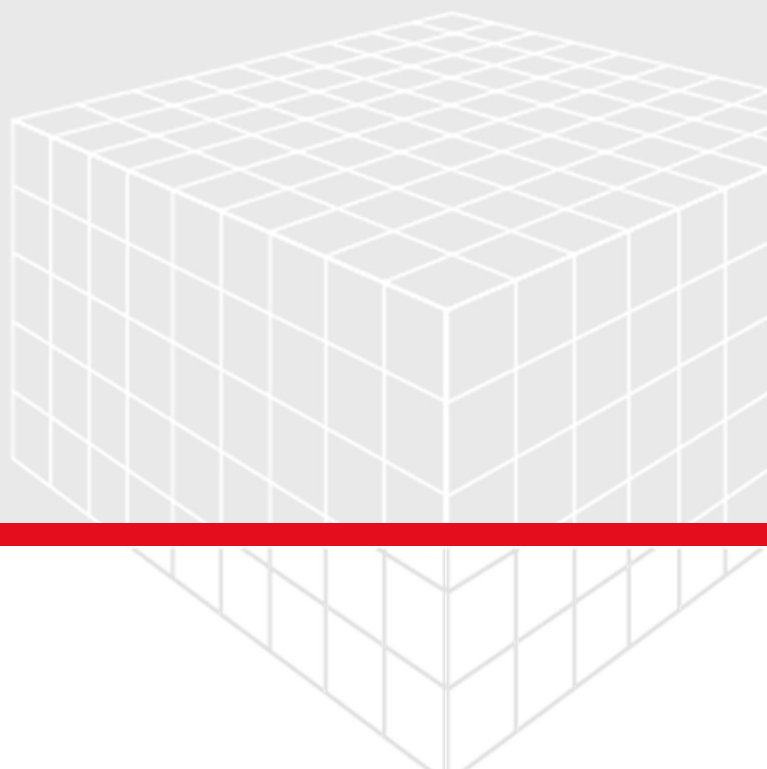


PaperGeo

User Guide

GEODICT Release 2026

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GEODICT

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PaperGeo

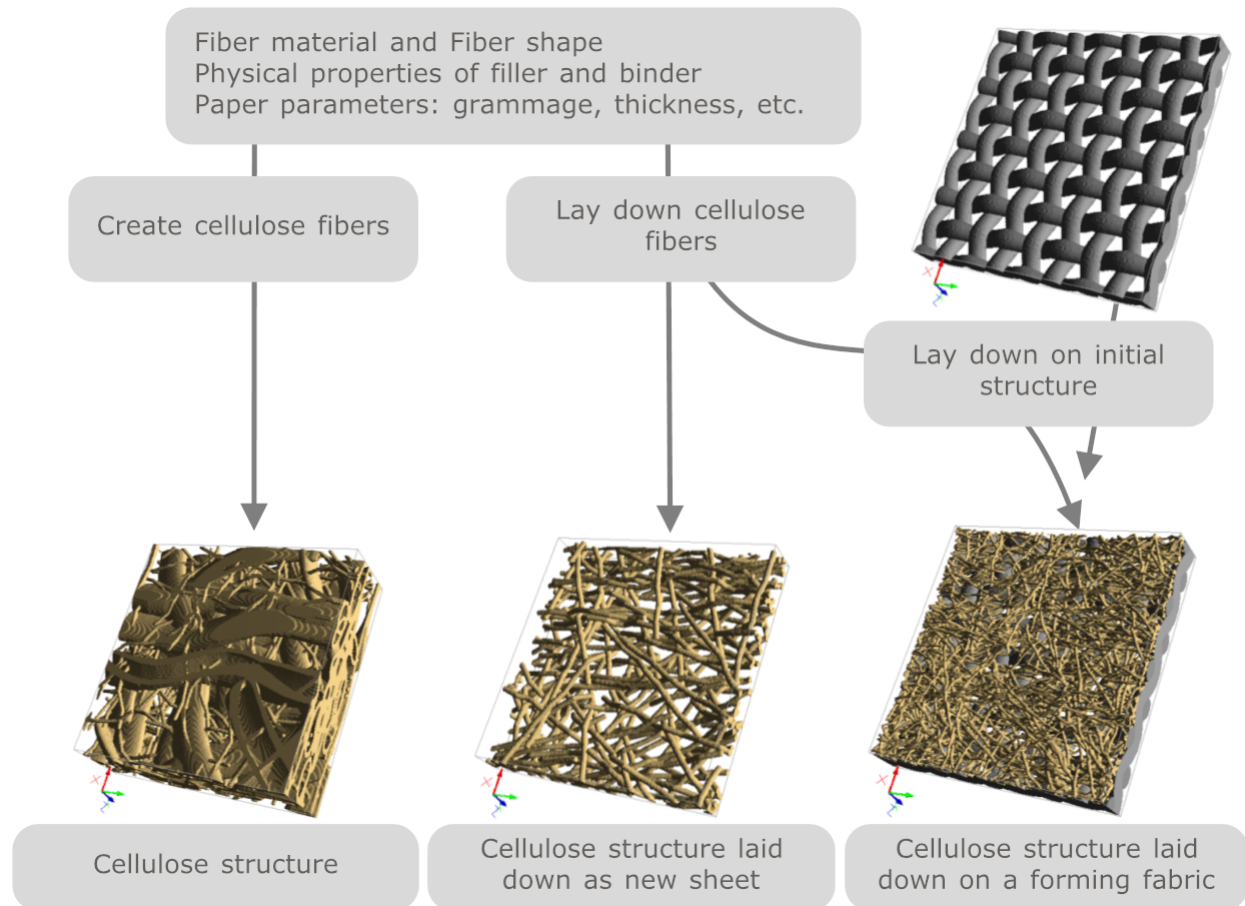
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1 PaperGeo

PaperGeo generates digital models of cellulose, elliptical, circular, and rectangular paper fibers, which model realistic organic paper structures.

The two available paper generation processes are to [Create Cellulose Fibers](#)^[5] and to [Lay-Down Cellulose Fibers](#)^[69] by themselves or on an existing structure.

PaperGeo also models the common practice of [adding binder](#)^[85] and [filler](#)^[101] used in the paper industry.



Paper structures modelled with PaperGeo may be the starting point to compute material properties of user-designed paper structures with other GeoDict modules for digital material analysis such as FilterDict, PoroDict, MatDict, ElastoDict, FlowDict, etc.

Learn to use PaperGeo:

- [Create Cellulose Fibers](#)^[5]
Forming paper structures of desired thickness and grammage.
- [Lay-Down Cellulose Fibers](#)^[69]
Forming a new paper structure e.g. by a lay-down process on a forming fabric.
- [Add Binder](#)^[85]
Adding material in the shape of a concave meniscus in locations where fibers in the structure model are close together. The addition of binder in paper structures can be modeled in this

Learn to use PaperGeo:

way.

- [Add Filler](#)¹⁰¹

Adding spherical particles to coat the paper structure, or to replace fibers, binder or other materials.



Join the conversation

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

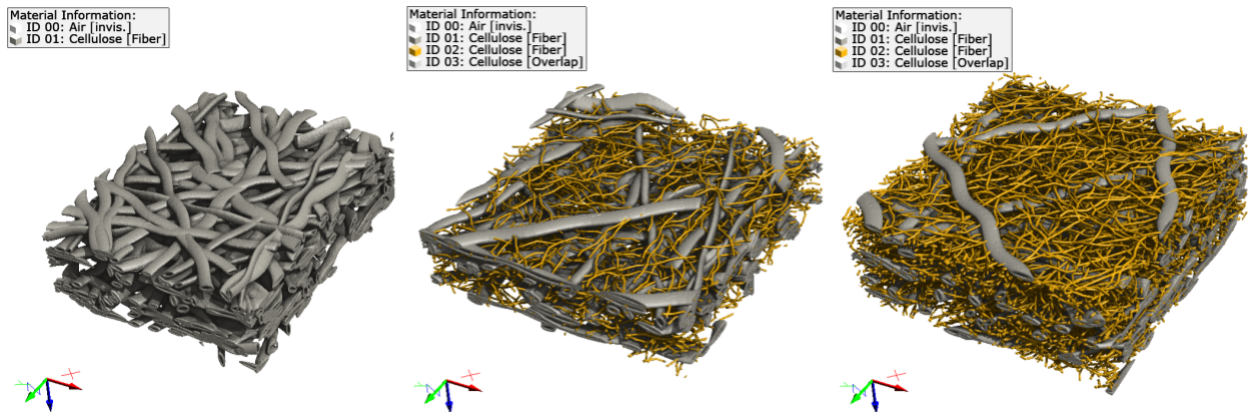
Find illustrative application examples on the [website](#).

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 Create Cellulose Fibers

With **Create Cellulose Fibers** you can form paper structures of desired thickness and grammage. Define diameters, orientations, curvature, and cross-section shapes. Set the size and resolution of the structure and the constituent materials. You can create the objects either in an empty domain or add them to already existing structures.



The Create Cellulose Fibers command:

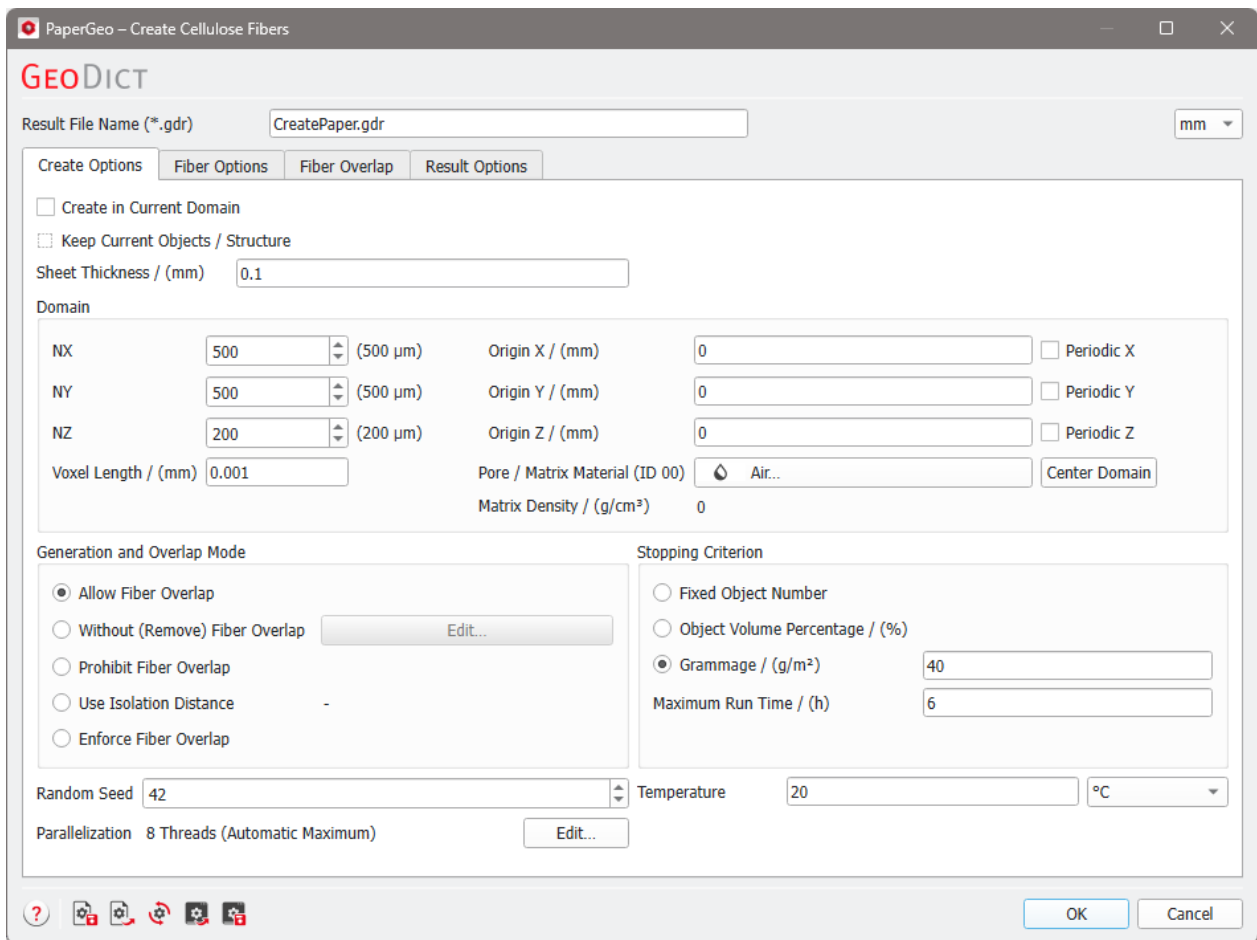
- [Options](#) ⁵
Set the parameters for your paper generation.
- [Results](#) ⁶⁵
Inspect the result file in the result viewer.

1.1.1 Options

At the top left of the dialog, the name for the file containing the generation results can be entered in the **Result File Name (*.gdr)** box. The default name can be kept, or a new name can be chosen, fitting the current project.

The result files are saved in the chosen project folder (**File** → **Choose Project Folder**, in the **Menu bar**). If a GeoDict result file (*.gdr) with the given name already exists in the project folder, a warning message is shown at the start of the creation process. You can either decide to rename the chosen file name to a new one, to cancel the generation process, to overwrite or to back up the old file. When nothing is selected, GeoDict uses the **Back-Up** option after a waiting time.

The available units (m, cm, mm, μ m, nm and Inch) are selectable from the pull-down menu at the top right of the dialog. When the units are changed, the entered values are adjusted automatically.



The options are organized into tabs:

- [Create Options](#)⁷
Determine the general properties of the resulting structure model, such as size, position, resolution, and solid volume percentage.
- [Fiber Options](#)²⁹
Define the geometrical properties of individual fiber types such as cross-section, length, and orientation. Up to eight different types can be used in one structure.
- [Fiber Overlap](#)⁶¹
Deal with how to define the Material ID in locations where objects in the structure overlap. The overlap locations may exhibit other properties than those of the original materials.
- [Result Options](#)⁶⁴
The Result Options determine if and how the resulting geometry is saved.



Opens the corresponding User Guide section.



Saves the settings to a GeoDict settings file (*.gps).



Loads the settings from a GeoDict settings file (*.gps) or a GeoDict result file (*.gdr).

-  Resets all parameter settings to the built-in default settings.
-  Resets all parameter settings to the saved start-up settings.
-  Saves the current parameter settings as start-up settings.

Each option is explained by a tooltip which appears when resting the mouse over the icon.

Create Options

The general properties of the paper structure are entered under the **Create Options** tab. These parameters are grouped into the panels **Domain**, **Generation and Overlap Mode**, **Stopping Criterion** and six single options. The three single options in the top control specific **Structure Options**. The other three at the bottom control **General Options**.

PaperGeo – Create Cellulose Fibers

GEODICT

Result File Name (*.gdr) mm

Create Options | Fiber Options | Fiber Overlap | Result Options

☐ Create in Current Domain

☐ Keep Current Objects / Structure

Sheet Thickness / (mm)

Domain

NX	500 (500 μ m)	Origin X / (mm)	0 ☐ Periodic X
NY	500 (500 μ m)	Origin Y / (mm)	0 ☐ Periodic Y
NZ	200 (200 μ m)	Origin Z / (mm)	0 ☐ Periodic Z
Voxel Length / (mm)	0.001	Pore / Matrix Material (ID 00)	Air... Center Domain
		Matrix Density / (g/cm ³)	0

Generation and Overlap Mode

☒ Allow Fiber Overlap

☐ Without (Remove) Fiber Overlap

☐ Prohibit Fiber Overlap

☐ Use Isolation Distance -

☐ Enforce Fiber Overlap

Stopping Criterion

☐ Fixed Object Number

☐ Object Volume Percentage / (%)

☒ Grammage / (g/m²)

Maximum Run Time / (h)

Random Seed

Temperature °C

Parallelization 8 Threads (Automatic Maximum)

The parameters are organized in the following groups:

- [Structure Options](#)⁸
Define the structure options Create in Current Domain, Keep Current Objects / Structure and Sheet Thickness.
- [Domain](#)¹⁰

The parameters are organized in the following groups:

Define the domain parameters, such as resolution, periodicity, and matrix material.

