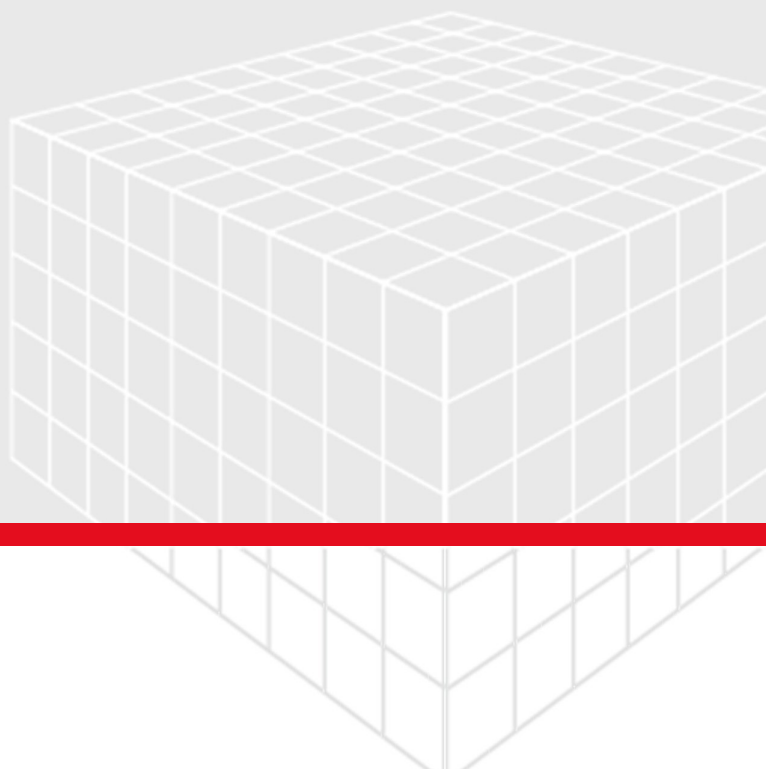


FiberFind

User Guide

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GEODICT

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FiberFind

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1 FiberFind

The FiberFind module covers the functionalities in GeoDict that aim to understand 3D scans of fibrous materials, like nonwovens and fiber-based composites, e.g., glass fiber reinforced or carbon fiber reinforced composites. FiberFind requires as input 3D models that are previously obtained from segmented micro CT scans or FIB/SEM scans of the material.

Three distinct approaches are pursued in FiberFind:

1. Estimate statistical properties of fibers: diameter distribution, orientation distribution, curviness, and curliness
2. Identify individual fibers by classical image processing methods
3. Identify individual fibers and binder by Artificial Intelligence (AI) approaches

In FiberFind, we assume that pores have already been separated from solids, and that the solids consist of individual fibers and possibly some binder. Binder and fibers usually have the same gray values in the images. An automatic separation based on the gray value is therefore not possible. FiberFind with the submodule **Identify Binder (AI)** provides the possibility of separating binder from fibers automatically prior to the identification of separate fibers.

FiberFind analyzes the diameter, orientation, and curvature of fibers, to estimate the performance of fibrous structures.

FiberFind is the starting point to reproduce fibrous structures with FiberGeo. The FiberGeo module can create innumerable models of fibrous media and can also add binder to these models. Variations of fiber diameters, fiber shape, fiber length, fiber curvature, fiber density, etc. and also the amount and location of binder can be carried out as needed. You can input the statistical parameters obtained with FiberFind in FiberGeo and model isotropic and anisotropic materials. Subsequently, the statistical parameters of the modelled structure may be easily varied to investigate the effect of material structure on the performance of materials. By being used together, FiberFind and FiberGeo are intended to close the digital fibrous material design loop.

FiberFind is particularly well suited for the analysis in fibrous structures made of non-hollow fibers with circular or slightly elliptical cross-section.



New in GeoDict 2026

- Current generations of NVidia GPUs are supported now again by GeoDict-AI, FiberFind-AI, GrainFind-AI and all other AI functionality in GeoDict.
 - PyTorch has been updated to 2.9.1 and CUDA to 12.8. Now all GPUs with a "Compute Capability" of 7.5 or higher are supported. On the other hand GPUs using the "Pascal" architecture and older are not supported anymore.
- For FiberFind-AI CPU parallelization for parts of the algorithm is enabled, resulting in a slight speedup.

- Improved handling of structures with parallel fiber bundles.
- Improved continuity of extracted fibers by considering incoming and outgoing directions in ambiguous high-density regions.

Topics of FiberFind

- [FiberFind AI modules](#)  ⁵
General remarks on the AI components in FiberFind.
- [Theoretical Background](#)  ⁶
Learn more about the theory behind the fiber identification and characterization.
- [Estimate Fiber Diameters](#)  ¹²
Set the parameters for the fiber diameters estimation.
- [Estimate Fiber Orientations](#)  ²¹
Set the parameters for the fiber orientation estimation.
- [Estimate Fiber Curvature](#)  ³³
Set the parameters for the fiber curvature estimation.
- [Identify Fibers \(AI\)](#)  ³⁵
Set the parameters for the fiber identification with the AI approach and analyze the result.
- [Identify Binder \(AI\)](#)  ⁶⁴
Set the parameters for the binder identification with the AI approach and analyze the result.
- [Reproducing Fibrous Media Using FiberFind and FiberGeo](#)  ⁷⁵
Example of how to use the FiberFind results in order to generate a digital twin with FiberGeo.
- [References](#)  ⁸⁸
References used in this section of the User Guide.



Join the conversation

Visit the Community on [GeoDict Forum](#) to be inspired and get answers to top questions.

Find illustrative application examples on the [website](#).

Our tutorials and seminar videos give you a first hands-on experience. They are collected in the [Learning Center](#).

Send your [Support Request](#) to our technical Support.

1.1 FiberFind AI modules

The AI modules of FiberFind – Identify Fibers (AI) and Identify Binder (AI) - are only available in the GeoDict GUI if a corresponding license (FiberFind-AI) is available. Otherwise, only the analytic modules of FiberFind can be used.

FiberFind - Identify Fibers (AI) and Identify Binder (AI) use PyTorch, one of the most used and well-known machine learning libraries. The required version of PyTorch will be installed during GeoDict installation and FiberFind will work out of the box.

FiberFind can run on the CPU (the main processor) or on the GPU (the graphics card). If a suitable GPU is detected, FiberFind- Identify Fibers (AI) and Identify Binder (AI) will run on the GPU, otherwise on the CPU. An example of how to choose the Batch Size is given under [GPU Options](#)⁴¹ in the Identify Fibers (AI) section.



Note! The **GPU version** is usually much faster (roughly factor 10) than the CPU version, but it requires:

- An NVIDIA graphics card (GPU) with compute capability of at least 7.5 according to the list given in <https://developer.nvidia.com/cuda/gpus>.

1.2 Theoretical Background

Topics of this section

- [AI Approach To Identify Binder And Fibers](#)^[6]

Here, the identification of binder and fibers with the AI approach, and the identification of fibers using the classical image processing approach is explained.

- [Analysis Of Fiber Diameter, Orientation, Curvature, Curliness, And Torsion](#)^[7]

A short explanation of the estimation of statistical fiber properties, diameter distribution, orientation distribution, curviness, curliness and torsion.

1.2.1 AI Approach To Identify Binder And Fibers

The FiberFind module provides the possibility of using Artificial Intelligence (AI) approaches for the separation of binder and fibers as well as the identification of individual fibers in a fibrous structure.

In the image taken from a material, fibers and binder often have the same gray values, and therefore cannot be separated based on this value. The same holds true for the separation of different fibers. However, it is possible to separate binder from fibers and fibers from each other based on the shape in the image.

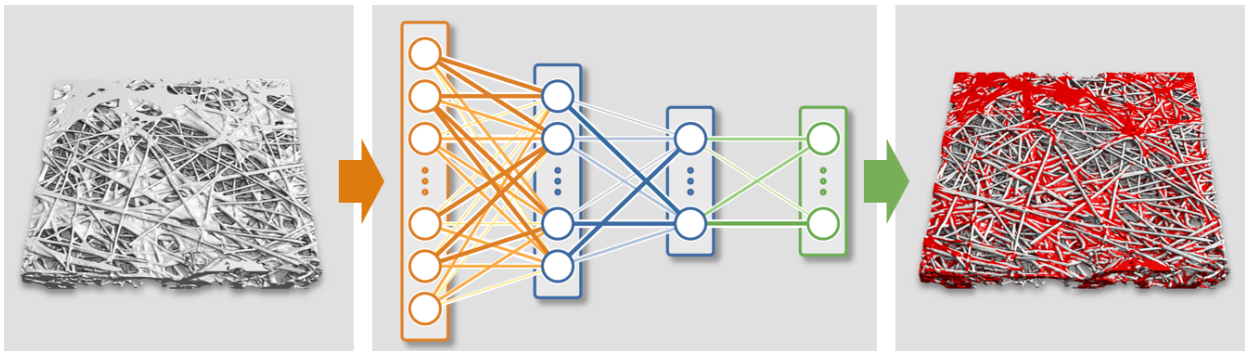


The fundamental idea of AI is that a neural network is trained to perform a special task, here the identification of separate fibers or the differentiation between fibers and binder. To train the neural network, enough examples need to be available to teach it. Clearly, for 3D-scans it is a very hard and time-consuming task to manually label materials or objects for the number of examples required, which are typically hundreds of millions. This is where **GeoDict's unique structure-generation** capabilities come in.

As long as the models are close enough to the real 3D-scans, GeoDict is capable of providing the needed ground truth data for the neural networks that embody the AI capability in FiberFind. Since GeoDict 2021, the capability to create and parameterize these neural networks is available in the module GeoDict-AI.

Based on the trained neural network, FiberFind decides for each voxel of the structure whether it is binder or fiber and sets the material ID accordingly.

In the same way, a trained neural network for FiberFind-Identify Fibers (AI) decides for each voxel to which fiber it belongs.



The current version of [FiberFind-Identify Fibers \(AI\)](#)^[35] and [FiberFind-Identify Binder \(AI\)](#)^[64] come with a single neural network each that can be applied to segment data sets in the FiberFind module. Therefore, currently some constraints on the input data exist which may make it necessary to preprocess the input data before applying the AI approach.

✓ Analytic Image Processing Approach To Identify Separate Fibers

For the identification of separate fibers using the image processing approach **Analytic**, FiberFind identifies fibers using a skeletonization algorithm which thins out the fiber structure until the fibers are reduced to a skeleton which represents the center lines of the individual fibers.

The identification of fibers with classical image processing methods is optimized for low density fibrous materials.

1.2.2 Analysis Of Fiber Diameter, Orientation, Curvature, Curliness, And Torsion

If analytic object data (GAD) is available, the properties are computed directly based on these objects. This is usually only true for structures generated with GeoDict. Otherwise, if only a voxel image is available, the fibers are identified first using image processing before running the analysis.

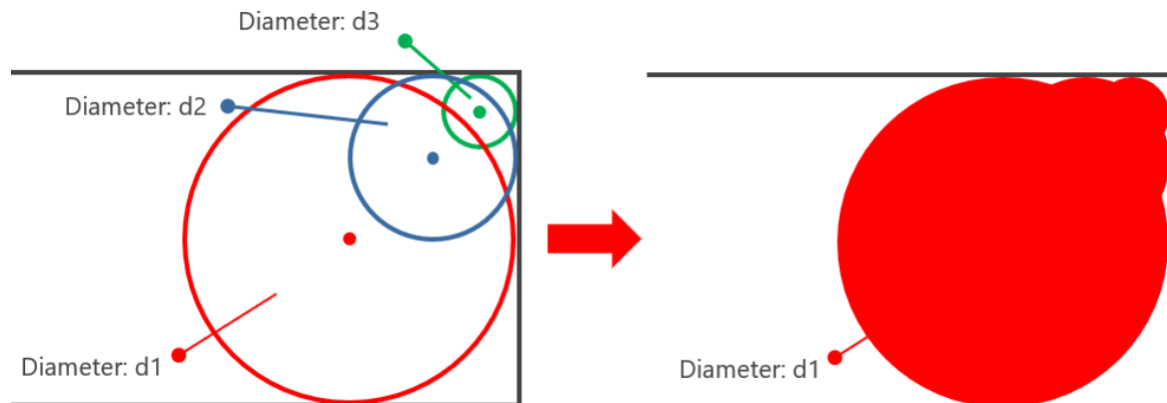
✓ Computation of fiber diameters

The algorithm to estimate fiber diameters works as follows: At the start, each fiber voxel gets assigned the value of the largest sphere fitting into the fiber in this position. Then, it is checked for each fiber voxel if it lays inside of a larger sphere compared to the diameter of the sphere already assigned to the voxel under consideration.

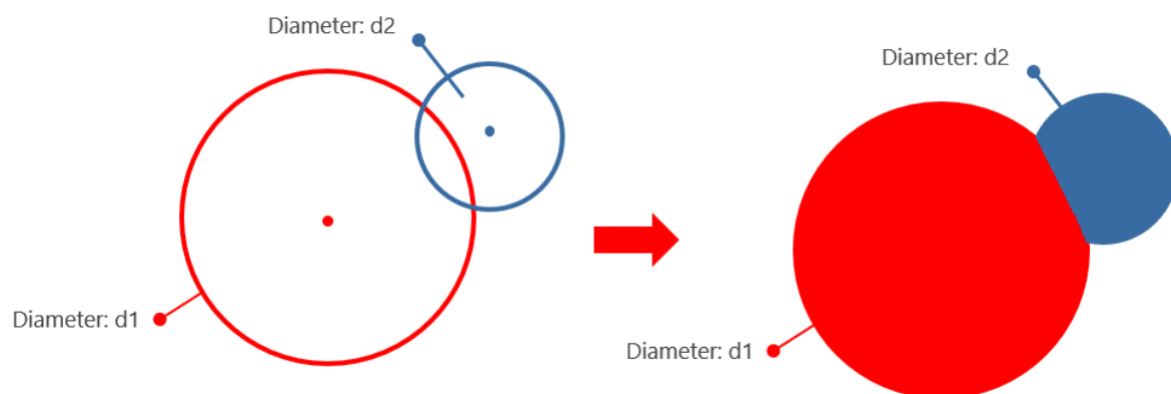
For this comparison, there are two possibilities:

- The center of the smaller sphere is contained within the larger sphere. Then, the diameter value of the larger sphere is assigned to all voxels in the smaller sphere. Voxels at the end of a fiber get like this the same diameter as neighboring parts of the fibers and not a

smaller one. See the following figure.



- The center of the smaller sphere is not contained within the larger sphere. Then, the overlapping area between both spheres is partitioned between both diameters. Like this, fibers overlapping each other both get the correct diameter. See the following figure.



✓ Computation of fiber orientation

To compute fiber orientations, two algorithms are used:

- Star Length Distribution (SLD):
 1. Analysis is done on a per-voxel basis.
 2. For each voxel, it analyzes chord lengths through the voxel for a pre-defined set of directions.
- Principal Component Analysis (PCA):
 1. The domain is cut into blocks of a fixed size (currently 32x32x32).
 2. For each block, all connected components are found. Ideally, they correspond to segments of individual fibers.
 3. For each component, it is assumed that the voxels of the component form a point cloud. An ellipsoid which best approximates this point cloud is computed using the PCA method (Principal Component Analysis) and provides the principal orientation.

4. The principal orientation vectors are averaged to get a per-block orientation.
5. Per-block orientations are averaged to obtain the desired number of orientation tensors.

In summary, the PCA method cuts the fibers into segments and determines the local average of the orientation of these segments to obtain an orientation tensor.

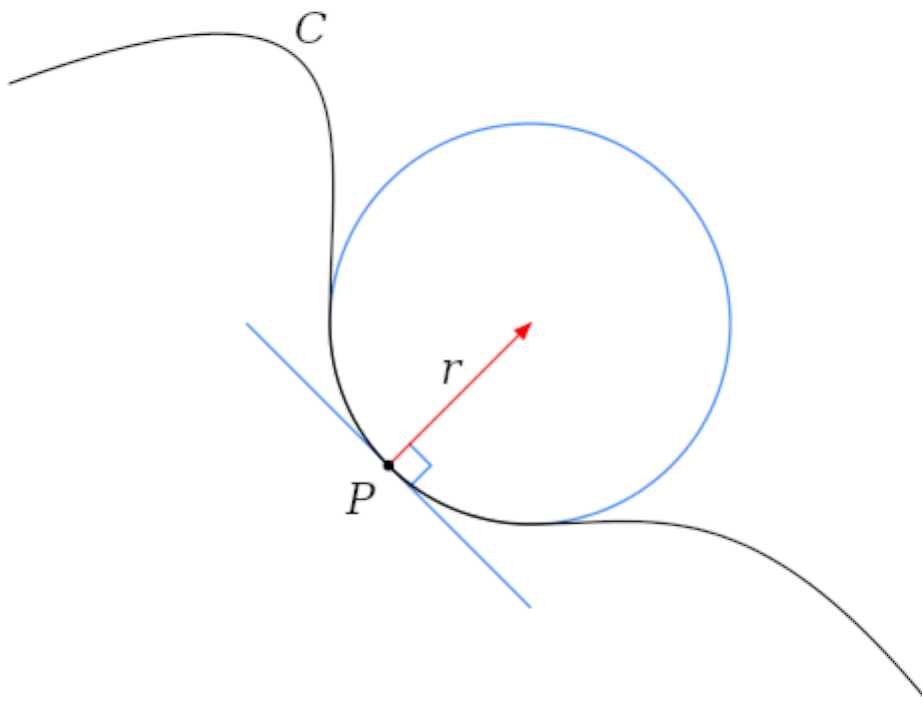
For both algorithms, GOF files (GeoDict Orientation Files) can be saved to allow for simulation of anisotropic properties (e.g., transverse isotropic) of fibrous structures. In case of transverse isotropy, the material properties in fiber direction differ from properties in the perpendicular direction.

These GOF files can be used, e.g., in ElastoDict for computations of mechanical properties in anisotropic materials.

✓ Estimate fiber curvature and curliness

FiberFind can calculate curliness and curvature distributions in models of fibrous structures. Curved fibers occur in materials for numerous industrial sectors: synthetic filter media, cellulose filter media, gas diffusion layers (GDL) in fuel cells, insulation materials, nonwovens for many applications, etc.

The calculated curvature is based on the definition of geometric curvature. At any point on the curve, the curvature is defined as the inverse radius of the osculating circle. The osculating circle has the same tangent vector as the curve at that point and approximates the curve locally.



The curl-index measured by FiberFind is the length of the fiber divided by the distance between its start and its end. For straight fibers, this results in a curl-index of 1.



FiberFind calculates the curvature and curliness based on the centerline and the length of fibers. If no analytic data (.gad) is available, e.g., from a previously run fiber identification, FiberFind identifies the fibers with the Analytic method first.

The curvature estimation component is intended to be used with highly porous fibrous media (>90%). Solid volume fractions above 10% can decrease the accuracy of the result.

Since GeoDict 2023, additionally the autocorrelation of the curvature is computed for the fibers identified. This is done by interpolating first the curvature over each fiber and computing the autocorrelation from the interpolated values. The mean of these autocorrelation is then computed over all fibers. The autocorrelation function is cut at the fiber length that is exceeded by only 20% of the fibers.

✓ Computation of torsion

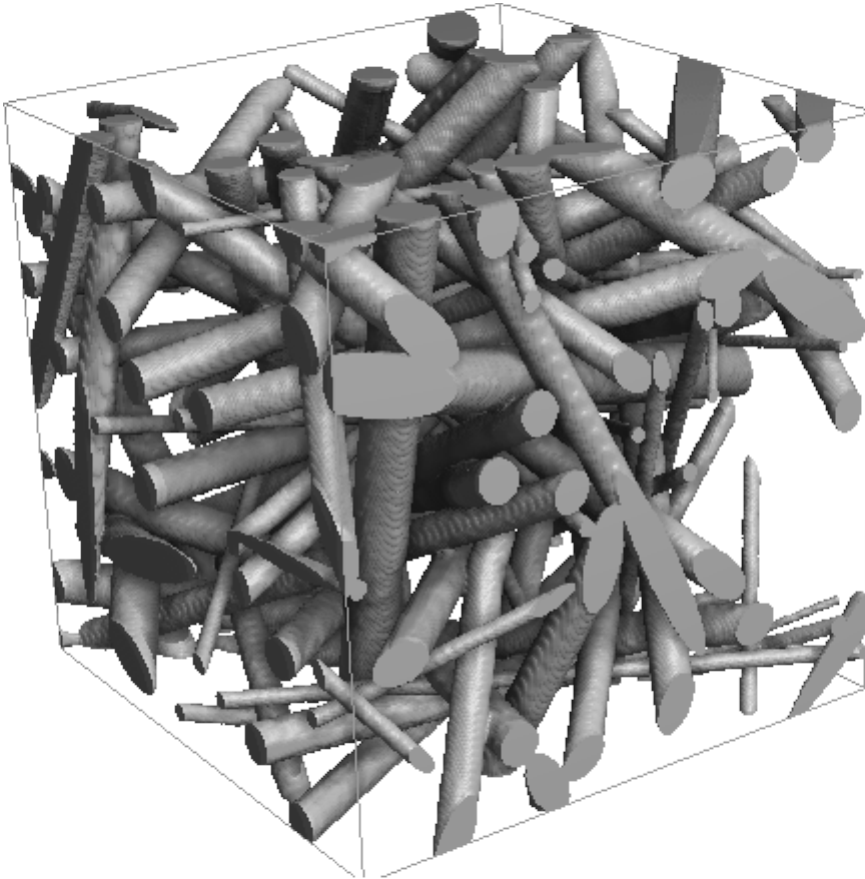
Since GeoDict 2023, the computation of the torsion of the cross-section area is available for the fibers identified. The torsion is computed for each fiber segment and as mean value for each whole fiber.

Like for the curvature, the autocorrelation of the torsion is computed as well. The torsion is first interpolated over the length of each fiber, and the autocorrelation is computed for each fiber separately. Then, the mean of this autocorrelation is computed over all fibers. At a fiber length that is exceeded by only 20% of the fibers, this autocorrelation function is cut.

So far, the result of the torsion computation is available only in the GeoDict result file under the [Report – Map tab](#)  ⁵¹.

1.3 Estimate Fiber Diameters

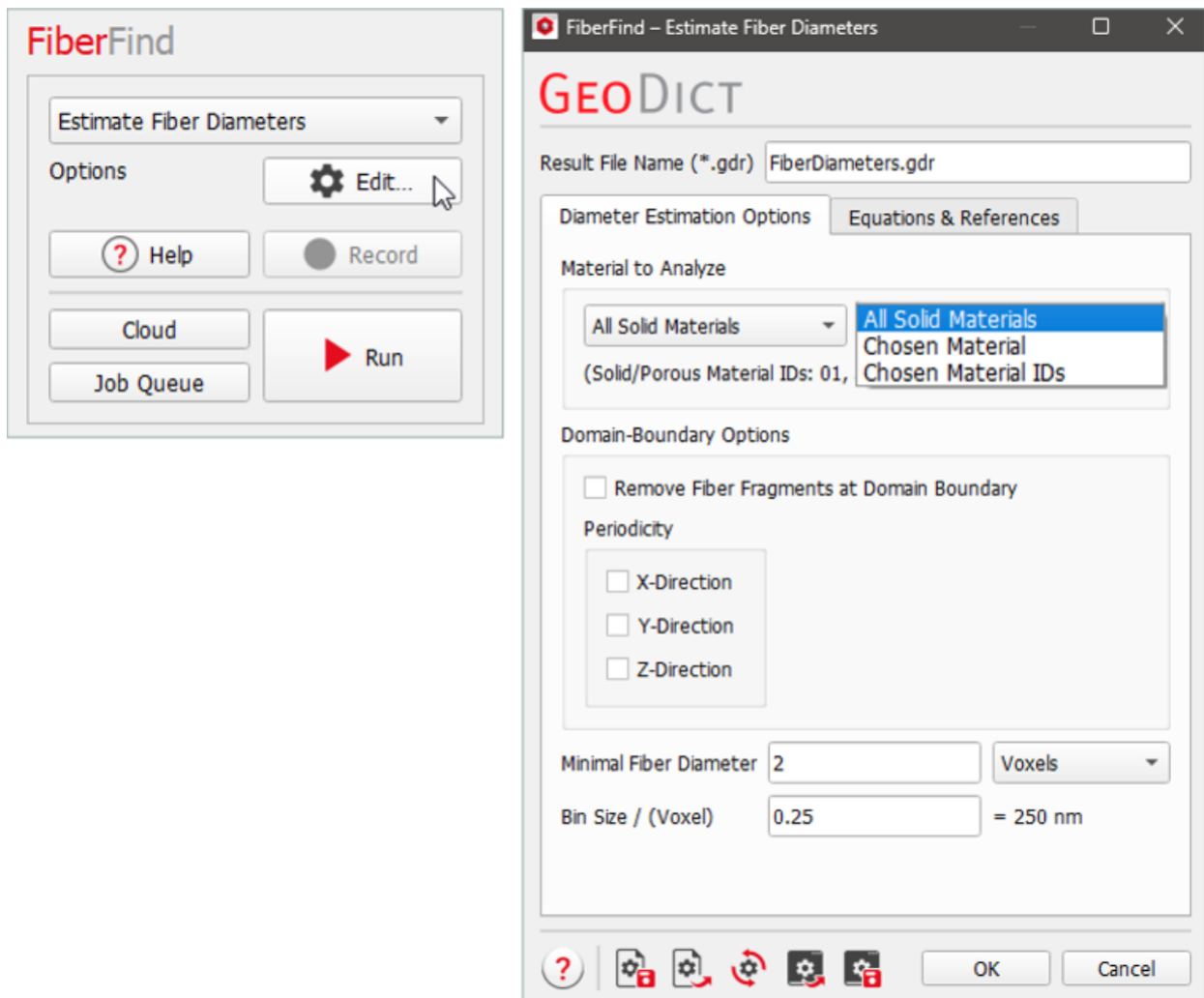
Start with a 3D-model of a fibrous material.



In the FiberFind section, select **Estimate Fiber Diameters** from the pull-down menu and click the **Options → Edit...** button.

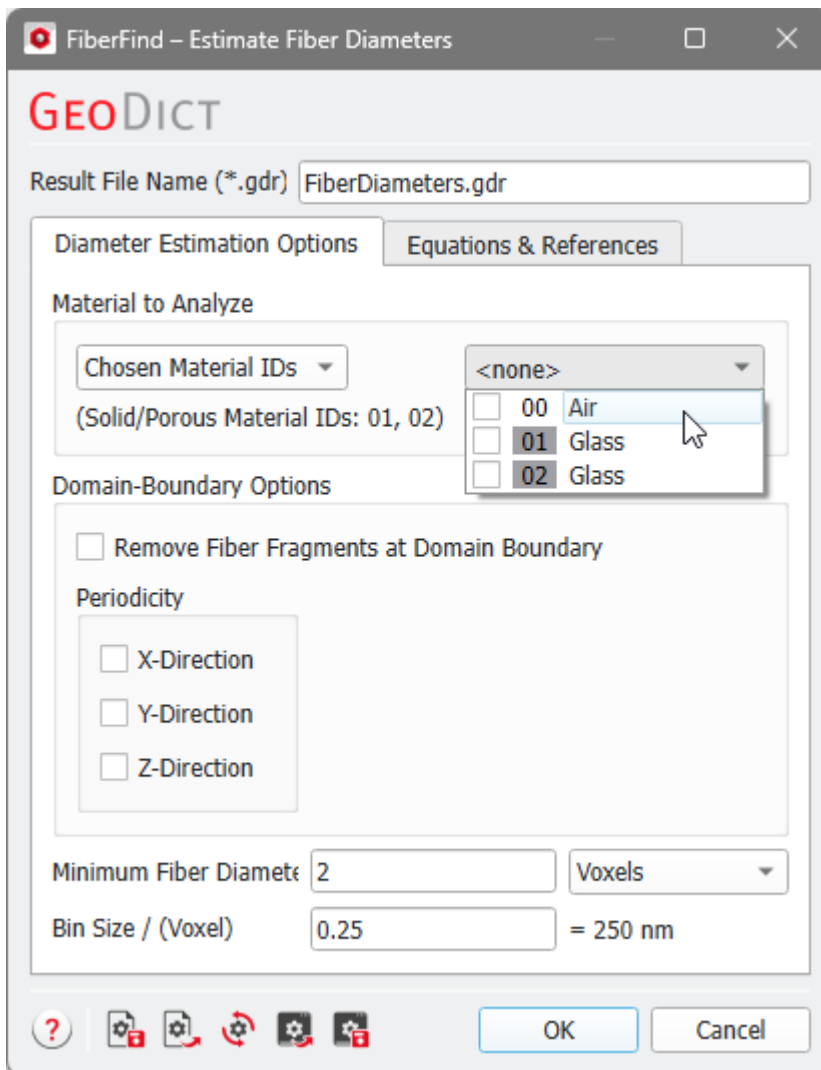
In the opening **Fiber Diameter Estimation** dialog, enter the desired **Result File Name (.gdr)** or keep the default **FiberDiameters.gdr**.

From the **Material to Analyze** pull-down menu, select to analyze **All Solid Materials** in the 3D-model (analyze all solid and porous materials), only a **Chosen Material**, or materials of the **Chosen Material IDs**.



When **Chosen Material** is selected, it is possible to analyze any material included in the model.

When **Chosen Material IDs** is selected, you can choose to analyze any of the 256 Material IDs that can appear in a model. This can be used when a material appears through overlapping of fibers, or to exclude binder from the fiber diameter analysis.



Check **Remove Fiber Fragments at Domain Boundary** to remove fragments of fibers that touch the domain boundary after running the fiber identification algorithm. Fibers which are cut at the domain boundary might distort the resulting statistics towards shorter lengths if this option is not selected. The diameter statistics might also be affected.

If the material is periodic in one or several directions, this can be accounted for by checking the boxes for **Periodicity**. For example, for periodicity in x-direction, fibers leaving the domain on one end in x-direction will be considered to relate to a fiber starting at the other end of the domain with similar y and z values. This is usually only true for periodically generated FiberGeo structures or, e.g., for weave structures. Most scans of real material will not exhibit periodicity.

If any information is available about the minimal fiber diameter, this information can be entered in **Minimal Fiber Diameter**. This speeds-up the computation, as the algorithm starts with this minimal diameter and not with zero for the diameter estimation. However, since fiber segments with diameter smaller than the value given are ignored if they are not connected to a larger fiber, the recommendation is to enter a fiber diameter slightly smaller than the one known, to make sure that all fiber segments are considered. The minimal diameter can be given in meter or as number of voxels.

The **Bin Size** (in Voxels) defines the resolution of the diameter analysis for the result visualization as histogram and for the computation of diameter distribution for one or several types of fibers. It can also be changed after the run from within the GeoDict Result Viewer.

A result file with the given Result File Name is saved in the chosen project folder (**File** → **Choose Project Folder...**) after the analysis, and a Result Viewer opens, showing the calculated values.

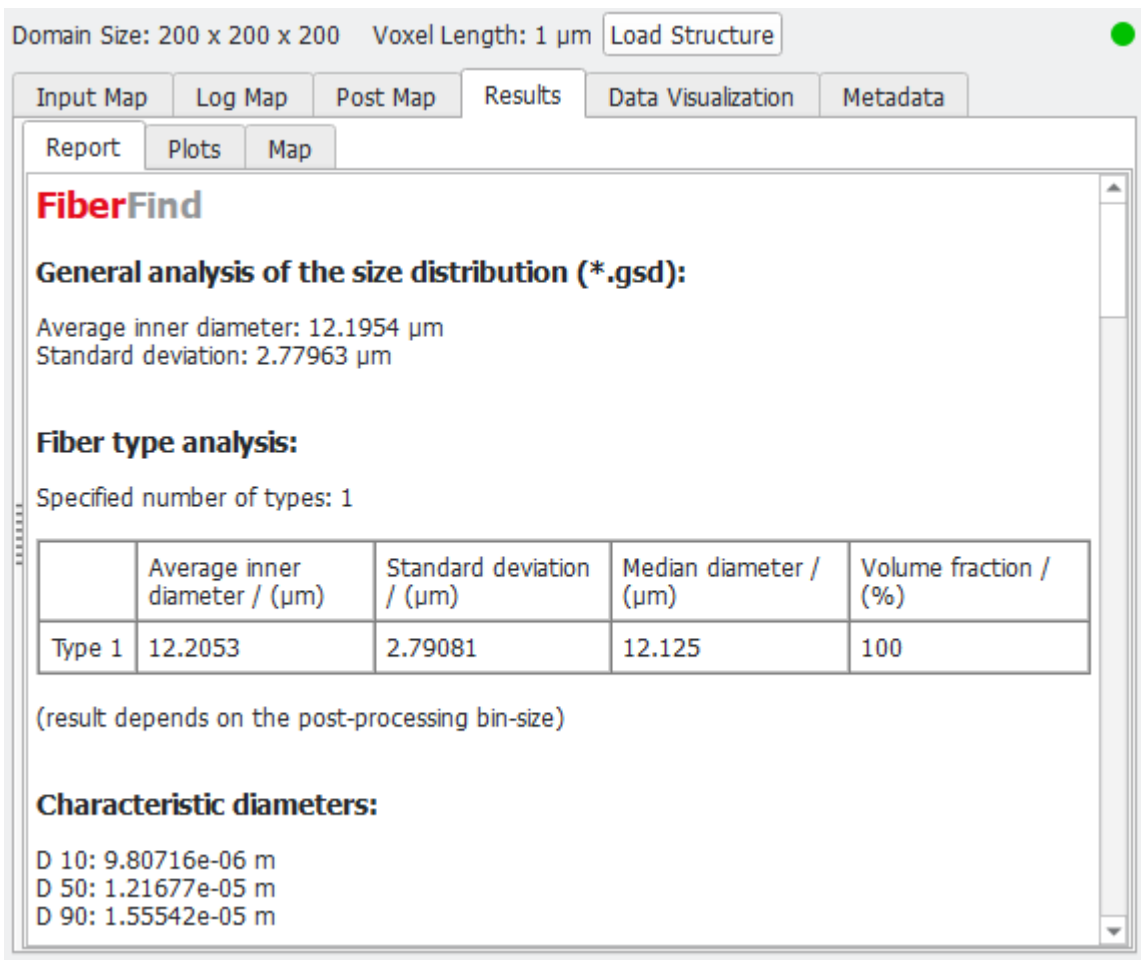


Know how! If you only have a 2D image of a fibrous material, you can perform a segmentation with GeoDict's 3D Image Processing and estimate the distribution of the fiber's diameters with **Estimate Fiber Diameter**.

1.3.1 Results

If the fiber diameter estimation ran successfully, a GeoDict Result Viewer opens. The header section can be collapsed and expanded. In the Result Viewer, the results are organized into **Input Map**, **Log Map**, **Post Map**, **Results**, **Data Visualization** and **Metadata**, which are accessed through the corresponding tabs.

Under the **Results - Report** sub-tab, the average diameter and the corresponding standard deviation for all fibers, as well as averages, standard deviations and medians of the binned histogram values for each fiber type are displayed. An example of two different fiber types is shown below. The histogram is also shown in tabular form, giving the minimum and maximum diameter of each bin, as well as the volume fraction of fibers with this diameter range.



In the post-processing section, left of the Results tab, the **Bin Size** (in Voxels), the **Thresholding Method**, and the **Number of Fiber Types** can be changed. These post-processing commands allow control on the display of the result data. The post-processing section can also be collapsed and expanded.

Changing the **Bin Size** changes the width of the histogram bin and, therefore, its resolution.

The **Thresholding Method** for the separation between fibers of different fiber types allows to choose between the **K-Means**, **Otsu's** method and a **Manual** selection of the threshold. This option is only relevant for two or more different fiber types.

