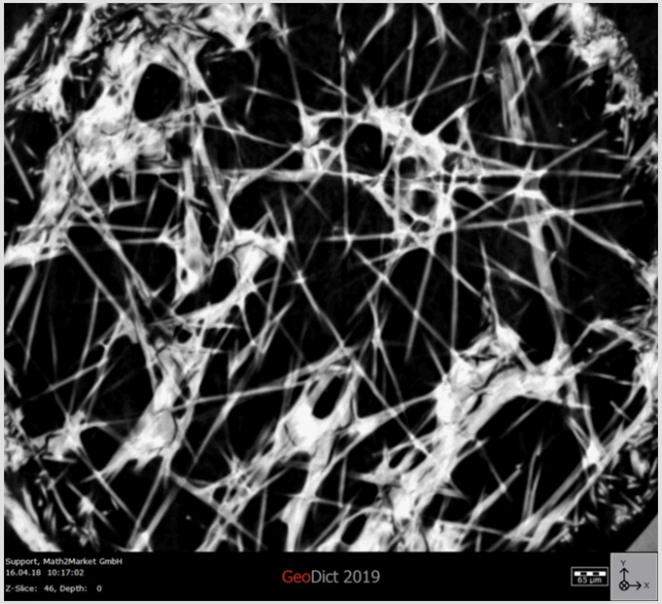


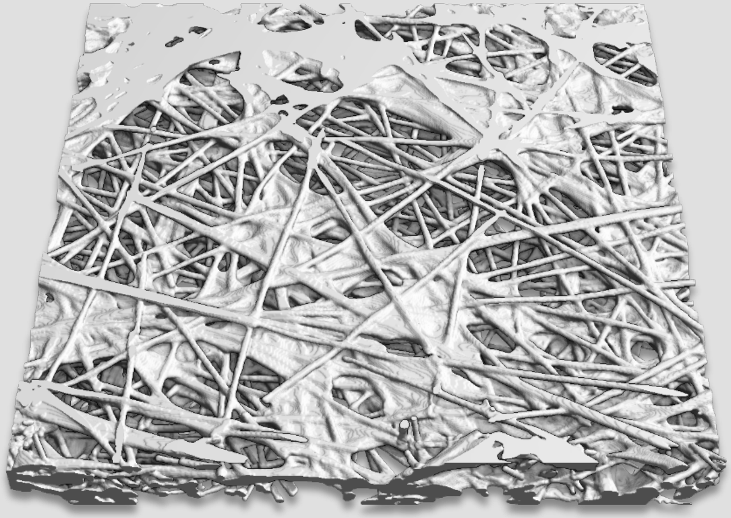




Overview

SEGMENTATION

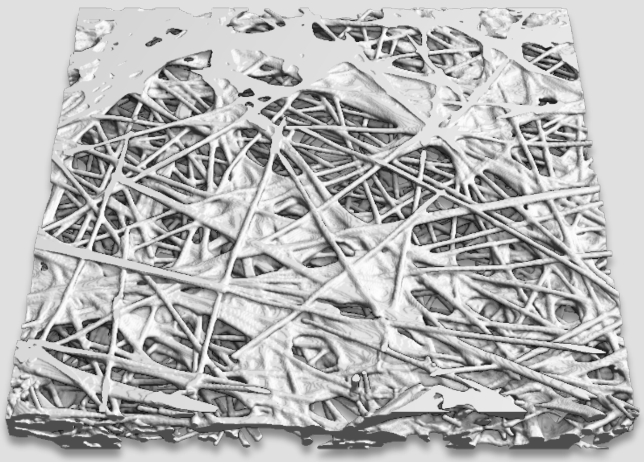


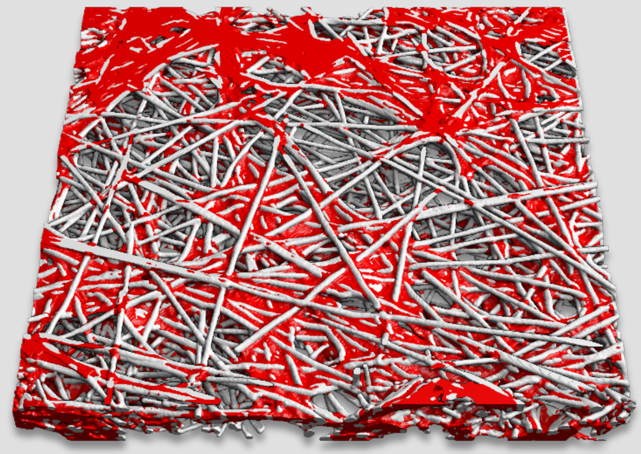


From stack of gray value slices

To 3-D empty / solid image

Binder identification - objective





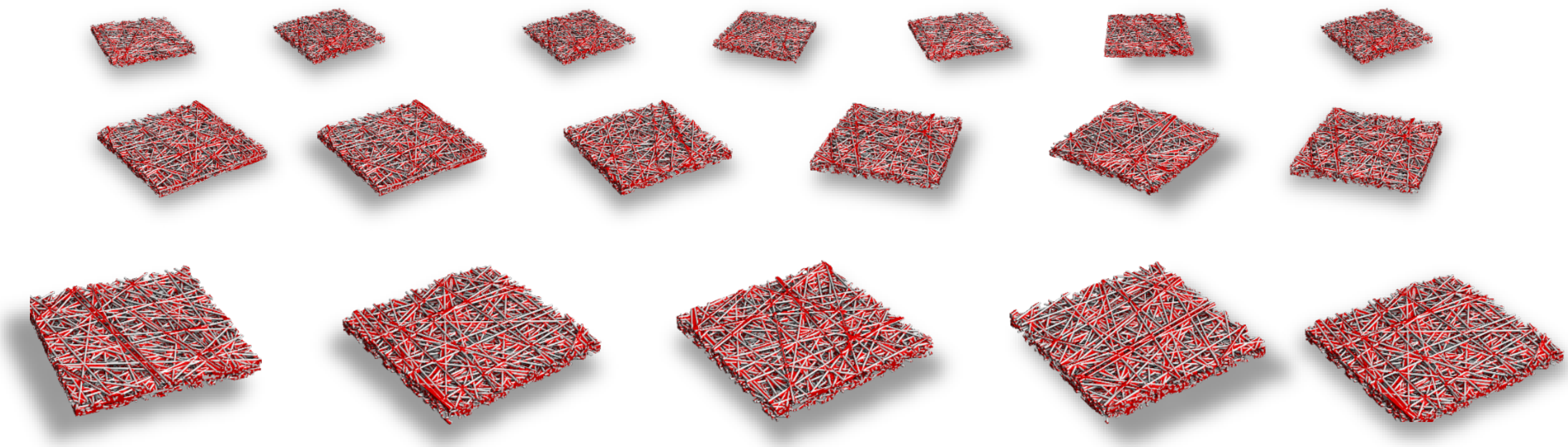
INPUT: segmented µCT-Scan
of fibers (white) + binder (also white)

OUTPUT: labeled fibers (white) and
identified binder (red)

Challenges:

- Training data sets require millions of data that neural network can learn
- Ground truth to train the network is not easily available
- Almost impossible to label enough 3D images manually

GeoDict DIGITAL TWINS PROVIDE GROUND TRUTH



Solution: Use GeoDict material modelling capabilities

- Modeled 18 digital models (512x512x256 Voxels) with **FiberGeo** as training data
- Varied porosity & binder volume fraction as estimated for 4 different (Toray GDL) samples
- corresponds to ~800 million solid voxels as training data points