- [Generation and Overlap](#)¹⁷

Decide about allowing, removing, or prohibiting overlap.

- [Stopping Criterion](#)²³

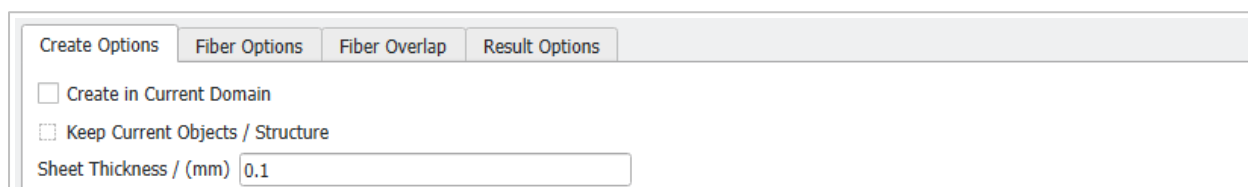
Define according to which criteria the fiber generation should be stopped.

- [General Options](#)²⁷

Define the temperature, the random seed, and the number of parallel processes.

Structure Options

Define the structure options **Create in Current Domain**, **Keep Current Objects / Structure** and **Sheet Thickness**.

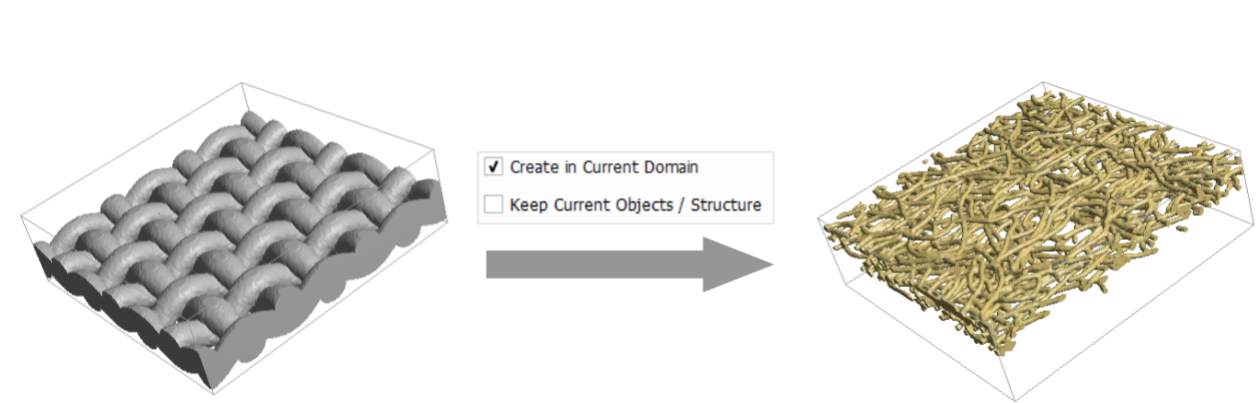


Create in Current Domain and Keep Current Objects / Structure

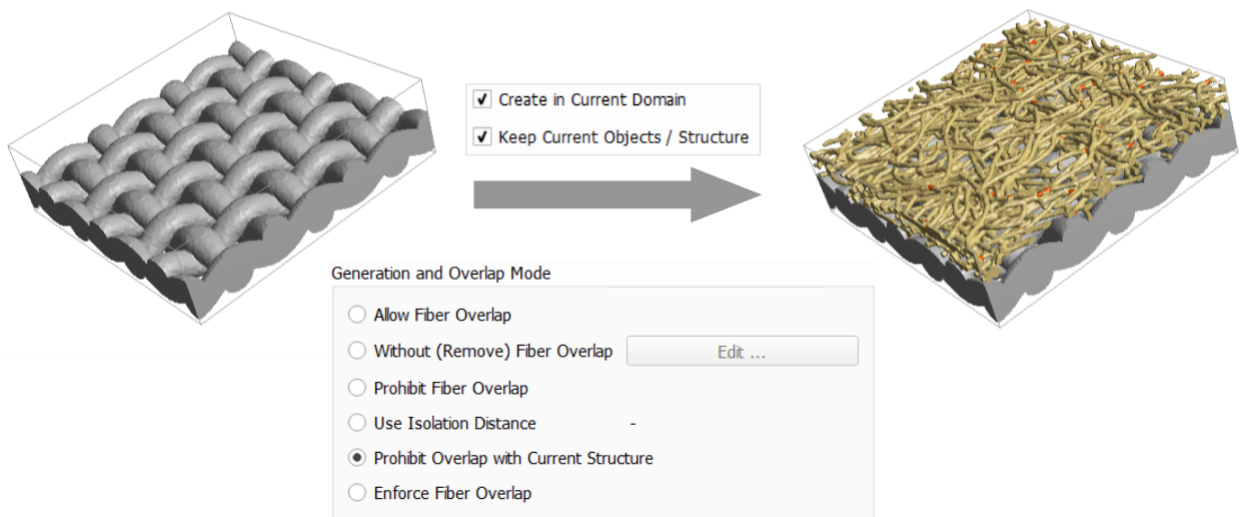
When checking **Create in Current Domain** the structure currently in memory, is considered during the generation of the paper structure. Additionally, when **Keep Current Objects / Structure** is checked, the structure in memory is kept and combined with the newly generated paper structure.

This feature is used in combination with checking **Prohibit Fiber Overlap** or **Prohibit Overlap with Current Structure** in the [Generation and Overlap Mode](#)¹⁷ panel. In this way, you can make the paper fibers cover and mold a structure in memory (for example a weave) and decide if the structure should be kept or not.

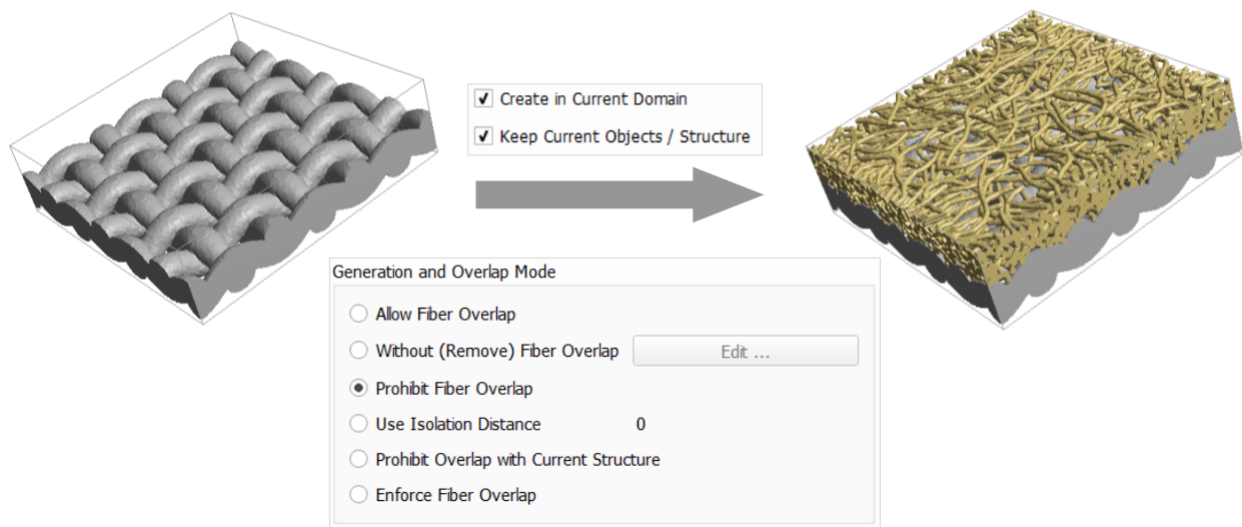
Once **Create in Current Domain** is checked, the parameters grouped under the **Domain** panel cannot be modified, including the voxel length, because they are taken from the structure already in memory.



Prohibit Overlap with Current Structure can be checked to avoid the paper fibers entering the weave, but the fibers can overlap each other. The regions of fiber overlap are assigned to the next Material ID (here shown in orange).



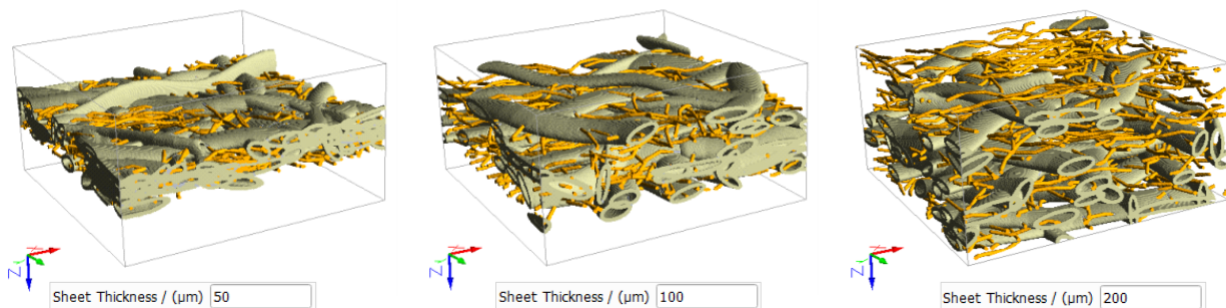
The more restrictive **Prohibit Fiber Overlap** or **Remove Overlap** should be checked if the fibers should not overlap each other nor the weave.



Sheet Thickness

The **Sheet Thickness** value defines the thickness of the paper sheet, i.e., the height of the area (Z-direction) in which the fibers are placed. If the value is set higher than the height of the domain, it is discarded, and the fibers are placed inside the domain.

In the following examples, the sheet thickness is increased from 50 μm to 100 μm and then to 200 μm . The size of the domain remains the same (height in Z-direction: 200 μm) but the paper structure appears more voluminous.



Domain

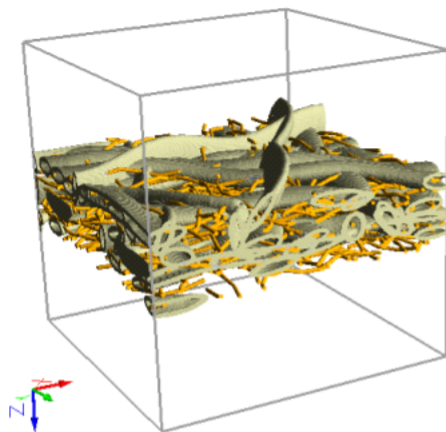
The **Domain** panel contains the parameters defining the structure size (**NX**, **NY**, and **NZ**) in combination with the resolution (**Voxel Length**), as well as the **Origin** parameters, the **Periodicity** check boxes, the **Center Domain** button, and the **Pore / Matrix Material** and **Matrix Density** selection.

Domain					
NX	500	(500 μm)	Origin X / (mm)	0	☐ Periodic X
NY	500	(500 μm)	Origin Y / (mm)	0	☐ Periodic Y
NZ	200	(200 μm)	Origin Z / (mm)	0	☐ Periodic Z
Voxel Length / (mm)	0.001		Pore / Matrix Material (ID 00)	Air...	Center Domain
			Matrix Density / (g/cm ³)	0	

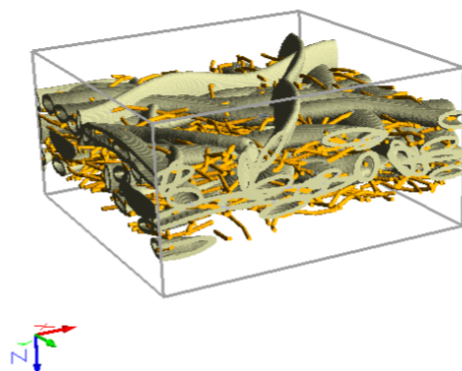
✓ NX, NY, NZ, and Voxel Length

The internal representation of a structure in GeoDict consists of rectangular 3D arrays of cubes, hereafter called volume elements or **voxels**.

NX, **NY**, and **NZ** are the number (N) of voxels in X, Y and Z directions. The **Voxel Length** is the size of one voxel in the chosen units. Varying the values for **NX**, **NY**, and **NZ** has the effect of changing the size of the domain in the given direction.



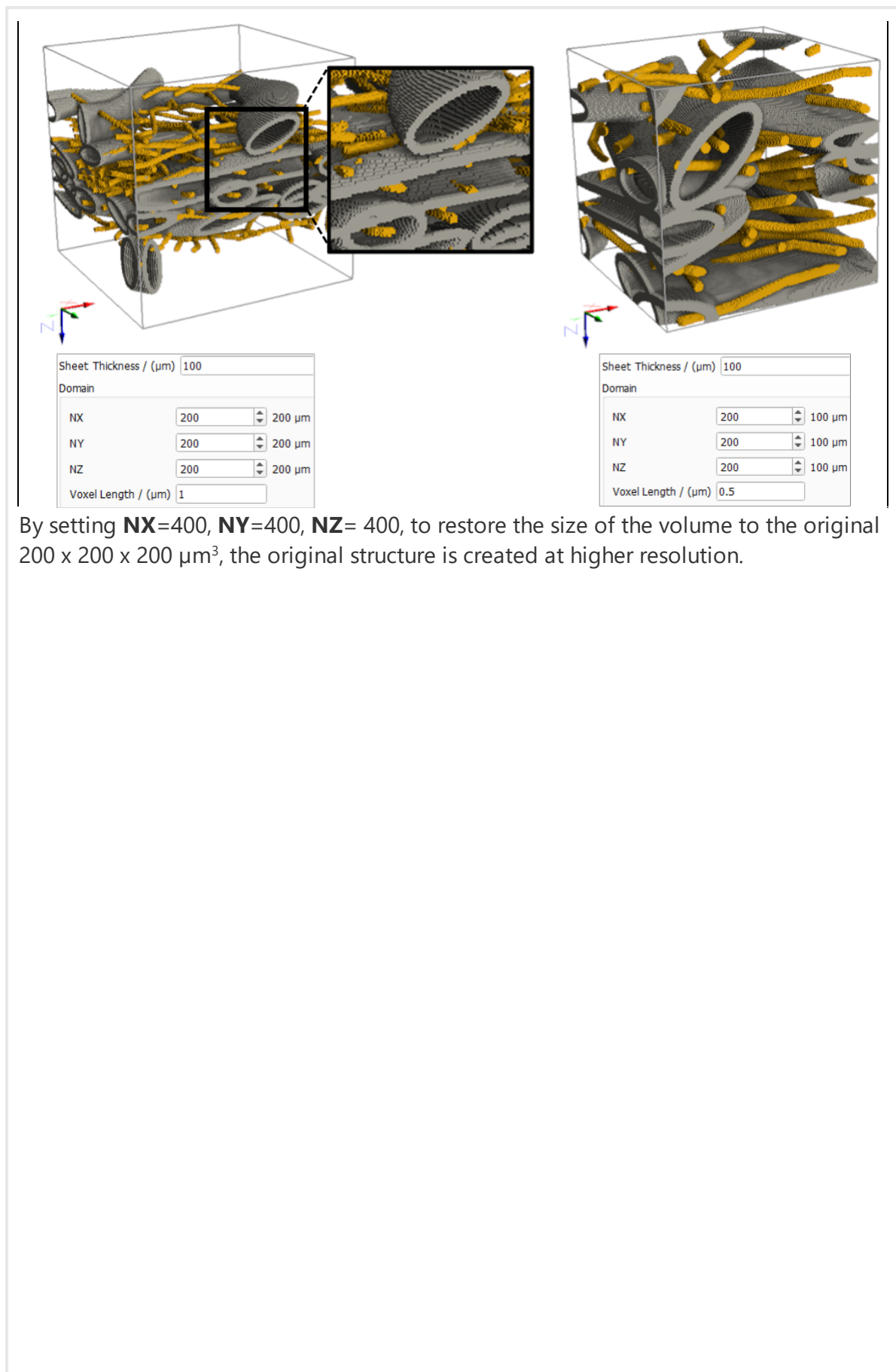
Sheet Thickness / (μm)	100
Domain	
NX	400 (400 μm)
NY	400 (400 μm)
NZ	400 (400 μm)
Voxel Length / (μm)	1