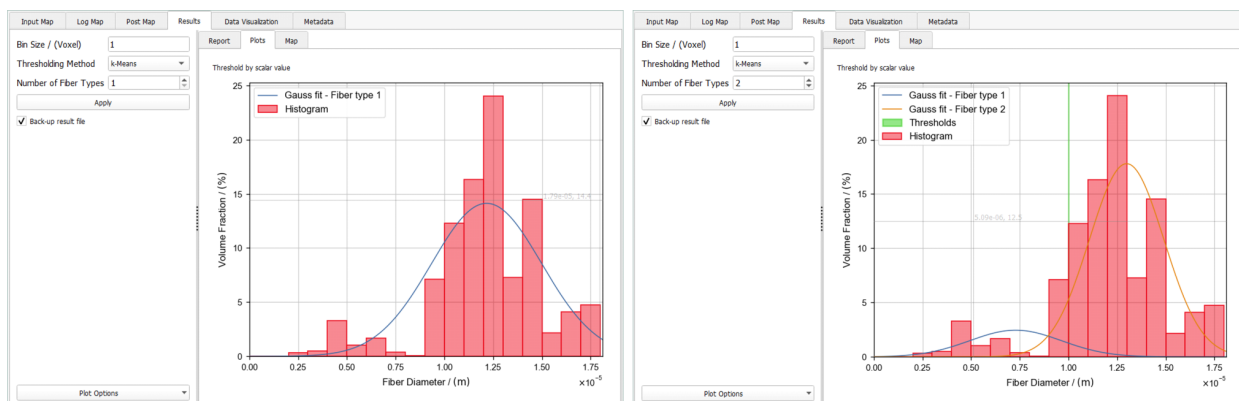
If the analyzed structure contains fibers of different types, specify the **Number of Fiber Types**, and for each type, a Gaussian curve is fitted to the data.

Click **Apply** to apply the changes to all presented results, like the distribution values shown in the **Report** subtab and the histogram plots on the **Plots** subtab.

If **Back-up result file** is checked, a back-up file describing the previous results is stored in a directory named as your result file in your project folder (e.g., FiberDiameters.gdr.bck1).

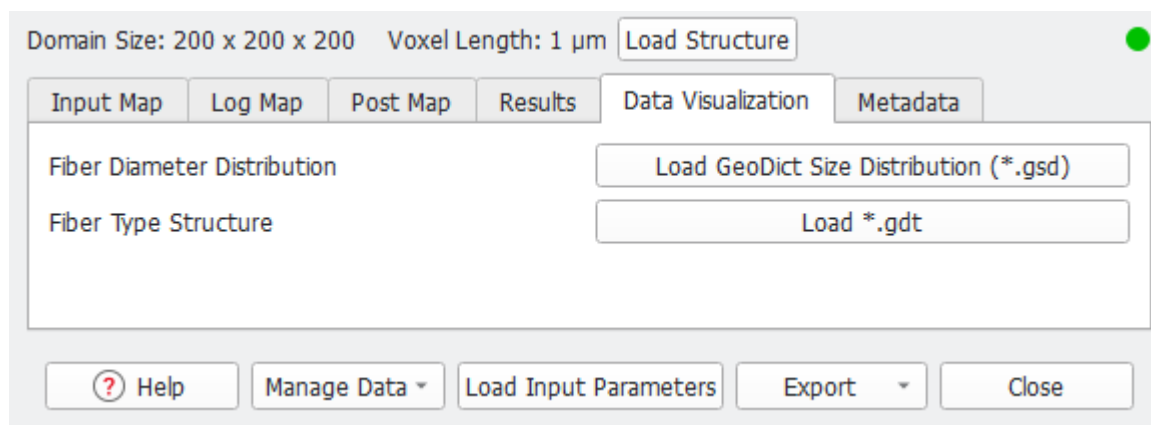
The histogram shown under the **Results - Plots** subtab shows the volume fraction of the fibers for each fiber diameter, together with a Gaussian fit to the histogram data. In the example shown below the highest volume fractions for one fiber type correspond to fibers with diameters around 12 μm .

However, in the example shown here, the structure consists of two fiber types: fibers with small diameter between 2-8 μm , and fibers with diameter between 9-18 μm .

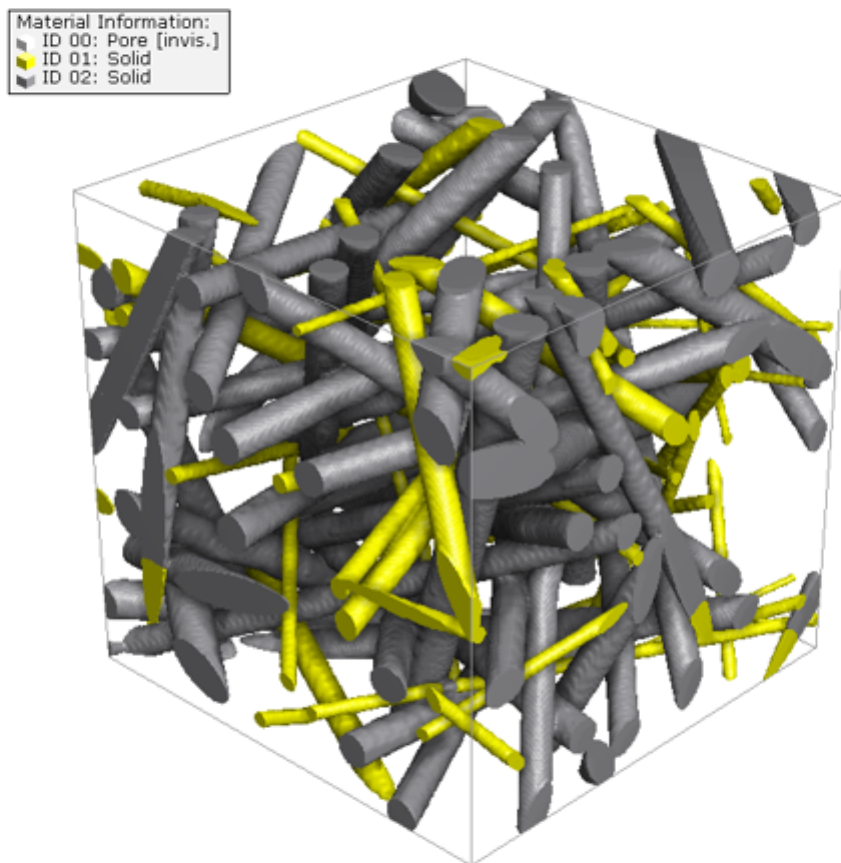


Choosing two different fiber types instead of one type, leads to Gaussian distributions that fit much better to the fiber diameters present in the structure. The structure with a separation of the two different types of fibers is shown below.

Under the **Data Visualization** tab, the **Fiber Type Structure** and the **Fiber Diameter Distribution** can be loaded.



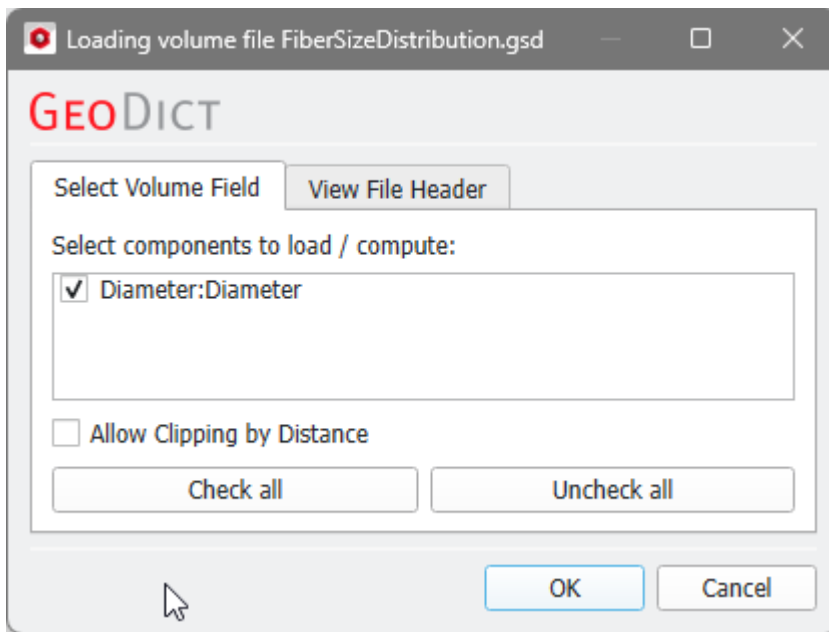
Clicking **Load *.gdt** opens a GeoDict structure. All fibers assigned to one fiber type have the same Material ID in this structure. In case of two different fiber types, as shown in the example here, fibers with small diameter have the Material ID 01 (here in yellow). Fibers with large diameter have Material ID 02 (here shown in gray).



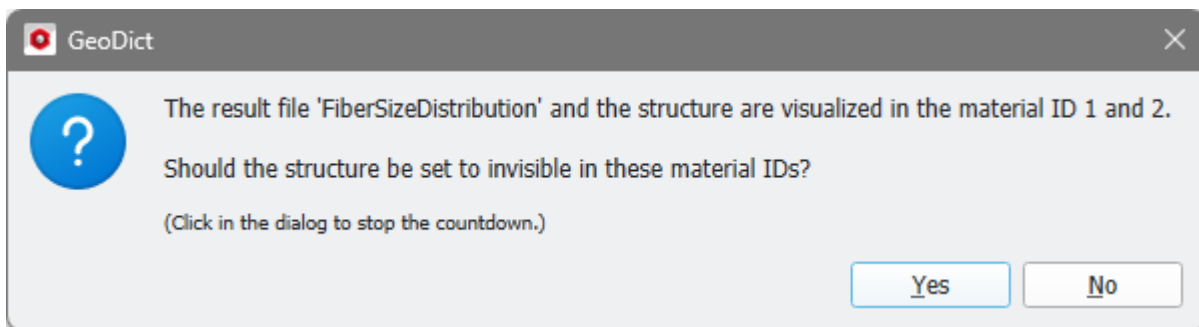
If postprocessing parameters in the **Results** tab (Bin Size, Thresholding Method, or Number of Fiber Types) are changed, the information in the .gdr file also changes.

This information can be used for the separation of fibers with different fiber diameters. Reassign, e.g., all voxels with Material ID 01 to ID 00 with ProcessGeo. In this way, only solid voxels with Material ID 02 remain in the structure and can be analyzed separately.

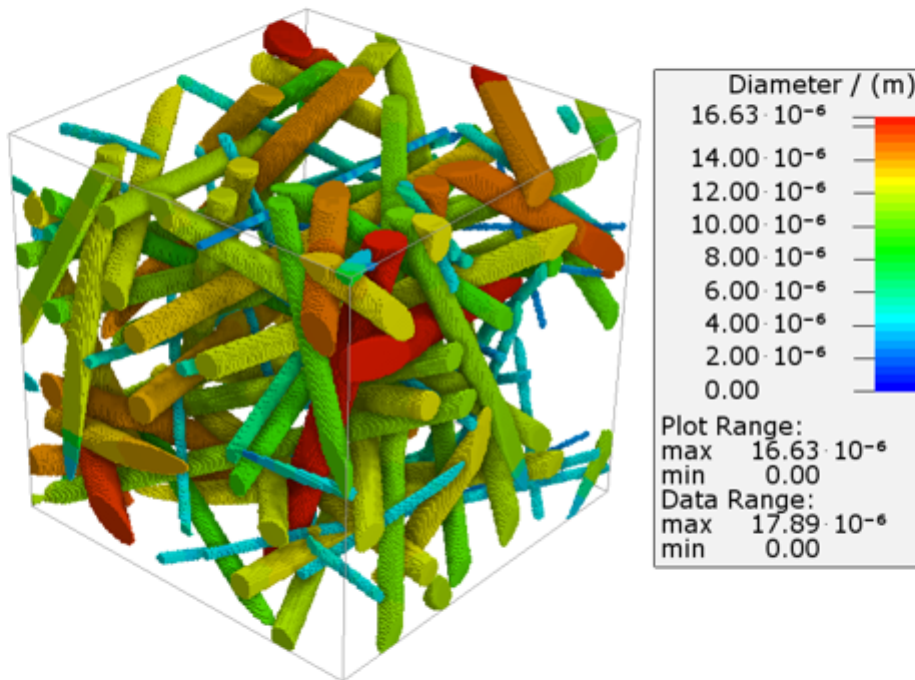
Now, click the **Load GeoDict Size Distribution (*.gsd)** button to observe the computed fiber diameter distribution. Check **Diameter** as the volume field to be loaded and click **OK**.



Then, deselect the visualization of the structure, by clicking **Yes** in the dialog that pops up (or by choosing **View** in the Menu bar and uncheck the **Structure** box).



In the **Volume Field** tab of the Visualization panel (above the Visualization area), with the **Visibility** set to material IDs 01 and 02, only the fibers are shown and not the pore space.

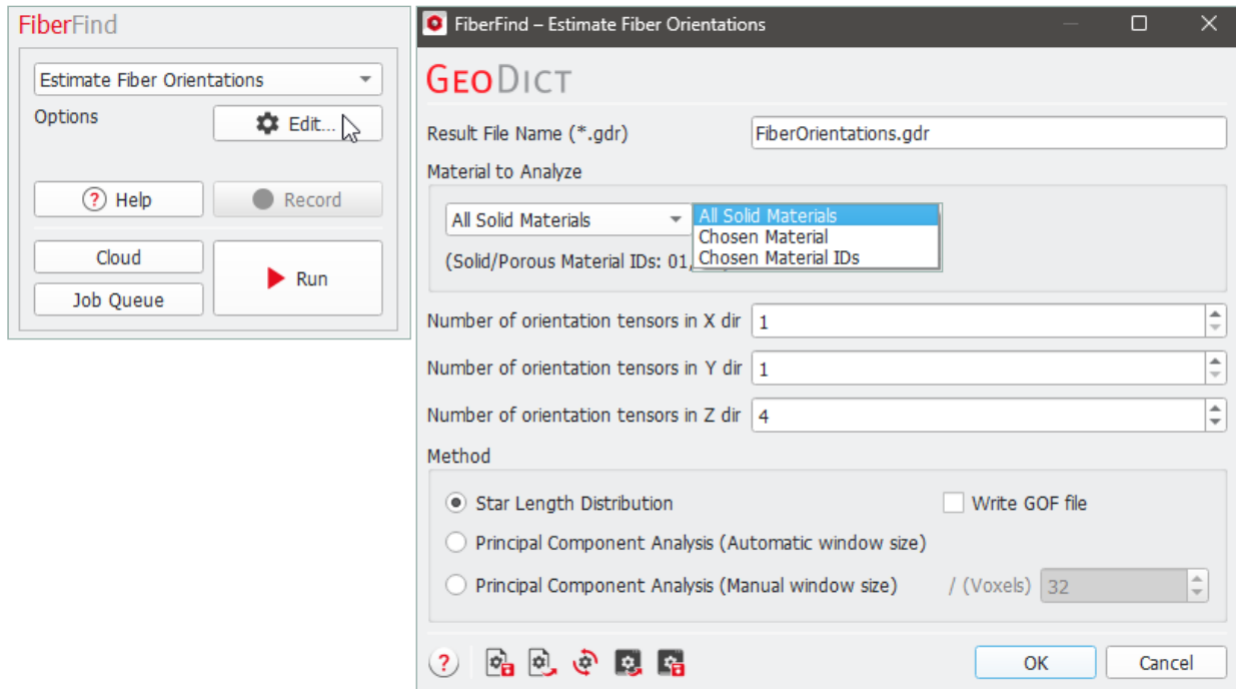


Please refer to the [Result Viewer](#) user guide for further detailed explanations, e.g., for the available data management buttons at the bottom of the Result Viewer.

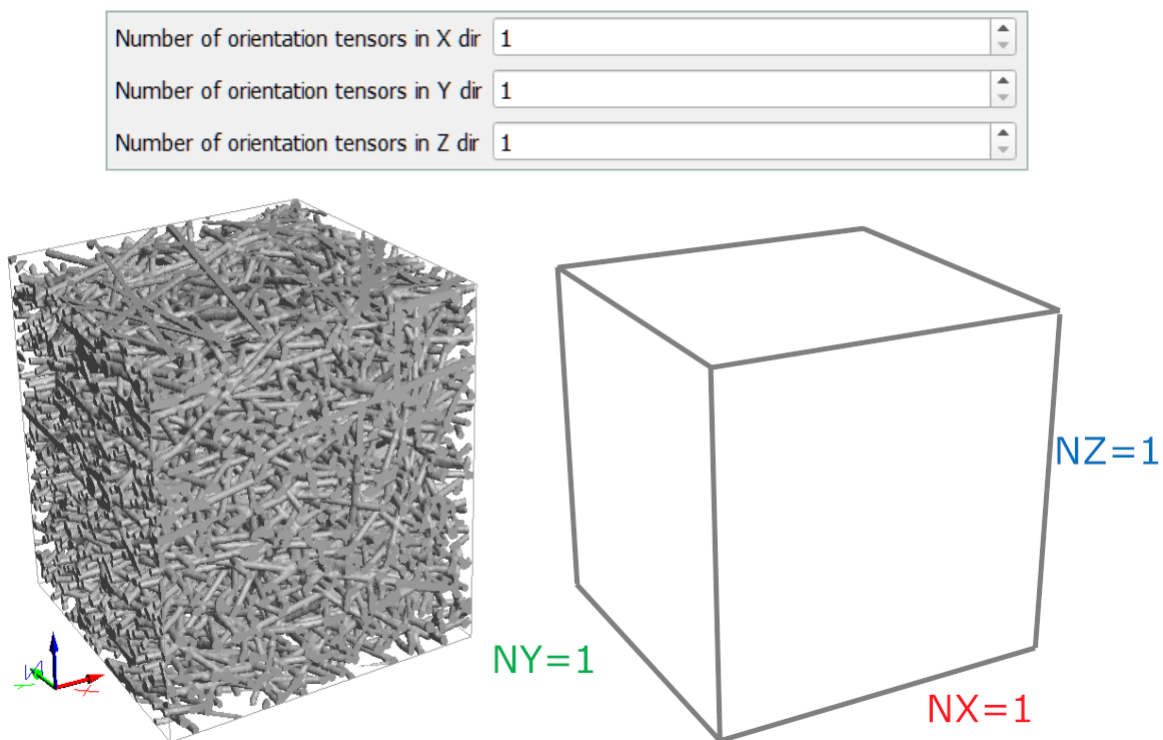
1.4 Estimate Fiber Orientations

Start with a 3D-model of a fibrous material. In the **FiberFind** section, select **Estimate Fiber Orientations** from the pull-down menu and click the **Options' Edit...** button.

In the opening **Fiber Diameter Estimation** dialog, enter the desired **Result File Name (.gdr)**, and select the **Material to Analyze** as explained for [Estimate fiber diameters](#) ¹².



For homogeneous materials, without variations in orientation, the domain can be analyzed as a whole and, therefore, the **Number of orientation tensors in X direction, in Y direction, and in Z direction** can be set to 1, 1, and 1.

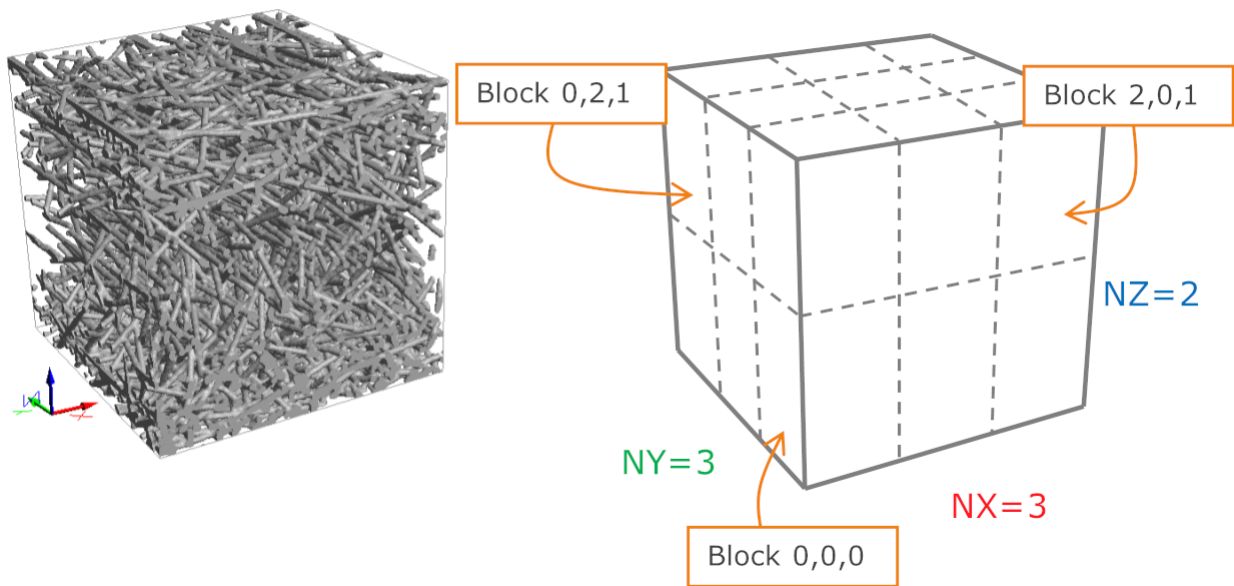


For non-homogenous fibrous materials, where fiber layers with varying orientations are present, the domain must be subdivided into blocks and an orientation tensor can be estimated for each block. The partition allows to analyze fiber orientation in these diverse areas of the domain, instead of having to cut the structure in parts and to analyze them separately.

The size of the blocks is defined by setting the **Number of orientation tensors**, for which values can be set, e.g., to 3, 3, and 2, producing 18 blocks.

Number of orientation tensors in X dir	3
Number of orientation tensors in Y dir	3
Number of orientation tensors in Z dir	2

These 18 blocks are labeled later in the result file as Block 0,0,0, Block 1,0,0, Block 2,0,0, Block 0,1,0, Block 1,1,0, etc.



Next, choose a method for the analysis of fiber orientation: **Star Length Distribution** (SLD) or **Principal Component Analysis** (PCA, Automatic or Manual window size).

Method

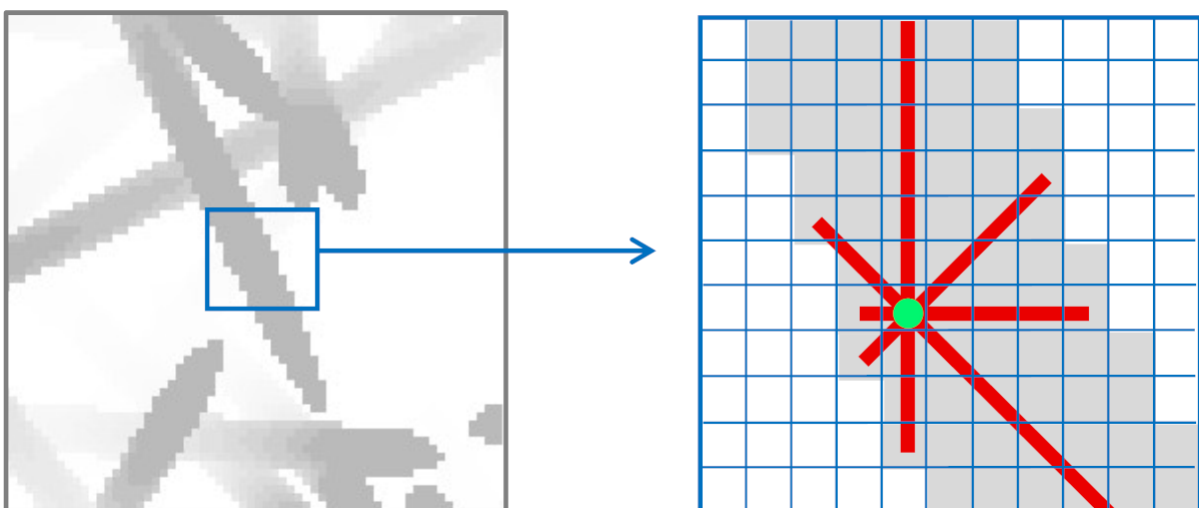
☒ Star Length Distribution
 ☐ Write GOF file

☐ Principal Component Analysis (Automatic window size)

☐ Principal Component Analysis (Manual window size) / (Voxels) 32

The Star Length Distribution (SLD) method works on a per-voxel basis. For each voxel, it analyzes chord lengths through the voxel for a pre-defined set of directions.

The relative length of the chords gives the per-voxel orientation tensor. Then, the tensors are averaged over all voxels included in a block.



The PCA method is an alternative approach that subdivides the domain into windows of a given size. The size of the window can be automatically determined based on maximum fiber diameter (Automatic window size) or manually entered in voxels (Manual window size).

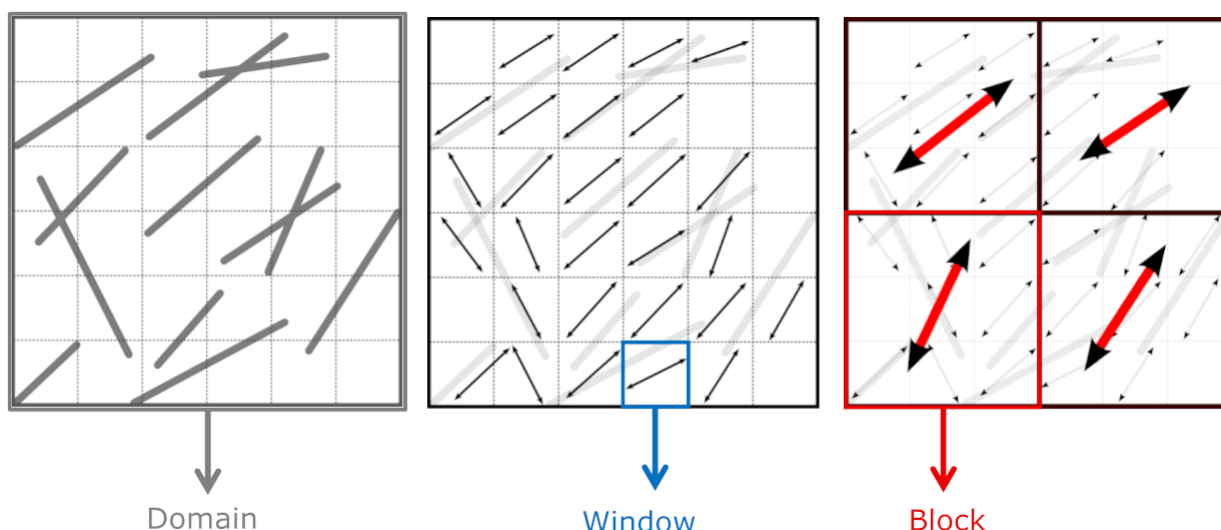
Method

☐ Star Length Distribution ☐ Write GOF file

☒ Principal Component Analysis (Automatic window size)

☐ Principal Component Analysis (Manual window size) / (Voxels)

The subdivision into windows is applied to eliminate the influence of fiber crossings. Our PCA-based algorithm identifies fiber fragments and analyzes the direction tensor within each window. Then, it averages the direction tensors over all windows within a block to obtain the orientation tensor for that block.



When needed, check **Write GOF file** to save a GeoDict Orientation File (GOF) with the per-voxel fiber orientation information.



Know how! If you only have a 2D image of a fibrous material, you can perform a segmentation with GeoDict's 3D Image Processing and estimate the distribution of the fiber's orientation with **Estimate Fiber Orientation**.

1.4.1 Results

After the calculations, a Result Viewer opens showing the calculated fiber orientation tensors and solid volume fraction for each block. The tensor describes the statistical distribution of orientation in that particular block.

With an undivided domain (1x1x1 blocks), only one tensor for the complete domain appears in the Result Viewer.

Domain Size: 200 x 200 x 200 Voxel Length: 1 μm

Per-block fiber orientation tensors:

Block 0,0,0: Solid volume fraction = 15.0141 %

0.429465	0.00816228	-0.000171053
-	0.451402	0.000805829
-	-	0.119133

Total runtime: 00:00:03, Total memory usage: 1.118 GiB

With the domain subdivided into 3x3x2 blocks, the number of tensors is 18.

Domain Size: 200 x 200 x 200 Voxel Length: 1 μm

Input Map Log Map Post Map **Results** Fiber Orientation Visualization Metadata

Report Plots Map

Per-block fiber orientation tensors:

Block 0,0,0: Solid volume fraction = 13.6796 %

0.38033	-0.00217077	-0.006726
-	0.4624	0.00877632
-	-	0.15727

Block 1,0,0: Solid volume fraction = 15.2288 %

0.370607	0.010879	-0.00315601
-	0.438704	-0.00639942
-	-	0.190688

Block 2,0,0: Solid volume fraction = 15.2933 %

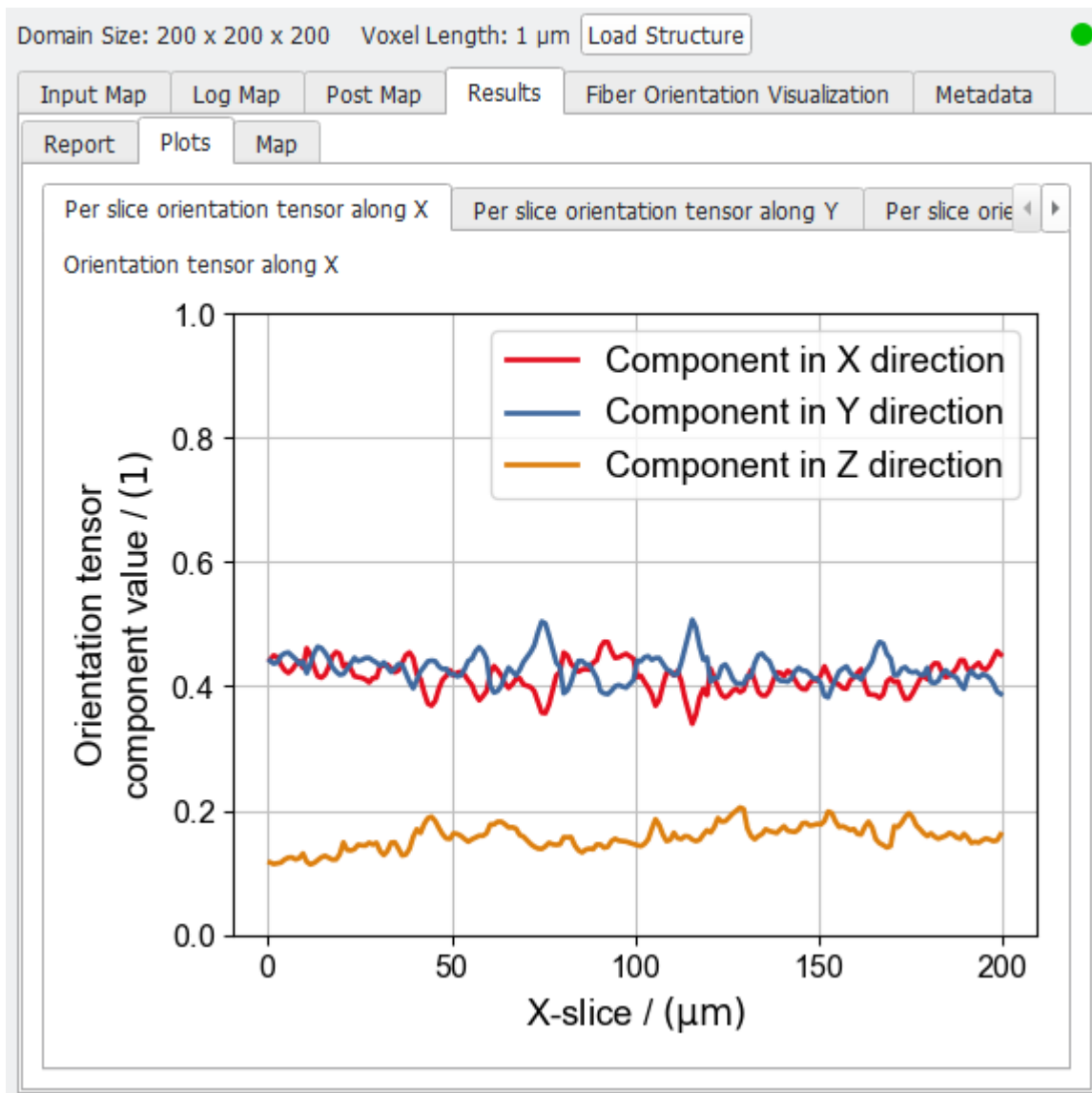
0.409837	0.0206828	0.000261297
-	0.42224	0.00754114
-	-	0.167923

Block 0,1,0: Solid volume fraction = 14.606 %

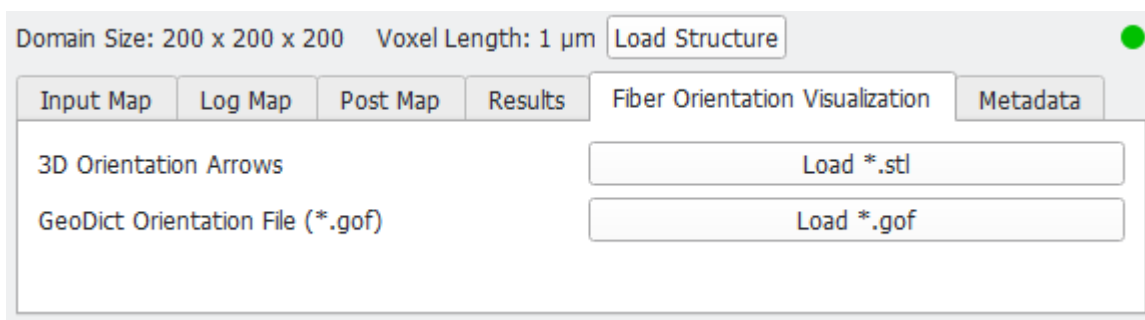
0.456209	-0.013129	0.00466685
-	0.40466	0.00470611
-	-	0.139132

A detailed description of the orientation tensor and its components is also given in the Orientation section of the FiberGeo user guide.

The components of the orientation tensor in X, Y and Z direction are shown for all three coordinate directions in the **Results - Plots** subtab.



The fiber orientation in the blocks can be visualized by clicking **Load .stl** to get the **3D Orientation Arrows** under the **Fiber Orientation Visualization** tab.

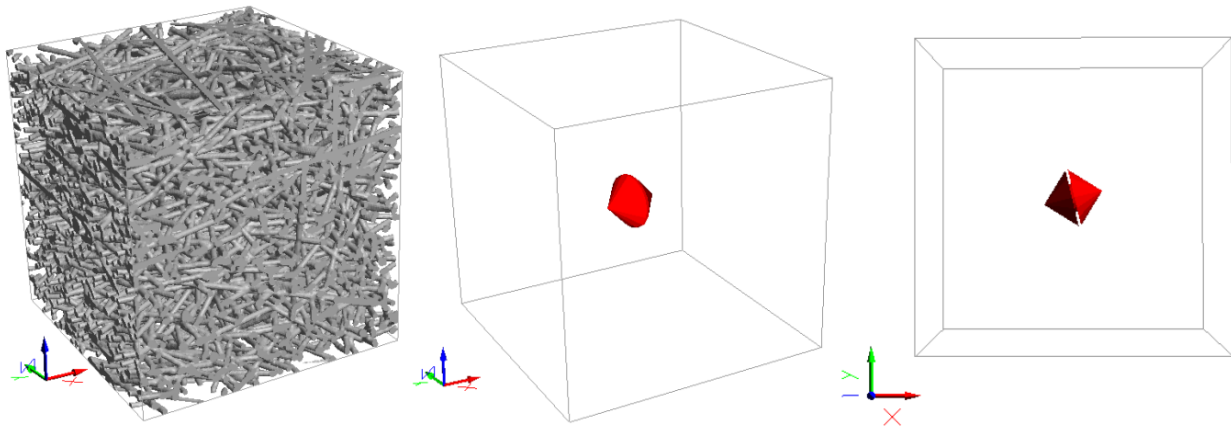


The fibers of the structure obscure the orientation arrows. Go to the menu bar and turn off the visualization of the fibers by un-checking **View** → **Structure**. Orientation arrows are visible only in 3D view. Switch to it by selecting **View** → **3D Rendering**.