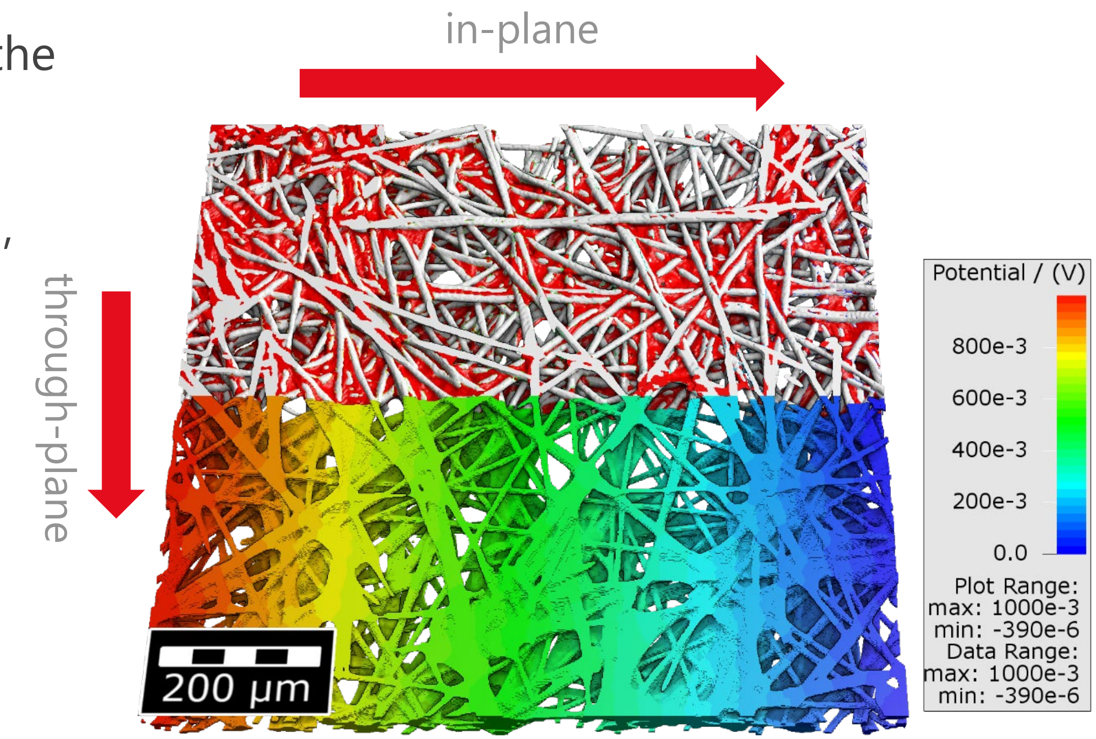
Toray Paper TGP-H-030

Simulation of Electrical Conductivity

Past experiments have shown that the ratio of in-plane & through-plane conductivity in experiments & simulations could not be compared, because it was not possible to differentiate fibers and binder [1]

$$r = \frac{\sigma_{in-plane}^{eff}}{\sigma_{through-plane}^{eff}}$$

<u>We can now run simulations where binder and fibers have different conductivity</u>.



Conductivity	σ *fiber* = σ *binder*	σ *fiber* = 10*σ *binder*
R	4.21	5.04

[1] J. Becker et. al.: Determination of Material Properties of Gas Diffusion Layers: Experiments and Simulations Using Phase Contrast Tomographic Microscopy, Journal of The Electrochemical Society, 2009.