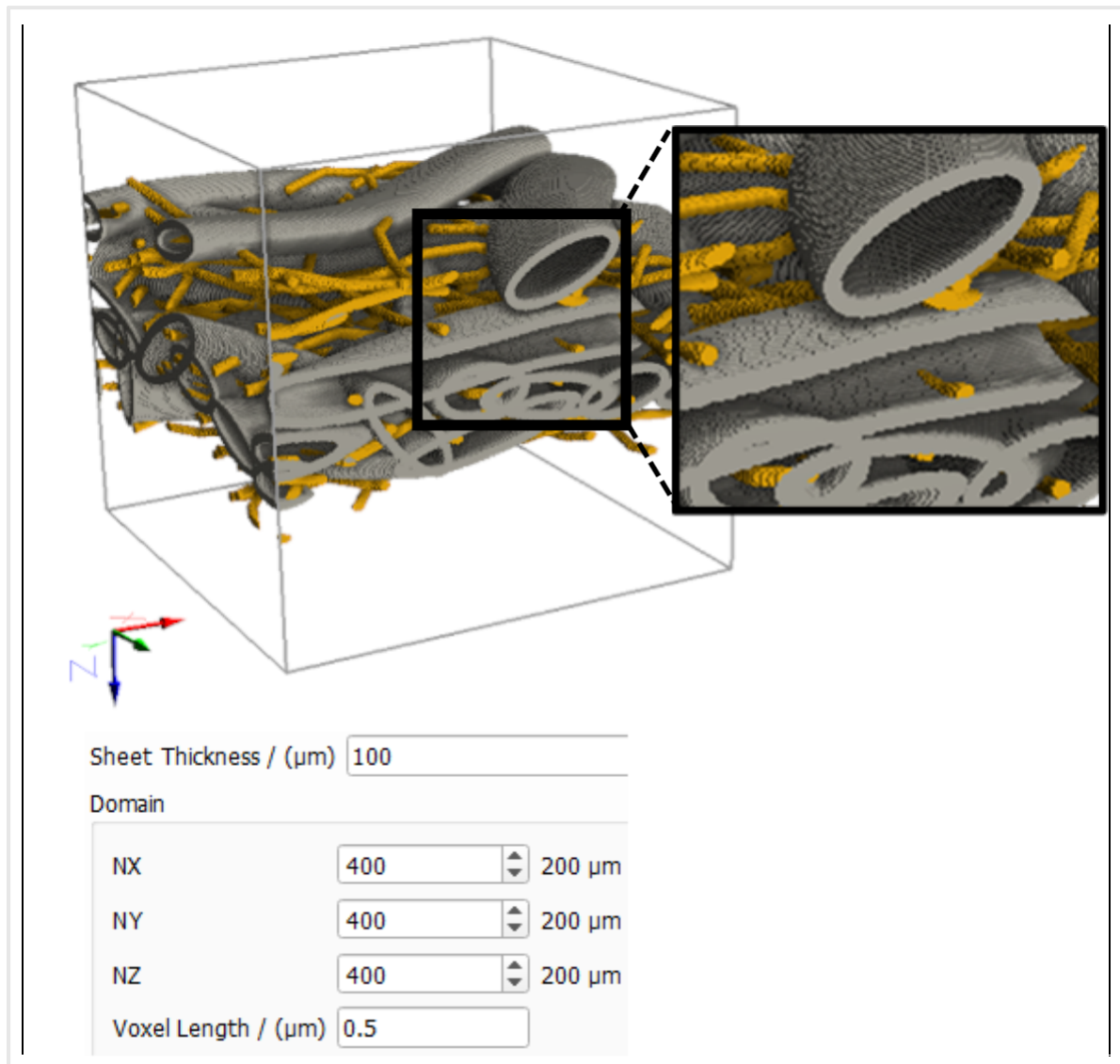


Sheet Thickness / (μm)	100
Domain	
NX	400 (400 μm)
NY	400 (400 μm)
NZ	200 (200 μm)
Voxel Length / (μm)	1

Low values for the voxel length in combination with high values for **NX**, **NY** and **NZ** result in a higher resolution, but also in a higher computational time. After setting the values of **NX**, **NY**, and **NZ**, and **Voxel Length**, the physical structure size is automatically displayed in the chosen units (here μm).

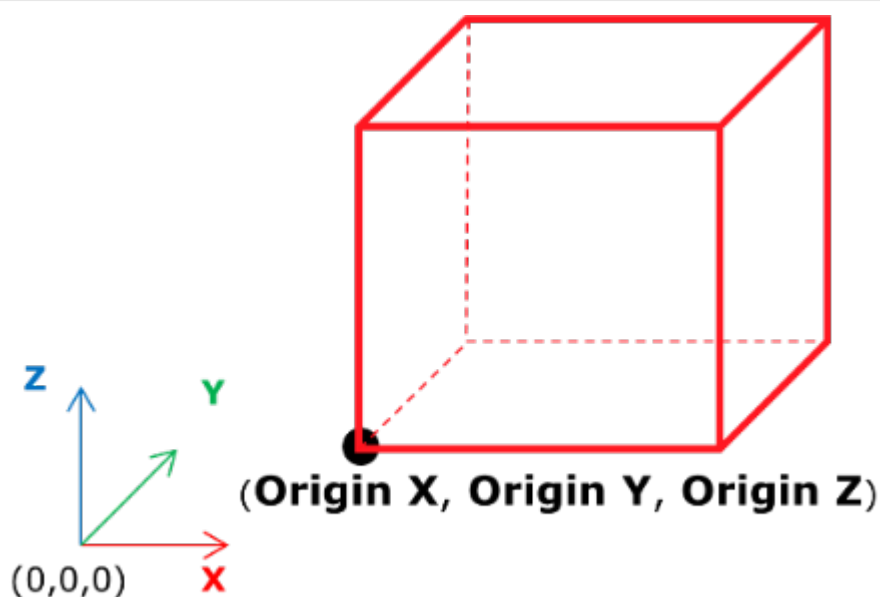
Observe in the figures below how starting with **NX**=200, **NY**=200, **NZ**= 200 (200 x 200 x 200 μm^3 , at voxel length 1 μm), and decreasing the **Voxel Length** from 1 μm to 0.5 μm , has the effect of refining the structure by increasing the resolution but decreases the size of the volume to 100 x 100 x 100 μm^3 .



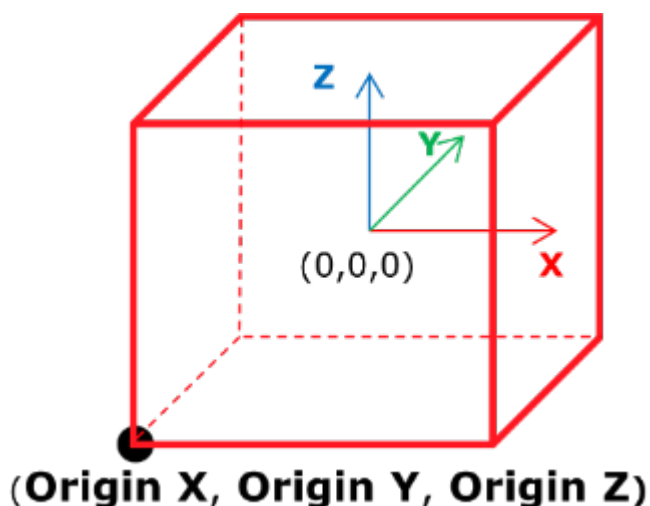


✓ Origin X, Origin Y, Origin Z, and Center Domain

The **Origin X**, **Origin Y**, and **Origin Z** parameters, together with the **Center Domain** button, determine the placement of the structure in the physical space. Zero values for Origin X, Origin Y, and Origin Z mean that the point with (0, 0, 0) coordinates is located at the lower left corner of the structure.



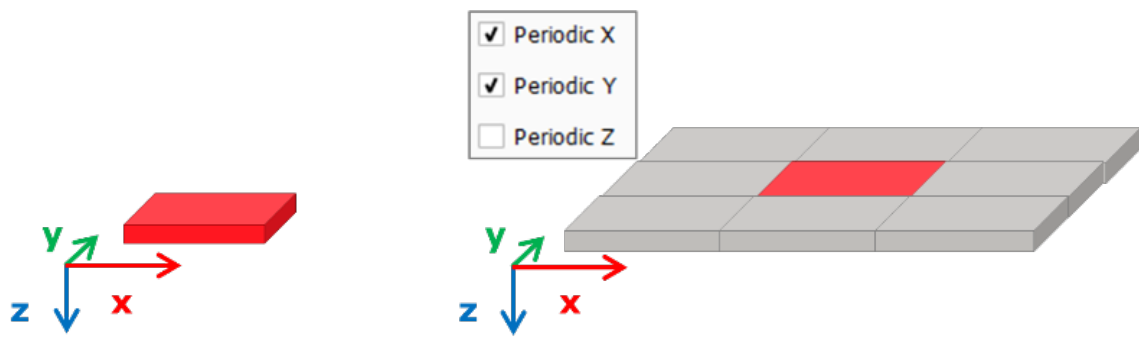
When clicking the **Center Domain** button, the (0, 0, 0)-point is set to the center of the structure as shown below.



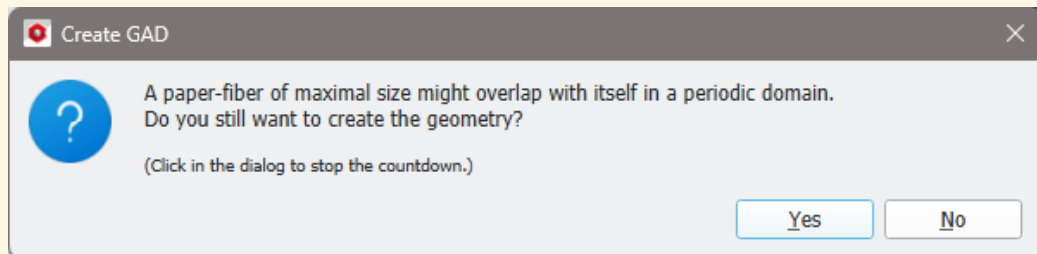
☒ Periodicity

The periodicity of the paper structure is determined by checking or un-checking the **Periodic X**, **Periodic Y**, and **Periodic Z** boxes in one or several directions.

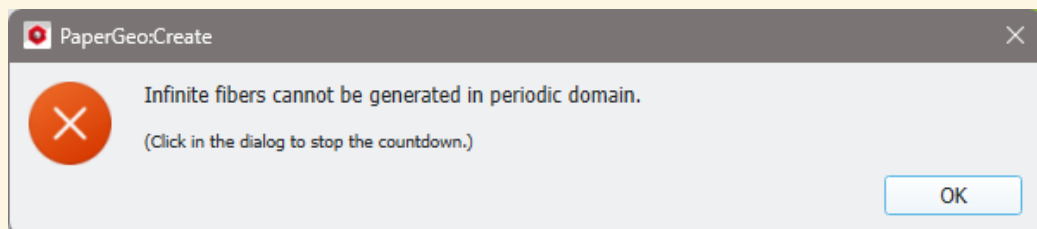
Periodicity has the effect that the fibers ending on one side of the domain reappear in the opposite side, so that when several domains with periodic fibers are combined, the structure emerges as a repetitive complex.



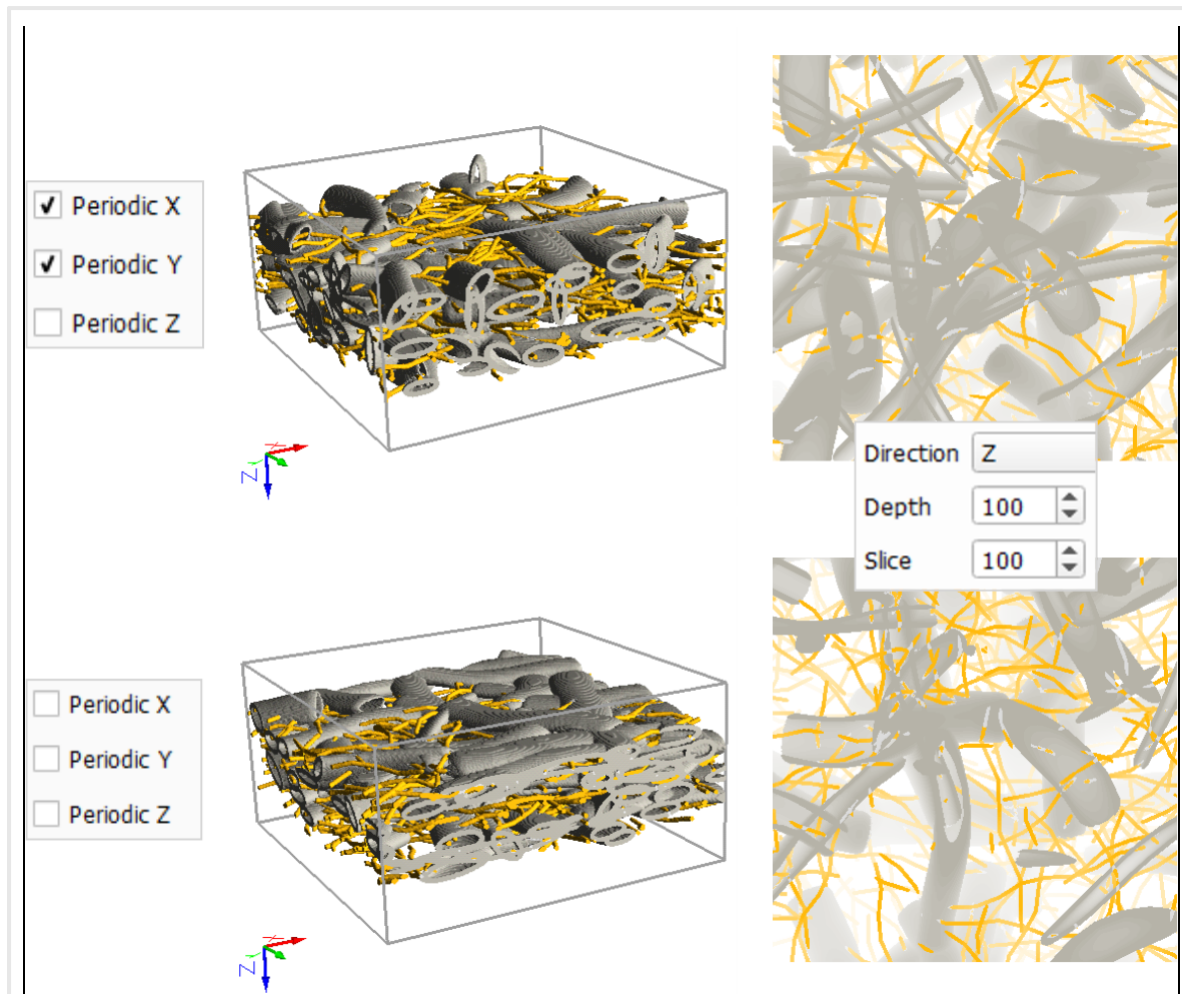
Know how! A warning message is displayed when trying to generate a periodic structure with **fibers that are longer than the domain size**, since they might overlap themselves.