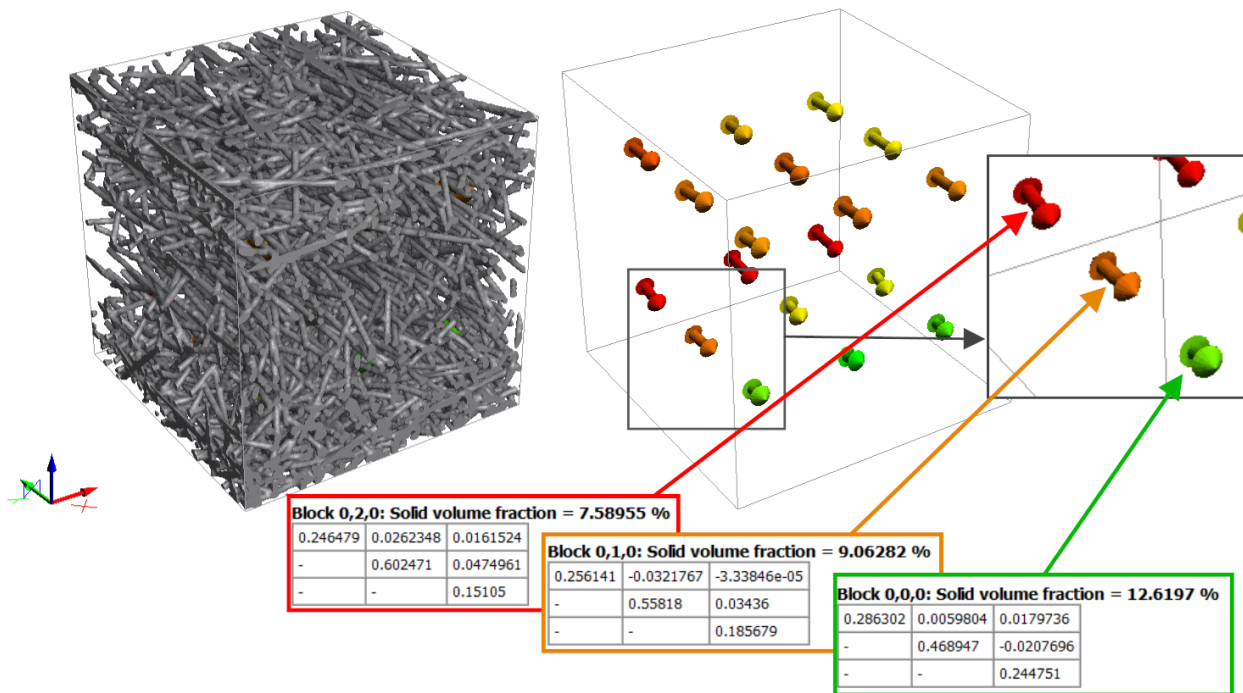
The **direction** of an arrow in a particular block shows the main fiber orientation in the block, and its length shows the strength of this main fiber orientation. The color of the arrows

indicates the fiber solid volume fraction (SVF) in a block. The color range is green-yellow-orange-red. Assignment of color in a block depends on its SVF relative to the SVF of the other blocks. The block with the highest SVF gets a green arrow. The block with the lowest SVF gets a red arrow. When there is only one block (homogeneous material), the arrow is red.

For a homogeneous material structure (no subdivision), only one arrow appears in the center of the single block. Here, the short arrow pointing in the X-direction indicates that although the fibers' main orientation is on the X-axis, there is a great deal of dispersion.

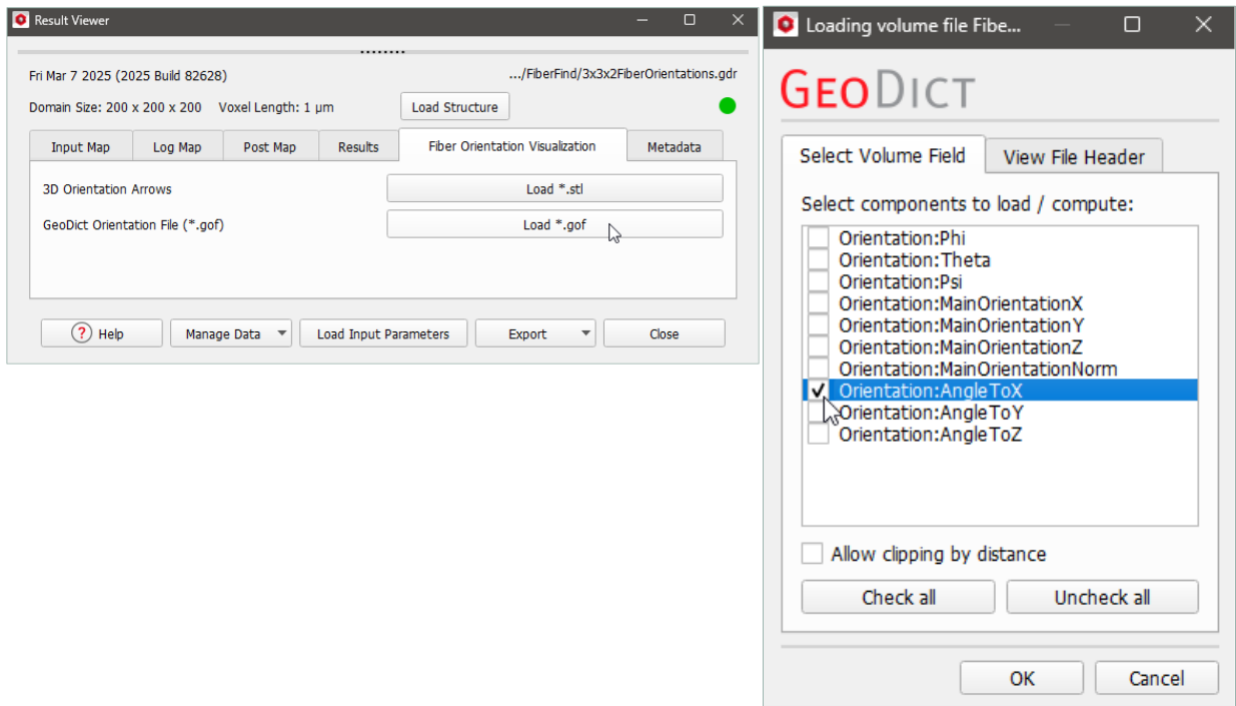


For a heterogeneous material structure, divided into 3x3x2 blocks, 18 arrows appear that occupy the centers of each of the 18 blocks. All arrows are oriented closely to the Y-axis. The range of colors indicates that the SVF of some blocks (green arrows) is higher than that of others (red arrows).

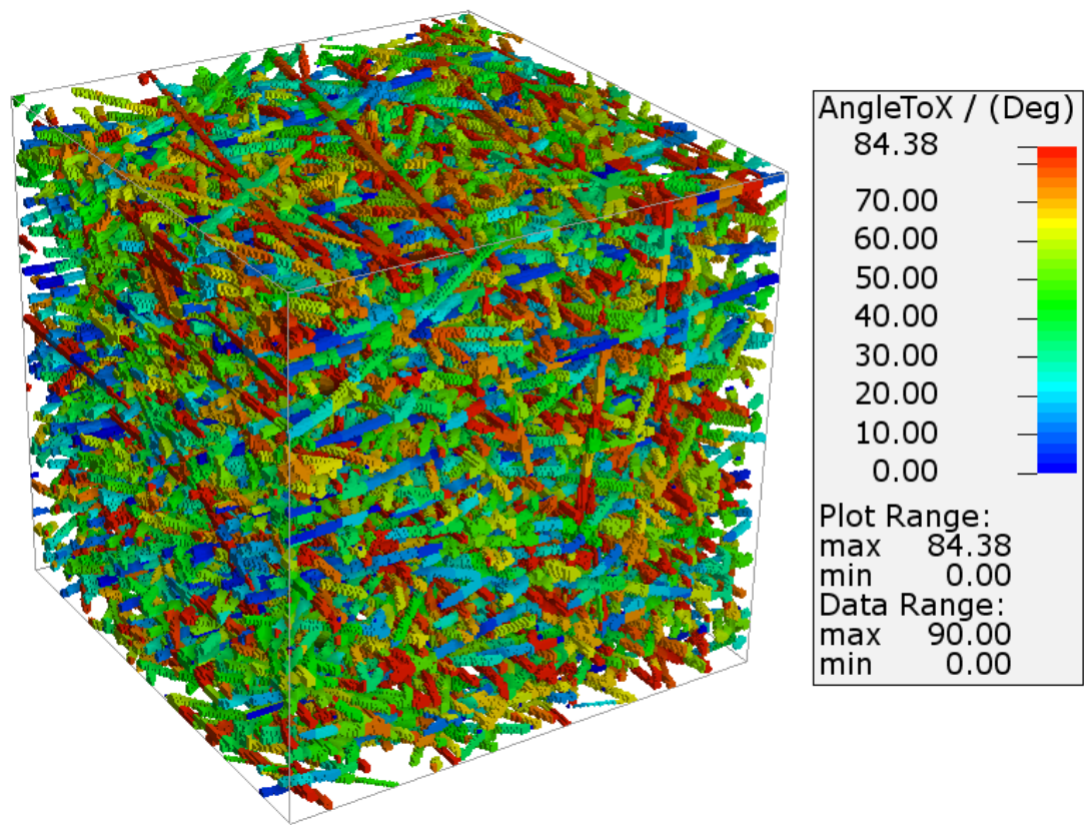


Besides the 3D orientation arrows it is possible to visualize the GOF file (if one was calculated). Click **Load *.gof** under the **Fiber Orientation Visualization** tab of the Result Viewer.

Select, e.g., to load the Orientation:AngleToX to get for each fiber segment the angle to the x axis.

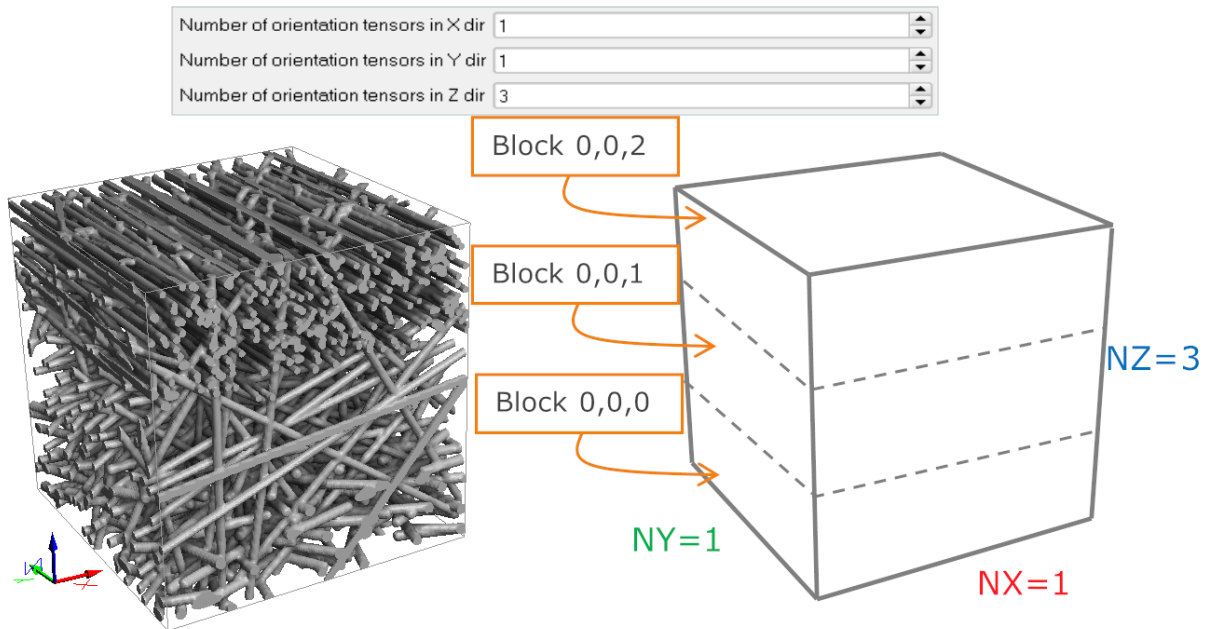


In the Visualization panel, above the Visualization area, uncheck the check box in the **Structure** tab. In the **Volume Field** tab, deselect **Visibility** for the pore space (Material 00).

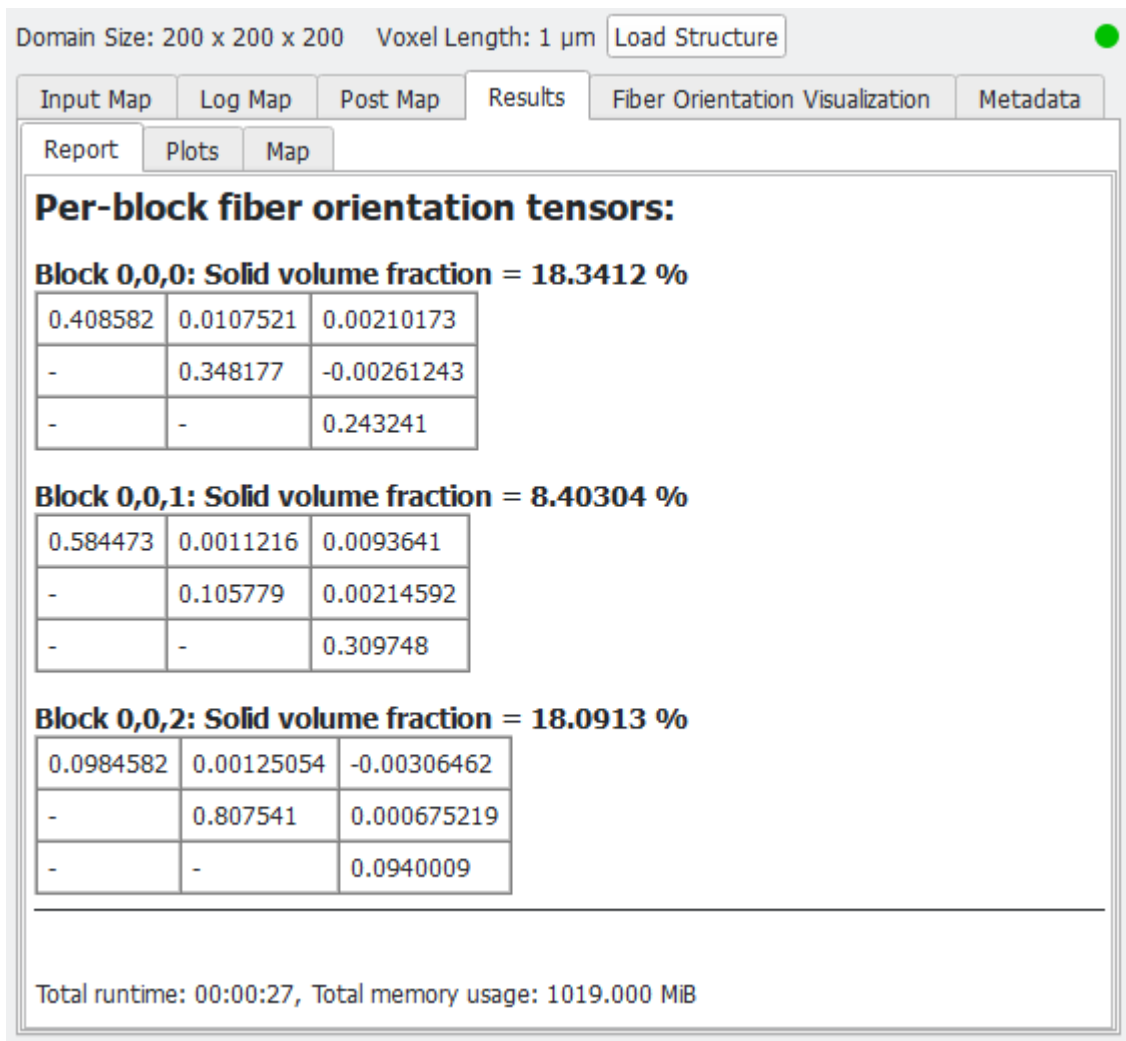


1.4.2 Layered Materials

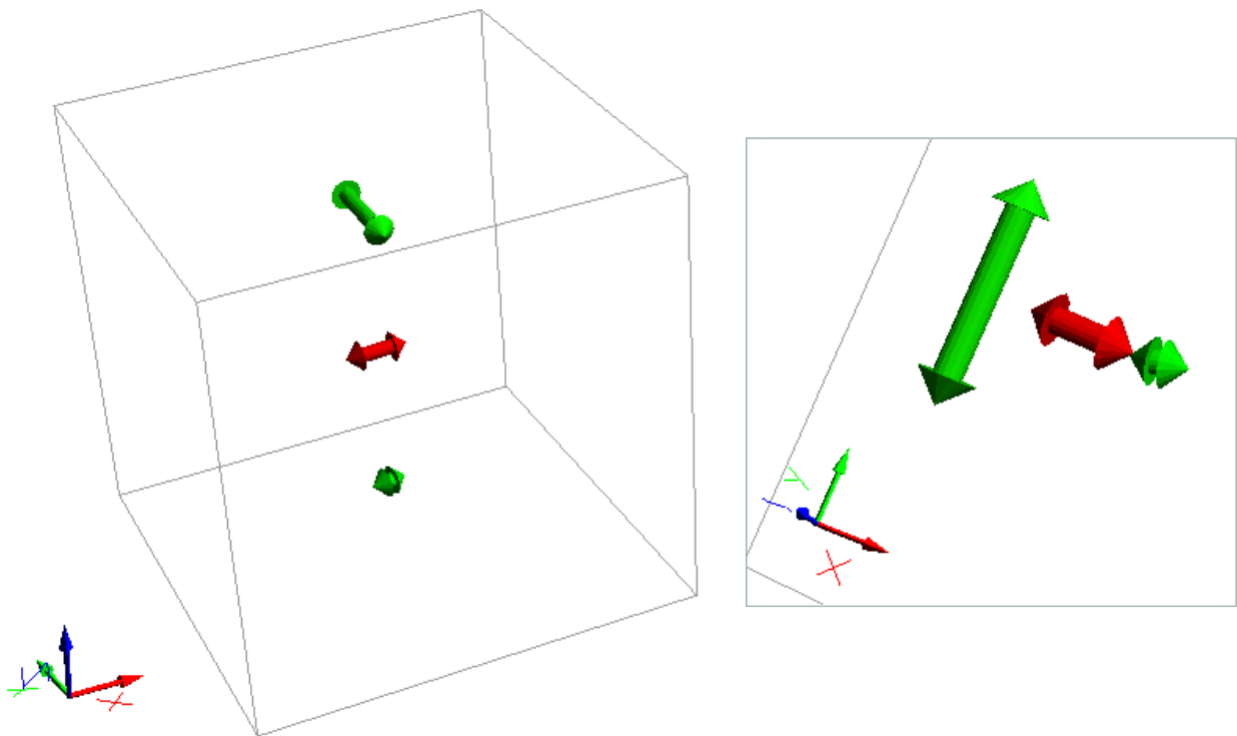
For a layered heterogeneous material, FiberFind can be used to estimate the fiber orientation in the layers by subdividing the domain according to the layers. For example, the domain of a material with three layers would be subdivided as follows:



When the calculations with FiberFind are finished, the Result Viewer for the fiber orientation result file (.gdr) opens showing the calculated fiber orientation tensors and solid volume fraction for each of the three blocks. The highest fiber solid volume fractions are in the top (Block 0,0,2) and bottom (Block 0,0,0) layers as can be seen in the **Results - Report** subtab.



Loading the 3D Orientation Arrows (**Load *.stl**) on the Fiber Orientation Visualization tab reveals that the main orientation of the top layer (Block 0,0,2) is in Y-direction, the main orientation of the middle layer (Block 0,0,1) is in X-direction and the main orientation of the bottom (Block 0,0,0) layer is in the X-Y-direction.



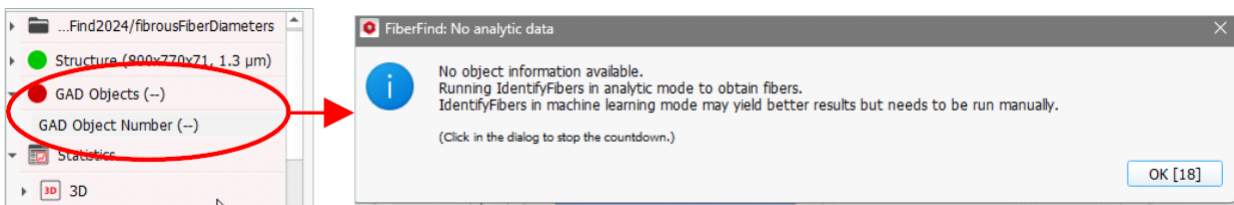
Whereas a great majority of fibers in the top layer are oriented in the Y-direction, the orientation in the middle layer and, particularly in the bottom layer, is more scattered.

1.5 Estimate Fiber Curvature

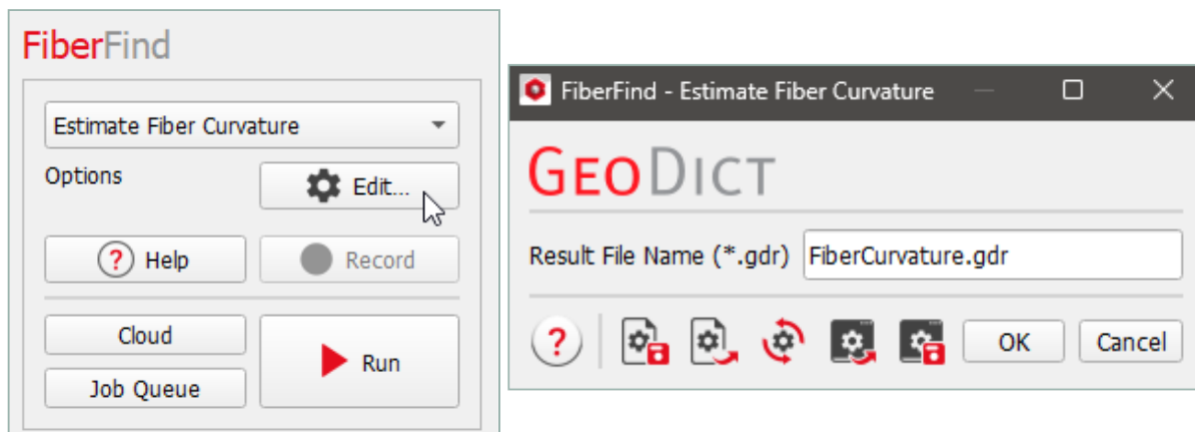
An analytic representation of the fibers (.gad file or .gdt file containing analytic data in GeoDict) is used for the estimation of curvature and curliness in FiberFind.

If such analytic data is available and loaded into the GeoDict GUI, the algorithm works directly on this representation, which can be created, e.g., by running a fiber identification with FiberFind (see [Identify Fibers](#)^[35]). The computation of curvature works for all fibers of one of the curved fiber types available in FiberGeo (Curved Circular, Curved Hollow, Curved Rosetta, Curved Elliptical, Curved Cellulose, Curved Rectangular, Curved Angular). For more details, see the FiberGeo user guide.

If no analytical data is available, i.e., the computation is started on a voxel image, the analytic fiber identification algorithm (i.e., the one available for the Identification Method Analytic) is applied to the structure before the curvature estimation. In that case a warning appears to inform the user:



For the estimation of curvature and curliness in FiberFind, in the **FiberFind** section, select **Estimate Fiber Curvature** from the pull-down menu and click the **Options' Edit...** button.

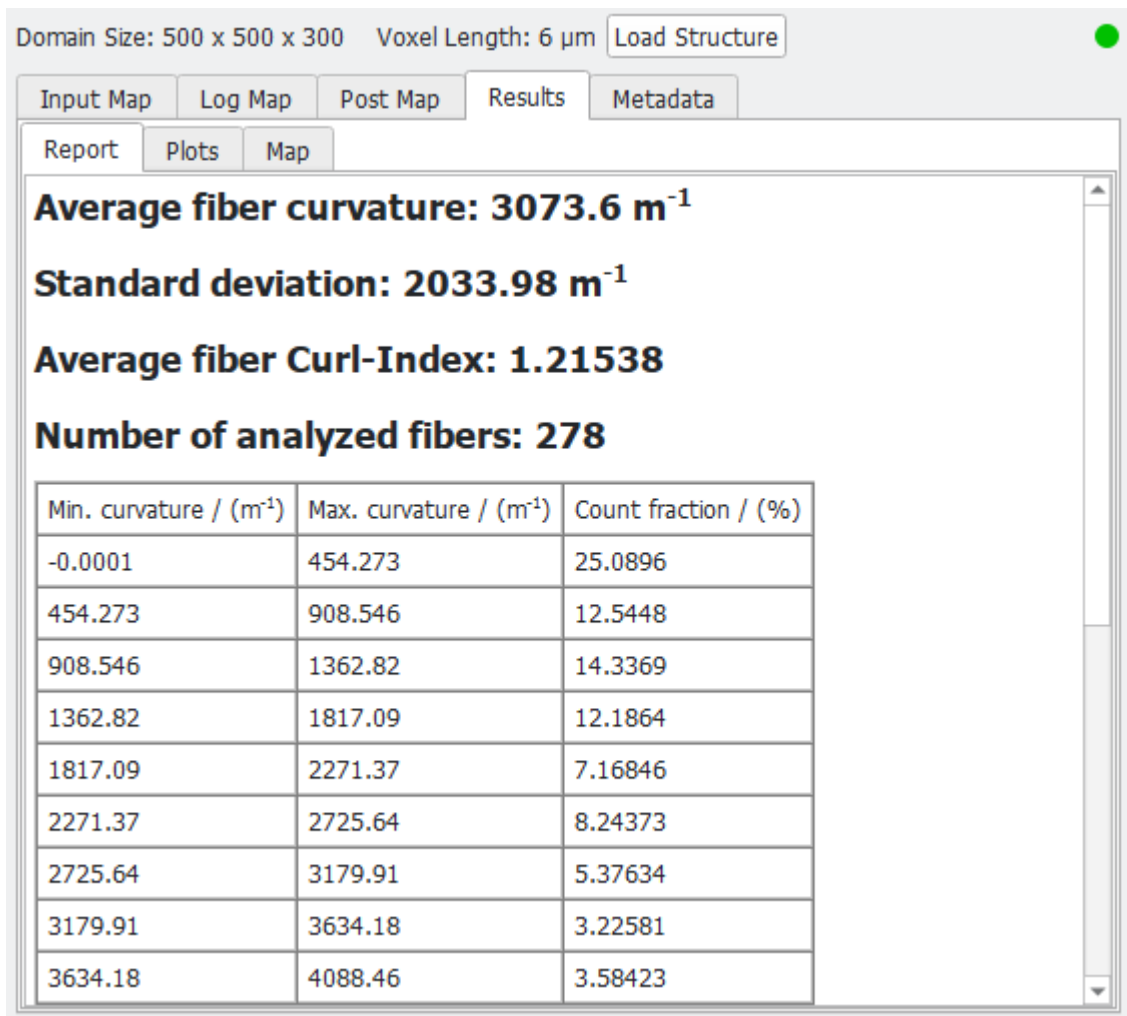


In the **Fiber Curvature Estimation** dialog, enter the desired **Result File Name (.gdr)**.

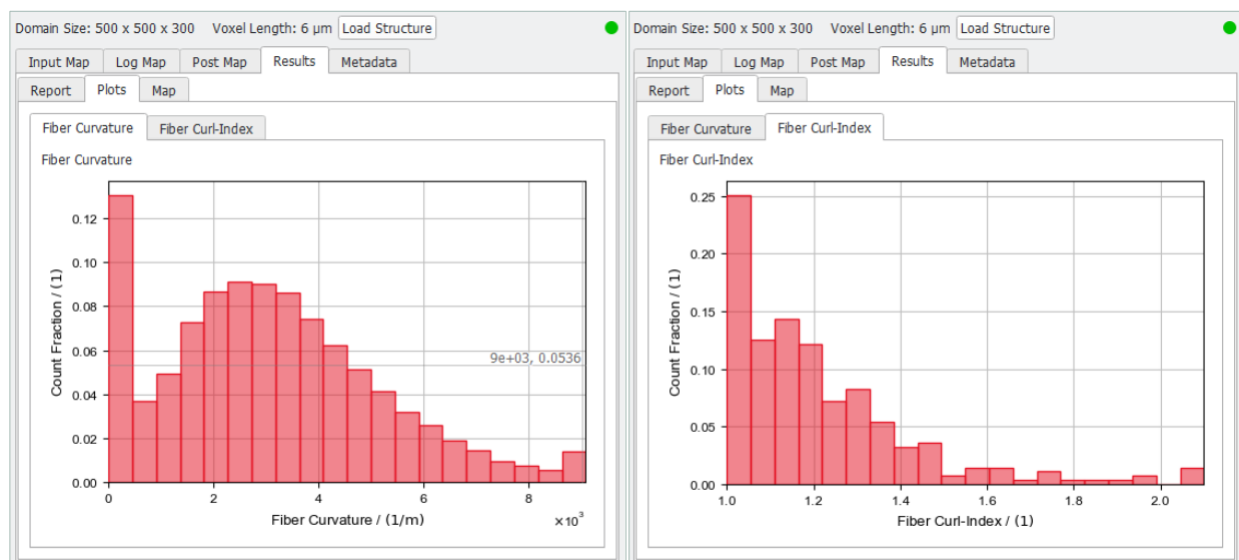
After the fiber curvature calculations are finished, a Result Viewer for the FiberCurvature.gdr file opens.

Under the **Results - Report** tab the identified **Average fiber curvature** (and its **Standard deviation**) and the **Average fiber Curl-Index** for the given **Number of analyzed fibers** are displayed.

Below, a table gives the distribution of fiber curvature, listing the **Count Fraction (%)** for the ranges of calculated fiber curvatures.



Under the **Results - Plots** sub-tab, diagrams show the distribution of fiber curvature and fiber curl-index, corresponding to the count fractions for curvatures and curl-index of fibers present in the domain.



In our example, the highest count fractions correspond to fibers with low curvature and low curl-index.

1.6 Identify Fibers (AI)

The final goal of all FiberFind tools is to obtain accurate statistical parameters for advanced material design, that can be used, e.g., as input data for FiberGeo.

There are two distinct approaches for the identification of individual fibers available in FiberFind. The first approach uses classical image processing methods, the second one is an Artificial Intelligence (AI) approach. Please refer to the [AI approach to identify binder and fibers](#)^[6] for more details on the theory.

1. The identification of fibers with classical image processing methods, the so-called **Analytic** method, is optimized for low density fibrous materials. FiberFind identifies fibers by creating a skeleton, that preserves the topology of the fibers. This skeleton is used to determine the center lines of the fibers.
2. The AI approach uses a neural network that has been trained with great amounts of input data. The training data for ground truth is created with FiberGeo. Therefore, this approach is capable of identifying individual fibers in a structure, as long as the input data for the training was close enough to the fiber properties in the real 3D-scan.

The start of the computation is a three-dimensional model obtained from segmented computer tomography (or FIB/SEM) scans of the material. Fiber identification provides advanced structure statistics, such as fiber length, number of fibers and better local fiber orientation, as well as object-based image manipulation (for example, changing the diameter of fibers directly from the imported CT-scan images).



Important! Since FiberFind ships with a limited number of neural networks for fiber and binder identification, currently some constraints on the input data exist:

- Fiber diameters should be 4 to 10 voxels for binder identification and 8 to 40 voxels for fiber identification.

If fiber diameters differ from this value, ImportGeo-Vol can be used to resample the voxel length. During the import of an image, the 3D Image Processing functionality Image Size→Scale can be used for scaling the 3D image with a different voxel length. Details can be found in the ImportGeo-Vol user guide.

- If fiber diameters in the structure are very different, and therefore, after resampling, not all diameters lie in the range listed above, we suggest separating the fibers and applying FiberFind - **Identify Fibers (AI)** for each kind of fiber.

To separate the fibers, **Estimate Fiber Diameters** in FiberFind can be used. Run the fiber diameter estimation and choose the number of fiber types in the Result Plots to fit to your structure. On the tab Result Visualization, you can then load a .gdt file with the fibers separated according to different fiber types. See [Estimate fiber diameters](#)^[12] for detailed instructions and an example.

- Some networks require fibers to be oriented mainly in the x-y plane. Please see the individual network description in the dialog. If necessary, the structure can be

rotated to fulfill this condition.

Changing the coordinate axis is done easily through **ProcessGeo** → **Permute** functionality. Details can be found in the [ProcessGeo](#) user guide.

Changing the coordinate axis or applying complex rotations to the structure by defining Euler angles is also possible through ImportGeo-Vol. Details are explained in the ImportGeo-Vol user guide.

- Fiber identification works for circular and elliptical fibers right now, not for other cross sections such as hollow or trilobal fibers.



Note! Besides this user guide, several tutorials showing the possibilities of the AI based FiberFind approach for different application cases are available on the [GeoDict Learning Center](#).

One tutorial is dealing with the analysis of four samples of different carbon paper gas diffusion layers used for a proton-exchange membrane in a fuel cell ([Digital analysis of fibers and binder content of a carbon paper GDL](#)). Synchrotron scan data for the sample is provided with the tutorial. The tutorial contains a detailed description of the import and preprocessing of the data, the binder and fiber identification using the AI approach, and postprocessing options for the results.

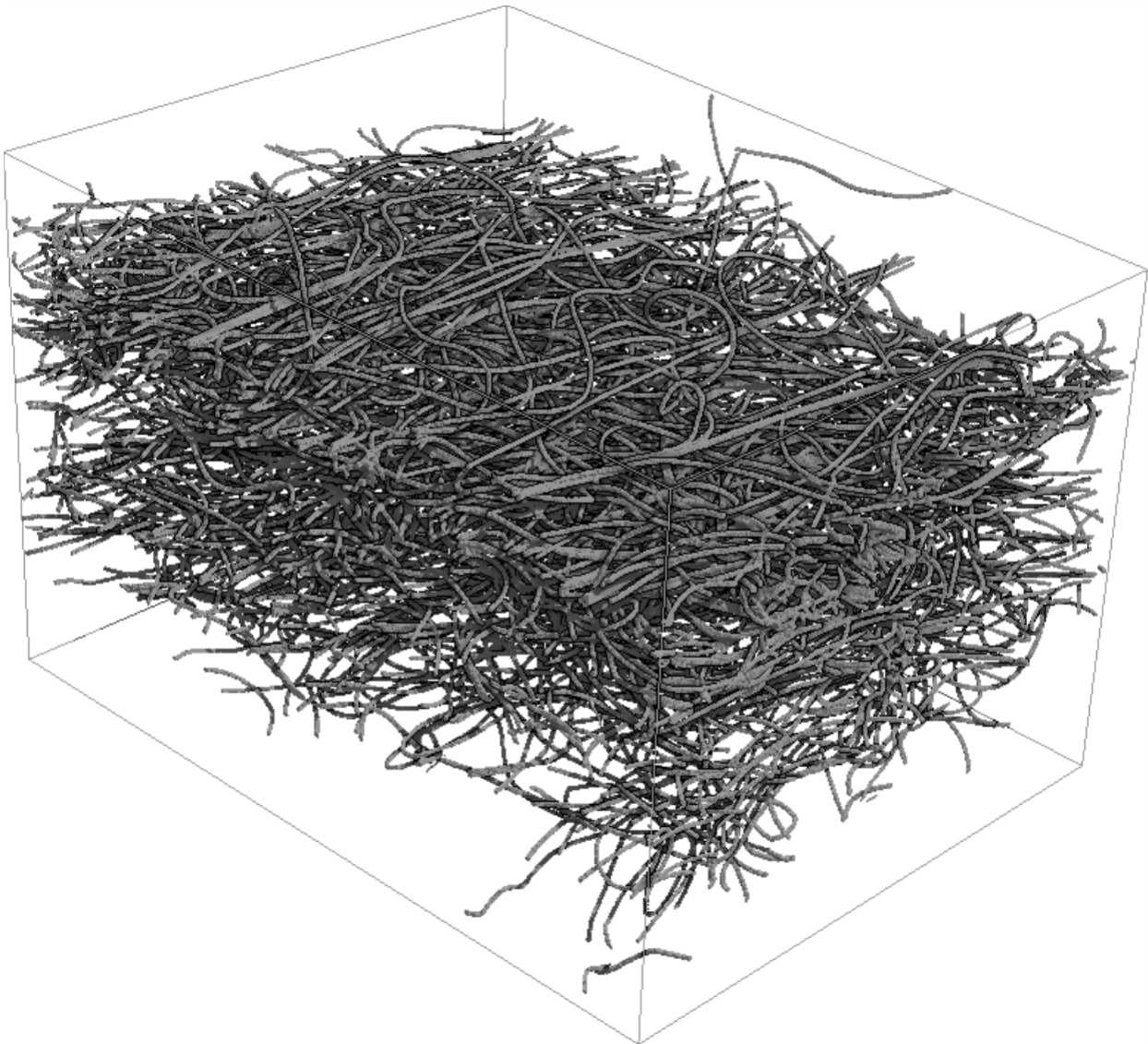
A second tutorial deals with the FiberFind identification of fibers of a composite material, a glass-fiber reinforced polymer, as well as the mechanical analysis of the digital 3D model with ElastoDict ([Digital analysis of a GFRP and generation of statistical Digital Twin](#)). Input data and a detailed description about preprocessing of the data is provided with the tutorial.