Overview

Conclusion

FiberFind-AI in GeoDict 2019

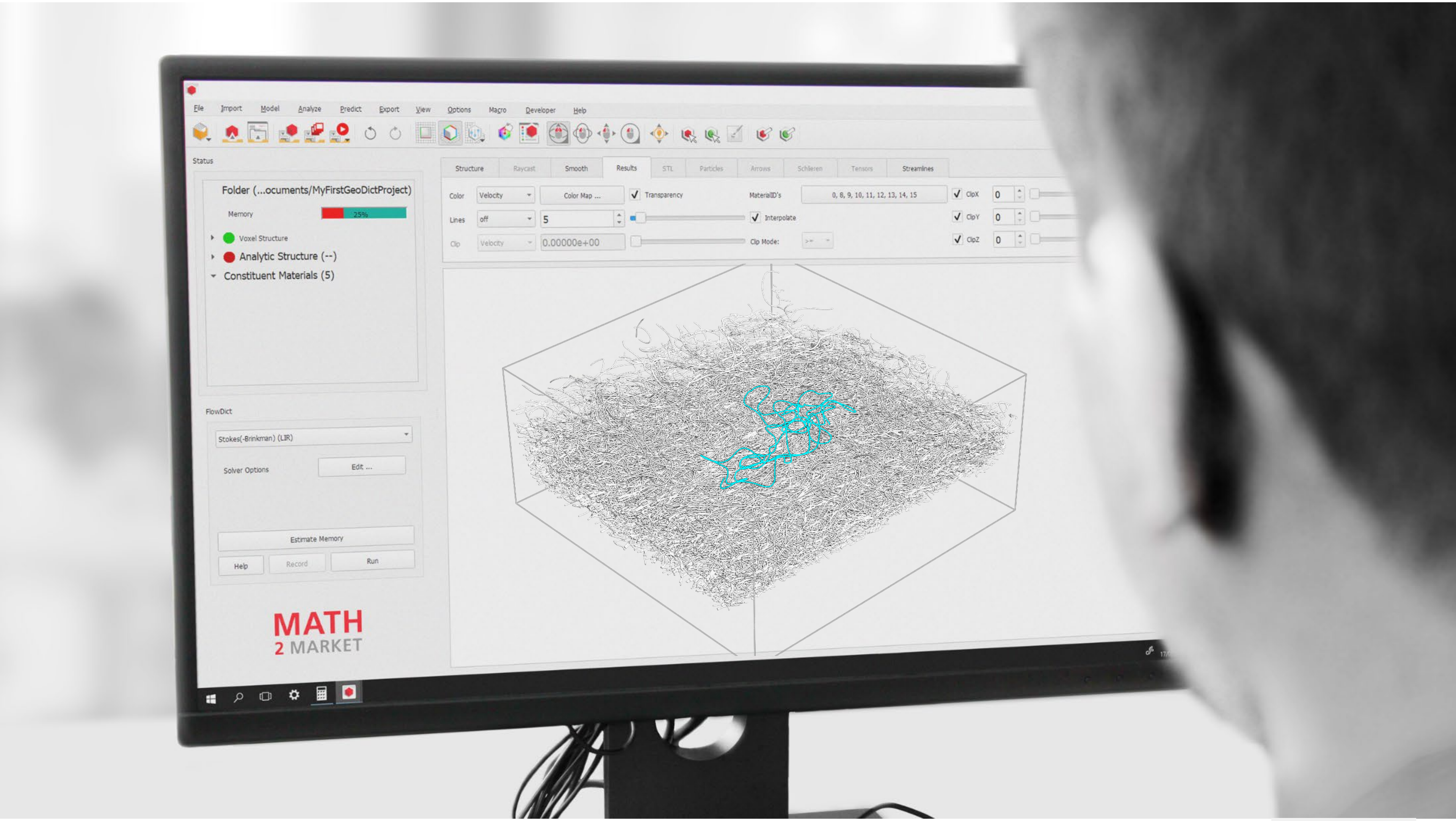
- Uses neural networks for shape-based binder identification, fiber identification and fiber separation
- Enables analysis of multi-material scans where materials can not be separated by thresholding or classical image processing
- Includes trained networks for **fiber** & **binder** identification

Using existing GeoDict functionality, this enables you to:

- Run simulations with different properties assigned to binder & fibers
- Run geometric analyses on each **separate** material, e.g.:
  - Total binder volume content
  - Binder distribution in through-plane & in-plane directions

THANK YOU FOR YOUR ATTENTION

GeoDict
The Digital Material Laboratory



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