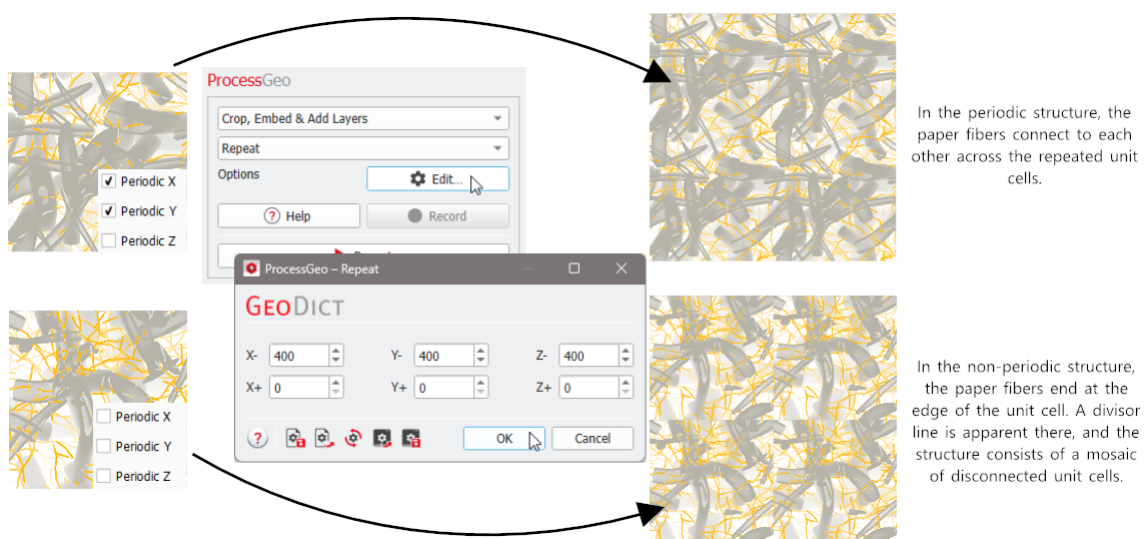
An error message appears when trying to generate a periodic structure with **Infinite fibers**. To avoid this error, go to **Fiber Options** and remove the **Infinite fibers** or, alternatively, do not choose to generate with periodicity.



Observe the effect that checking or leaving unchecked the **Periodic X** and **Periodic Y** boxes has on the periodicity of a generated fibrous structure. View the paper structure in 3D Rendering and in 2D Cross-Section.



The effect is readily observed when repeating the sample structure with ProcessGeo (**Model** → **ProcessGeo** – **Crop, Embed & Add Layers** → **Repeat: X-, Y-, Z- 400 voxels**) and viewing it again in 2D View from the Z-direction.



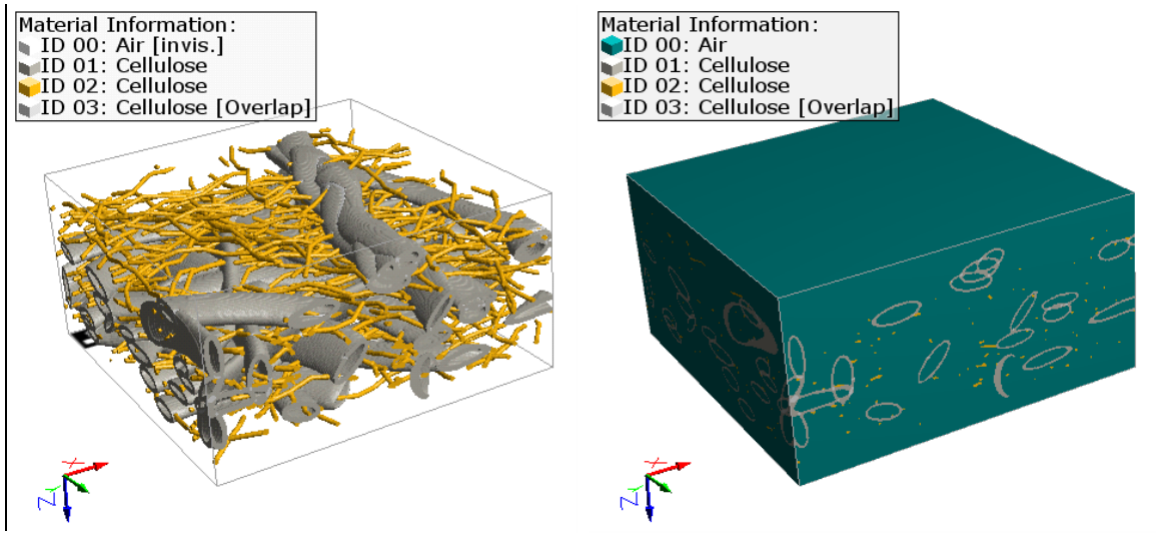
✓ Pore / Matrix Material and Matrix Density

Choose the material of the matrix around the fibers from the material selector.

When the default pore material (Air) is chosen, the fibers are embedded in empty pore space. When the chosen **Pore / Matrix Material** is a solid, the density of this material can be entered or is directly taken from the GeoDict Material Database.

Pore / Matrix Material (ID 00)	 Air...	Pore / Matrix Material (ID 00)	Solid...
Matrix Density / (g/cm ³)	0	Matrix Density / (g/cm ³)	0.27

The color representing the pore/matrix material can be made visible (default is invisible rendering) and changed through the **Color & Visibility** tab in the GUI side bar on the right-hand side of GeoDict.



Generation and Overlap

The options in the **Generation and Overlap Mode** panel control the relative position among objects or of the structure currently in memory. It is possible to choose **Allow Fiber Overlap**, **Without (Remove) Fiber Overlap**, **Prohibit Fiber Overlap**, **Use Isolation Distance**, or **Enforce Fiber Overlap**.

If checking **Create in Current Domain**, additionally **Prohibit Overlap with Current Structure** appears. When choosing this option, the objects in the newly generated structure can intersect with each other but not with those of the already existing structure.

Generation and Overlap Mode	
☒ Allow Fiber Overlap	
☐ Without (Remove) Fiber Overlap	Edit...
☐ Prohibit Fiber Overlap	
☐ Use Isolation Distance	-
☐ Enforce Fiber Overlap	

Generation and Overlap Mode	
☒ Allow Fiber Overlap	
☐ Without (Remove) Fiber Overlap	Edit...
☐ Prohibit Fiber Overlap	
☐ Use Isolation Distance	-
☐ Prohibit Overlap with Current Structure	
☐ Enforce Fiber Overlap	



Know how! The algorithm under **Allow Fiber Overlap** is fast, especially for big structures and, in most cases, leads to excellent results.

If you choose **Remove Fiber Overlap**, the generation time may be longer when generating structures with high solid volume percentages. The objects are first positioned in the structure allowing overlap. Afterwards they are moved to remove overlap as good as possible.

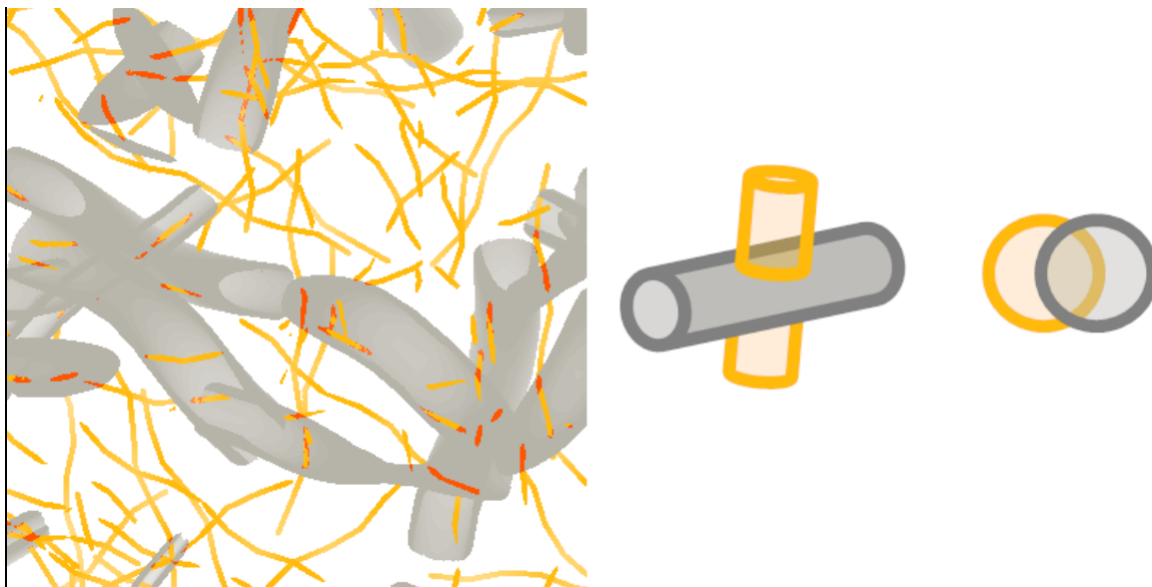
Prohibit Fiber Overlap or **Prohibit Overlap with Current Structure** directly position the objects one after the other without overlap. This is fast for low densities, but may be very slow or even unfeasible when generating dense geometries since the positioning of new non overlapping objects might be geometrically impossible.

For the same reasons, with **Use Isolation Distance**, the generation time may be long, or the generation might be impossible depending on the chosen value for the isolation distance and the selected value for stopping criterion. Then, use the isolation distance option in the Remove Fiber Overlap dialog.

Generally, structures with overlapping objects can be used for processes in the pore space, as filtration and flow simulation. For simulations of mechanical properties, structures without overlap should be generated.

✓ Allow Fiber Overlap

Fibers may overlap when **Allow Fiber Overlap** is selected. The overlap is shown here in dark orange.



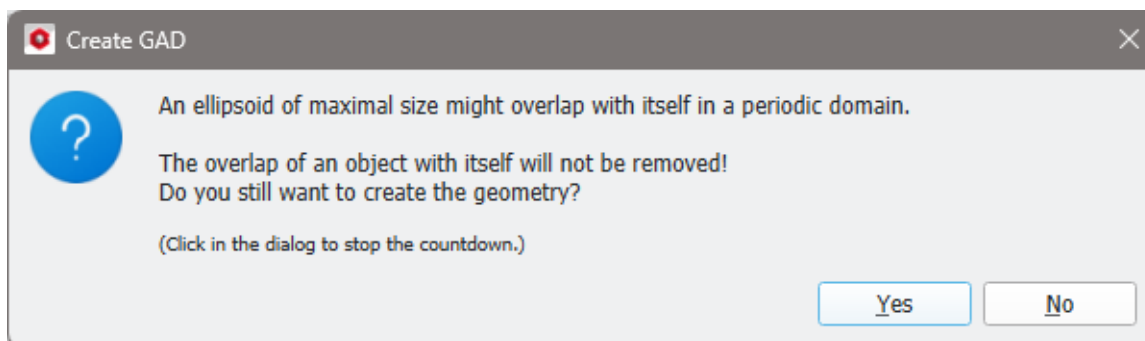
✗ Without (Remove) Fiber Overlap

Checking **Without (Remove) Fiber Overlap** eliminates existing overlaps after the generation step.

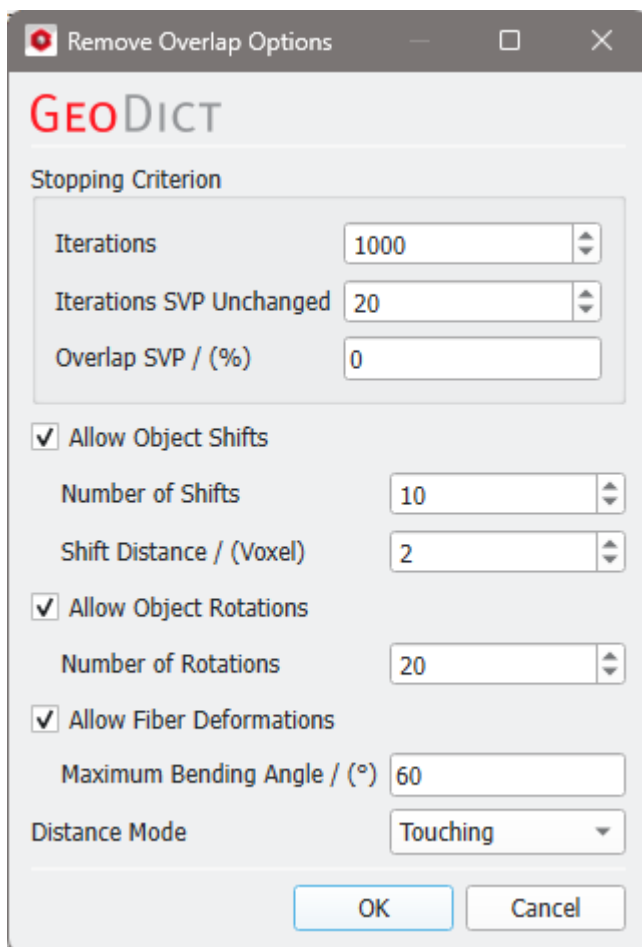


Note! The statistical properties might change slightly after removing overlap.

Overlaps can be removed from periodic structure models with objects smaller than the domain size or non-periodic structure models with arbitrary object sizes. In a periodic domain, objects which are longer than the domain might overlap with themselves. This type of overlap cannot be removed. In this case, a message appears:



The way in which the overlap removal occurs can be controlled through the **Remove Overlap Options** accessible via the **Edit...** button.