Topics of this section

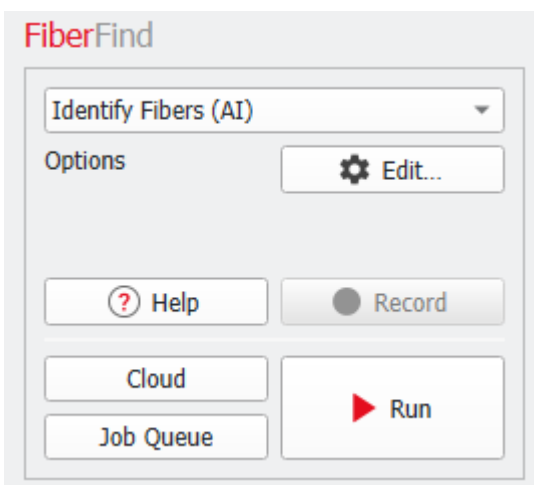
- [Fiber Identification](#)³⁶
Set the parameters on the Fiber Identification tab.
- [GPU Options](#)⁴¹
Set the batch size and define GPU usage.
- [Output Options](#)⁴²
Set the output options.
- [Results](#)⁴³
How to understand the IdentifyFibers (AI) results.

1.6.1 Fiber Identification

As an example for available Identify Fibers (AI) options serves a sample of a scan of bulky nonwoven fabric.



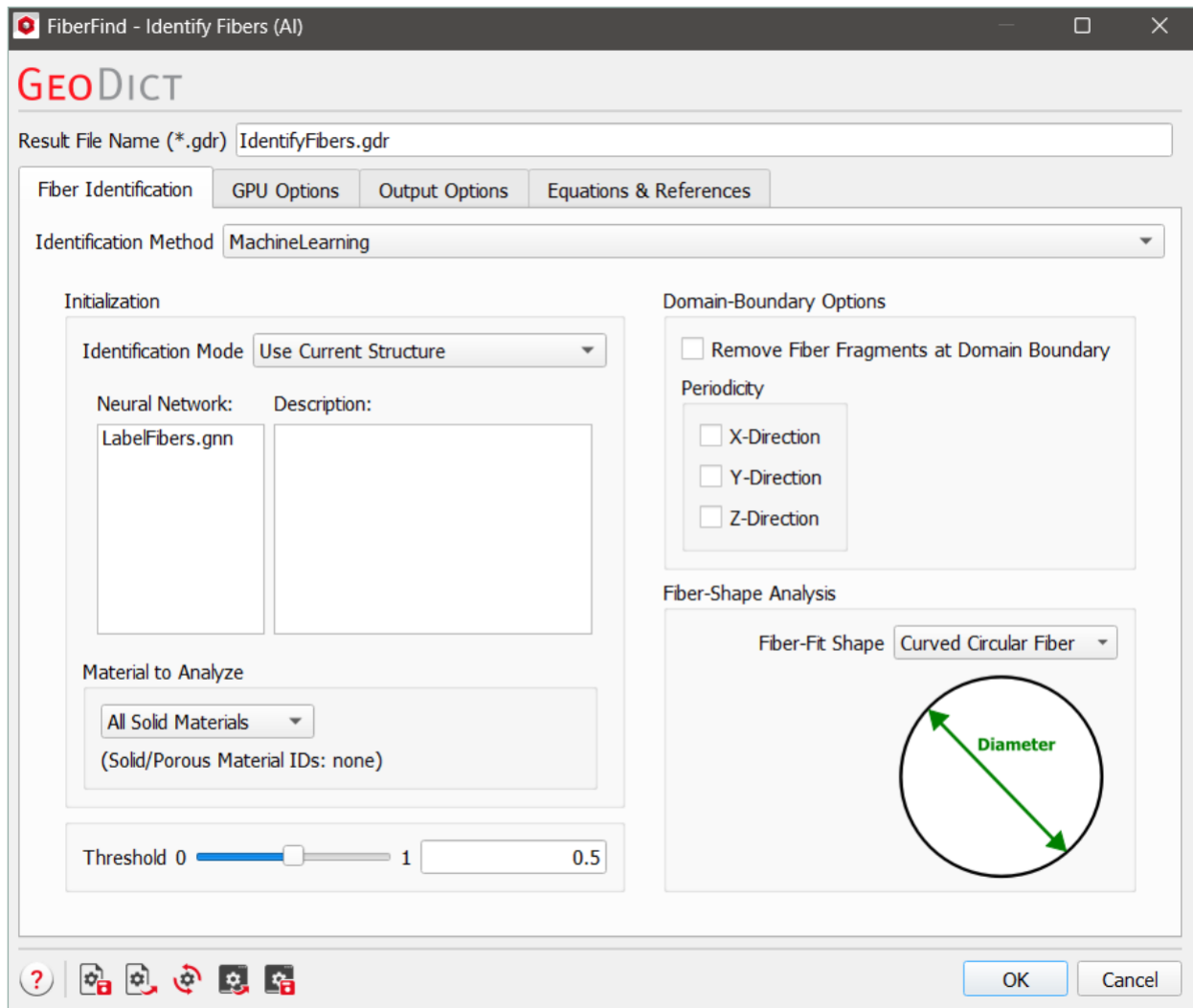
To start, select **Identify Fibers (AI)** from the pull-down menu in the FiberFind section. Click the **Options' Edit...** button.



The **Fiber Identification** dialog that opens contains four tabs: **Fiber Identification**, **GPU Options**, **Output Options** and **Equations & References**.

First, choose between two Identification Methods: **Machine Learning** for the AI approach, or **Analytic** to use the classical image processing approach. Note, that the **Analytic** method is deprecated and will be removed in future GeoDict versions.

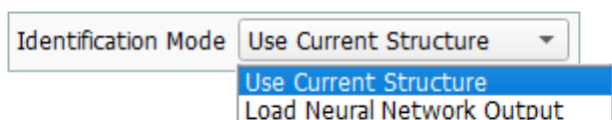
For **Machine Learning** as the **Identification Method**, several options are available in the **Fiber Identification** dialog. However, for most of the application cases, the default values can be kept for most of the options.



Initialization

Identification Mode

Two choices are available as Identification Mode: Use Current Structure and Load Neural Network Output.

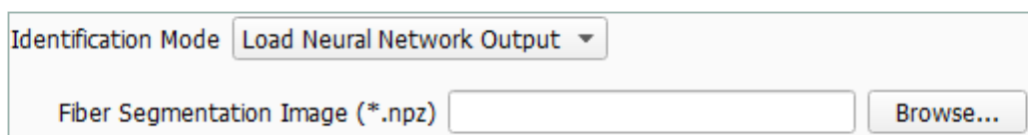


If you choose the default **Use Current Structure, Identify Fibers (AI)** will be applied to the structure that GeoDict currently has in memory.

Select the neural network listed under **Neural Network** (.gnn stands for **GeoDict neural network**). Besides the latest Neural Network provided with the software (LabelFibers.gnn), Neural Networks trained with GeoDict-AI can be used, too. For this, the corresponding .gnn-file has to be copied into the installation directory for **Identify Fibers (AI)** (e.g., `C:\Program Files\Math2Market GmbH\GeoDict 2026\FiberFind\IdentifyFibers`) in order to be selectable in the **Neural Network** field.

In the **Description** field, the current constraints for the application of the neural network are listed, such as the compatible fiber diameter range.

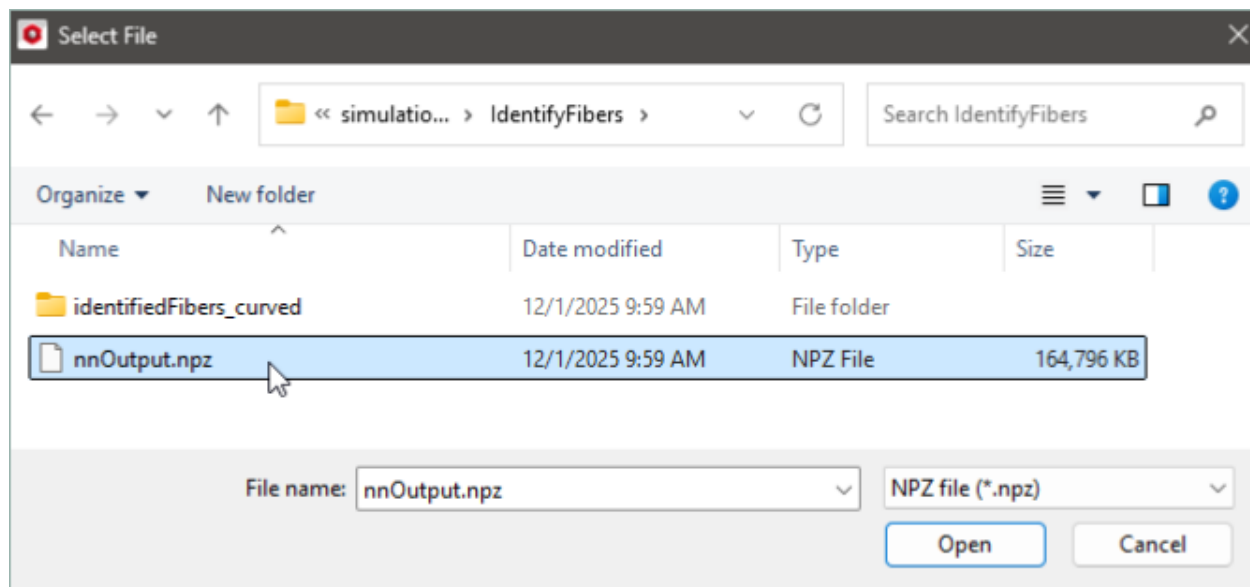
On occasion, you want to change the threshold without having to run the identification for each voxel with the neural network again, the option **Load Neural Network Output** may be very useful. Starting with a given Neural Network Output saves calculation time, as the Neural Network probability results can be used before new threshold-based calculations are made.



Identification Mode **Load Neural Network Output** ▼

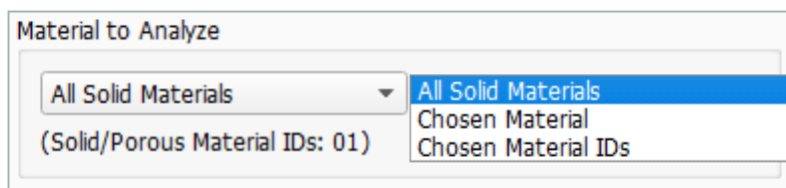
Fiber Segmentation Image (*.npz) **Browse...**

Browse to a GeoDict result folder of a previous run of **Identify Fibers (AI)** and select a nnOutput.npz file from that folder. The setting **Material to Analyze** must match the settings the **Neural Network** was trained with, and the loaded structure needs to be the same.



Material to Analyze

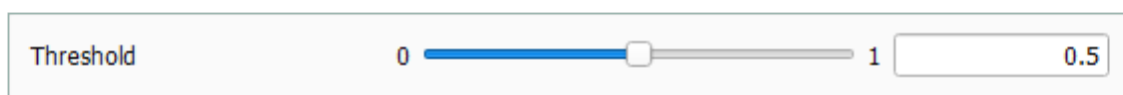
The **Material to Analyze** panel offers the choice of whether **Identify Fibers (AI)** should be applied to all solid and porous materials in the structure or only on a subset, defined either by choosing Material IDs or Materials.



Threshold

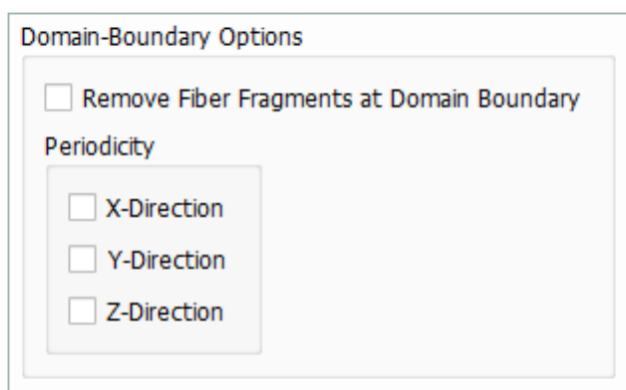
The neural network provides probabilities about whether a solid voxel is a fiber centerline voxel or not. The **Threshold** parameter defines the limit for this labelling and can therefore be defined by the user between 0 and 1 (default 0.5). It is strongly recommended using a threshold higher than 0, since otherwise every voxel with solid material will be defined as the centerline of a fiber, and it becomes very hard to identify two fibers if they are connected.

Another aspect is that in the case of identified fibers are over-segmented, choosing a smaller threshold can lead to better results, see example in the [Fiber identification visualization](#)⁵² section.



Domain-Boundary Options

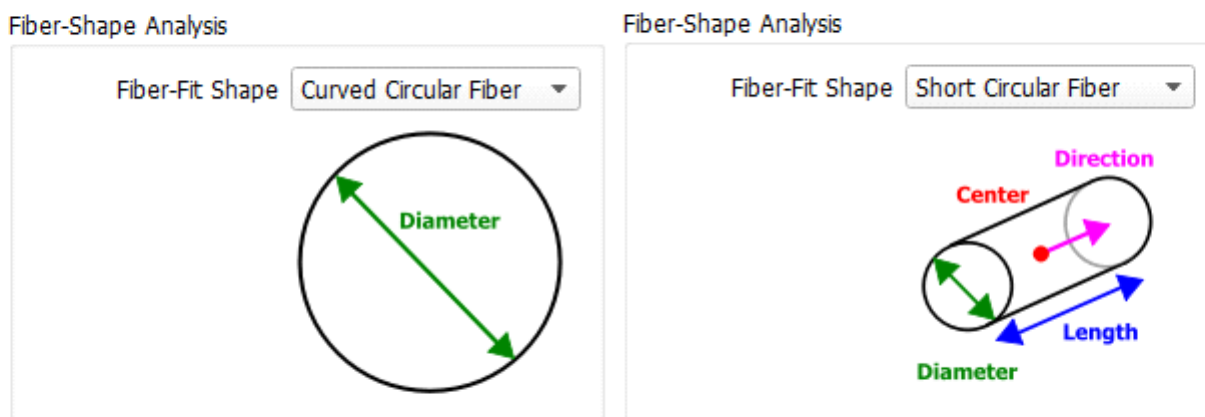
Check **Remove Fiber Fragments at Domain Boundary** in the **Domain-Boundary Options** panel, to remove all fibers that touch the boundary of the domain after the fiber identification algorithm.



The underlying domain can be set as periodic for the fiber identification by checking one or several of the boxes in the **Domain-Boundary Options** panel. However, periodicity is unusual for most 3D scans and the default setting is rarely changed.

Fiber-Shape Analysis

Finally, in the lower right of the **Fiber Identification** tab, you can select the type of fibers in the structure in the **Fiber-Shape Analysis** panel. **Curved Circular Fiber** or **Short Circular Fiber** are available as **Fiber-Fit Shape**.



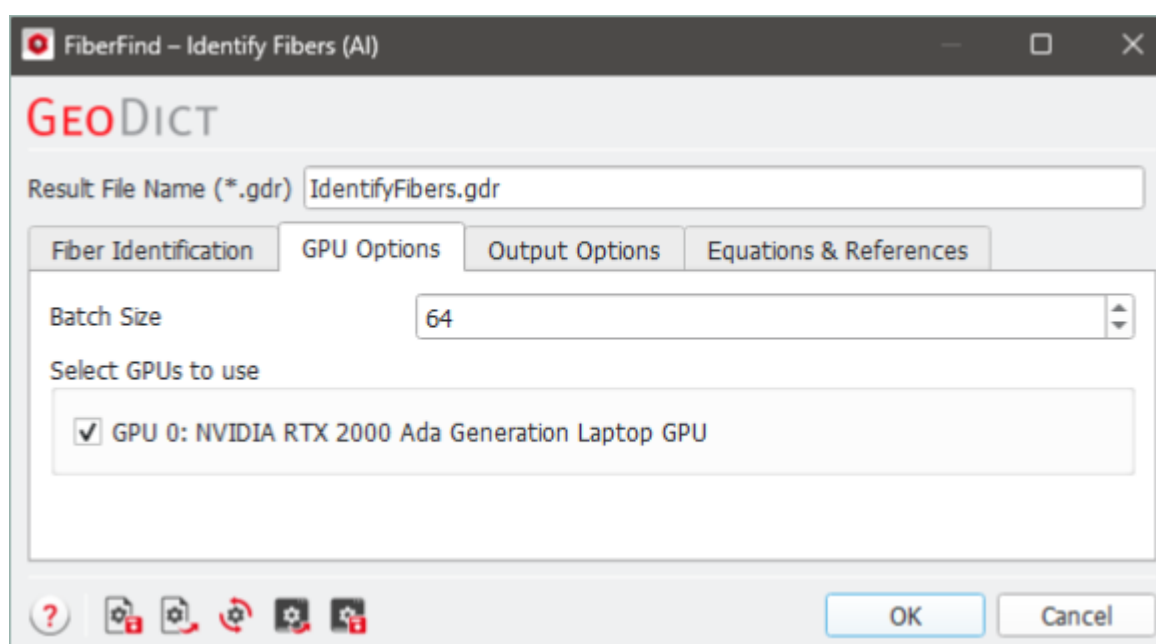
Selecting **Curved Circular Fiber**, FiberFind performs the identification under the assumption that the structure might contain curved fibers.

If **Short Circular Fiber** is chosen, fibers are identified twice: once with the default option of curved fibers and once under the assumption of straight fibers only. For the computation of fiber length distribution and fiber orientation, always the result of the curved fiber identification is used.

1.6.2 GPU Options

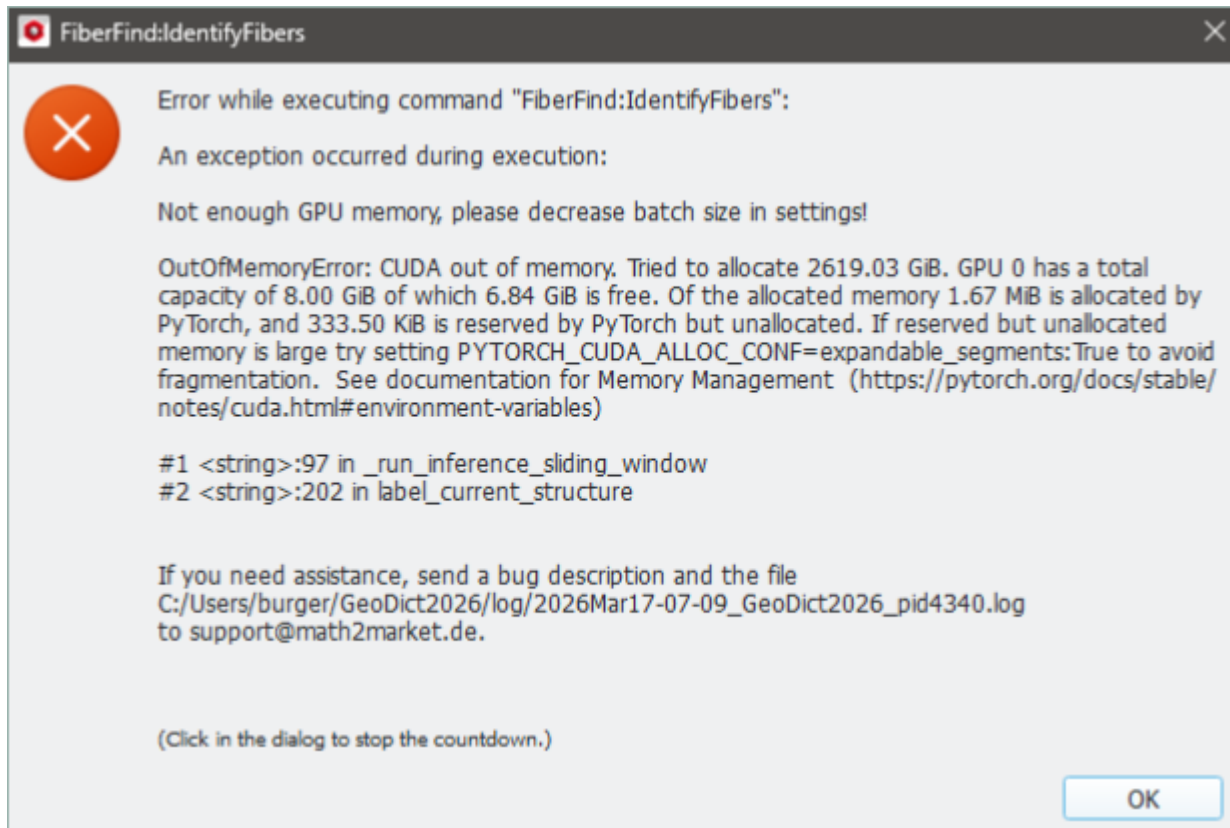
Note that this tab is only used as long as **Machine Learning** is selected from the **Identification Method** pull-down menu under the **Fiber Identification** tab.

If suitable graphics cards are detected during installation of GeoDict, the preferred GPU can be chosen via a checkbox and will be used for running **Identify Fibers (AI)**, otherwise it is running in CPU mode.



The choice for **Batch Size** is related to the memory available on the graphics card (GPU). Conceptually, FiberFind loads the graphics card with portions of work called **batches**. The higher the number of batches, the faster the computation. Currently, the selection must be made manually by entering an appropriate value in the **Batch Size** field.

In case of a Batch Size, which is too large for the available graphics card, the following error message appears.

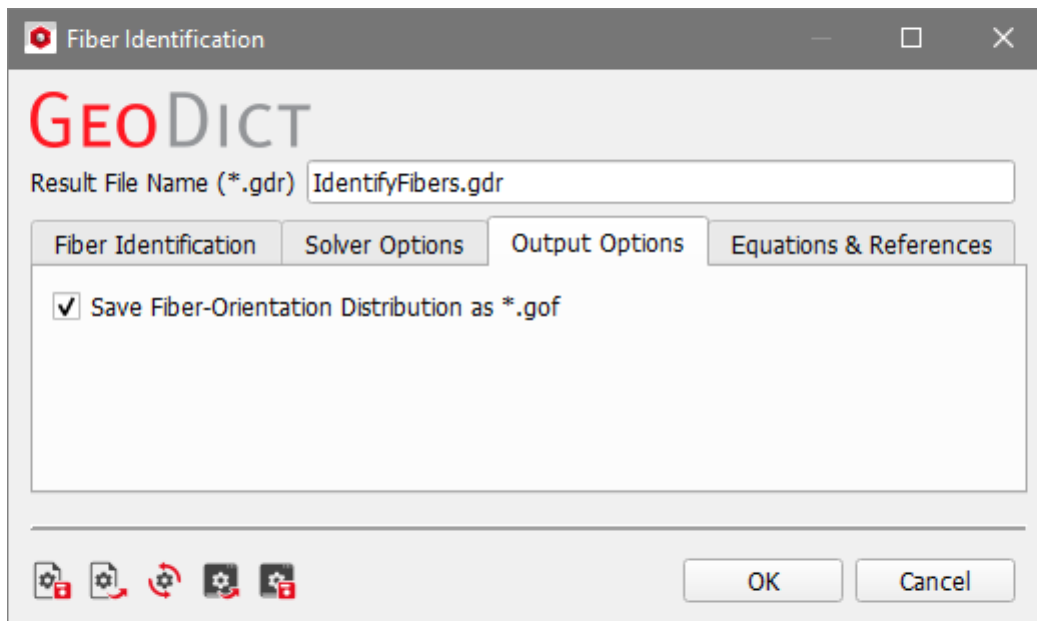


In this case, the number of batches needs to be reduced. Note that for CPU-based computation, the choice of batch size is not critical and can be left at the default.

1.6.3 Output Options

On the output options tab, check **Save Fiber-Orientation Distribution as *.gof** if the information about fiber orientation should be saved for later [visualization](#)⁵².

The .gof file contains a volume field with an orientation tensor for each voxel.



1.6.4 Results

After running the fiber identification, a folder with the same name as the GeoDict result file is saved in the chosen project folder (**File** → **Choose Project Folder...** in the menu bar). This folder contains folders and files needed internally for the calculations. The content of the folder depends on the selected **Identification Method** and parameters. The original structure model on which the identification was done is also saved in the folder.

The result file will be automatically opened into the GeoDict Result Viewer.

Topics of this section

- [Report](#)⁴³
Description of the most relevant results on the Report tab.
- [Plots](#)⁴⁵
Description of the most relevant results on the Plots tab.
- [Map](#)⁵¹
Description of the most relevant results on the Map tab.
- [Fiber Identification Visualization](#)⁵²
Description of the most relevant results on the Fiber identification visualization tab.

Report

The information about fiber orientation, fiber length distribution, fiber diameter distribution, fiber curvature distribution and fiber curl-index distribution is available in tables under the **Report** sub-tab.

In this report, first the total number of identified fibers is shown, for this example it is 1107.

Next, a table shows the number of fibers, the mean diameter, mean length, mean curvature, mean curl-index and mean torsion and the orientation for each fiber type, defined via the **Threshold by Fiber Property**.

Domain Size: 1500 x 2000 x 1296 Voxel Length: 2.7 μm Load Structure

Input Map Log Map Post Map Results Fiber Identification Visualization Metadata

Bins for Fiber Length Distribution: 20
 Bins for Fiber Diameter Distribution: 20
 Bins for Orientation Distribution: 18
 Bins for Curvature Distribution: 100
 Bins for Curl-Index Distribution: 20

Threshold by Fiber Property

Fiber Property: Diameter
 Number of Bins: 100
 Thresholding Method: k-Means
 Number of Fiber Types: 2

Layered Fiber Property: Diameter
 Layered Fiber Property Weighting: Count

Apply

☒ Back-up result file

Plot Options

Report Plots Map

FiberFind

Found **1107** individual fibers in the structure

Fiber properties segmented by **Diameter**:

Property	Class1	Class2																		
Number of fibers	134	973																		
Diameter	13.0886 μm	24.7363 μm																		
Length	185.368 μm	3.02497 mm																		
Curvature	0.00915372 1/ μm	0.00235424 1/ μm																		
Curl-Index	1.18444	3.19849																		
Orientation	Orientation tensor: <table border="1"> <tr><td>0.3707</td><td>-0.0016</td><td>-0.0162</td></tr> <tr><td>-</td><td>0.4729</td><td>-0.0127</td></tr> <tr><td>-</td><td>-</td><td>0.1563</td></tr> </table> Anisotropy 1: 1.993 Anisotropy 2: 1.257 Euler angles (Phi, Theta, Psi): 118.208, 4.876, -117.787	0.3707	-0.0016	-0.0162	-	0.4729	-0.0127	-	-	0.1563	Orientation tensor: <table border="1"> <tr><td>0.5000</td><td>0.0015</td><td>0.0051</td></tr> <tr><td>-</td><td>0.4094</td><td>-0.0082</td></tr> <tr><td>-</td><td>-</td><td>0.0906</td></tr> </table> Anisotropy 1: 3.820 Anisotropy 2: 0.829 Euler angles (Phi, Theta, Psi): -154.086, 1.638, 154.991	0.5000	0.0015	0.0051	-	0.4094	-0.0082	-	-	0.0906
0.3707	-0.0016	-0.0162																		
-	0.4729	-0.0127																		
-	-	0.1563																		
0.5000	0.0015	0.0051																		
-	0.4094	-0.0082																		
-	-	0.0906																		

Fiber properties for all fibers:
 Orientation tensor:

0.4981	0.0015	0.0048
-	0.4103	-0.0083
-	-	0.0916

The fiber type specific information is followed by the values for all fibers. First, the orientation of all fibers is reported.

Since most of the fibers in the example are oriented in X/Y plane, the diagonal entries of the orientation tensor for X-direction (0.4981) and Y-direction (0.4103) are larger than for Z-direction (0.0916). The value for X is higher than the one for Y, showing again the dominance of X- over Y-direction.

The anisotropy values, together with the Euler angles, are another representation of the orientation tensor.

Both representations of the orientation tensor can be used directly in FiberGeo to create a structure with the same properties than the structure analyzed (see [Reproducing fibrous media using FiberFind and FiberGeo](#)⁷⁵).

Next, in the **Report**, the mean value and the standard deviation for fiber length and fiber diameter and the mean values for fiber curvature and fiber curl-index are shown, followed by tables with the histogram values of the **Plots** subtabs.

Note that for the mean values of fiber curvature shown here, a mean over all curvature values of all fibers is computed. In contrast to this, the mean curvature of each fiber class is obtained

by computing first the mean curvature of each fiber of the fiber class individually and then taking the mean over all these values.

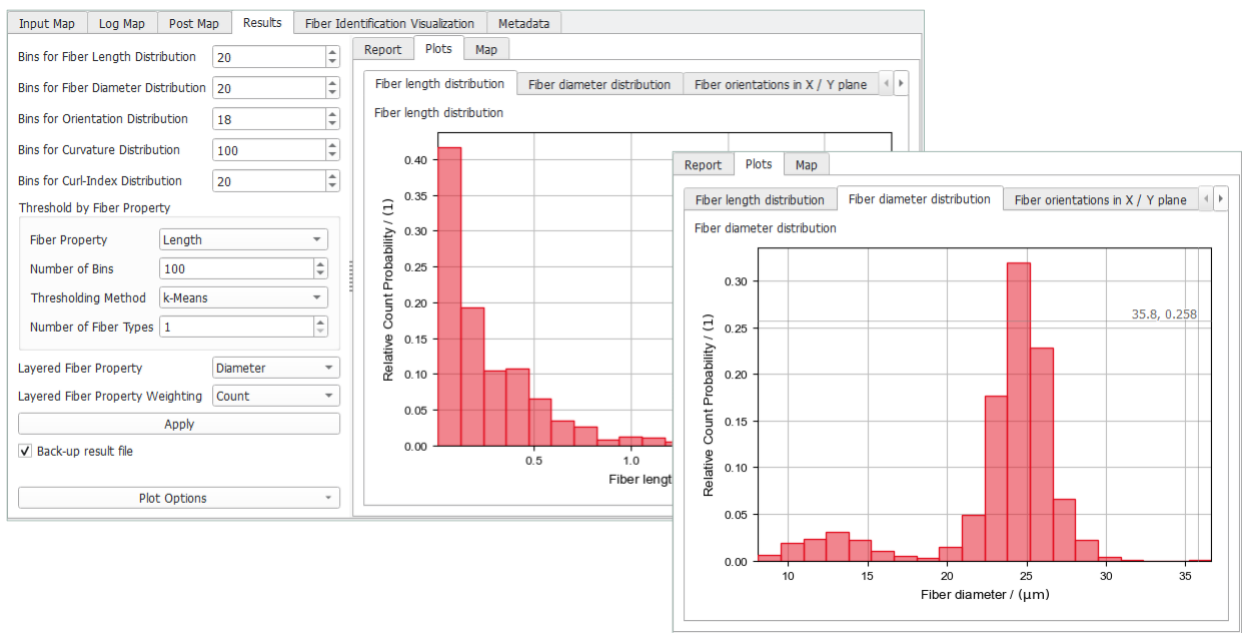
Report	Plots	Map
Mean fiber length: 2.68124 mm Standard deviation of fiber length: 3.11271 mm		
Object fiber length histogram:		
Min. Fiber length / (μm)	Max. Fiber length / (μm)	Relative Count Probability
37.8963	1208.9	0.417344
1208.9	2379.9	0.192412
2379.9	3550.9	0.104788
3550.9	4721.91	0.107498
4721.91	5892.91	0.065944
5892.91	7063.91	0.0352304
7063.91	8234.91	0.0261969
8234.91	9405.91	0.00813008
9405.91	10576.9	0.0117435
10576.9	11747.9	0.0108401
11747.9	12918.9	0.00451671
12918.9	14089.9	0.00361337
14089.9	15260.9	0.00271003

Plots

Under the **Plots** subtab of the Result Viewer the identification results are visualized. With different post-processing option, these plots can be modified and additional plots generated, to get a full representation of the available results.

Length and diameter distribution

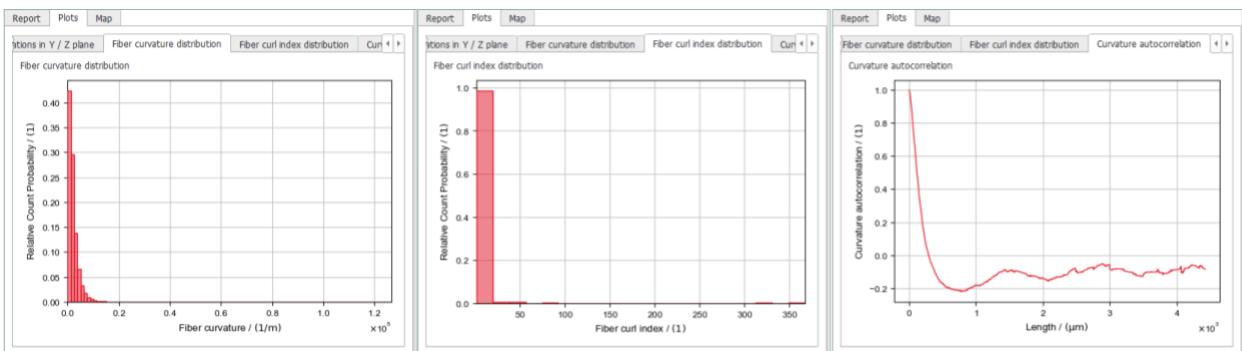
The first plots shown under the Plots subtab are histograms of the fiber length distribution and, for **Identification Method Machine Learning**, the distribution of fiber diameter.



On the left panel of the **Results** subtab, the number of bins for all distributions shown in the plots can be changed. Click **Apply** to generate the plots for a different number of bins.

Curvature and Orientation

Also available are curvature and orientation information, under the **Results - Plots** subtab plots of the **Fiber curvature distribution**, the **Curvature autocorrelation** and the **Fiber curl-index distribution** as well as three plots showing the fiber orientation as histograms of projections of the fibers to two-dimensional planes can be found.



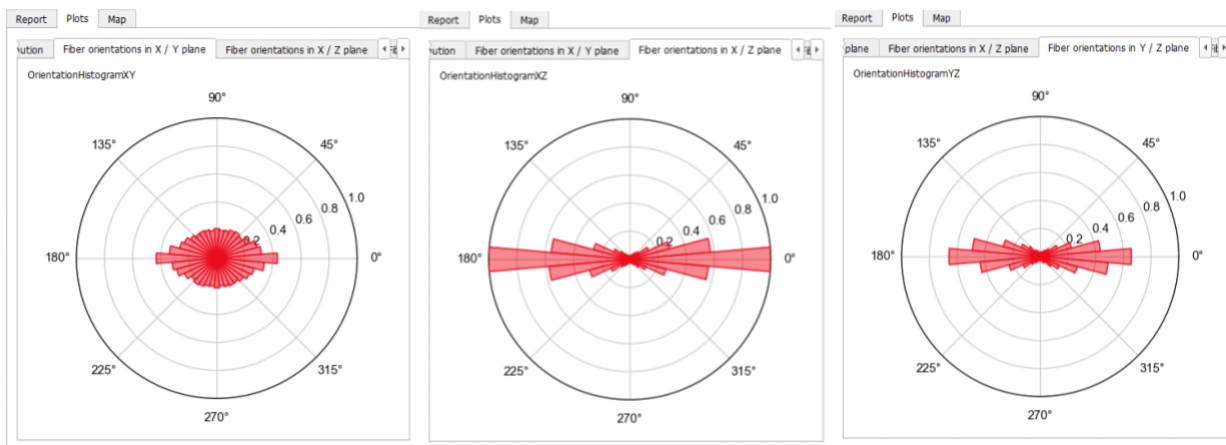
The **Curvature autocorrelation** indicates how strongly the changes in curvature at different points of the fiber are related.