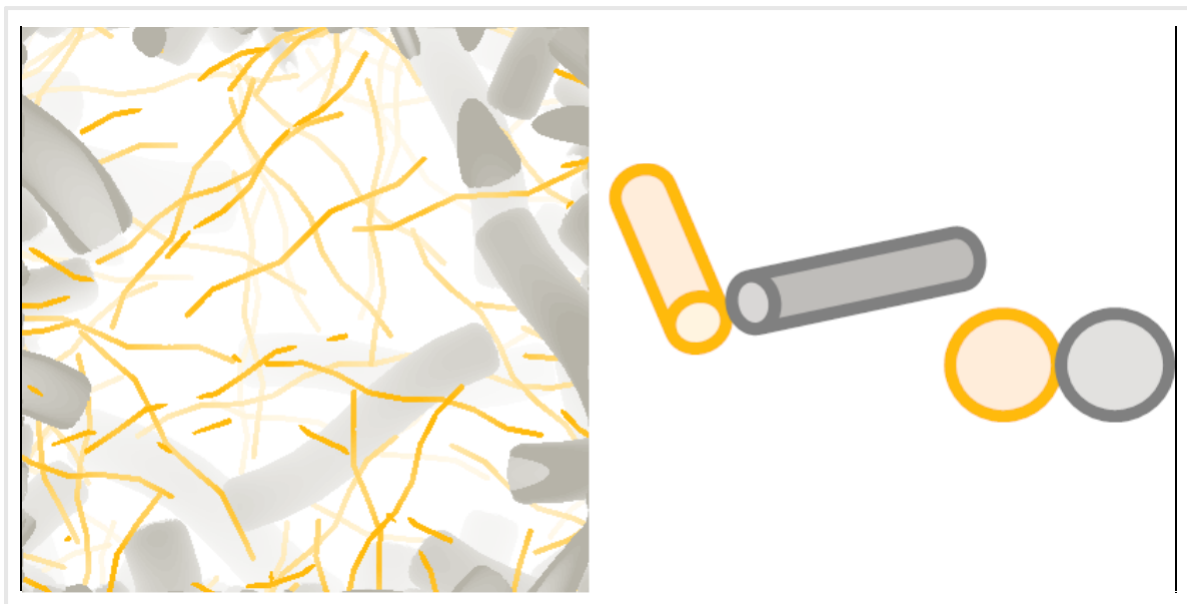


In the **Remove Overlap Options** dialog, the following parameters can be set:

- **Iterations:** Defines after how many iterations the removal stops.
- **Iterations SVP Unchanged:** The removal stops if the SVP (Solid Volume Percentage) remained unchanged during this number of iterations.
- **Overlap SVP / (%):** Defines the final allowed Overlap SVP.
- **Allow Object Shifts:** Check if shifting the objects should be an allowed operation for overlap removal. Define the **Number of Shifts** per iteration and the maximal **Shift Distance** in voxel per iteration.
- **Allow Object Rotations:** Check if rotating the objects should be an allowed operation for removal. Define the maximal **Number of Rotations** allowed per iteration. Objects will be rotated in all directions, where the maximal rotation angle per iteration is one degree.
- **Allow Fiber Deformations:** Check if bending fibers should be an allowed operation for overlap removal. Define the **Maximum Bending Angle** allowed between two segments. Each fiber consists of several segments. The center points of the segment connections are shifted in all directions, while the other shape parameters, as, e.g., fiber length and segment length are kept constant. The maximal point shift distance is the same as for the object shift. This option is only applied to fibers, as other objects do not consist of segments.
- **Distance Mode:** The pull-down menu offers four options:
 - The objects can be **Touching** (distance zero).
 - Enter a maximal **Defined Overlap** allowed for the objects.
 - Enter a minimal **Defined Isolation** distance for the objects.
 - **Avoid Contacts** means a defined isolation of one voxel volume diagonal.

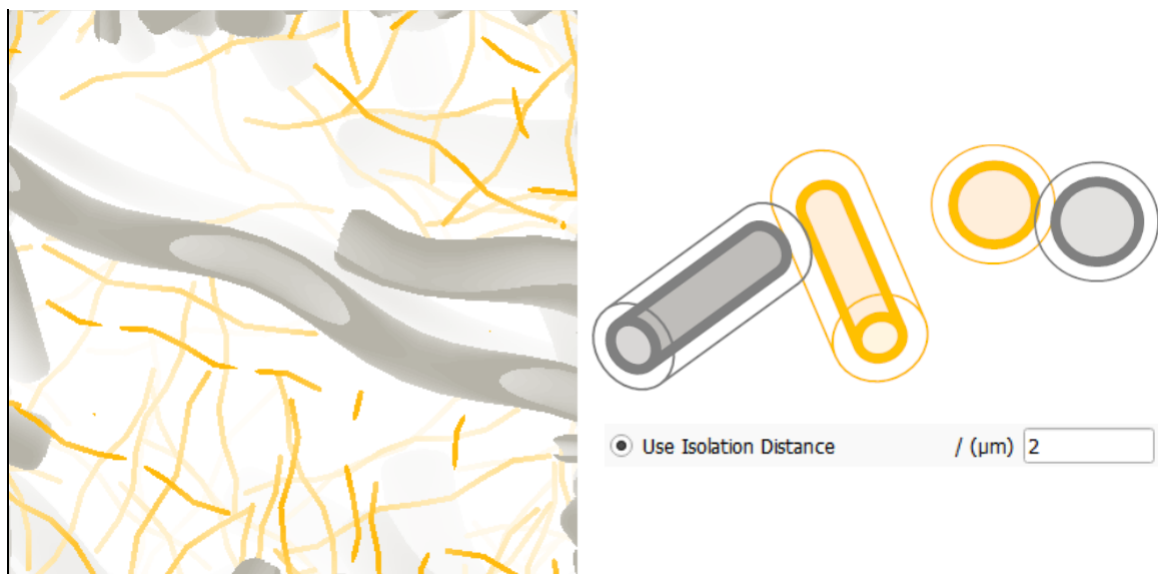
Prohibit Fiber Overlap

Fibers may touch but not overlap when **Prohibit Fiber Overlap** is selected.



✓ Use Isolation Distance

By selecting **Use Isolation Distance**, and inserting a positive value, the gaps between fibers have at least this preset distance.



Negative values for the isolation distance are useful to model paper structures with synthetic fibers that melt together during the lay down, or natural fibers that deform at touching points during the generation of the paper sheet. Then, the distance between the centers of the fibers is less than the sum of the two radii.

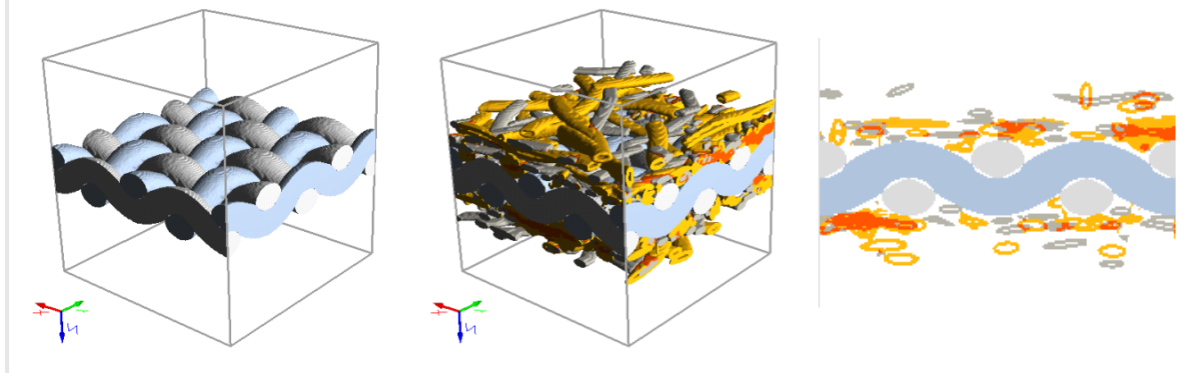
When the option **Use Isolation Distance** is set to negative values (e.g., $-10\ \mu\text{m}$), the effect is that the fibers may overlap with maximally $10\ \mu\text{m}$ (the negative isolation distance). Here, the effect is that some fibers penetrate other fibers and pass through them. The overlaps between fibers are assigned to a new Material ID and shown in a different color, which here is dark orange.



✓ Prohibit Overlap with Current Structure

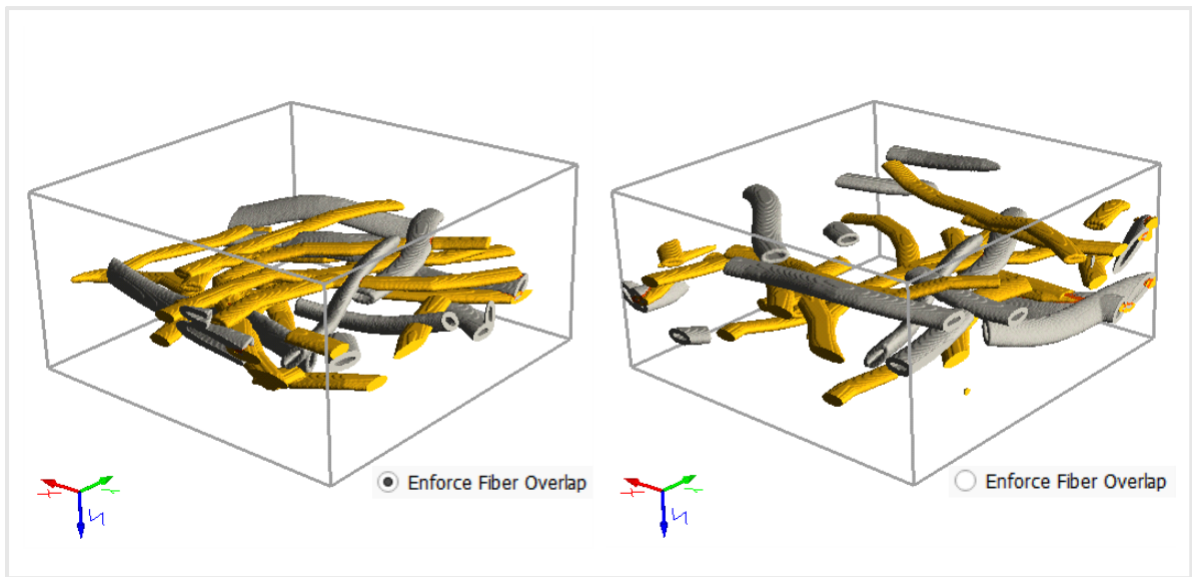
When choosing **Prohibit Overlap with Current Structure** (after checking [Create in Current Domain](#) ⁸), the fibers in the newly generated paper structure can intersect with each other but not with those of the already existing structure.

Observe this effect in a structure made of a woven screen over which a paper structure is generated. Whereas the paper fibers overlap with each other (in dark orange), they do not overlap with the pre-existing woven screen.



✓ Enforce Fiber Overlap

By checking **Enforce Fiber Overlap**, the structure's fibers are required to join each other, forming a large connected component. This effect is obvious when the **solid volume percentage (SVP)** of the structure is low (here 10%), i.e., the fibers do not already form a connected component.



Stopping Criterion

The parameters in the **Stopping Criterion** panel control when the generation process is stopped, and the material is finished.

Stopping Criterion

☒ Fixed Object Number

☐ Object Volume Percentage / (%)

☐ Grammage / (g/m²)

Maximum Run Time / (h)

The available parameters are [Fixed Object Number](#)^[24], [Object Solid Volume Percentage](#)^[24], or [Grammage \(g/m²\)](#)^[25].

Additionally, when the [Maximum Run Time / \(h\)](#)^[26] has passed, the process is stopped even when the desired stopping criterion is not achieved.

If checking **Create in Current** and [Keep Current Objects / Structure](#)^[8] only the criteria [Fixed Object Number](#)^[24], [Add Object Solid Volume Percentage](#)^[24] and [Maximum Run Time](#)^[26] are available.

Stopping Criterion

☒ Fixed Object Number

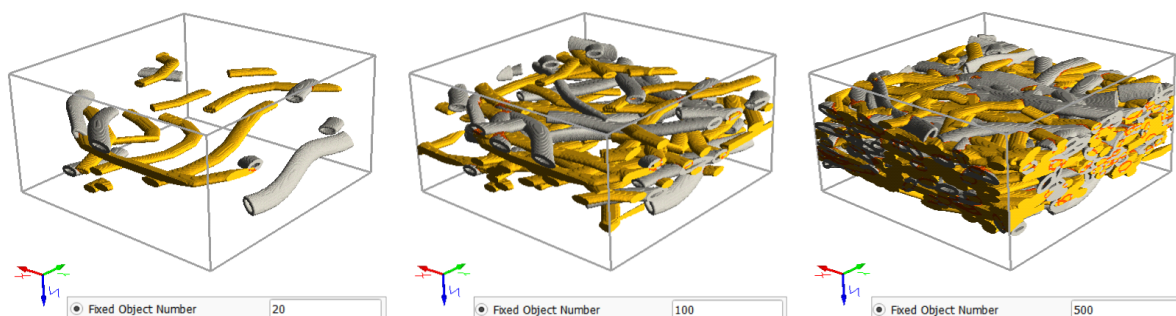
☐ Add Object Solid Volume Percentage / (%)

Maximum Run Time / (h)

✓ Fixed Object Number

When **Fixed Object Number** is chosen as stopping criterion, PaperGeo places the given number of fibers in the structure and then the generation stops.

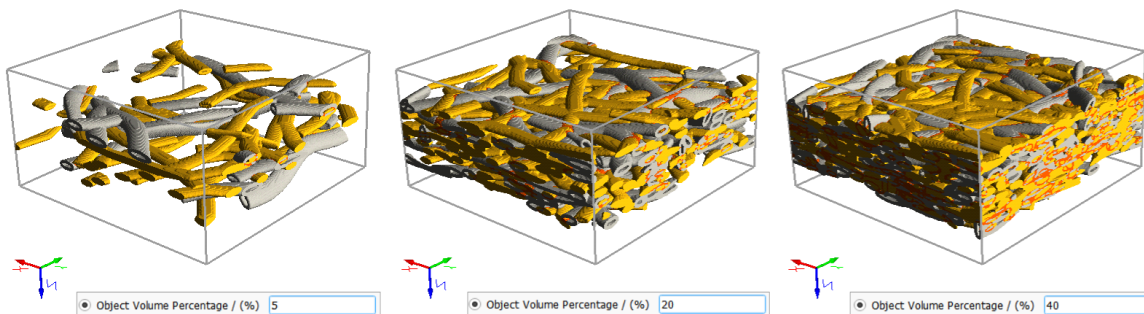
Observe the effect of setting a fixed number of objects (20, 100, or 500) as stopping criterion, for the generation of a paper structure with two fiber types. All other parameters are left untouched, including the default **Allow Fiber Overlap**. Note how the overlapping of fibers, shown in dark orange, increases with the number of objects present in the structure.



✓ (Add) Object Solid Volume Percentage

The **Object Solid Volume Percentage** (SVP) determines the fraction of the total volume that the paper structure should have. Accepted values range from 0% to 100%. For example, a structure with an **Object Solid Volume Percentage** of 40% consists of 40% fibers and 60% void space. Porosity is defined as $(1 - \text{SVP}/100)$.

Observe the difference in a structure when varying the solid volume percentage from 5% to 20% and finally to 40%, while all other parameters are left unchanged. Note that the **Sheet Thickness** has not changed, so that the increase in SVP has the effect of producing a denser cellulose sheet.

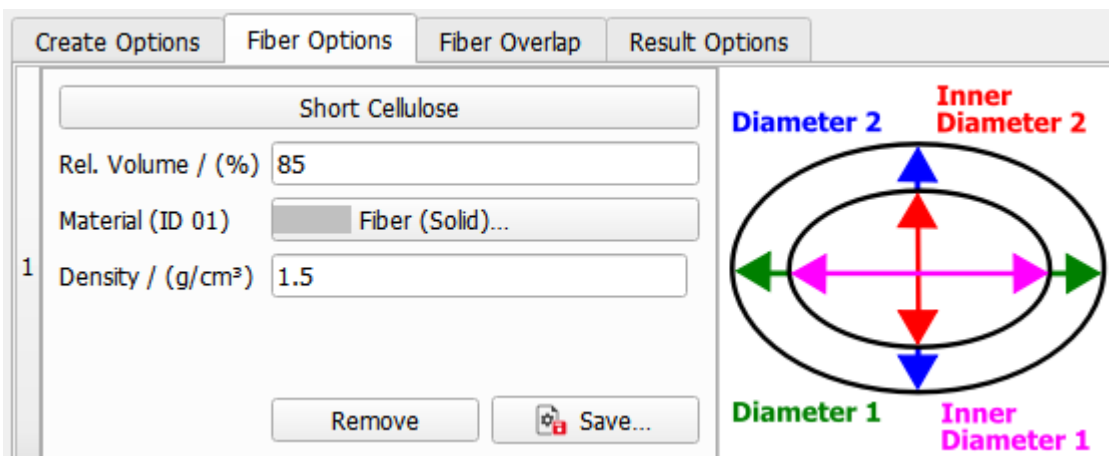


If **Create in Current** and [Keep Current Objects / Structure](#)⁸ are selected, the parameter changes to **Add Object Solid Volume Percentage**. Only the added solid volume percentage counts, i.e., only the fibers not overlapping with the current structure are considered for the stopping criterion. Therefore, it is important to prevent overlap, for example by checking [Prohibit Overlap with Current Structure](#)¹⁷.