- A **high positive autocorrelation** suggests that if the curvature is strong at one point, it is likely to repeat after a certain length distance (i.e., similar curvature behavior at a later point of the fiber).
- A **negative autocorrelation** suggests that strong curvature at one point is followed by opposite curvature at a later point.
- The autocorrelation of curvature values can reveal **periodic behavior** or **cyclical variations** in the curvature, helping to identify regular structures or trends in the underlying data

For the above example, the autocorrelation diagram shows that the curvature changes its direction after a length distance of $0.29\text{ }\mu\text{m}$ on average, i.e. if the curvature is positive at one point of the fiber, the curvature is negative again on average after a distance of $0.29\text{ }\mu\text{m}$.

To compute the three orientation histograms, each fiber is projected to the two-dimensional plane. The angle of each fiber segment, weighted with the length of the segment, gives an entry in one bin of the histogram, i.e., in one segment of the circle.

The number of fiber segments for an orientation in the plane is given by the size of a segment of the circle. Since the histograms are normalized, this number is always a value between 0 and 1. The histogram is symmetric since fiber orientations of 0° and 180° are indistinguishable.



Fibers in this example are oriented mainly in the X/Y plane with a bias in X-direction. Histograms of X/Z plane and Y/Z plane show large segments for 0° and 180° , and segments in Y-direction are even a bit larger. In contrast, the plot of X/Y plane shows a more homogeneous distribution of fibers in this plane, but the preference for X-direction is also visible there.

Besides the bin size for each of the histograms shown, that can be selected by the user, additional post-processing options are available.

Identification result w.r.t. different fiber properties

In the histograms of fiber length and diameter, the fibers can be classified with respect to many fiber properties.

Fiber Property	Diameter	Length Diameter CurlIndex Curvature CenterOfMassZ AngleToX AngleToY AngleToZ BoundaryContacts
Number of Bins	100	
Thresholding Method	Otsu	k-Means Otsu Manual
Number of Fiber Types	2	

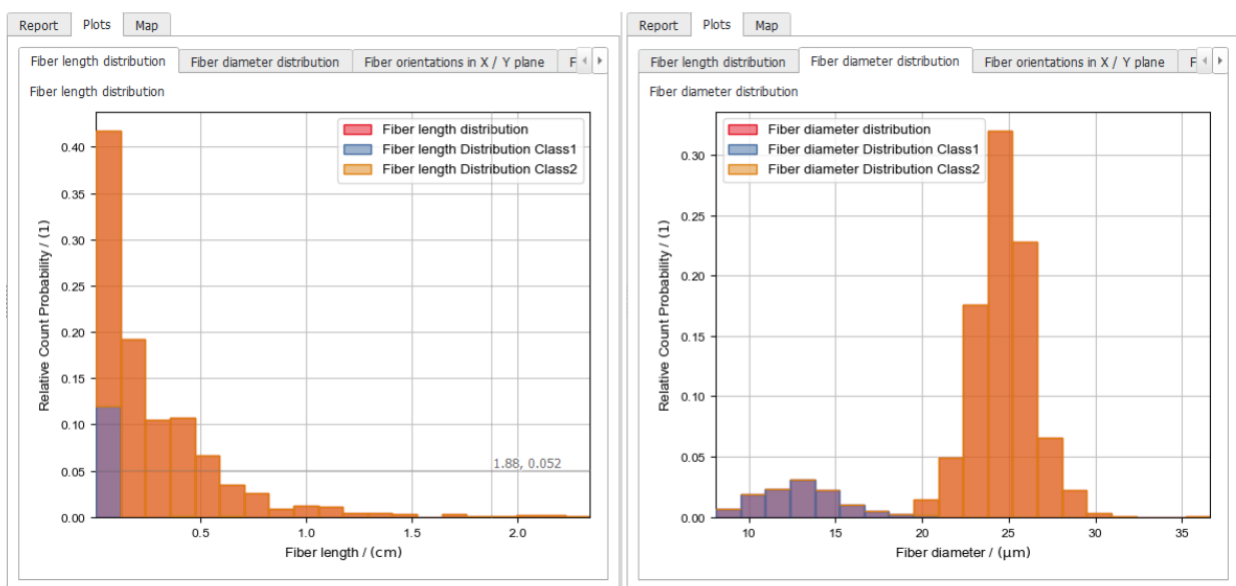
Select a **Fiber Property** for the classification and define the number of different classes by choosing the **Number of Fiber Types**.

In this example, the fiber diameter distribution (plotted [above](#)) implies that fibers are of mainly two different diameter classes. To classify the result accordingly choose **Diameter** for **Fiber Property** and the number **2** for **Number of Fiber Types**.

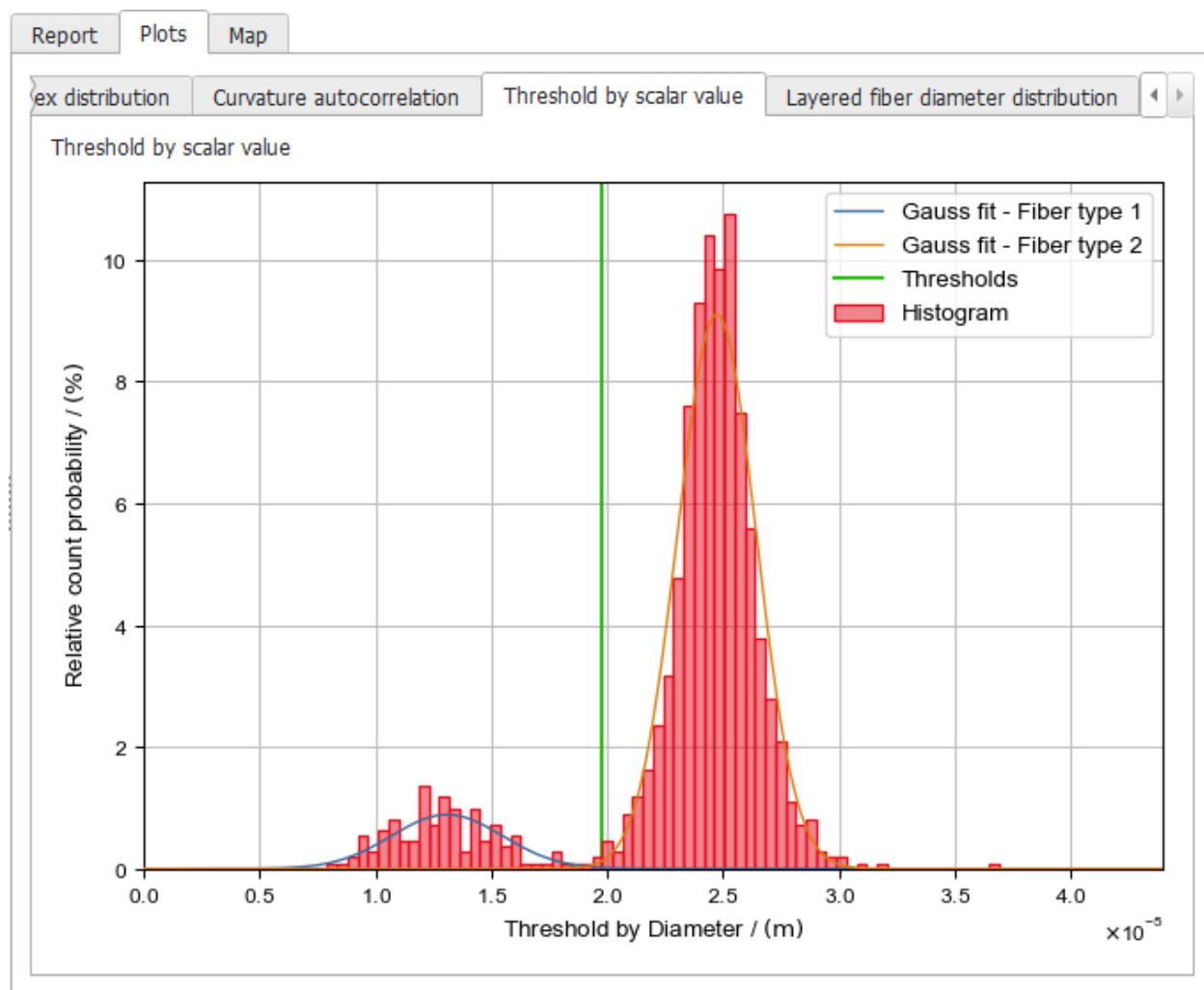
Set Thresholds

Select a **Thresholding Method** for the differentiation of fibers of different type (**k-Means**, **Otsu's method** or define a **Manual** threshold) and the **Number of Bins** used for the separation of fibers.

Here, 100 bins are used to separate the fibers according to the Otsu's method. Click **Apply** to change the **Fiber length distribution** histogram and, if available, the **Fiber diameter distribution** histogram. These histograms are shown now with stacked values for both fiber types additionally.



An additional tab (**Threshold by scalar value**), containing the fiber diameter distribution with the number of bins defined for the thresholding, the resulting threshold(s) for the selected method and a Gaussian fit for both fiber types, is created.



Note that the threshold (the green vertical line in this example) changes for different Thresholding Methods or can directly be defined by the User after choosing **Thresholding Method – Manual**.

The classification of fibers is also included in the [Results Report](#)^[43] tab.

The structure with the separated fiber types, can be loaded to the Visualization Area under the [Fiber Identification Visualization](#)^[52] tab.

Layered fiber information

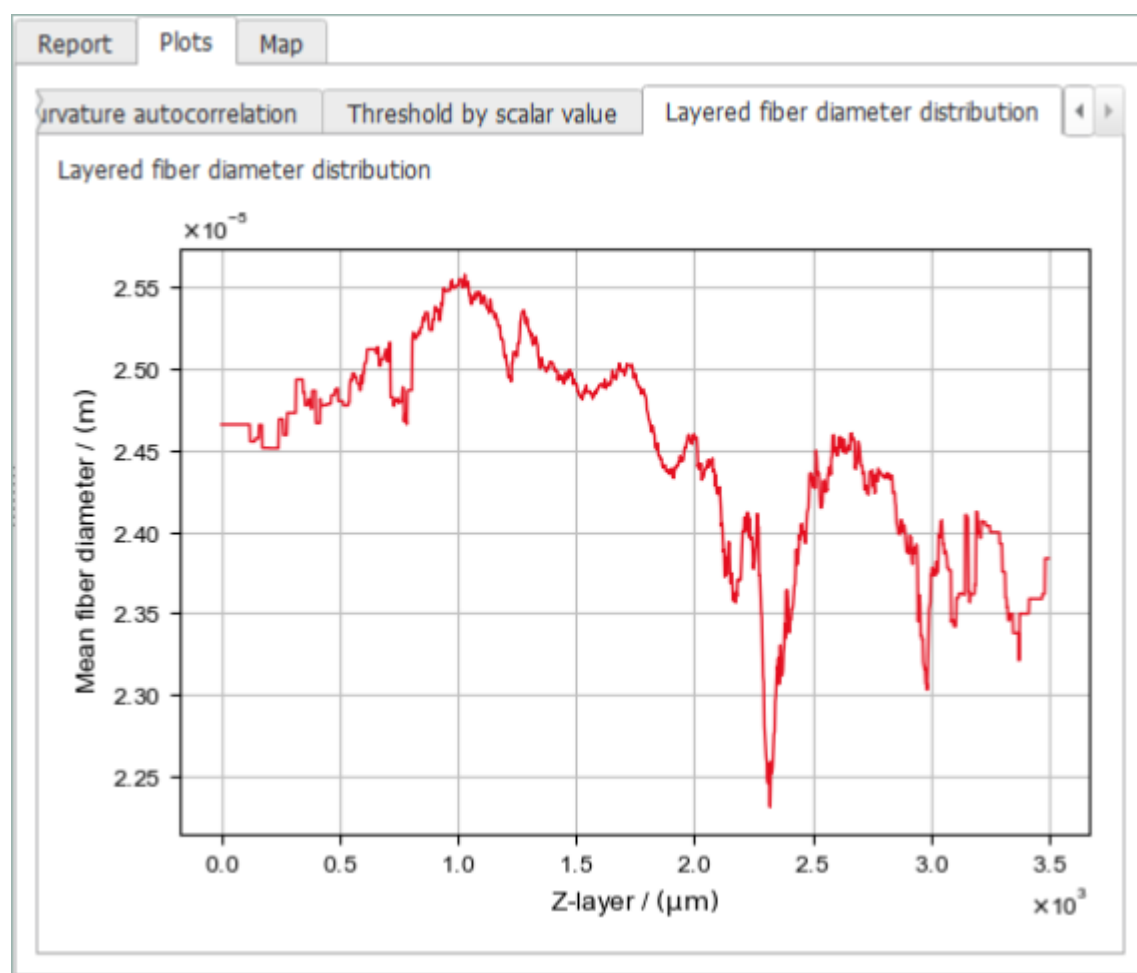
To create an additional tab, showing the layered values in z-direction for a fiber property, select a **Layered Fiber Property** from the pull-down menu. With **Layered Fiber Property Weighting** define if the mean in each layer is computed with respect to the number, the volume or the length of the fibers.

Click **Apply** to start the creation.

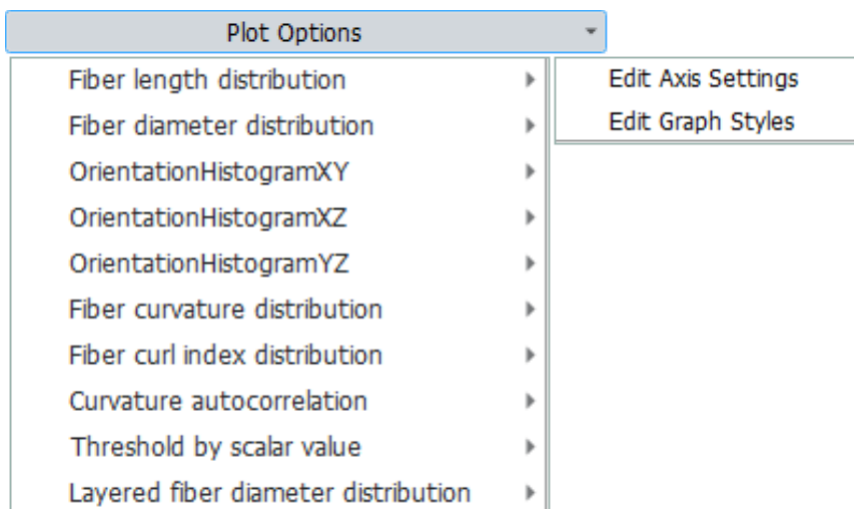
Layered Fiber Property	CurlIndex	Length
Layered Fiber Property Weighting	Volume	Diameter
Apply		CurlIndex
		Curvature
		CenterOfMassZ
		AngleToX
		AngleToY
		AngleToZ
		BoundaryContacts
		Count
		Volume
		Length

A new tab for the layered distribution is added to the **Plots** subtab, according to the values selected.

For the example shown here, the tab **Layered fiber diameter distribution** is created, showing the mean fiber diameter (weighted with respect to the fiber volume) for each layer in z-direction of the structure.



Click on **Plot Options** and select one of the histograms available, to access directly the dialog boxes for changing the Axis Settings or Graph Styles. These dialogs can be accessed as well by a right mouse-click in the histogram.



For more details on modifying plot settings, see the [Result Viewer](#) user guide.

Map

The **Map** subtab gives access to the computed values for the corresponding command as Key : Value Map. The numbers contained in the Report subtab also are available in the Map subtab. Additional details are found here, e.g., solution file names and information about the iteration process (number of iterations, reached stopping criteria, etc.).

An example result for the Fiber Identification (AI) command are the **Torsions** of the fibers. The torsion of the fibers as well as the torsion autocorrelation are available in the GeoDict result file (*.gdr), but currently not on the **Plots** subtab. They are shown on the Map subtab, and can be found in the *.gdr file under the keys *DerivedResults:Torsions*, for the torsion of each identified fiber segment, *DerivedResults:MeanTorsions*, for the mean torsion of each identified fiber and *DerivedResults:TorsionAutocorrelation* for the autocorrelation function of the torsion values.

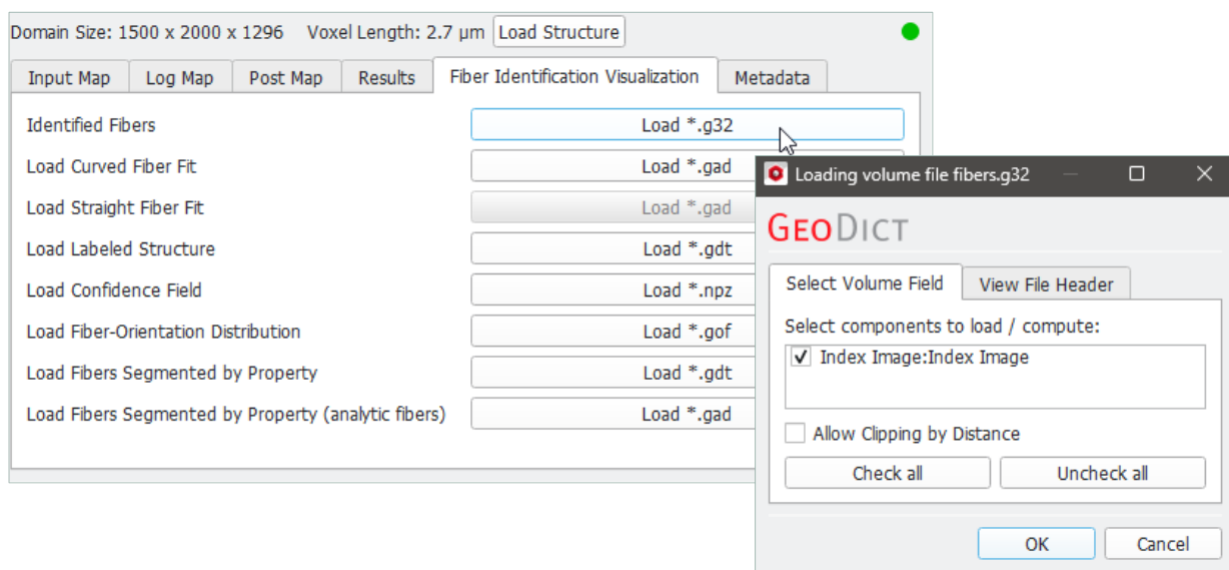
Report	Plots	Map	
Key	Unit	Value	
▼ CoreResults			
NumberOfFibers		1107	
MaterialID		2	
▼ DerivedResults			
FiberLengths	m	0.0007492673786, 0.0004630263883, 0.001895454588...	
FiberDiameters	m	2.720141099e-05, 2.374238511e-05, 2.382416044e-05,...	
MeanCurvatures	1/m	1857.4942, 2674.169215, 2024.576668, 1108.092856, ...	
CurlIndexValues		1.038054809, 1.060407813, 1.475891278, 1.20198421...	
FiberAnglesToX	Deg	81.48438349, 35.44940985, 37.73717932, 53.5409856...	
FiberAnglesToY	Deg	33.82449911, 65.90983716, 72.79590804, 56.4821016...	
FiberAnglesToZ	Deg	58.5220057, 69.63951171, 61.50368873, 59.92268177,...	
MeanTorsions	1	-0.02892792686, -0.05559926598, 0.06703492407, -0.1...	
Curvatures	1/m	2899.317984, 2899.317984, 2899.317984, 2899.31798...	
Torsions	1	-0.01514102033, -0.01514102033, -0.01514102033, -0....	
CurvatureAutocorrelation		1, 0.9903830851, 0.987717671, 0.9821065005, 0.9754...	
TorsionAutocorrelation		1, 0.9516203785, 0.9463768831, 0.9400370803, 0.932...	
BoundaryContacts		2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 1, 2, ...	
OrientationTensor		0.4980605625, 0.4103490229, 0.09159041458, 0.0014...	
Anisotropy1		3.779243271	
Anisotropy2		0.8342851263	
Phi	Deg	-155.4964367	
Theta	Deg	1.63237815	
Psi	Deg	156.4044088	
▶ Diameter			
▶ Length			
▶ CurlIndex			
▶ Torsion			
▶ Curvature			
▶ OrientationHistogramXY			
▶ OrientationHistogramXZ			
▶ OrientationHistogramYZ			

Fiber Identification Visualization

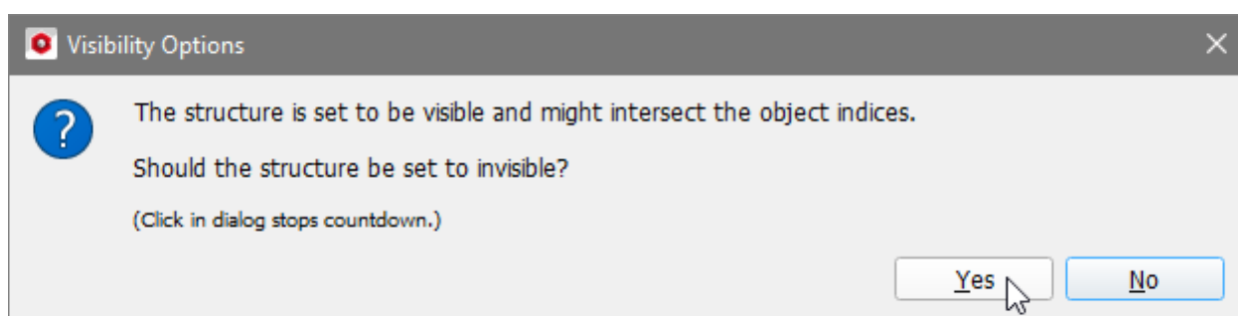
On the **Fiber Identification Visualization** tab next to the Results tab, several possibilities of visualizing the results are listed.

Identified Fibers

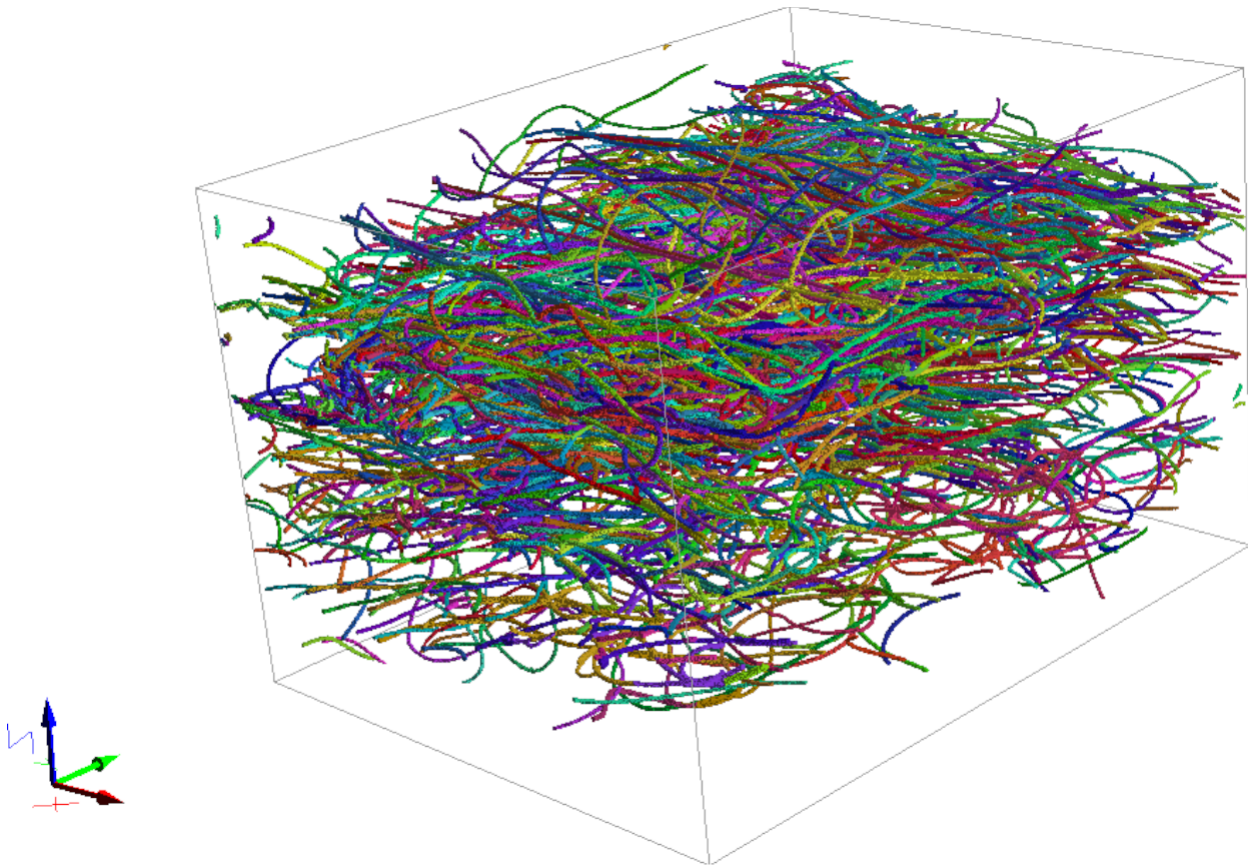
To visualize the fibers identified by the algorithm, click **Load *.g32** in the GeoDict Result Viewer under the Fiber Identification Visualization tab.



Set the structure to invisible, to see only the identified fibers, by clicking **Yes** in the opening dialog.

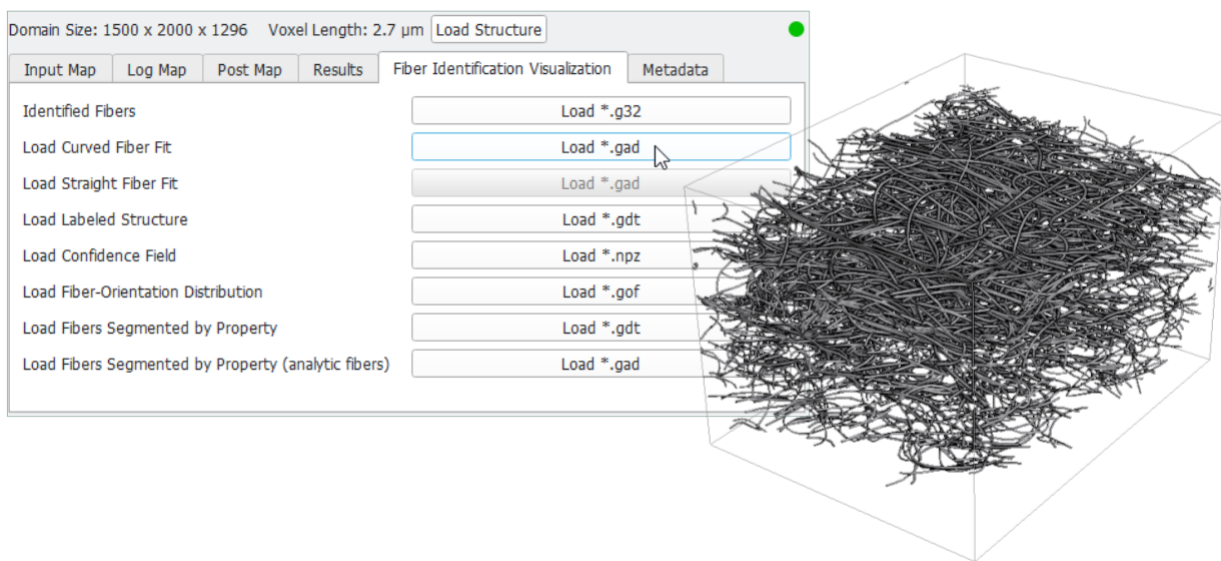


The identified fibers are shown in a variety of colors.



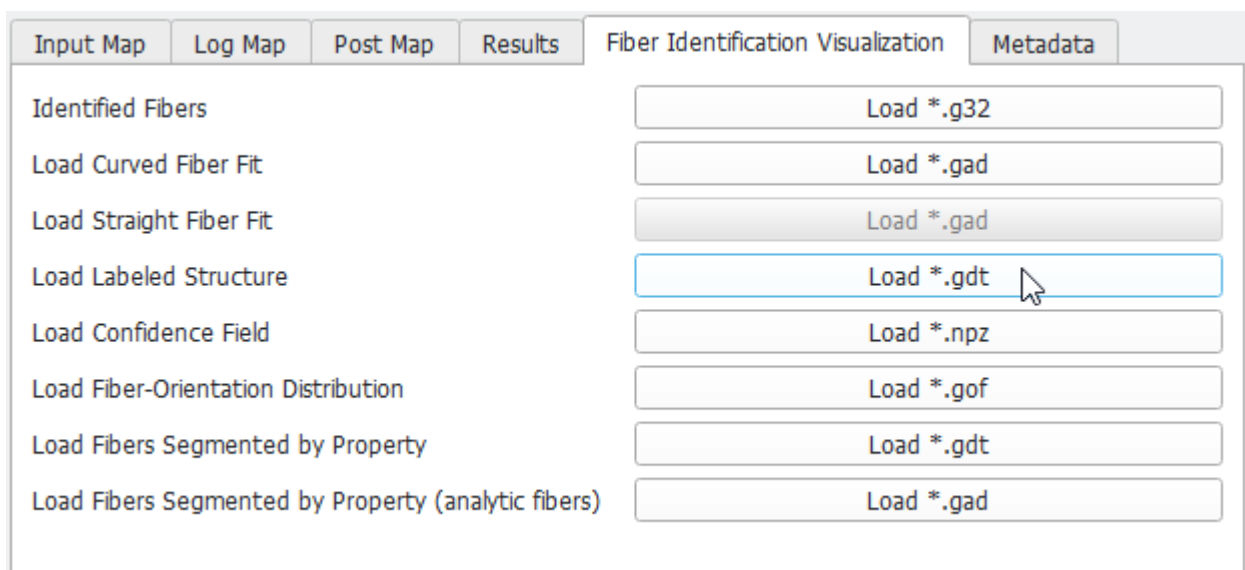
Load Curved Fiber Fit / Load Straight Fiber Fit

In the same way, the curved fiber fit (and the straight fiber fit if **Short Circular Fiber** was selected in the **Fiber-Shape Analysis** panel of the **Identify Fibers (AI)** options) can be loaded by clicking on their **Load *.gad** buttons under the **Fiber Identification Visualization** tab. In the loaded .gad files, fibers are contained as analytical objects, with information about fiber diameter, etc. After the identification of fibers, the analytic information contained in the .gad files can be used for modifications of the structure model or further calculations that require fiber analytic data.



Load Labeled Structure

Clicking the (Load labeled structure) **Load *.gdt** button under the **Fiber Identification Visualization** tab, loads the fibers together with the identified centerlines.



Visualize the loaded labeled structure with the centerlines in 2D (**View** → **2D Cross section** in the menu bar).



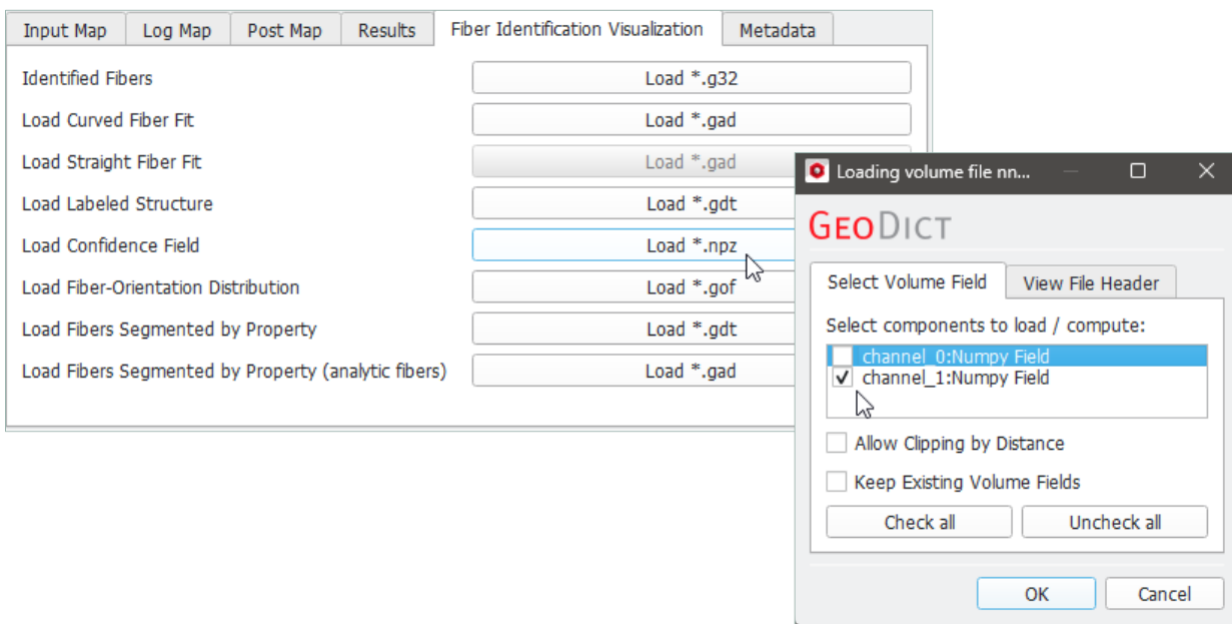
Looking at the centerlines helps you judge how well the fibers were identified and whether the threshold setting is appropriate.

- If the centerlines are broken or fragmented, try running FiberFind – Identify Fibers (AI) again with a lower threshold.
- If the centerlines look too thick, increasing the threshold may improve the result.

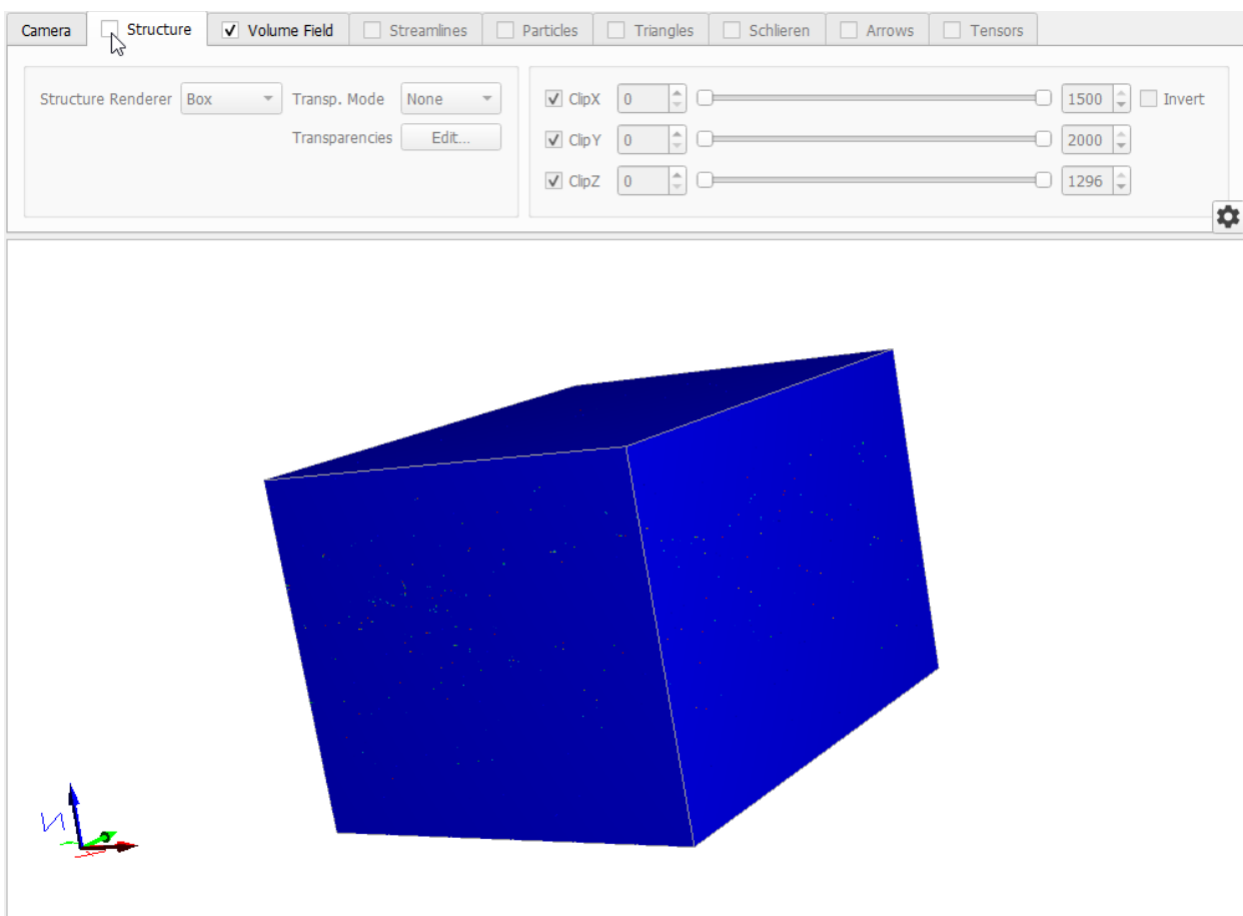
You can explore the influence of the threshold interactively by loading the **Confidence Field** as described in the following.

Load Confidence Field

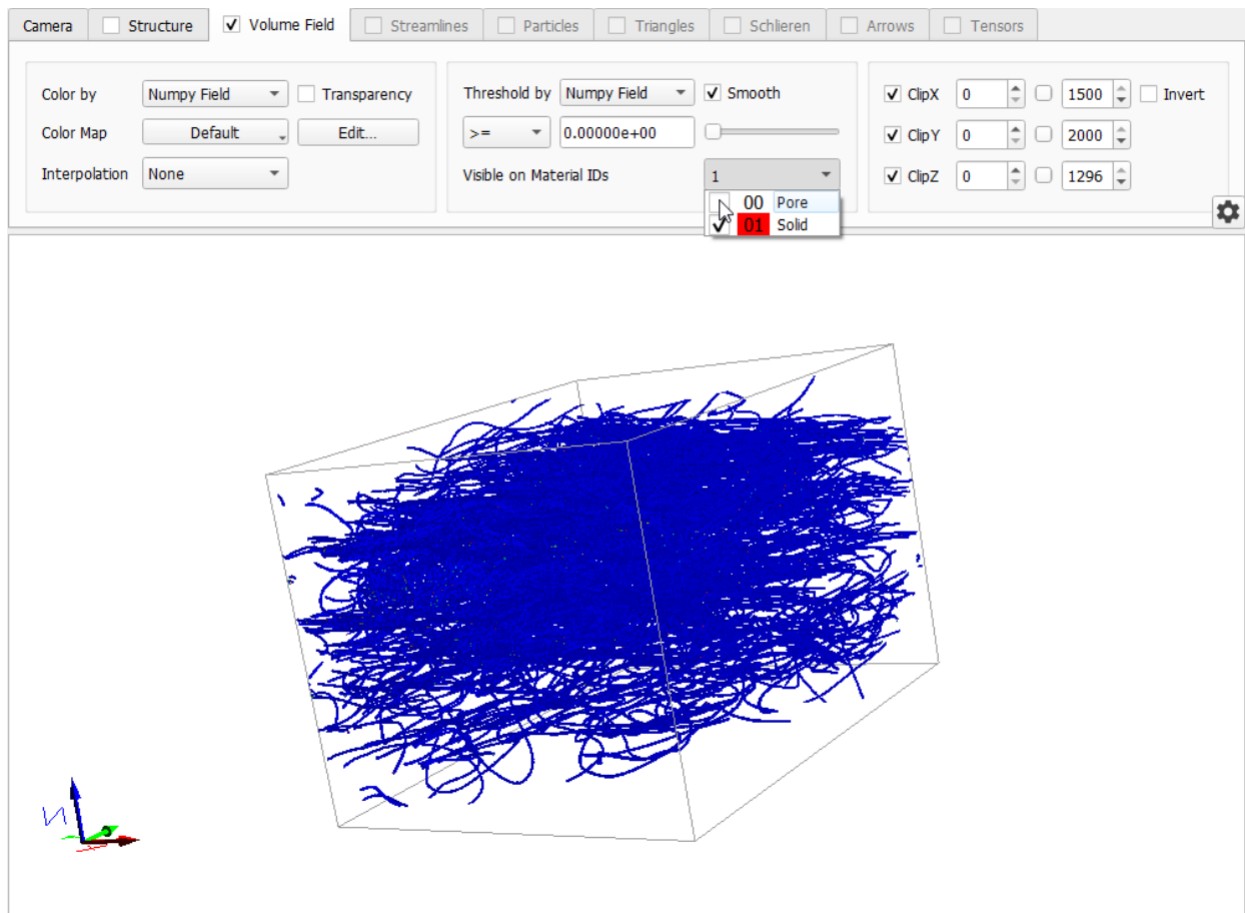
Click the (Load Confidence Field) **Load *.npz** button to load the unsegmented data of the fiber identification. The confidence field is stored **channel_1:Numpy Field**, so it is recommended to only check and load this component.



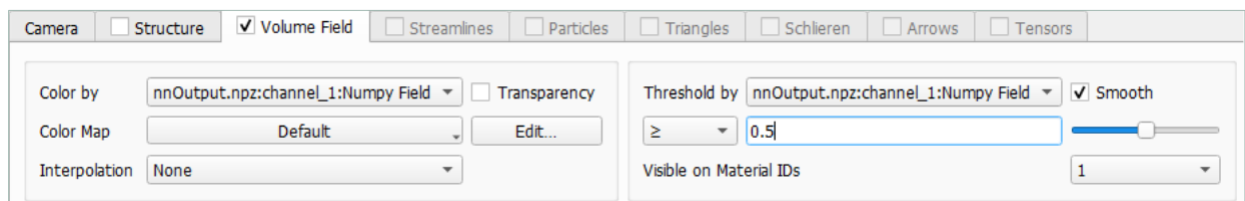
Set the structure to invisible, by unchecking the **Structure** tab in the Visualization panel, above the Visualization area of the GUI.



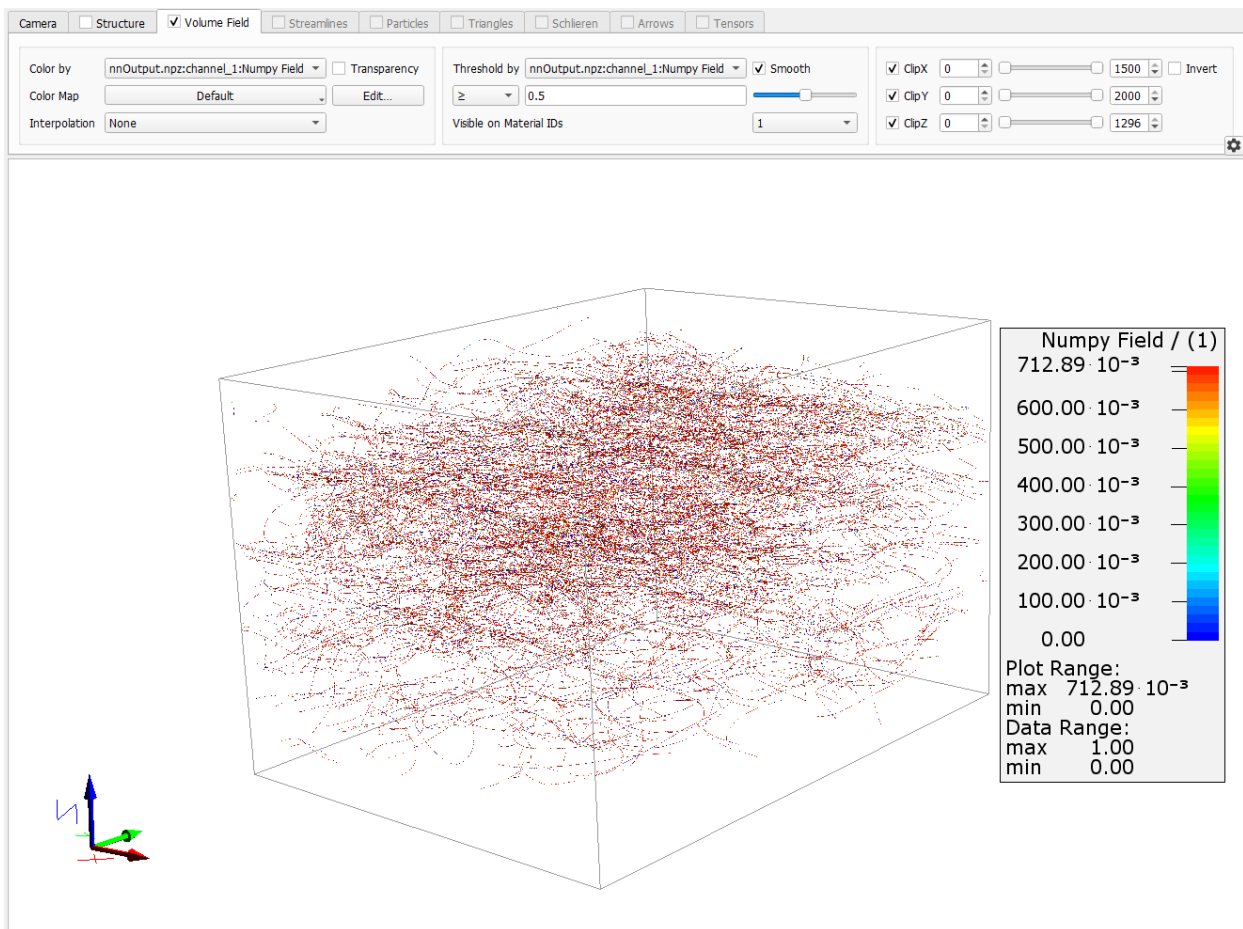
Show the result only for the fibers, by deselecting the material with ID 0 in the **Visibility** pull-down menu of the **Volume Field** tab.



The **Threshold** parameter defines the limit probability value for the decision whether a voxel is a centerline voxel or not. Select $\geq$ as **Clip Mode** to see the voxels that are identified for separate fibers if this value were to be set as Threshold for the fiber identification (see [Fiber identification section](#) ⁴⁰).



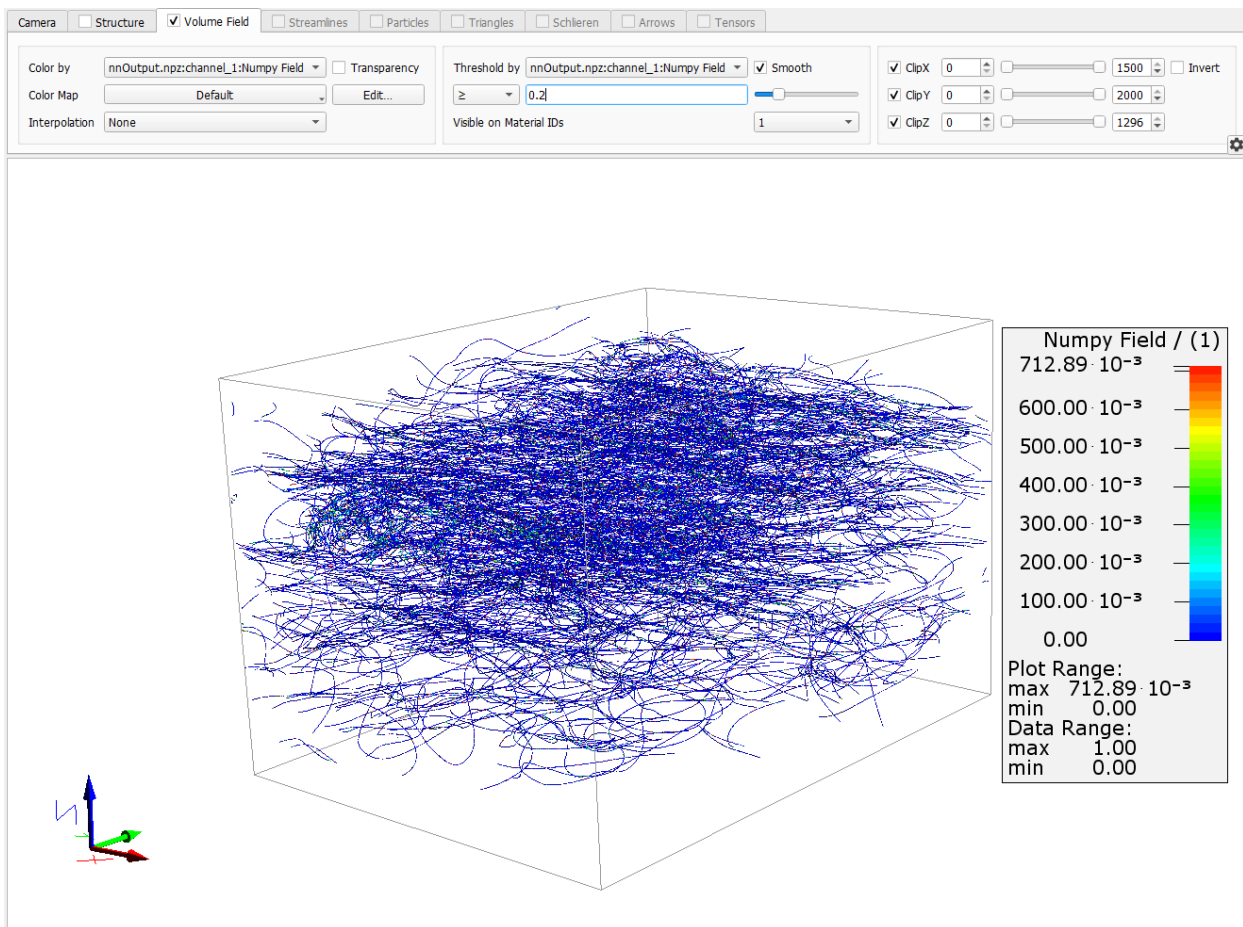
The goal is to find a **threshold** which does not result in fragmented centerlines but also does not fuse the centerlines of neighboring fibers. For this example a default threshold value of 0.5 would lead to a strong fragmentation of fibers as many voxels are not identified to be the centerline of a fiber and thus the fiber itself is subdivided into multiple parts. The representation of identified fibers with threshold 0.5 in the Volume Field tab implies that the fibers are too thin (left side of the following figure).



A threshold of 0.2 in turn seem to be a more appropriate value for this example, as seen below.

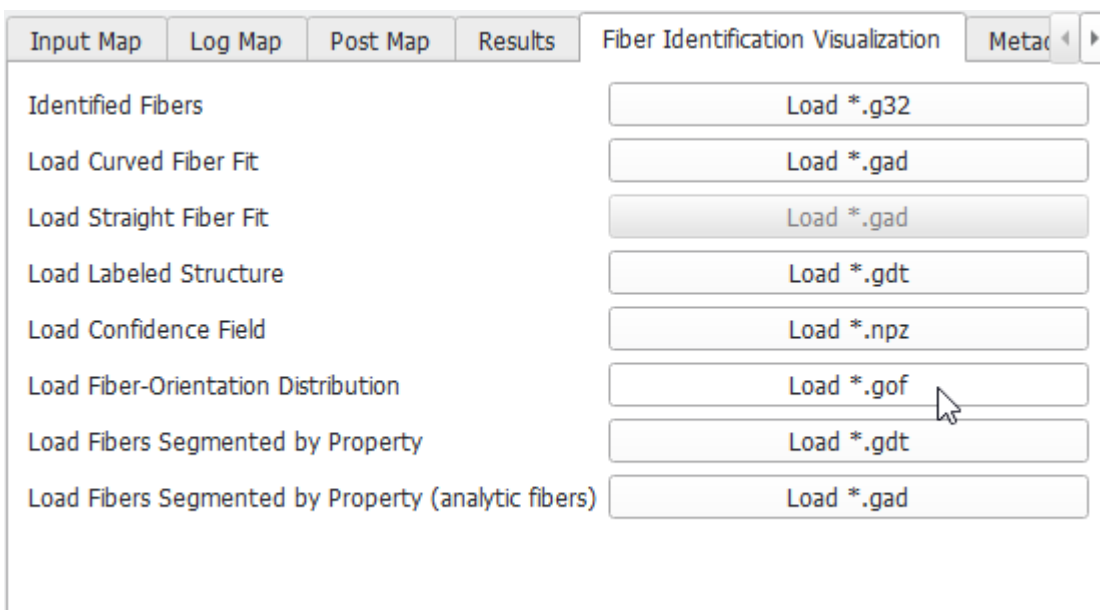
Taking this observation into account an Identify Fibers (AI) run can be done by setting the threshold to 0.2 and, if an identification result is available already, using the neural network output nnOutput.npz in order to save computation time (see [Fiber identification section](#))³⁸.

FiberFind: Identify Fibers (AI)



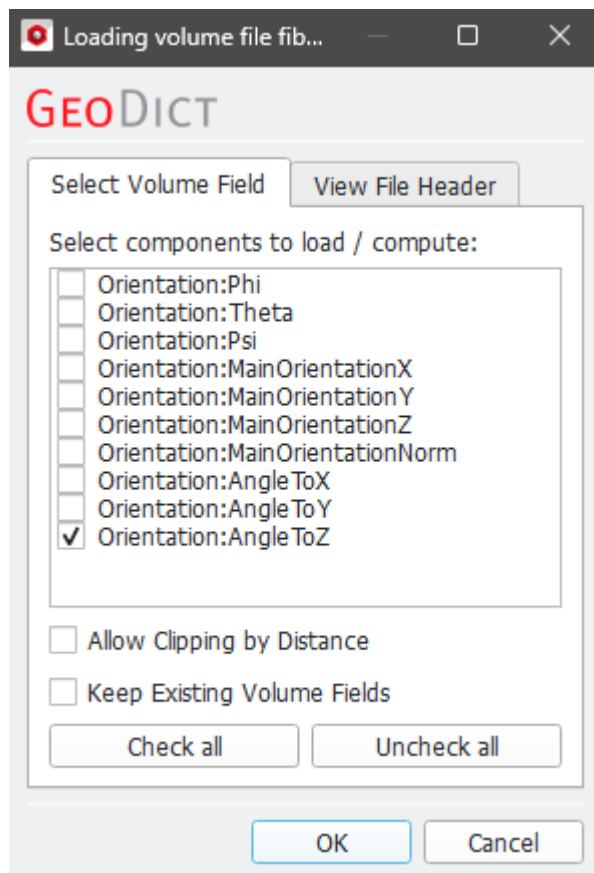
Load Fiber-Oriented Distribution

Select the (Load Fiber-Orientation Distribution) **Load *.gof** button to load information about the fiber orientation.



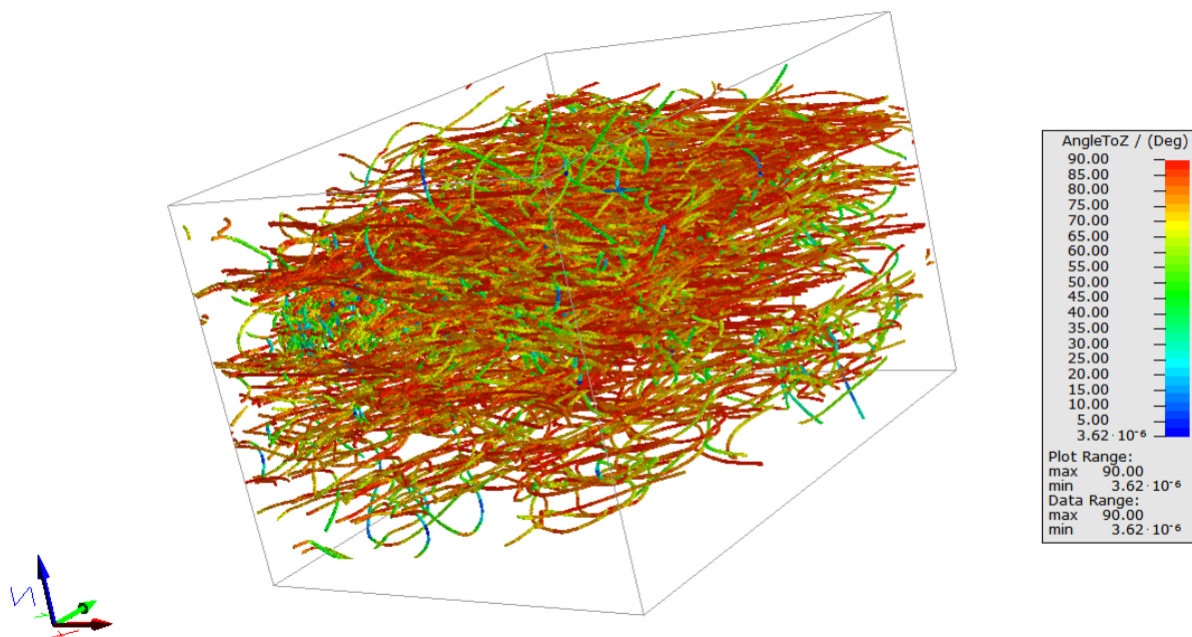
Select, e.g., Orientation:AngleToZ to get a visualization of the angle with respect to the z-axis for each identified fiber segment.

This option is available only if **Save Fiber-Orientation Distribution as .gof** was selected on the [Output Options](#) ⁴² tab.



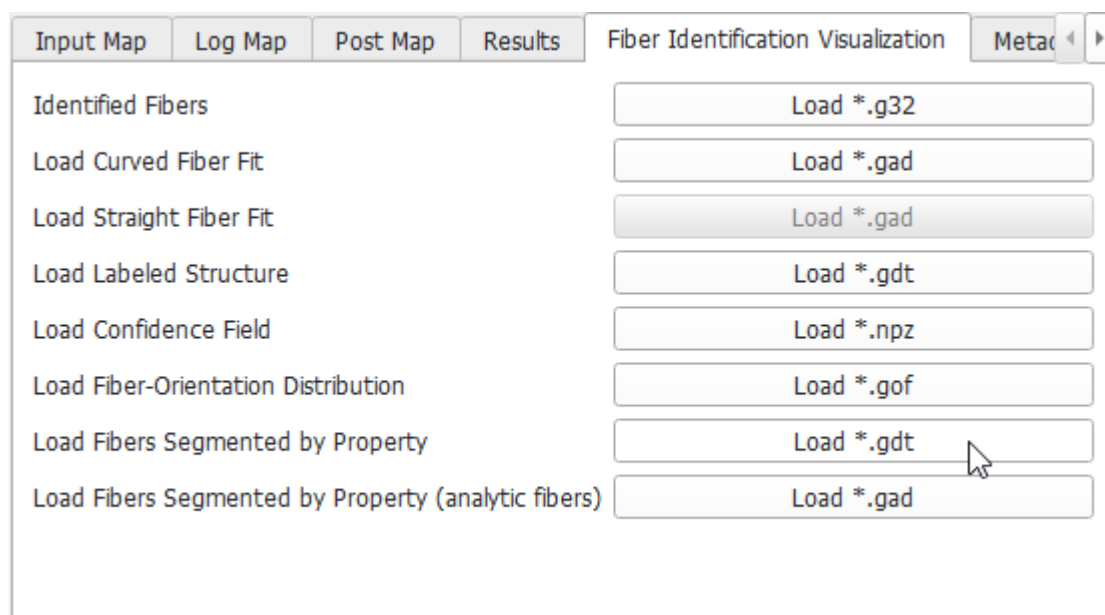
Again, set the structure to invisible by unchecking the **Structure** tab in the Visualization panel, above the Visualization area of the GUI. Show the result only for the fibers by deselecting the material with ID 0 in the **Visibility** pull-down menu of the **Volume Field** tab.

Since in the example shown here, fibers are oriented mainly in x- and y-direction, the angle to the z-axis is high for most of the segments.



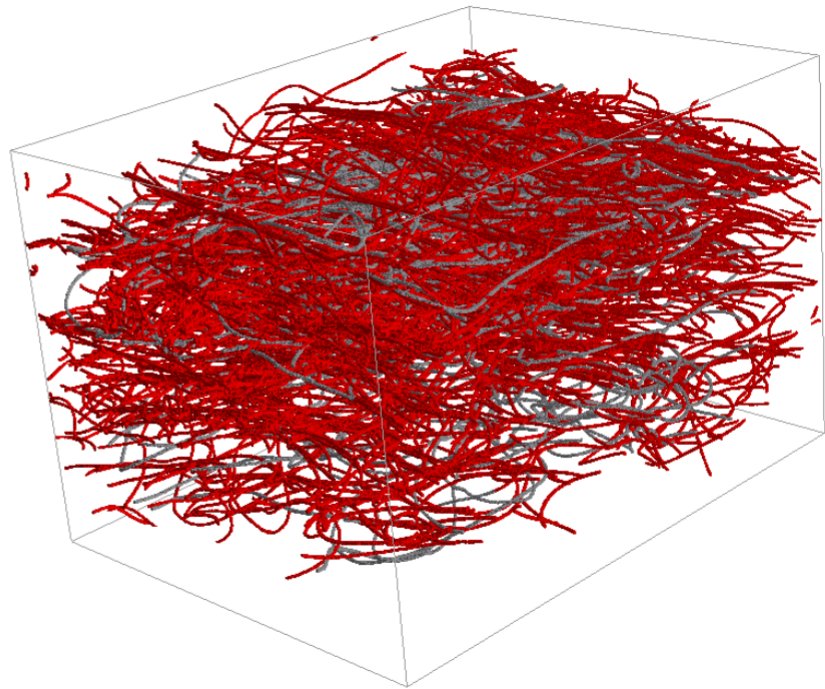
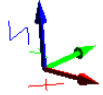
Load Fiber Segmented by Property

Load the structure with fibers of different type assigned to different material IDs in *.gdt format or with analytic data in *.gad format, by clicking Load *.gdt for Load Fibers Segmented by Property and Load *.gad for Load Fibers Segmented by Property (analytic fibers), respectively.



Fibers with different material IDs, according to the number of different fiber types selected under the [Results](#) ⁴³ tab, are shown in the Visualization Area.

Material Information:	
	ID 00: Pore [invis.]
	ID 01: Fiber Type 1 (Solid)
	ID 02: Fiber Type 2 (Solid)



Additionally, GAD objects can be loaded and visualized for the fibers segmented by property with the last available button **Load Fibers Segmented by Property (analytical fibers)**.

1.7 Identify Binder (AI)

The separation between solid and pores of a structure, can usually be done using image processing methods during the import of the scanned data sets (see the [ImportGeo-Vol](#) user guide for more details). However, the separation of binder from fibers is often not possible, since they have the same gray values in the scan.

With GeoDict's Identify Binder (AI) functionality the binder can be identified and separated from fibers automatically prior to the identification of separate fibers.

Please refer to the [AI approach to identify binder and fibers](#)^[6] for more details on the theory.



Important! Since FiberFind ships with a limited number of neural networks for fiber and binder identification, currently some constraints on the input data exist:

- Fiber diameters should be 4 to 10 voxels for binder identification and 8 to 40 voxels for fiber identification.
If fiber diameters differ from this value, ImportGeo-Vol can be used to resample the voxel length. During the import of an image, the 3D Image Processing functionality Image Size→Scale can be used for scaling the 3D image with a different voxel length. Details can be found in the ImportGeo-Vol user guide.



Note! Besides this user guide, two tutorials showing the possibilities of the AI based FiberFind approach for different application cases are available on the [GeoDict Learning Center](#).

The first tutorial, [Digital analysis of fibers and binder content of a carbon paper GDL](#), analyzes a carbon paper gas diffusion layer samples used in proton-exchange membrane fuel cells. It includes provided synchrotron scan data and covers data import, preprocessing, AI-based identification of fibers and binder, and postprocessing of the results.

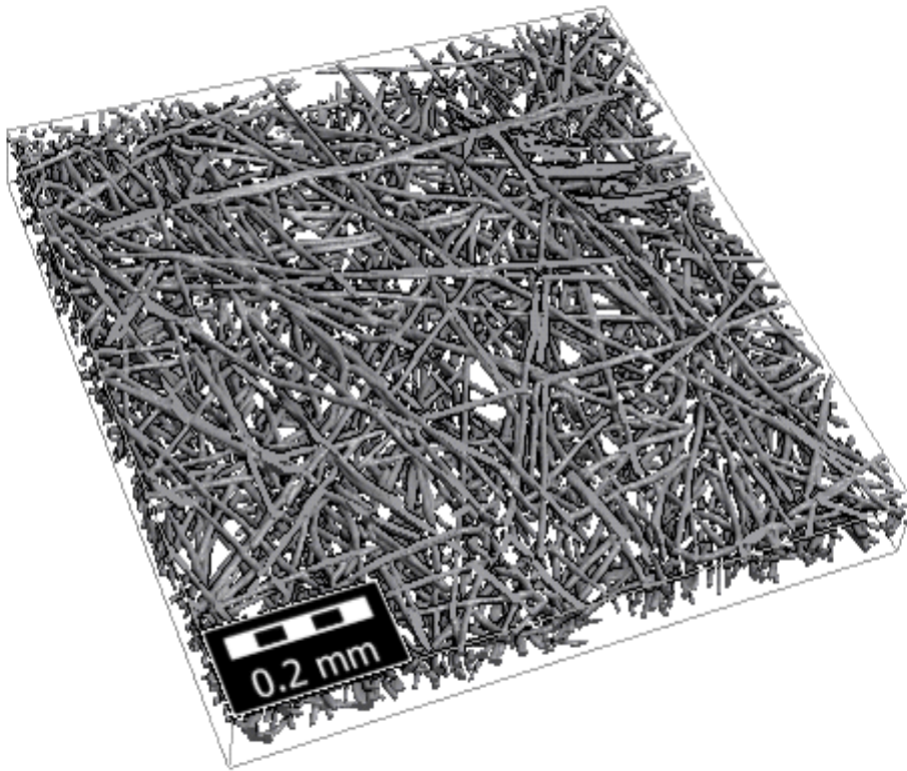
The second tutorial, [Digital Analysis of a glass fiber-reinforced polymer and generation of a digital twin](#), guides you step by step through importing 3D scans of an engine mount, analyzing fiber distribution and mechanical properties using AI-based tools, and post-processing the results. It also shows how to create a statistical digital twin of the microstructure and validate its properties by comparing simulation results with the original scan.

Topics of this section

- [Binder Identification](#)^[65]
Set the parameters for the binder identification.
- [Results](#)^[69]
How to understand the IdentifyBinder (AI) results.

1.7.1 Binder Identification

The example shown here, is a part of the imported μ CT image of a carbon paper gas diffusion layer (GDL) used for a proton-exchange membrane (PEM) fuel cell. The fibers and binder contained in it are undistinguishable by their gray value in the FIB/SEM image.

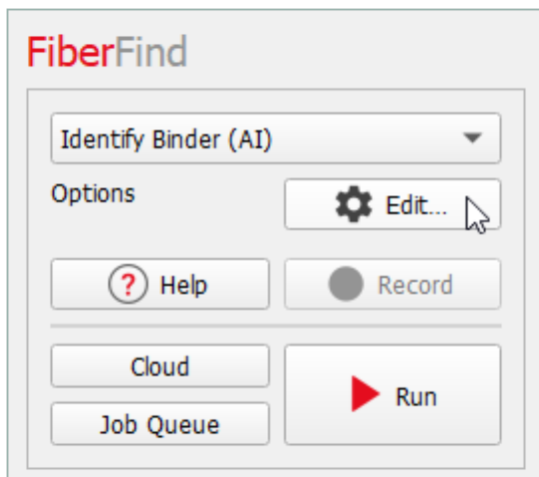


The input data used, as well as a detailed description of the necessary processing steps, can be found in the tutorial [Digital analysis of fibers and binder content of a carbon paper GDL](#).

Some exemplary slices of the structure in Z and X-direction, imported into GeoDict, are shown here.

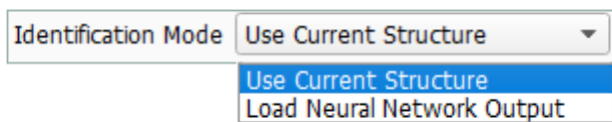


To start, select **Analyze** → **FiberFind** from the menu bar and, in the **FiberFind** section, select **Identify Binder (AI)** from the pull-down menu. Click the **Options' Edit...** button.

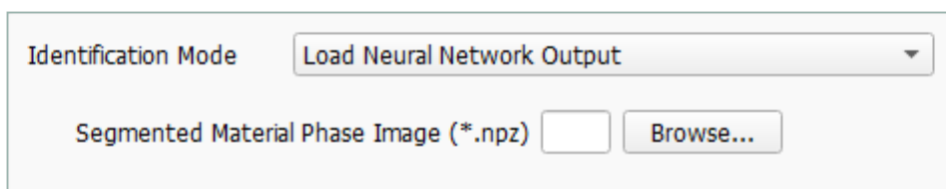


The **Binder Identification** dialog that opens includes the **Binder Identification**, the **GPU Options** and the **Equations & References** tabs. The **GPU Options** tab is similar to the [GPU Options](#) tab for **Identify Fiber (AI)**.

Two choices are available as **Identification Mode**: **Use Current Structure** and **Load Neural Network Output**.

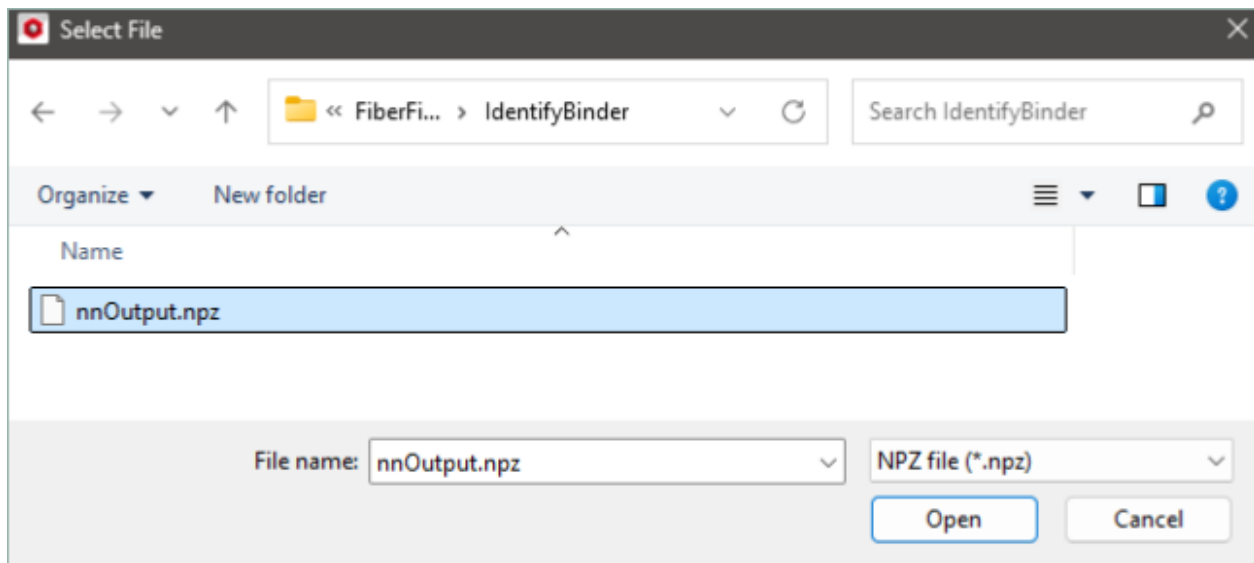


The default **Use Current Structure** applies the binder identification to the structure currently available in GeoDict memory and is used for most of the cases. If a binder identification step has already been done successfully and you want to re-run the postprocessing step with another threshold, **Load Neural Network Output** may be chosen.