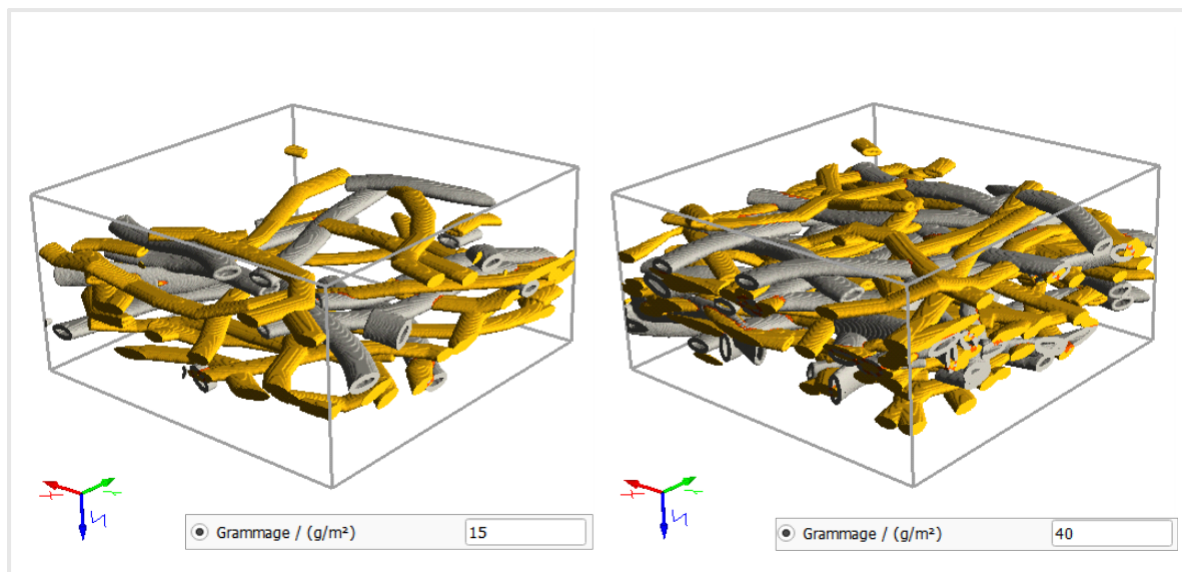
✓ Grammage

The **Grammage / (g/m²)** determines the weight of the resulting paper/cellulose structure.

When **Grammage** is checked as stopping criterion (under the **Create Options** tab), the **Density / (g/cm³)** of the fiber material(s) can be seen in the materials panels under the **Fiber Options** tab or must be entered if **Manual** instead of a **Database Material** (such as cellulose) is chosen.



Observe the effect of increasing the **Grammage** from 15 to 40 g/m², whereas all other parameters are left unchanged.



✓ Maximum Run Time

The **Maximum Run Time (h)** becomes important when generating complex structures with elevated solid volume fraction. When **Prohibit Fiber Overlap** has been checked, the required number of objects in the structure may become unattainable. In that case, the structure generation is stopped after the time entered in **Maximum Run Time** has passed and the achieved structure is considered as the result. The analysis of the GDR result file shows any disparity between the achieved result values and the desired ones.

✓ How to know if the stopping criterion is achieved?

The relationship of the variables **Fixed Object Number**, **Object Solid Volume Percentage**, **Grammage** and **Weight Percentage** can be observed in the Result Viewer of the result file, under the **Results - Report** subtab.

In this example, a **Count** (Fixed Object Number) of 52 corresponds to a **Volume** (Object Volume Percentage) of 10.35%, a **Grammage** of 50.46 g/m² and a **Density** of 0.2523 g/cm³.

Input Map	Log Map	Post Map	Results	Data Visualization	Metadata
Report	Plots	Map			
Absolute object distribution:					
	Count	Volume / (%)	Grammage / (g/m ²)	Density / (g/cm ³)	Weight / (%)
Total	realized: 52 target: --- error: ---	realized: 10.35 target: --- error: ---	realized: 50.46 target: --- error: ---	realized: 0.2523 target: 0.2500 error: 0.0023	realized: 0.00 target: --- error: ---
Object type 1	realized: 32 target: --- error: ---	realized: 7.09 target: --- error: ---	realized: 43.94 target: --- error: ---	realized: 0.2197 target: --- error: ---	realized: 0.00 target: --- error: ---
Object type 2	realized: 20 target: --- error: ---	realized: 3.26 target: --- error: ---	realized: 6.53 target: --- error: ---	realized: 0.0326 target: --- error: ---	realized: 0.00 target: --- error: ---

Stopping criterion error: 0.93 %

General Options

Define the general parameters temperature, random seed and parallelization.

Random Seed	42	Temperature	20	°C
Parallelization	8 Threads (Automatic Maximum) Edit...			

Temperature

When **Grammage** (or **Density** or **Object Weight Percentage**) is chosen as **Stopping Criterion**, a temperature can be entered. The temperature is considered for materials with temperature dependent density.

Choose the temperature in Kelvin, Celsius, or Fahrenheit.

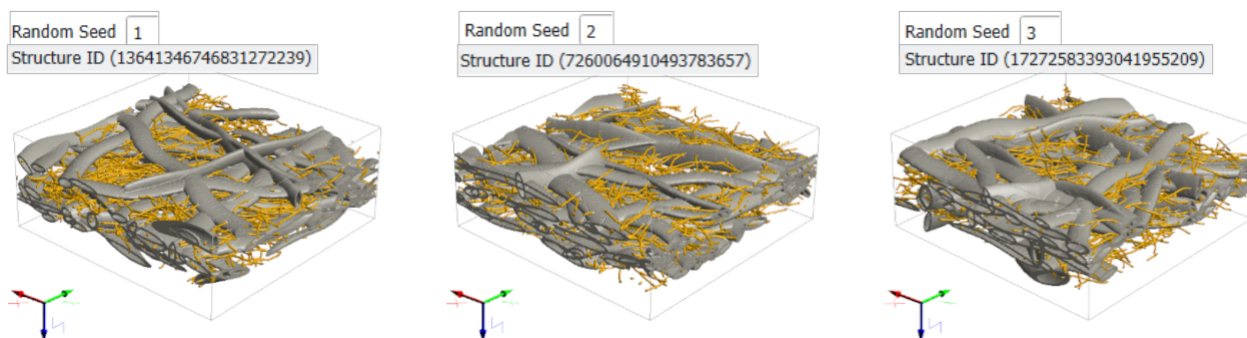
Temperature	20	°C
		K °C °F

Random Seed

Random Seed initializes the random number generator behind the structure generator. Changing its value produces different sequences of random numbers and hence, different realizations of the specified structure. If all settings are equal, generating with the same **Random Seed** value produces exactly the same structure, as shown by the **Structure ID** number in the Status section. The **Random Seed** is a non-negative integer number, it increases automatically with every generation run.

Varying the **Random Seed** allows generating different samples of the same structure for a

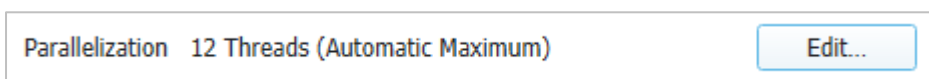
series of experiments. In the following examples, all parameters are unchanged while the random seed is modified with every generation run.



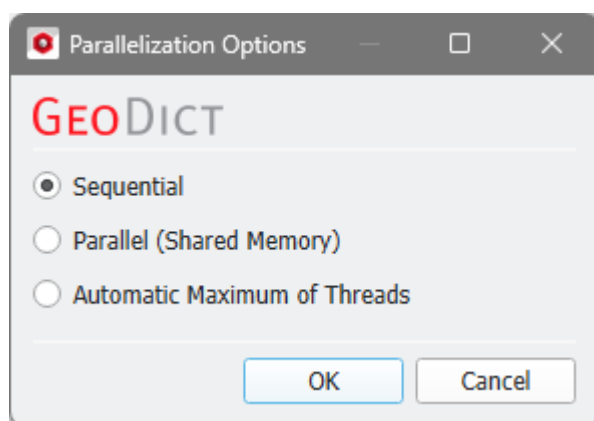
Parallelization

Control how many threads are used for the computation. Parallelization is possible if your license and hardware allow it.

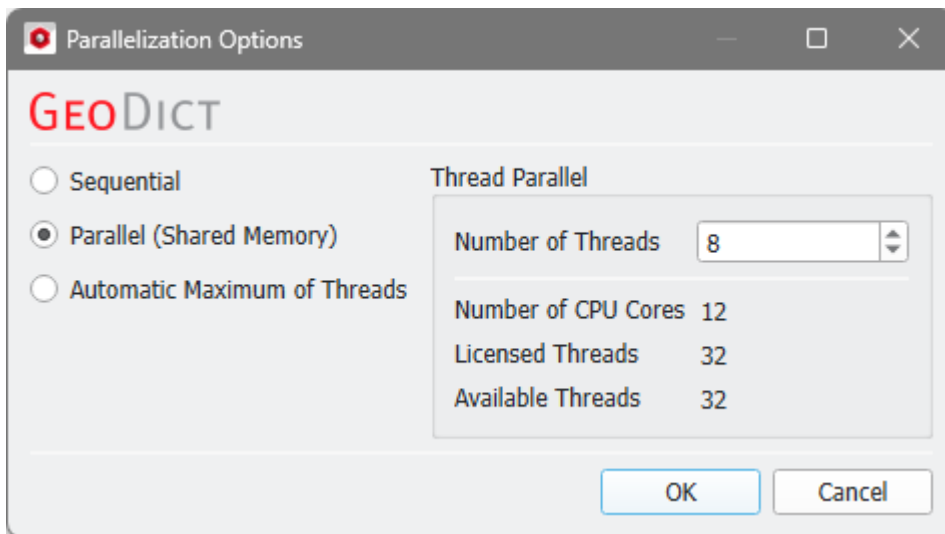
The **Parallelization Options** dialog opens when clicking the **Edit** button and you can choose between **Sequential**, **Parallel (Shared Memory)**, or **Automatic Maximum of Threads**.



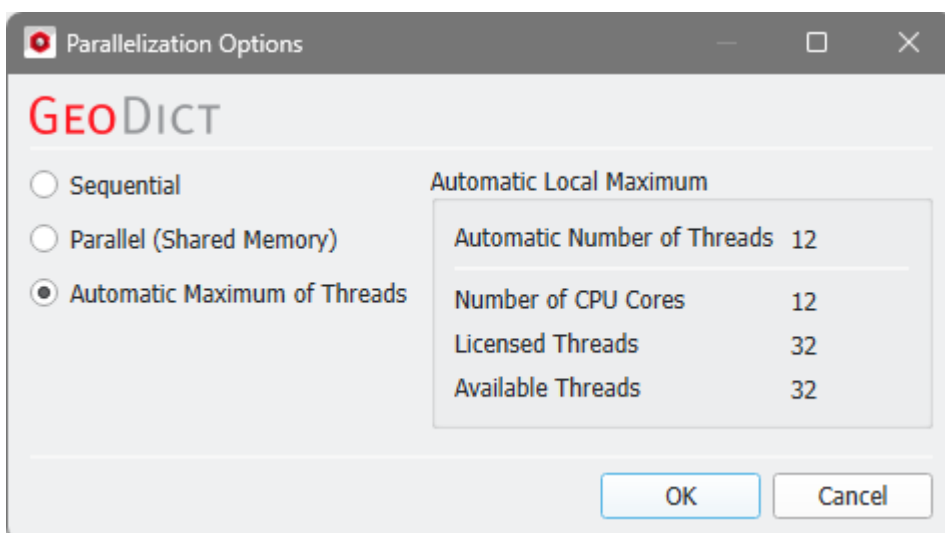
Selecting **Sequential** will not apply parallelization and only one thread is used for the computation.



When **Parallel (Shared Memory)** is selected, the **Number of Threads** can be entered. Below, the **Number of CPU Cores** that the current machine has, the maximum number of **Licensed Threads** and the number of those licensed threads that are available (**Available Threads**) are shown in the dialog. Of course, the maximal number of parallel processes you can use, is the smallest of those three numbers.



If **Automatic Maximum of Threads** is selected, the number of parallel processes is automatically selected for optimal speed, based on the CPU cores and licensed parallel processes.



The **Automatic Local Maximum** of processes is automatically selected, which is the minimum of **Number of CPU Cores**, **Licensed Threads**, and **Available Threads**.

Fiber Options

In the **Fiber Options** tab you can define the geometrical properties of your fiber types. Add up to eight individual fiber types to your structure.

The fiber type parameters are organized and listed in three columns. In the left one define the [Fiber Type](#)^[30] together with its percentage and material, the center one shows a [cross-section](#)^[33] of the chosen fiber type and in the right one you can edit the [Fiber Parameters](#)^[35]. In the bottom, find the options to choose additional fiber types and how the fiber percentage should be given.

The parameters are organized in the following columns:

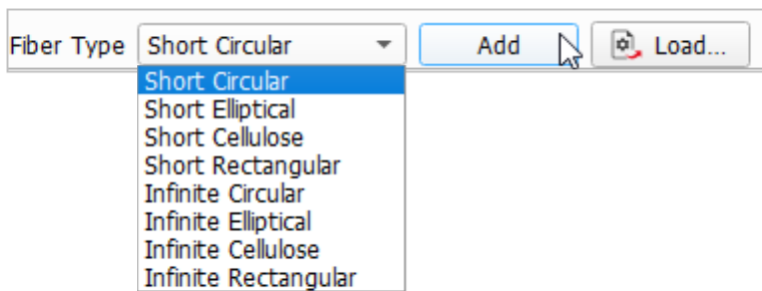
- [Fiber Type and Percentage](#)³⁰
Define the name of the fiber type, the fiber percentage in the structure, and the material.
- [Available Cross Sections](#)³³
Overview of the available fiber types and preview of their cross-sections.
- [Fiber Parameters](#)³⁵
Edit the parameters that define the fiber.

Fiber Type and Percentage

For all fibers, the left column of the panel contains the name of the fiber type, the fiber percentage in the structure, and the material.

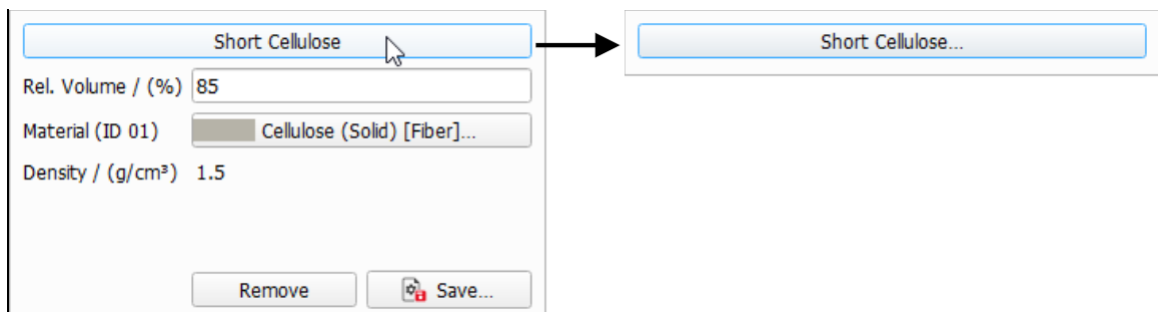
✓ Adding and removing fiber types

Short Cellulose and **Short Elliptical** are the two default **Fiber Types**. At the bottom left of the dialog box, clicking **Add** inserts other fiber types chosen from the **Fiber Type** pull-down menu (Short Circular, Infinite Cellulose, Infinite Rectangular, etc.).

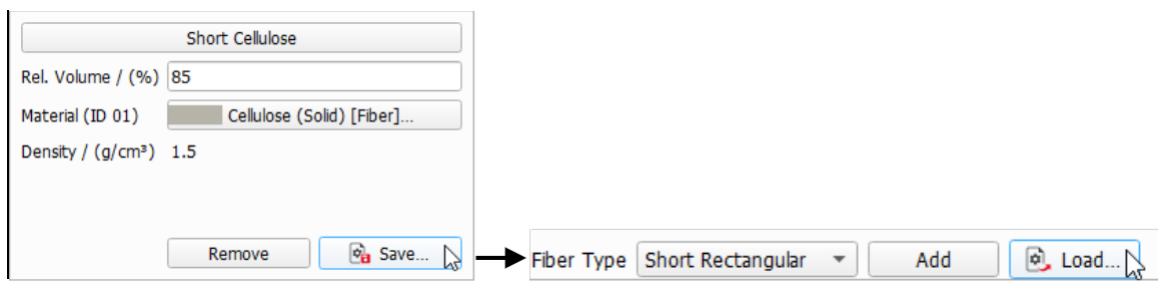


Unwanted fiber types can be discarded when clicking **Remove** in the left column for that fiber type.

Clicking on the fiber type name minimizes the object panel, and clicking on it again when minimized, expands it. A scroll bar at the right allows to navigate up and down in the list of chosen fiber types.



The settings for a fiber can be saved with all its options by clicking **Save...** and later reloaded by clicking **Load...**



✓ Percentage

The percentage of a certain fiber type can be specified as **Count %**, **Volume %**, or **Weight %**, as selected from the pull-down menu at the bottom right of the dialog box.

Note that, if the **Weight** option is chosen, the material density must be provided (or it is taken from the GeoDict material database) even when **Grammage** is not selected under the **Create Options** tab.

✓ Rel. Volume and Abs. Volume

If **Volume**³¹ is selected for **Percentages**, enter the **Relative Volume**. If **Fixed Object Number**²⁴ or **(Add) Object Solid Volume Percentage**²⁴ is chosen as **Stopping Criterion**, the **Absolute Volume** is automatically computed and given below.

✓ Material

Material designates the constituent material assigned to the fiber type used in the paper structure. The pull-down menu gives access to selecting the desired material from the GeoDict Material Database. When none of the materials available in the database fit the preferred specifications, **Manual** should be chosen.

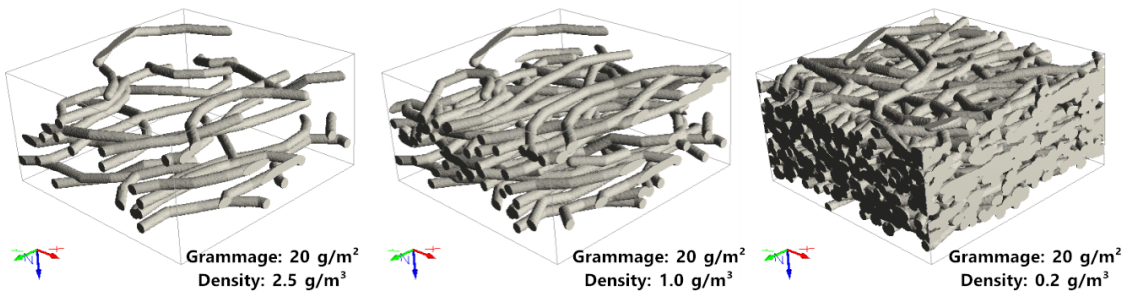
To match realistic material colors for visualization in a certain application, or to distinguish the constituent materials more easily, the colors of the materials can be changed through **Settings** → **Color & Visibility Settings** in the Menu bar, or by

unfolding the **Color & Visibility** sidebar next to the GeoDict visualization area as described in the Visualization chapter.

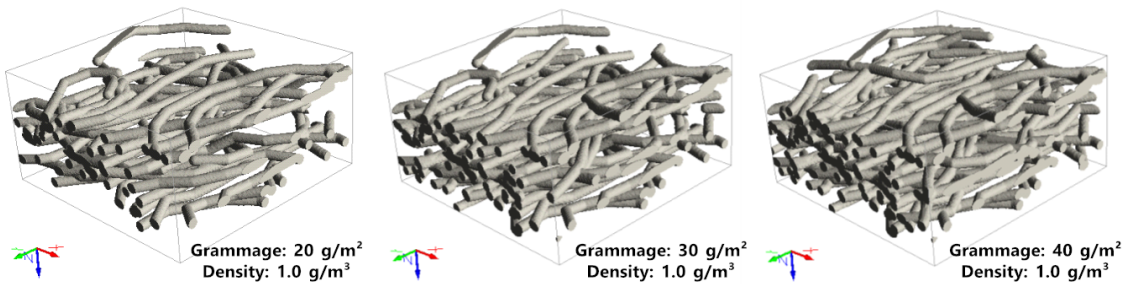
✓ **Density and Weight**

When **Grammage**²⁵ is chosen as **Stopping Criterion** or **Weight %** for **Percentage**³¹, the material **Density / (g/cm³)** of that fiber type appears. For materials included in the GeoDict Material Database, the density is automatically entered. For other materials (manual, user-defined), the density must be entered manually.

The fiber **Density**, given in g / cm³, is a property of the selected fiber type, affecting the final weight of the paper structure. The density of fiber is related to the **Grammage / (g/m²)** of the created paper structure. When denser fibers are used, and the grammage is unchanged, less fibers of this type appear in the paper structure.



Vice versa, when the same fiber type is used but an increase in grammage should be achieved, the structure must contain more fibers.



Available Cross Sections

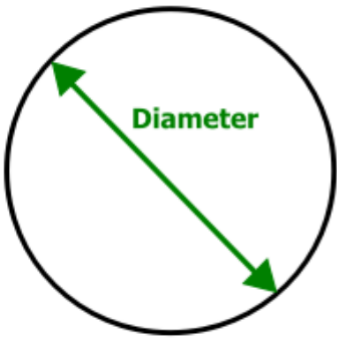
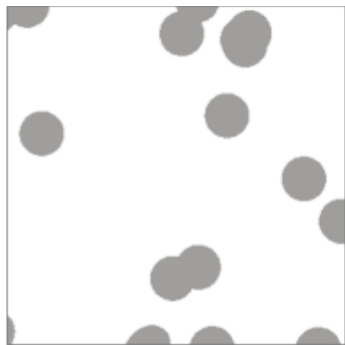
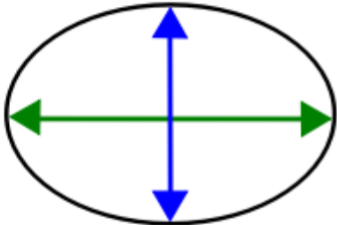
The following eight combinations of fiber cross-section with fiber length are available:

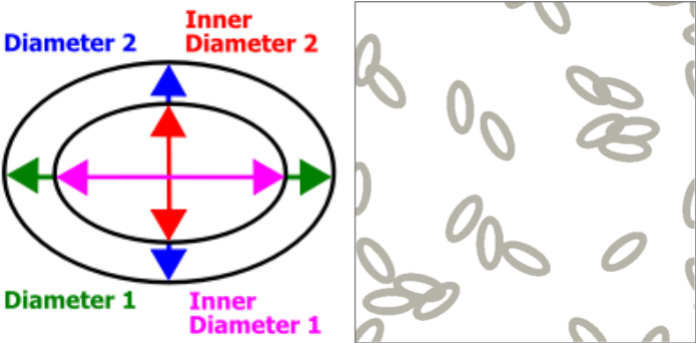
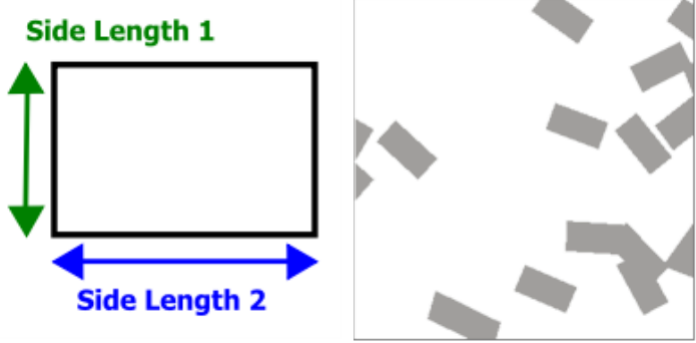
	Short	Infinite
Circular	Short Circular	Infinite Circular

	Short	Infinite
Elliptical	Short Elliptical	Infinite Elliptical
Cellulose	Short Cellulose	Infinite Cellulose
Rectangular	Short Rectangular	Infinite Rectangular

All fiber cross-sections

A drawing of the fiber cross-section is shown in the center column of each fiber type panel. The available fiber cross-sections and their defining parameters are:

Cross-section	Defining parameters
Circular  	Diameter / μm
Elliptical  	Diameter 1 / μm Diameter 2 / μm
Cellulose	Diameter 1 / (μm) Diameter 2 / (μm)

Cross-section	Defining parameters
	Wall Thickness / (μm) Inner Diameter 1 and 2 are defined by the parameters above
Rectangular 	Side Length 1 / (μm) Side Length 2 / (μm)

Fiber Parameters

The right column of the fiber type panel contains the parameters controlling the geometrical and physical properties of each fiber type in the paper structure.

These geometrical properties include diameter, orientation, length, position, etc. Many parameters can be set to a constant value or follow a [distribution](#)⁵⁵.

Fiber	Orientation	Shape	Torsion
Size Mode	Independent		
Diameter 1 / (mm)	Uniformly in [0.035,0.053]		Edit...
Diameter 2 / (mm)	Uniformly in [0.015,0.025]		Edit...
Fiber Length / (mm)	2		Edit...
Wall Thickness / (mm)	0.004		Edit...
Center in Sheet	Uniformly Distributed		Edit...
☒ Rounded Endings			

Fiber	Orientation	Shape	Torsion
Orientation in Plane	Angle Distribution		
Orientation Angle / ($^{\circ}$)	Uniformly in [0,360]		Edit...
Rotation Angle / ($^{\circ}$)	Probability Distribution		Edit...

Fiber	Orientation	Shape	Torsion
Shape Mode	Sine Fiber		
Segment Length / (mm)	0.025		
Sine Length Lateral / (mm)	0.25		Edit...
Sine Length Vertical / (mm)	0.25		Edit...
Sine Amplitude Lateral / (mm)	0.01		Edit...
Sine Amplitude Vertical / (mm)	0.005		Edit...

Fiber	Orientation	Shape	Torsion
Torsion Angle / ($^{\circ}$)	0		Edit...
Max Torsion Change / ($^{\circ}$)	0		

The fiber parameters are described in the following groups:

- [Fiber Tab](#) ³⁶
Define the general fiber parameters such as diameter, fiber length, and center in sheet.
- [Orientation Tab](#) ⁴²
Define the orientation parameters such as anisotropy and angle distribution.
- [Shape Tab](#) ⁴⁷
Define the shape parameters such as curved or straight.
- [Torsion Tab](#) ⁵³
Define the torsion parameters such as torsion angle.
- [Distribution](#) ⁵⁵
For many parameters a constant value or a distribution can be given. The different distribution options are described for the diameter of a circular fiber as an example.

Fiber Tab

Define the general fiber parameters such as diameter, fiber length and center in sheet.

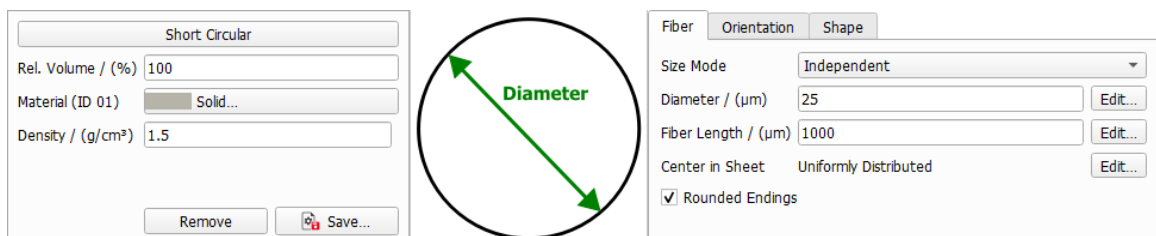
The different fiber types have different options. For example, the infinite fiber types don't have a parameter to define their length, since they are infinite.

Size Mode

All fiber types except for **Infinite Circular** have the parameter **Size Mode**. From the pull-down menu, three options can be selected. Here you can decide if the different diameter and length parameters of one fiber type should be interdependent.

✓ Independent

All diameter and length parameters are independent from each other, and thus have their own values and distributions available through their **Edit...** buttons.



Short Circular

Rel. Volume / (%) 100

Material (ID 01) Solid...

Density / (g/cm³) 1.5

Remove Save...

Fiber Orientation Shape

Size Mode Independent

Diameter / (µm) 25 Edit...

Fiber Length / (µm) 1000 Edit...

Center in Sheet Uniformly Distributed Edit...

☒ Rounded Endings

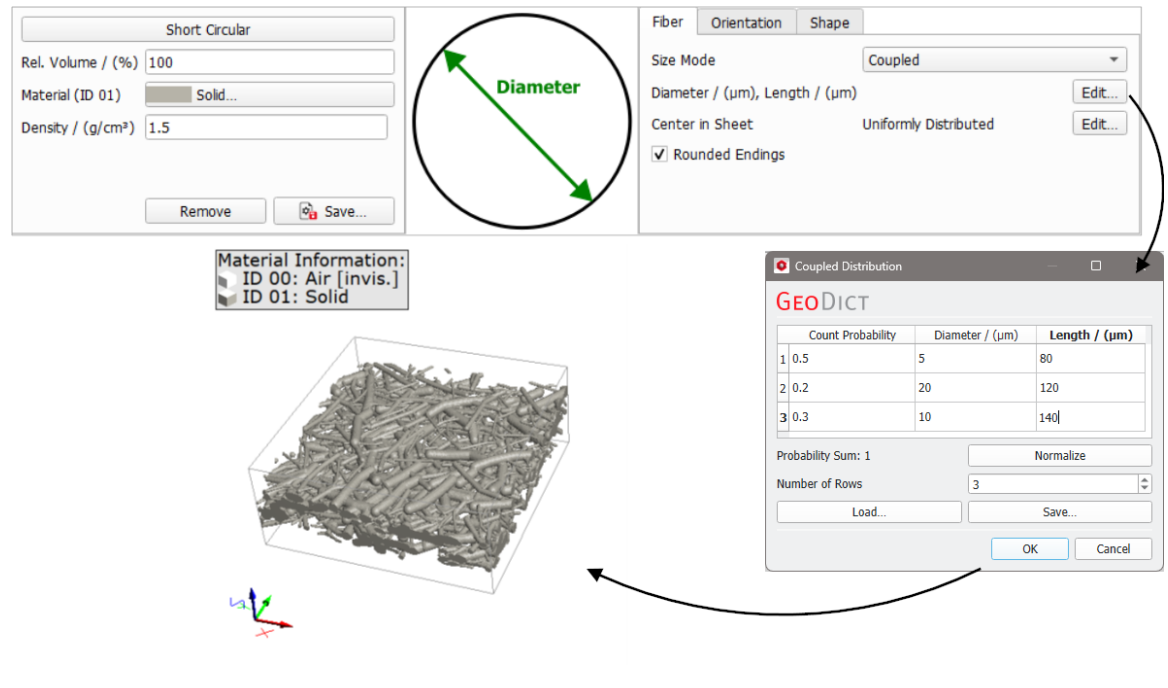
Diameter

✓ Coupled

The different diameter/length parameters are coupled. Clicking the **Edit...** button for these parameters, the coupling can be defined in the distribution table.