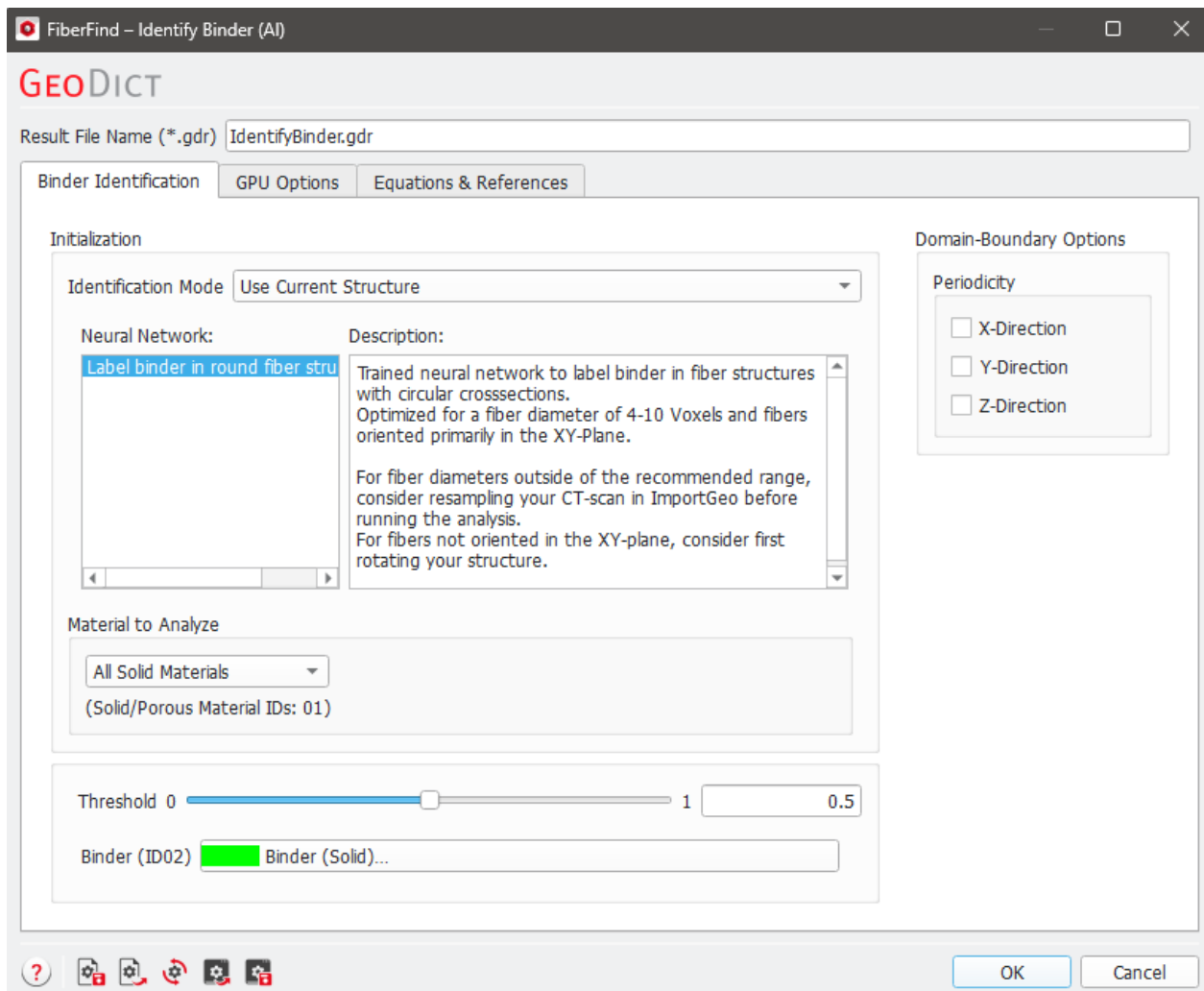


Browse to a .npz file from the result folder of a previous run of FiberFind - **Identify Binder (AI)**. Since already the output of the neural network is used in that case, no selection of **Neural Network** or **Material to Analyze** is possible and the loaded structure needs to be the same.

FiberFind: Identify Binder (AI)

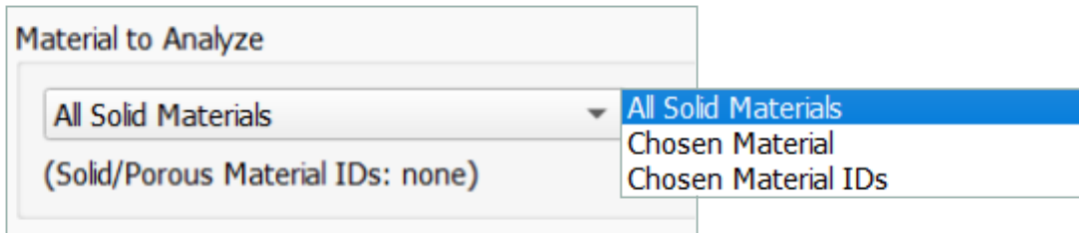


On the **Binder Identification** tab, select the neural networks available under **Neural Network**. GeoDict provides one neural network to identify binder. The application constraints, like the fiber cross-section and diameter of the structures with which the neural network was trained, are listed in the **Description** field.

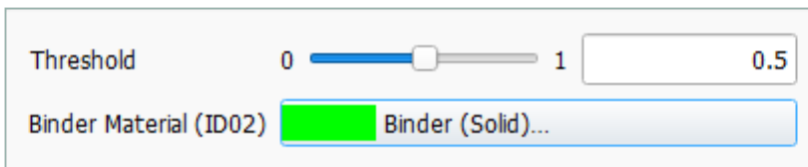


Neural networks trained with GeoDict-AI can be used by copying the corresponding .gnn-file into the installation directory for **Identify Binder (AI)** (e.g., in `C:\Program Files\Math2Market GmbH\GeoDict 2026\FiberFind\IdentifyBinder`). Then, these neural networks appear as further options in the **Neural Network** field.

The **Material to Analyze** panel offers the choice of whether the binder identification should be applied to all solid and porous materials in the structure or only on a subset, defined either by choosing Material IDs or Materials.

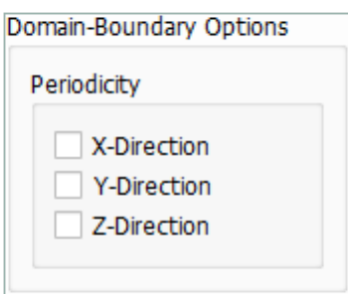


The neural network provides probabilities about whether a solid voxel is binder or not. The **Threshold** parameter defines the limit for this labelling and can therefore be defined by the user between 0 and 1 (default 0.5).



The **Binder Material** specifies the material to label the binder. The material chosen should be different from the material of any solid or pore material present in the original structure. The ID assigned to the binder material is the first ID that is not present in the current structure.

Select one or several boxes on the **Domain-Boundary Options** panel if the underlying structure for the binder identification is periodic in one or several directions. However, periodicity is unusual for most 3D-scans and this setting is rarely used.



1.7.2 Results

After the successful binder identification, the GeoDict Result Viewer opens for the result file (.gdr).

Report

Under the **Results - Report** tab, the percentage of voxels identified as binder is shown.

Domain Size: 400 x 370 x 71 Voxel Length: 1.3 μm

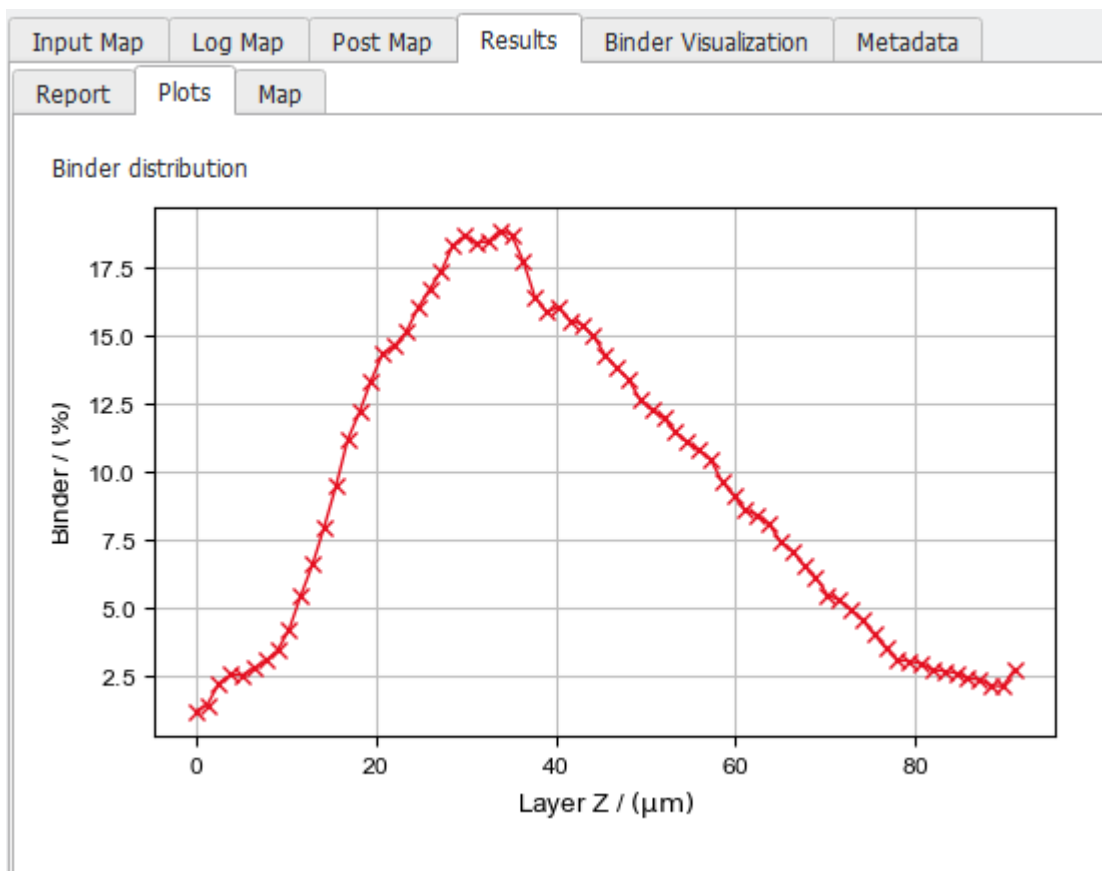
BinderFind

Found 9.27928 % binder in the structure

Total runtime: 00:00:05, Total memory usage: 2.032 GiB

Plots

In the **Results – Plots** subtab the binder distribution is presented by terms of binder percentage for each layer in z-direction of the structure.

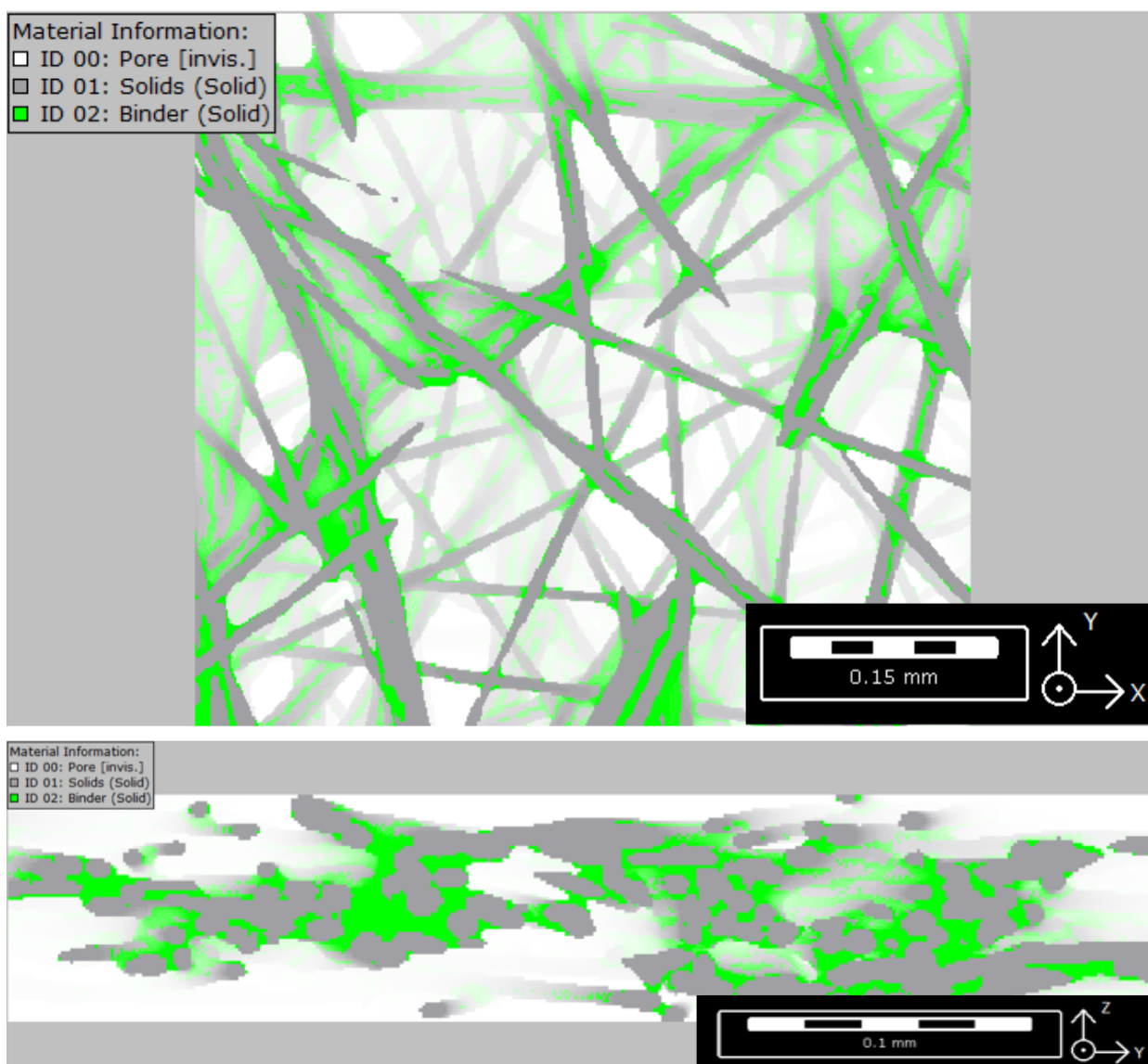


Binder Visualization

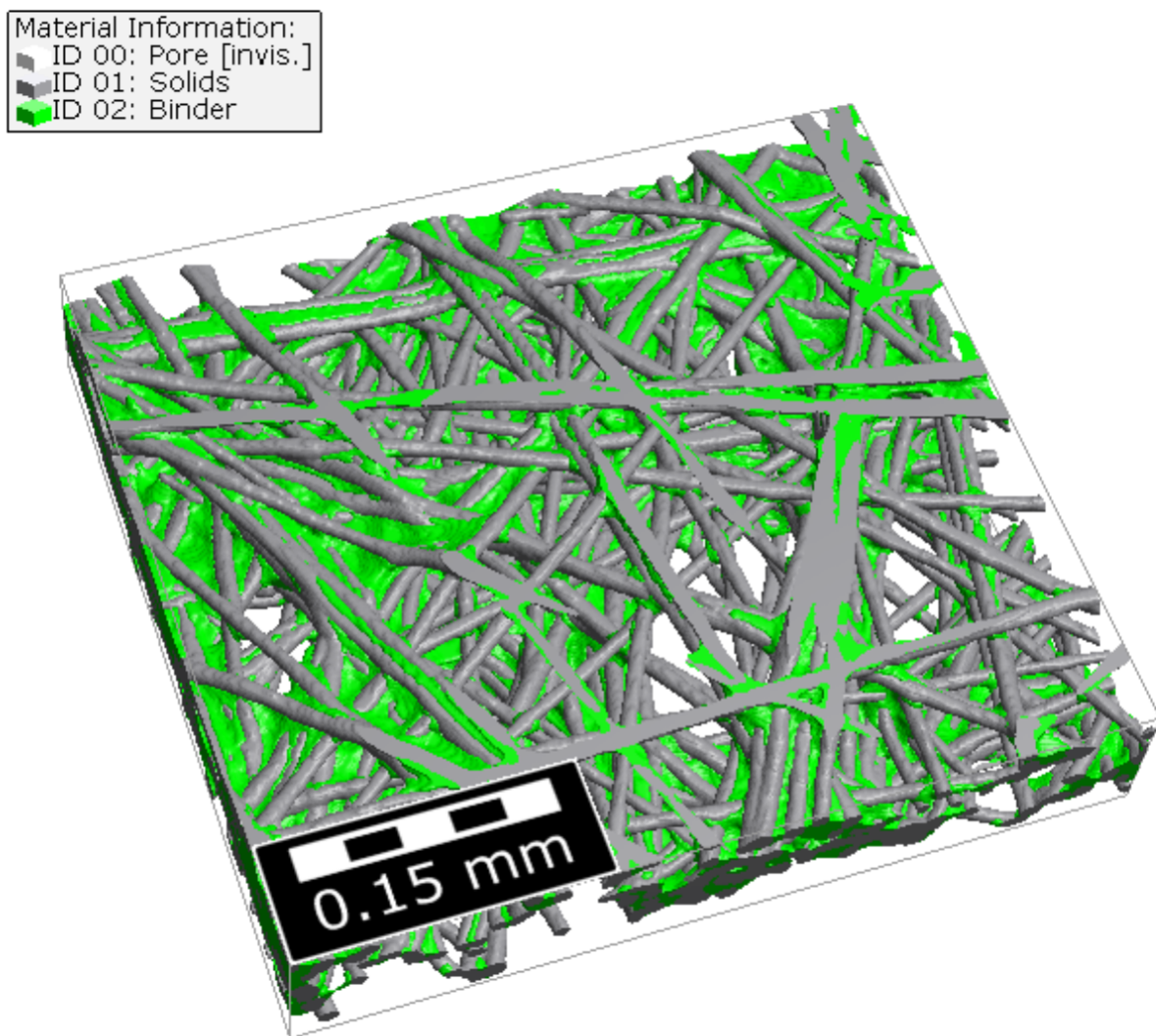
Load the structure with identified binder, by clicking **Load *.gdt** under the **Binder Visualization** tab.



The same slices of the structure as shown in 2D in the [Binder identification section](#)⁶⁵ can be seen here, now with binder separated from the fibers.



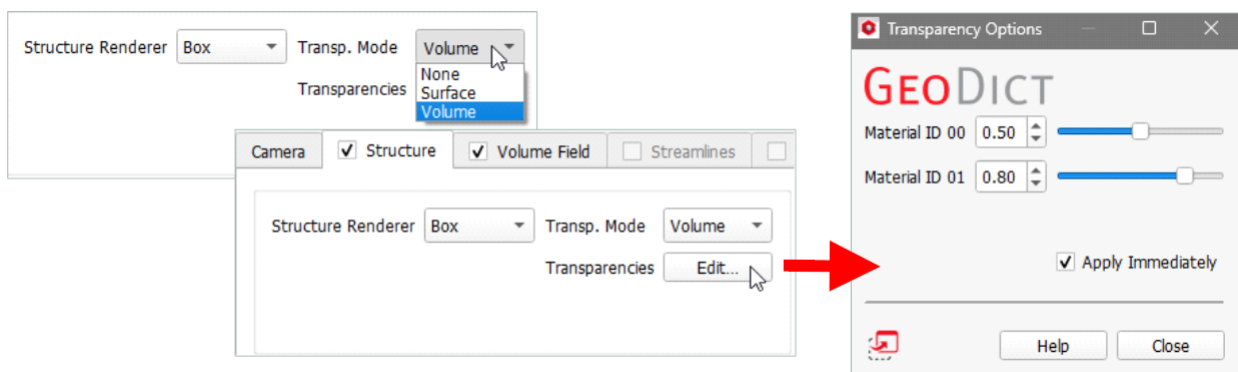
In the 3D visualization, the distribution of binder between the fibers is visible for the whole domain.



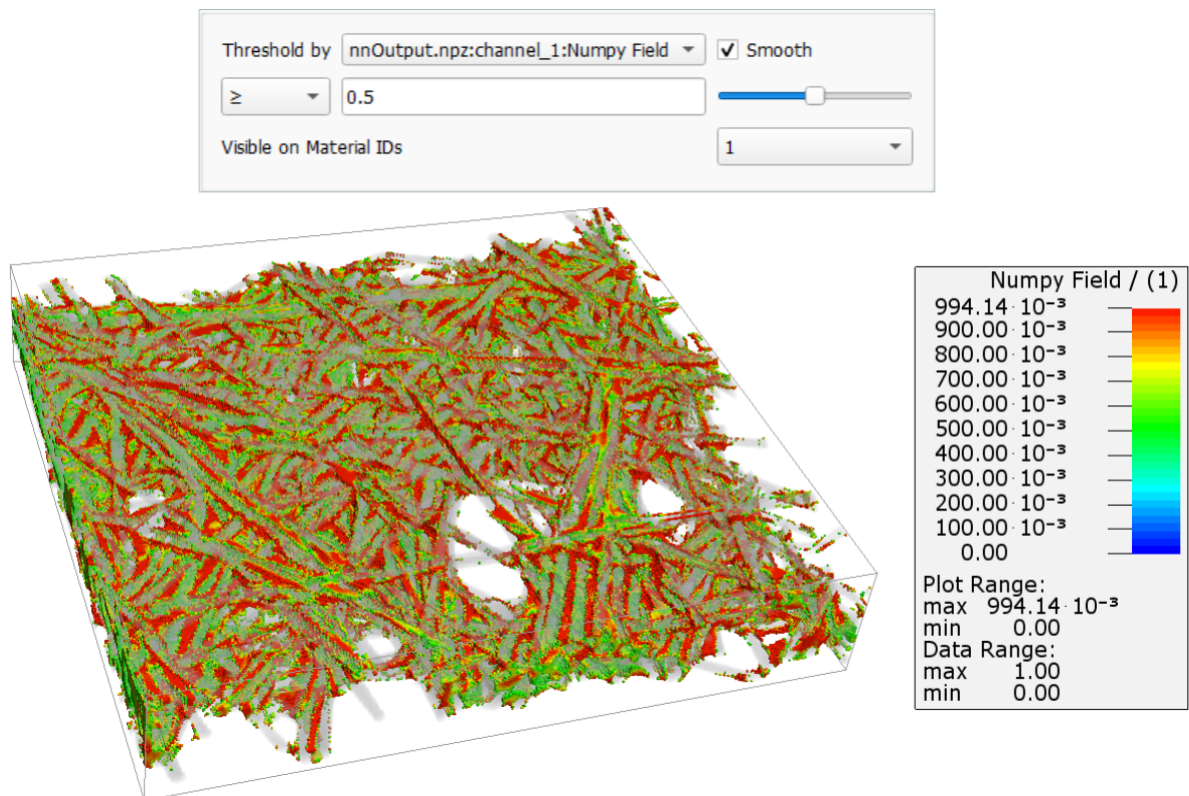
Analogous to Identify Fiber (AI) you can load the confidence field of the binder identification result by selecting **Load *.npz** under the **Binder Visualization** tab. The confidence field is stored in **channel_1:Numpy Field**, so it is recommended to only check and load this component.



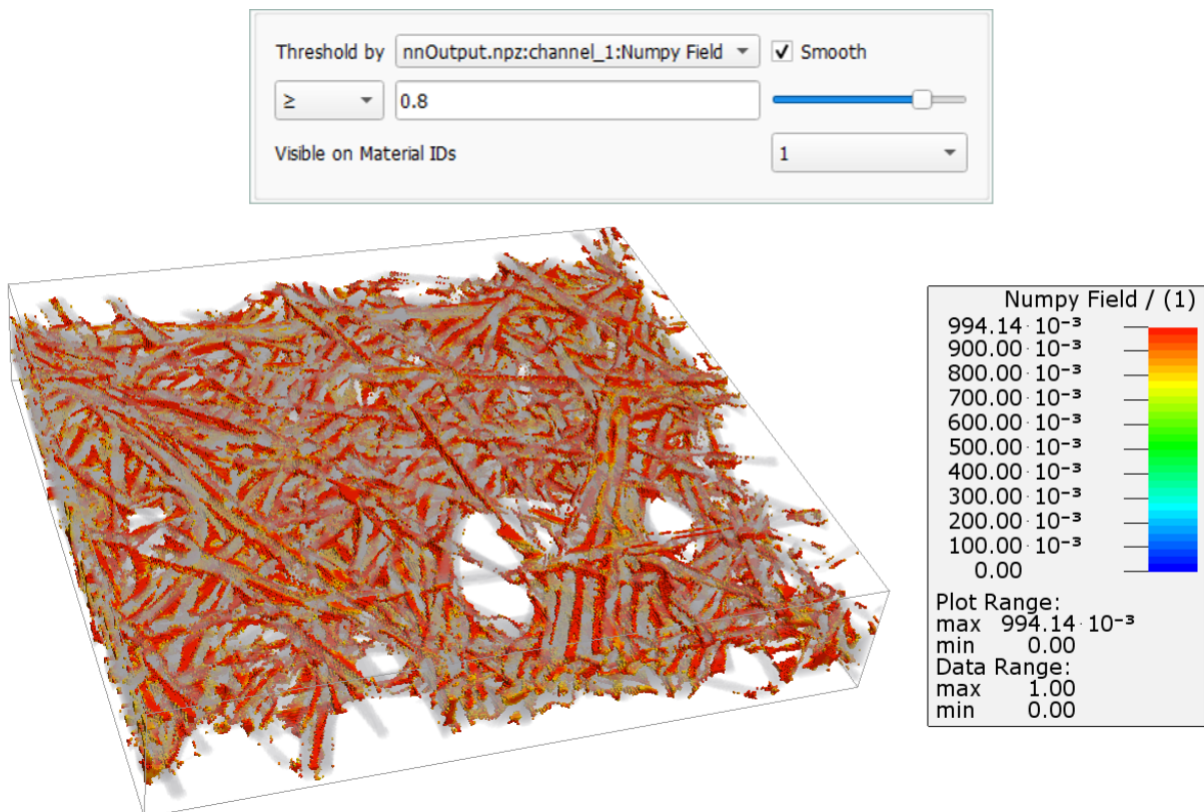
In order to verify and comprehend the binder identification process it might be useful to simultaneously visualize the **Structure** and the **Volume Field**. For a better visibility choose **Transp. Mode** as **Volume** and edit the **Transparencies Options** for Material ID 01 (fibers and binder coupled) such that you can see it properly (e.g., 0.80 like in this example).



To identify voxels with a predicted confidence larger than 0.5, choose a threshold value of **0.5** and the Clip Mode $\geq$ on the **Volume Field tab**. The identified binder voxels are now displayed in green to red and the remaining solid voxels in (transparent) gray.



This can be compared, e.g., with the result for a threshold of 0.8, where less voxels are identified as binder (displayed in orange and red), see figure on the right.



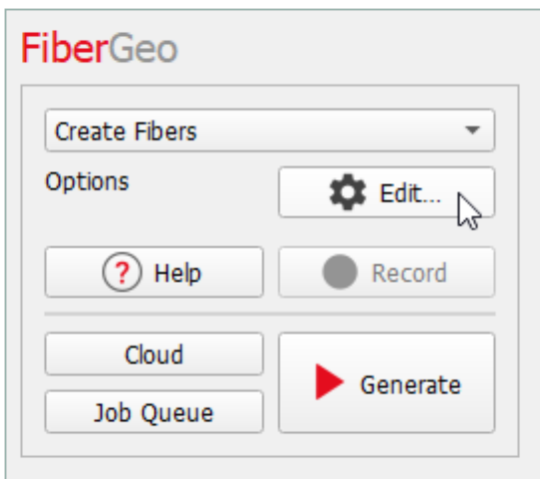
1.8 Reproducing Fibrous Media Using FiberFind and FiberGeo

This example demonstrates the workflow of creating a digital twin based on results from FiberFind.

The values of the orientation tensors and the calculated diameters in the FiberFind result can be entered in FiberGeo to generate a matching digital material model.

Start with the values estimated by FiberFind for the fibrous material: the average fiber diameter and the diameter distribution for the whole domain, as well as the fiber orientation tensors for each block. This diameter distribution and the per-block orientation tensors can now be entered in FiberGeo to reproduce the fibrous material.

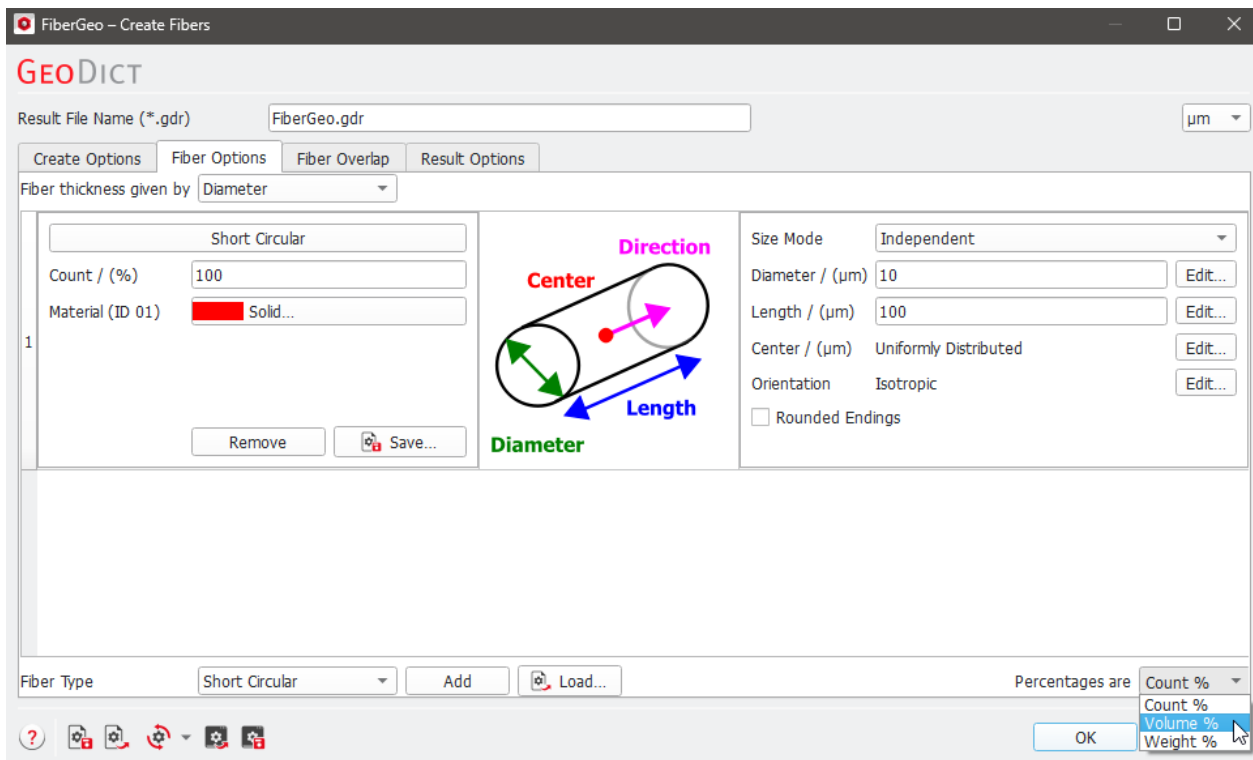
Select **Model** → **FiberGeo** in the menu bar and click the **Options' Edit...** button in the **FiberGeo** section.



In FiberGeo, go to the **Fiber Options** tab and begin entering as many fibers of type Short Circular or Infinite Circular as the number of blocks in which the domain has been subdivided. For a homogeneous material, this is a single fiber type. For a layered heterogeneous material, this is one fiber type per media layer. In FiberGeo, it is possible to use up to 8 different fiber types.

Later, all fibers can be assigned to the same Material ID.

Set the **Percentages are** as Volume % (bottom right) to be able to define the desired fraction of the total volume of the fibrous structure according to an Object Solid Volume Percentage (SVP) value. Please refer to the FiberGeo user guide for a more detailed description of the different FiberGeo Create Fibers options.



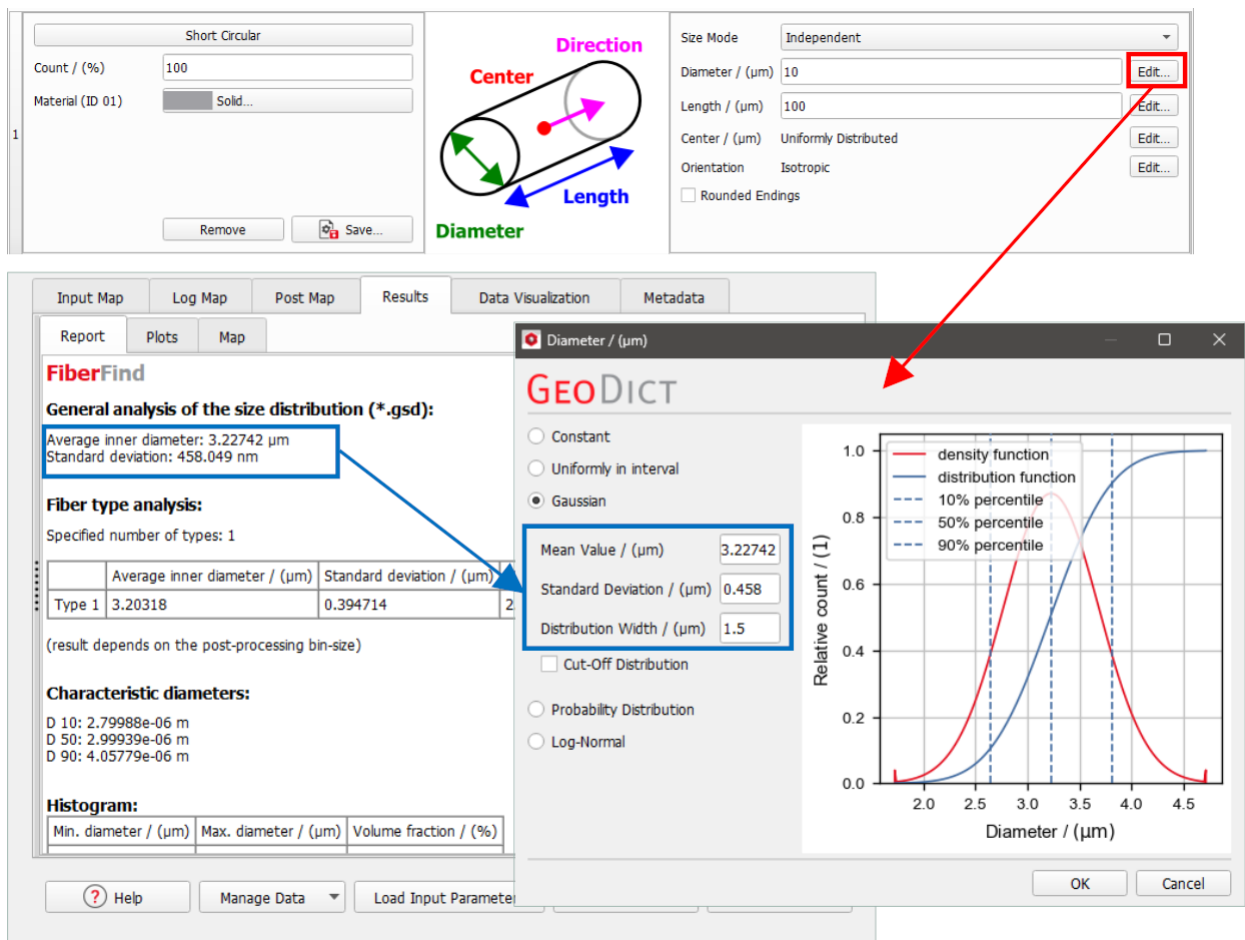
Topics of this section

- [Homogeneous Fibrous Media](#)⁷⁶
Set up a digital twin for homogeneous fibrous media based on FiberFind results.
- [Heterogeneous \(Layered\) Fibrous Media](#)⁸⁰
Set up a digital twin for layered fibrous media based on FiberFind results.
- [Reproducing Curvature Of Fibrous Media](#)⁸⁶
Hot to model curved fibers in a digital twin based on FiberFind results.

1.8.1 Homogeneous Fibrous Media

For a homogeneous material with one single fiber type, use the data from an Estimate Fiber Diameter result file (*.gdr) obtained with FiberFind and, for **Diameter**, enter the value of the estimated **Average inner diameter**.

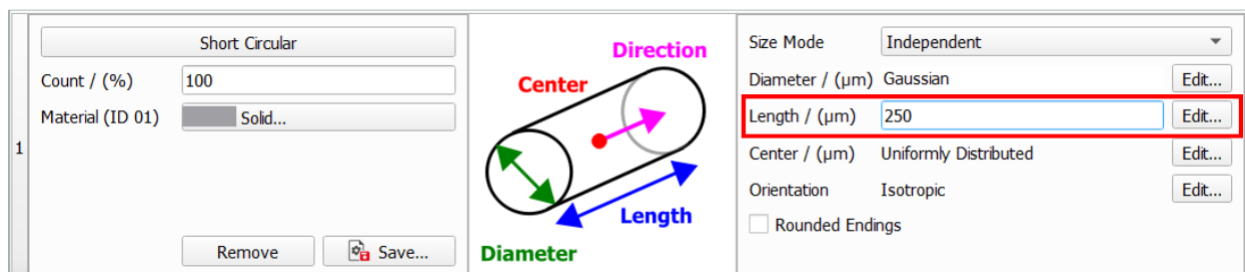
Alternatively, click the **Diameter's Edit...** button and choose **Gaussian** (or Log-Normal) to enter the values of the **Average inner diameter** and the **Standard deviation** from the fiber diameter result file.



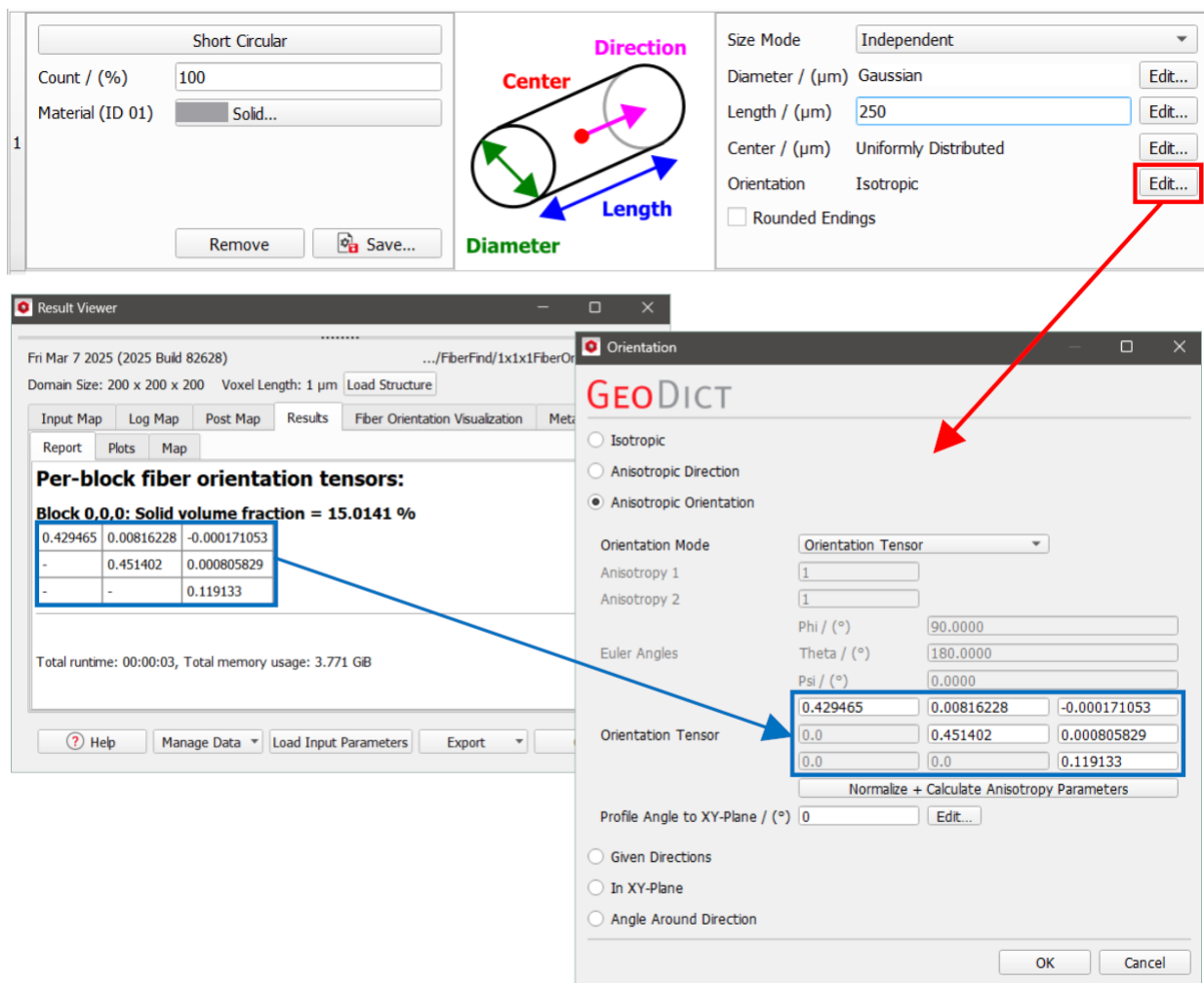
It is also possible to choose **Probability Distribution** and to enter a stepwise distribution, e.g., from the histogram values of the fiber diameter estimation.

Enter a **Length** that fits to the length of fibers in the structure (e.g., the length estimated during fiber identification (see [Identify Fibers](#)^[35])).

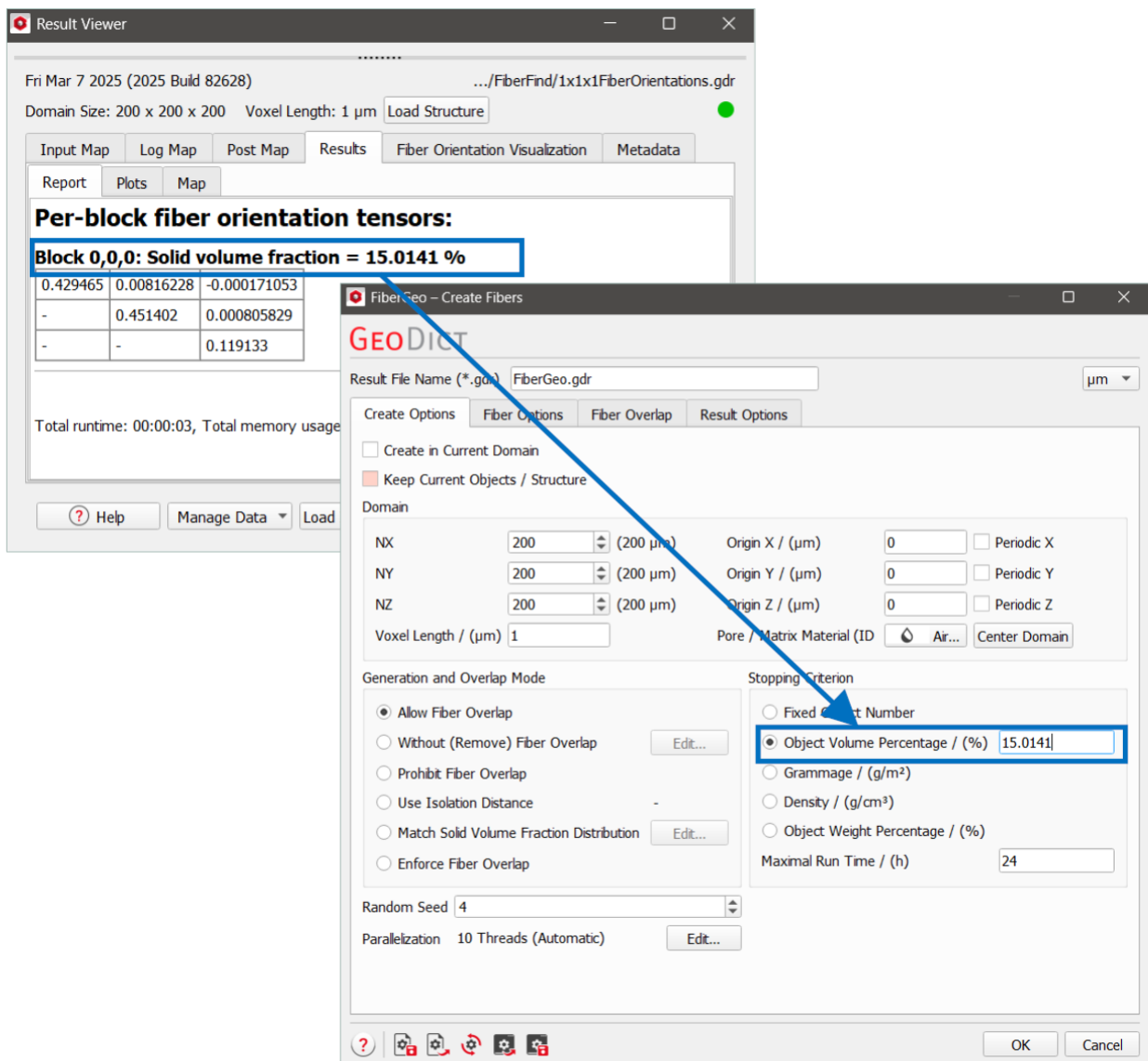
For the example shown above, with fibers having their start and end points beyond the domain, enter a **Length** that is larger than the largest side of the domain. For a domain of 200 μm x 200 μm x 200 μm used here, enter, e.g., a length of 250 μm. Infinite circular fibers could be chosen as fiber type as well here. They already extend beyond the domain.



Using an Estimate Fiber Orientation file (*.gdr) obtained with FiberFind, click now the **Orientation Edit...** button to enter these computed values.



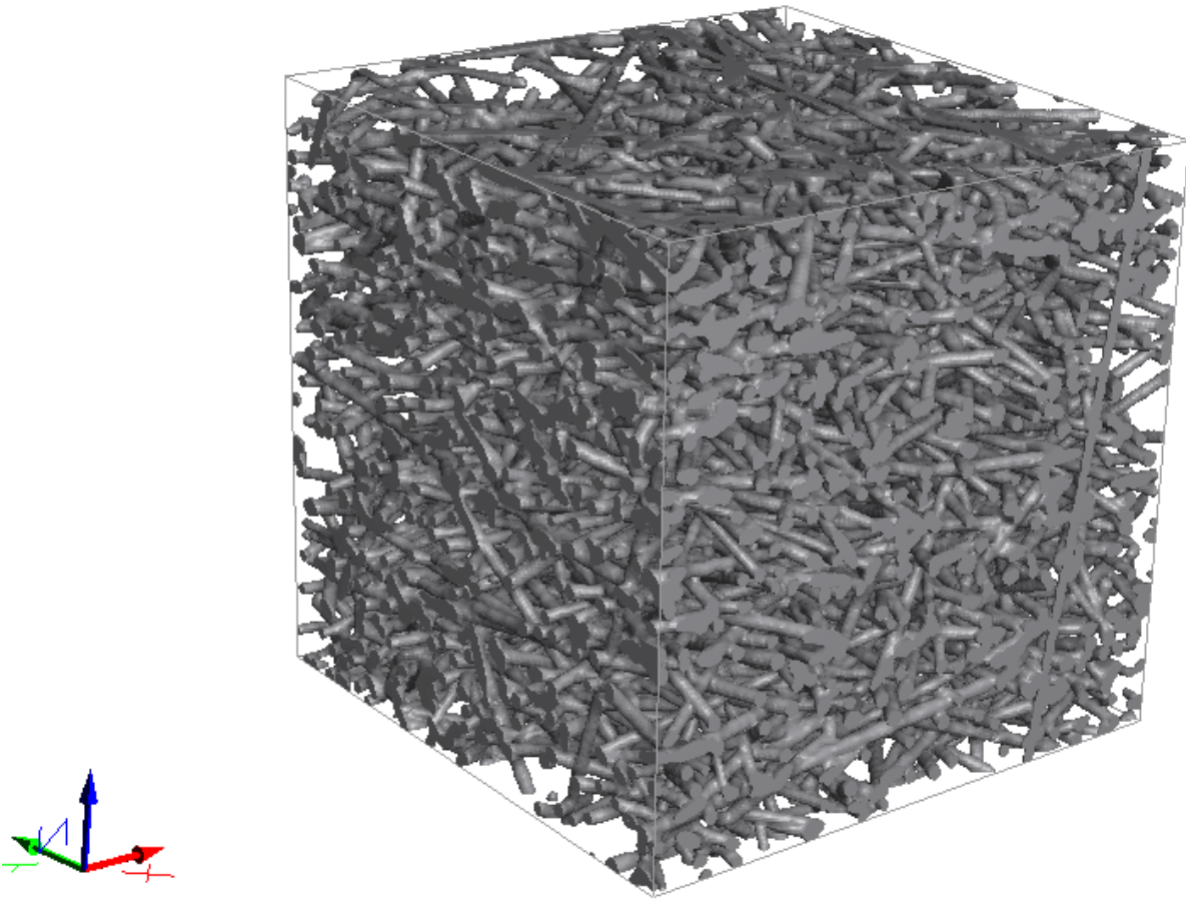
Now, under the **Create Options** tab of FiberGeo, enter the estimated **Solid Volume Fraction** as **Object Solid Volume Percentage** in the Stopping Criterion panel. There are no layers and, thus, the calculated SVF corresponds to the **Object Solid Volume Percentage** of the complete media.



Remember to set the correct domain size (**NX**, **NY**, **NZ**) and **Voxel Length** in the Domain panel (**Create Options** tab).

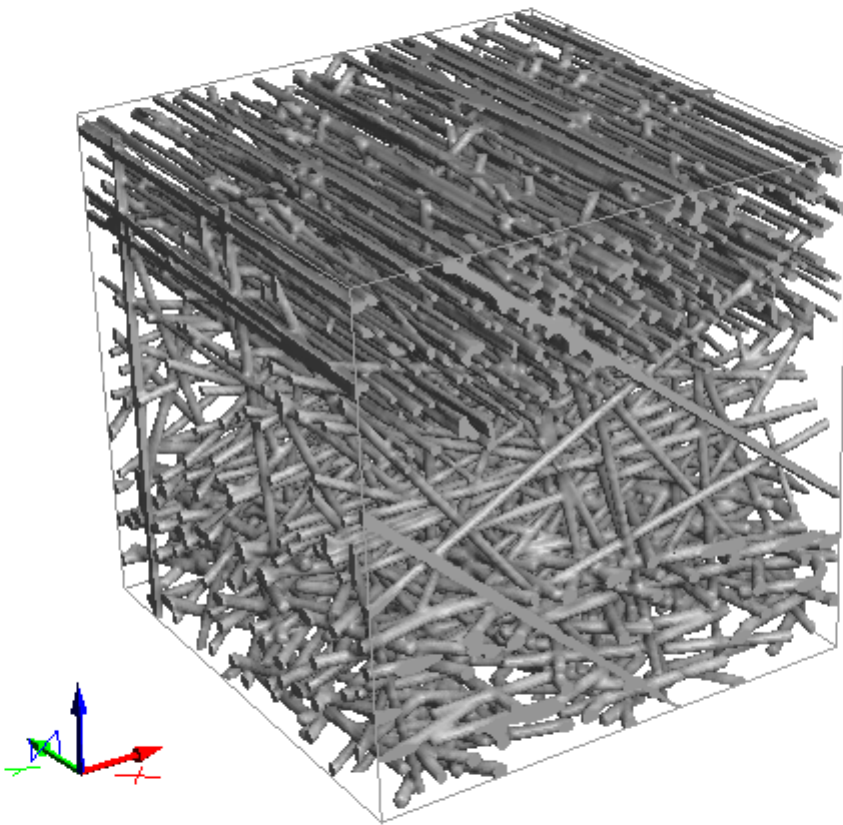
Click **OK** to close the **FiberGeo Create Options** dialog and click **Generate** in the **FiberGeo** section.

The reproduced fibrous material model appears in the Visualization area, matching the values estimated by FiberFind for the 3D material model obtained from importing (μ)CT images.



1.8.2 Heterogeneous (Layered) Fibrous Media

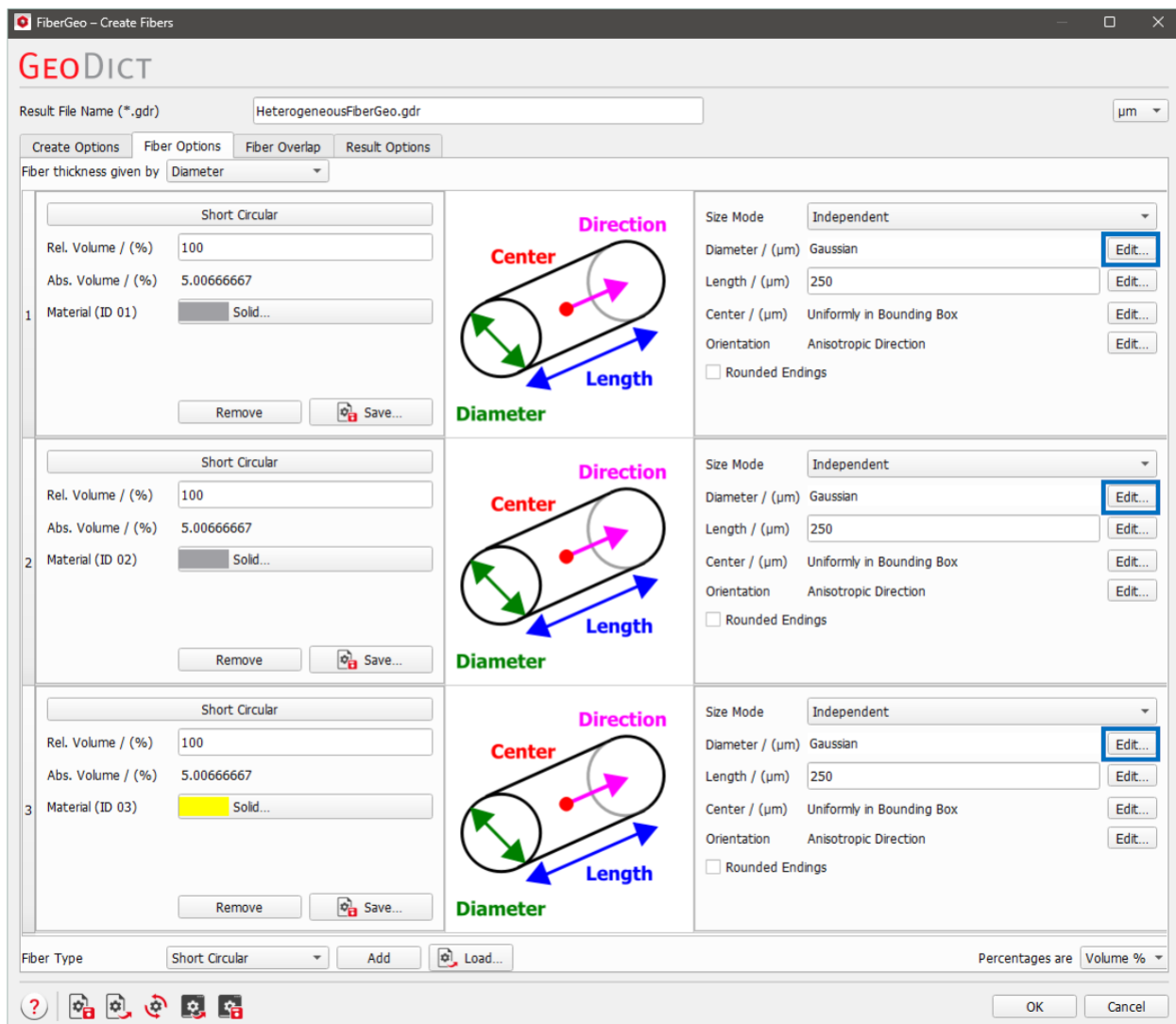
For a heterogeneous material (layered), add as many fiber types as layers are in the media, corresponding to the blocks estimated by computations with FiberFind (for example, on a 3D material structure model obtained from importing a (μ)CT image).



To enter the fiber type and the fiber diameter for each of them, use the data from the fiber diameter estimation result file (*.gdr) obtained with FiberFind and enter the estimated **Average inner diameter** directly.

Alternatively, click the **Diameter Edit...** button for each fiber type, choose **Gaussian** (or Log-Normal), and enter the value of the estimated **Average inner diameter** and the value of **Standard deviation** for all fiber types (as shown in the [Homogeneous Fibrous Media](#)⁷⁶ section).

Notice that the fiber diameters of the different layers look fairly similar in the example shown. Because of this, only one fiber type (short circular) and the same values for the Gaussian distribution are selected. If the diameters should be different in each layer, it is possible to choose three different fiber types and a different diameter distribution for each layer under the **Fiber Options** tab in FiberGeo.



In the example shown, most fibers do not end inside the domain. For short circular fibers, enter therefore a **Length** that is larger than the largest side of the domain. For example, if the domain is 200 μm x 200 μm x 200 μm , enter a length of 250 μm .

The fiber type Infinite Circular cannot be used here, since we want to model a structure with three different layers and therefore also need to define the center of the fibers for each layer, see below.

From the fiber orientations file (*.gdr), enter the values from the orientation tensors calculated for each block (layer) by clicking the **Orientation's Edit...** buttons in the panels on the right.

Domain Size: 200 x 200 x 200 Voxel Length: Load Structure

Input Map Log Map Post Map Results Fiber Orientation

Report Plots Map

Per-block fiber orientation tensors:

Block 0,0,0: Solid volume fraction = 18.747 %

0.4135	0.0101681	-0.00474351
-	0.343832	0.00361791
-	-	0.242668

Block 0,0,1: Solid volume fraction = 8.294 %

0.581382	-0.00328144	0.000782094
-	0.118961	0.00136107
-	-	0.299657

Block 0,0,2: Solid volume fraction = 17.7374 %

0.0819457	0.00125646	0.00187785
-	0.836602	0.000883724
-	-	0.0814521

Total runtime: 00:00:19, Total memory usage: 3.631 GB

Orientation GEO-DICT

☐ Isotropic

☒ Anisotropic Direction

Direction Mode: Orientation Tensor

Anisotropy 1: 1.585

Anisotropy 2: 0.8457

Phi / (°): 37.7818

Euler Angles: Theta / (°): 2.8147

Psi / (°): -29.4101

Orientation Tensor:

0.4135	0.0101681	-0.00474351
-	0.343832	0.00361791
-	-	0.242668

Normalize + Calculate Anisotropy Parameters

Orientation GEO-DICT

☐ Isotropic

☒ Anisotropic Direction

Direction Mode: Orientation Tensor

Anisotropy 1: 1.849

Anisotropy 2: 0.2696

Phi / (°): -160.5822

Euler Angles: Theta / (°): 0.4737

Psi / (°): 160.1732

Orientation Tensor:

0.581382	-0.00328144	0.000782094
-	0.118961	0.00136107
-	-	0.299657

Normalize + Calculate Anisotropy Parameters

Orientation GEO-DICT

☐ Isotropic

☒ Anisotropic Direction

Direction Mode: Orientation Tensor

Anisotropy 1: 1.062

Anisotropy 2: 6.675

Phi / (°): 89.7936

Euler Angles: Theta / (°): 26.9975

Psi / (°): -89.8815

Orientation Tensor:

0.0819457	0.00125646	0.00187785
-	0.836602	0.000883724
-	-	0.0814521

Normalize + Calculate Anisotropy Parameters

☐ Anisotropic Orientation

☐ Given Directions

☐ In XY-Plane

☐ Angle Around Direction

OK Cancel

Next, for each layer, click the **Center's Edit...** button and place the three types of fibers in layers by setting their centers uniformly in a box.

Center / (μm) GEO-DICT Block 0,0,0

☐ Uniformly

☒ Uniformly in Box

Choose box laterally bigger than domain to avoid boundary effects.

X-min / (μm): -60 X-max / (μm): 260

Y-min / (μm): -60 Y-max / (μm): 260

Z-min / (μm): -60 Z-max / (μm): 66.6

☐ Density Distribution

OK Cancel

Center / (μm) GEO-DICT Block 0,0,1

☐ Uniformly

☒ Uniformly in Box

Choose box laterally bigger than domain to avoid boundary effects.

X-min / (μm): -60 X-max / (μm): 260

Y-min / (μm): -60 Y-max / (μm): 260

Z-min / (μm): 66.6 Z-max / (μm): 133.33

☐ Density Distribution

OK Cancel

Center / (μm) GEO-DICT Block 0,0,2

☐ Uniformly

☒ Uniformly in Box

Choose box laterally bigger than domain to avoid boundary effects.

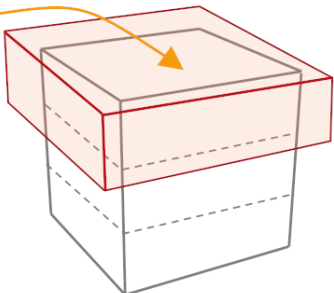
X-min / (μm): -60 X-max / (μm): 260

Y-min / (μm): -60 Y-max / (μm): 260

Z-min / (μm): 133.33 Z-max / (μm): 260

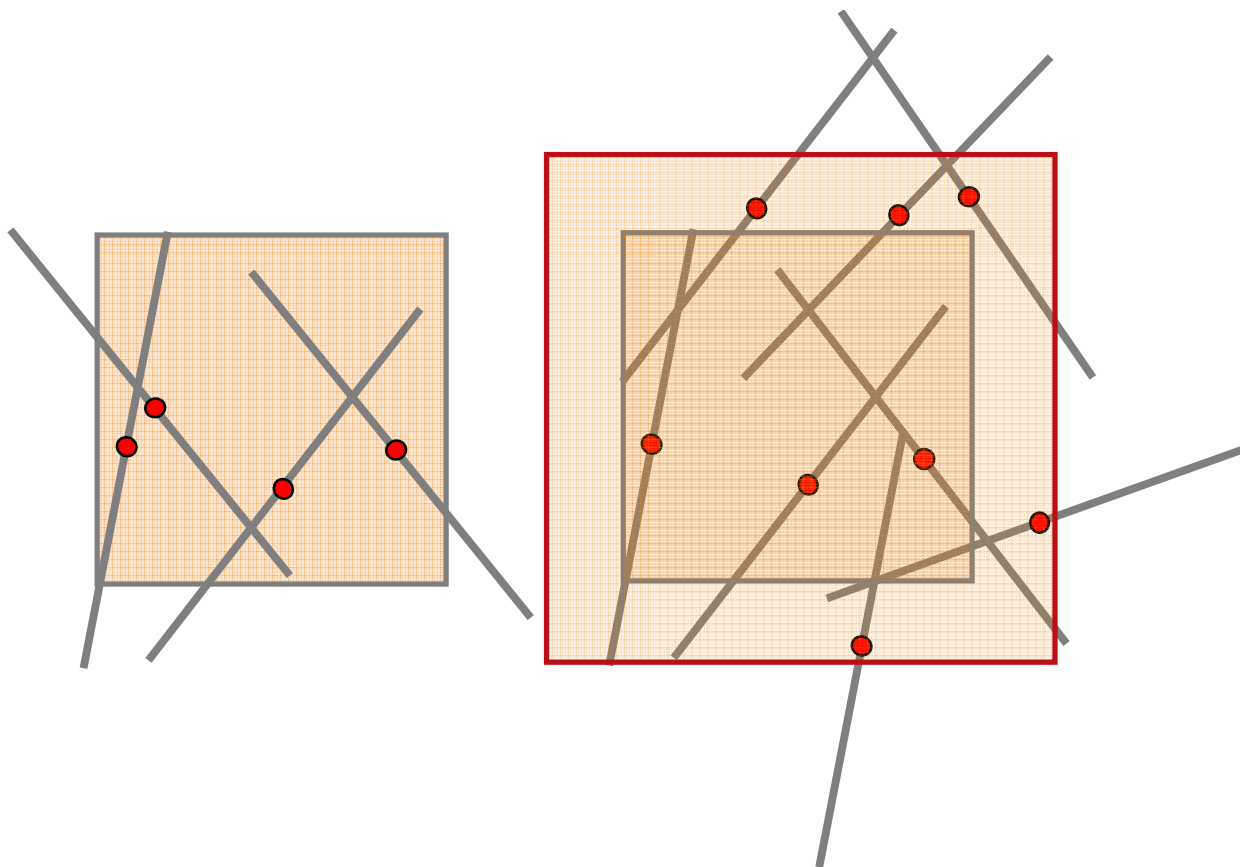
☐ Density Distribution

OK Cancel



The box for each layer should be constructed laterally bigger than the domain ($200 \times 200 \times 200 \mu\text{m}^3$). When the box is constrained to the domain, only fibers whose centers are inside of the

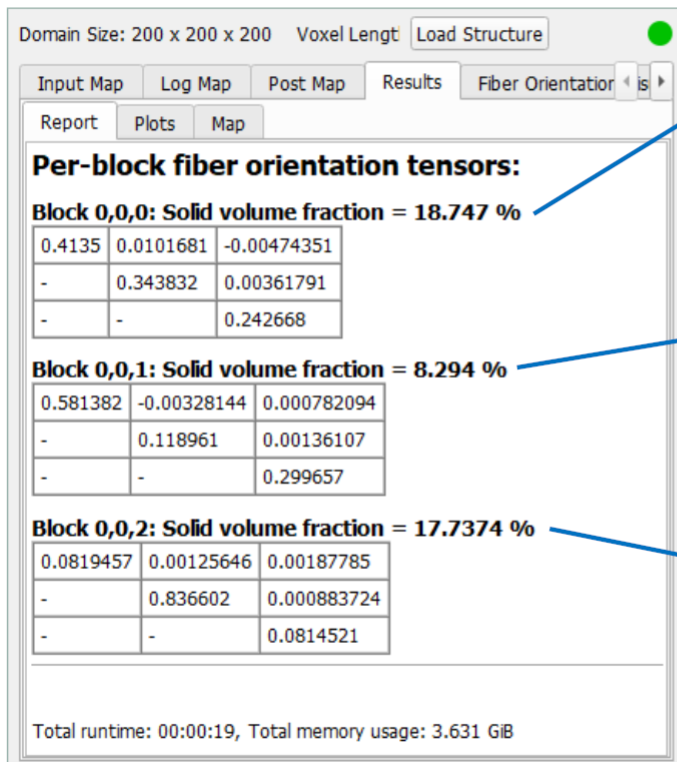
domain are created. For a larger box, also fibers with a smaller part inside the domain are possible (see also the illustration below).



Finally, it is necessary to consider the contribution of every layer (fiber type) to the domain's solid volume fraction (object solid volume percentage).

Under the **Fiber Options** tab, the [percentages](#)⁷⁵ had been selected to be viewed as **Volume %**. Enter the estimated solid volume fractions of the three blocks (18.747%, 8.294%, 17.737%).

After clicking **OK** in the dialog, FiberGeo adjusts the percentages automatically to sum up to 100%. For example, for Block 0,0,0 with SVP of 18.747%, the contribution is 41.8662% after percentages are automatically updated.



Short Circular

Rel. Volume / (%) 18.747

Abs. Volume / (%) 6.27992514

1 Material (ID 01) Solid...

Remove Save...

Short Circular

Rel. Volume / (%) 8.294

Abs. Volume / (%) 2.77834849

2 Material (ID 02) Solid...

Remove Save...

Short Circular

Rel. Volume / (%) 17.7374

Abs. Volume / (%) 5.94172637

3 Material (ID 03) Solid...

Remove Save...

Enter the Solid Volume Percentage of fibers in the structure as the Object Solid Volume Fraction in the Stopping Criterion panel, under the **Create Options** tab. You can find the **Statistics** information in the **Status and Modules** section on the left side of the GeoDict GUI.

Status and Modules

10% 27% 77%

85 15

GAD Objects : 984

Material IDs

00	85.00 % (6800289 Voxel)
01	15.00 % (1199711 Voxel)

Stopping Criterion

☐ Fixed Object Number

☒ Object Volume Percentage / (%) 15.00

☐ Grammage / (g/m²)

☐ Density / (g/cm³)

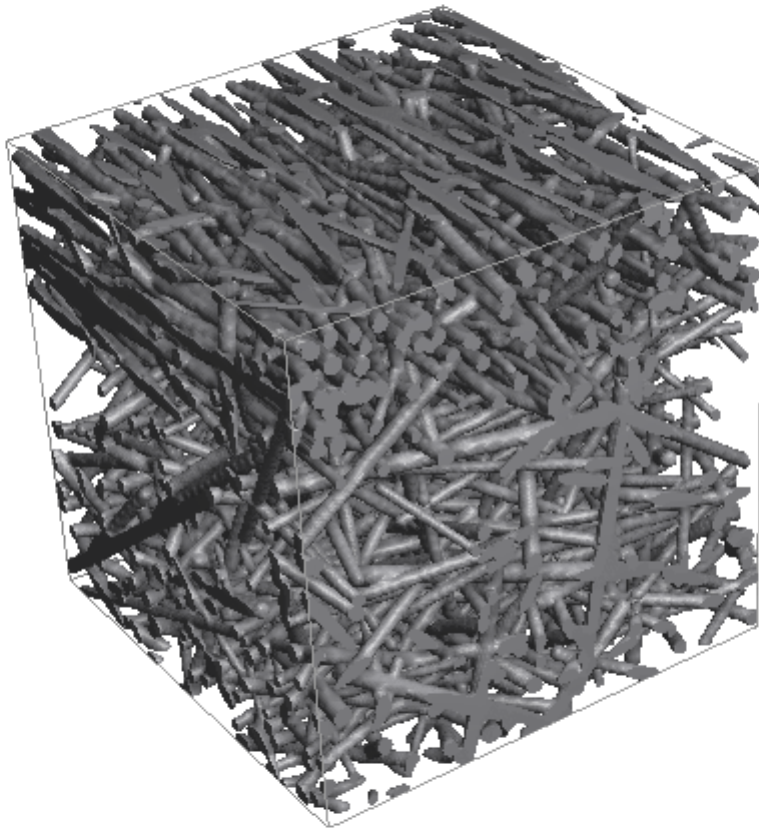
☐ Object Weight Percentage / (%)

Maximal Run Time / (h) 24

Remember to set the correct domain size (**NX, NY, NZ**) and **Voxel Length** in the Domain panel.

Click **OK** to close the **FiberGeo Create Options** dialog and click **Generate** in the **FiberGeo** section.

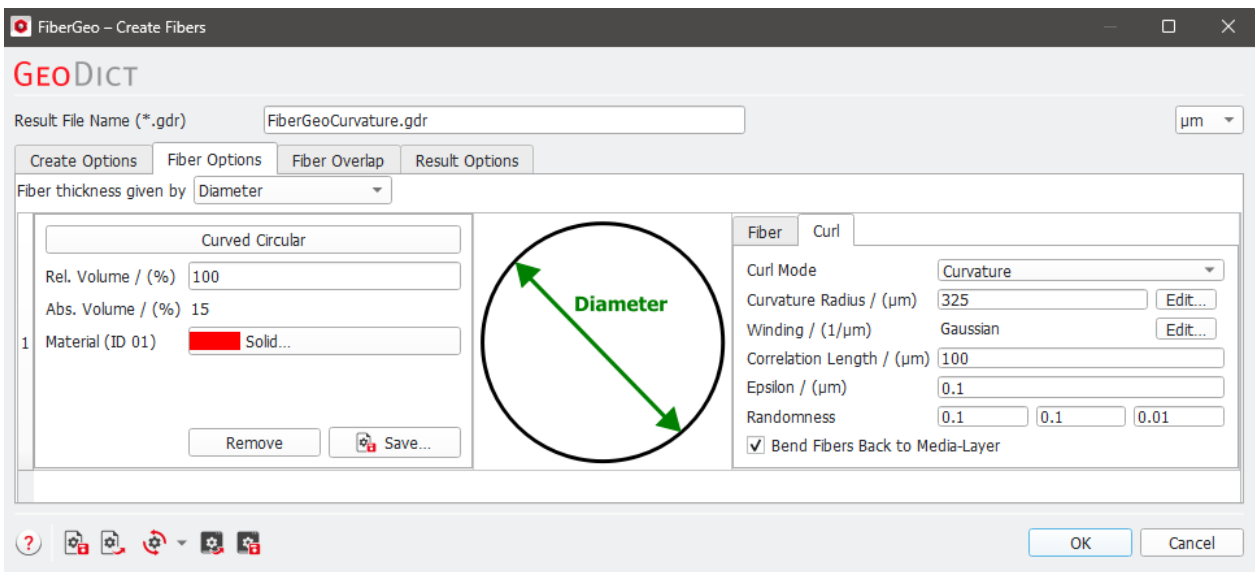
The reproduced fibrous material model is shown in the Visualization area, matching the values estimated by FiberFind for the 3D material model obtained from importing (μ)CT images.



1.8.3 Reproducing Curvature Of Fibrous Media

You can create fibrous structures with **curved fibers** in FiberGeo. The curvature definition for the fibers can be set up based on a **FiberFind** [identified curvature](#)³³ result.

For this, use a curved fiber type, like, e.g., Curved Circular. Here, you can choose the Curl Mode Curvature and define the Curvature Radius as well as other parameters. The Curvature Radius is the inverse of the curvature computed in FiberFind. For more details on **Curl Parameters**, see the FiberGeo user guide.



As an alternative to the options shown for creating a digital twin of a fibrous structure with FiberGeo, you can also use the GeoApp **Generate Nonwoven Twin** (under GeoApp - General - Structure Generation).

1.9 References

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