The following structure, entirely made of short circular fibers, is generated with the coupled values for diameter and length entered in the coupled distribution table shown here. Observe the three distinct diameter-length combinations of short circular fibers:

- 50% with diameter 5 µm and length 80 µm,
- 20% with diameter 20 µm and length 120 µm, and
- 30% with diameter 10 µm and length 140 µm.



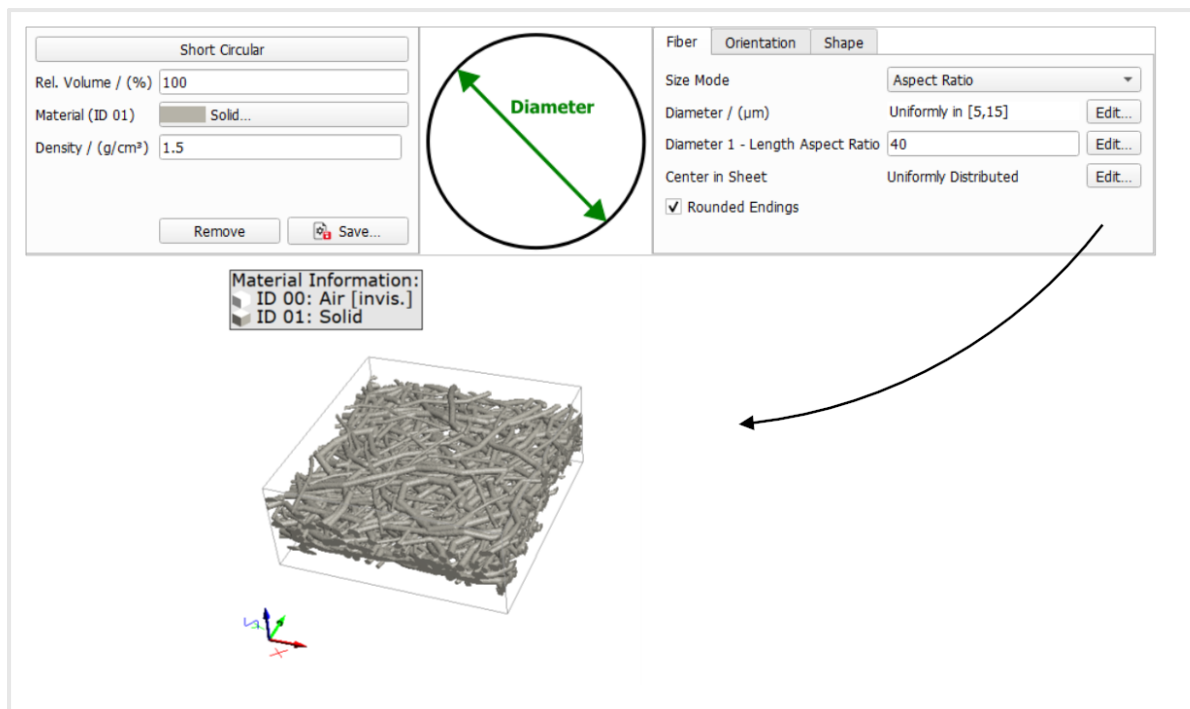
✓ Aspect Ratio

The different diameter/length parameters are given with an aspect ratio. They depend on the first **Diameter**. The resulting diameter/length value then is the aspect ratio multiplied with the first parameter value, for example:

$$\text{Length} = \text{Diameter 1} \cdot \text{Aspect Ratio} \quad (1)$$

where Aspect Ratio is short for Diameter 1 - Length Aspect Ratio.

This way, you can, for example, generate fibers with a diameter [distribution](#)⁵⁵ keeping the same aspect ratio to their length as shown below.



Diameter

✓ Circular Fiber

A circular fiber has only one diameter value. The **Diameter** value can be edited by clicking the **Edit...** button to open the **Diameter** dialog box. The circular fiber diameter can be set to have a **Constant** value, or to follow a [distribution](#)⁵⁵ (**Uniformly in interval, Gaussian, Probability Distribution, or Log-Normal**).

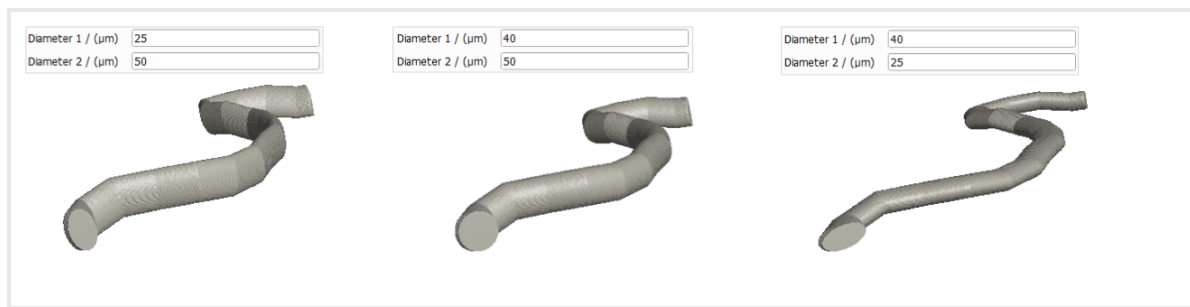
Diameter / (μm) 25

Diameter / (μm) 50



✓ Elliptical and Cellulose Fiber

For non-circular fibers, such as elliptical and cellulose fibers, two diameter values (**Diameter 1** and **Diameter 2**) need to be entered. Both diameter values are editable by clicking on the **Edit...** button and choosing the desired settings in the **Diameter** dialog boxes. They can be set to have a **Constant** value, or to follow a [distribution](#)⁵⁵ (**Uniformly in interval, Gaussian, Probability Distribution, or Log-Normal**).



Wall Thickness

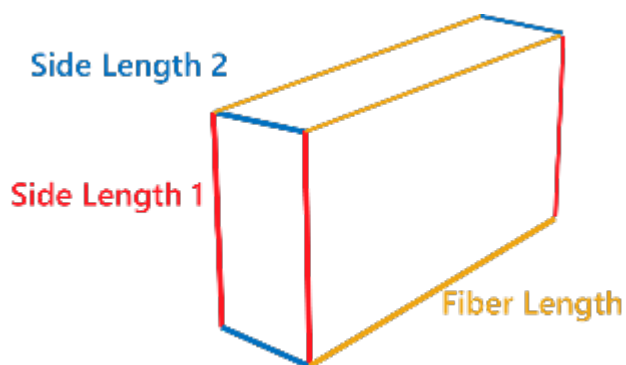
✓ Cellulose Fiber

For cellulose fibers, the **Wall Thickness** must also be defined. The wall thickness is editable by clicking on the **Edit...** button and choosing the desired settings in the **Wall Thickness** dialog box. It can be set to have a **Constant** value, or to follow a [distribution](#)⁵⁵ (**Uniformly in interval**, **Gaussian**, **Probability Distribution**, or **Log-Normal**).



Length

Fibers can have **Finite** (Short Fibers) or **Infinite** length. For short fibers the length must be defined. Additionally, for fibers with rectangular cross-section the parameters **Length 1** and **Length 1 - 2 Aspect Ratio** define the side lengths of the cross section.

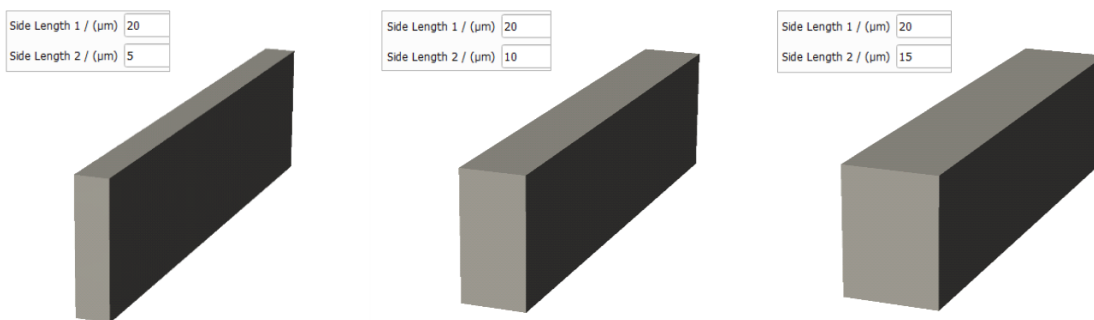


✓ Fiber Length

Fibers can be **Short** or have **Infinite** length. The length of short fibers is editable by clicking on the **Edit...** button and choosing the desired settings in the **Fiber Length** dialog box. It can be set to have a **Constant** value, or to follow a [distribution](#)⁵⁵ (**Uniformly in interval**, **Gaussian**, **Probability Distribution**, or **Log-Normal**).

✓ Side Length

The the **Side Length 1** and **Side Length 2** for **Rectangular** fibers is editable by clicking on the **Edit...** button and choosing the desired settings in the **Side Length** dialog boxes. It can be set to take a **Constant** value, or to follow a [distribution](#)⁵⁵ (**Uniformly in interval**, **Gaussian**, **Probability Distribution**, or **Log-Normal**).



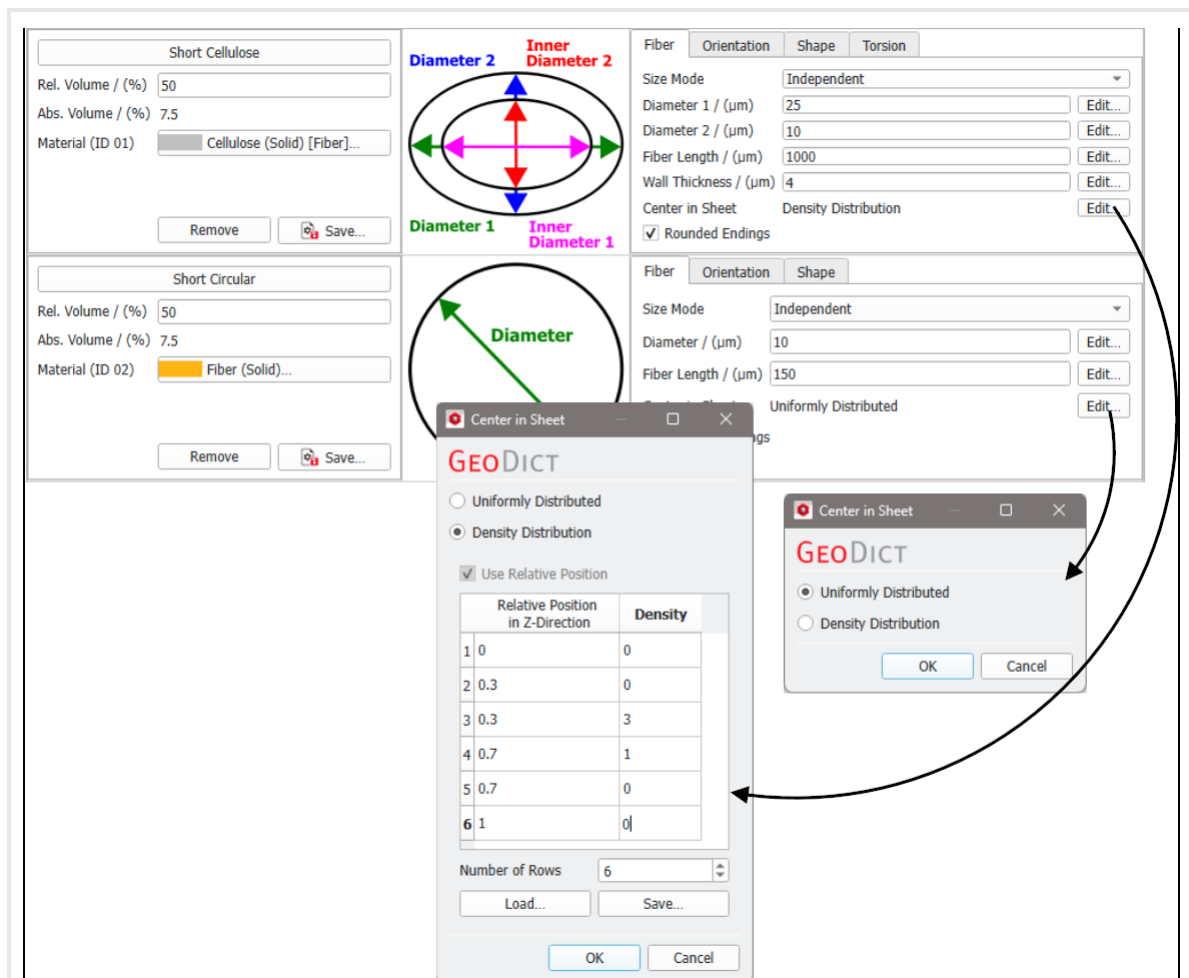
Note, that the side lengths can also be oriented differently in the domain. This is because fibers can have different orientations in the domain which can be defined from the [Orientation](#)⁴² tab. For a fiber oriented in Y-direction with a [rotation angle](#)⁴⁶ of 90° the **Side Length 1** is parallel to the Z-axis and the **Side Length 2** parallel to the X-axis. With an orientation angle of 0, the **Side Length 1** will be in X-direction and the **Side Length 2** will be in Z-direction.

Center in Sheet

The position of the fiber centers in Z-direction can be set to be **Uniformly** distributed in the sheet of paper or to follow a user-defined **Density Distribution**. This option is available for all fiber types. The values for **Center in Sheet** define the relative position in Z-direction of the fibers in relation to the given [Sheet Thickness](#)¹⁰ (which can be defined in the **Create Options** tab).

✓ Density Distribution

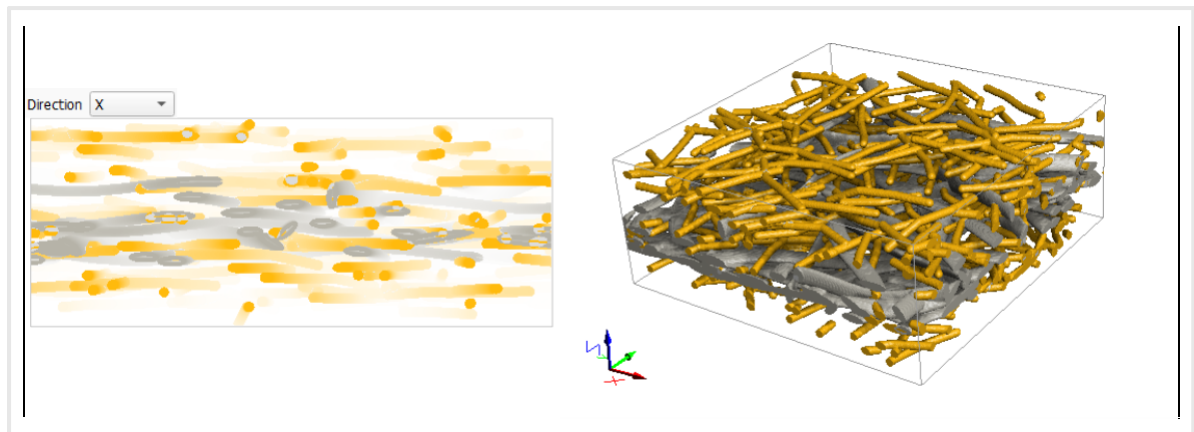
In the following example, a paper with two types of fibers is generated. The gray fibers are **Short Cellulose** fibers with centers following a user-defined density distribution. The yellow fibers are **Short Circular** fibers with centers uniformly distributed in the paper sheet.



In the density distribution table, the left column values from 0 to 1 correspond to locations in the structure. In the Z-direction, the value 0 is the bottom and the value 1 is the top of the sheet.

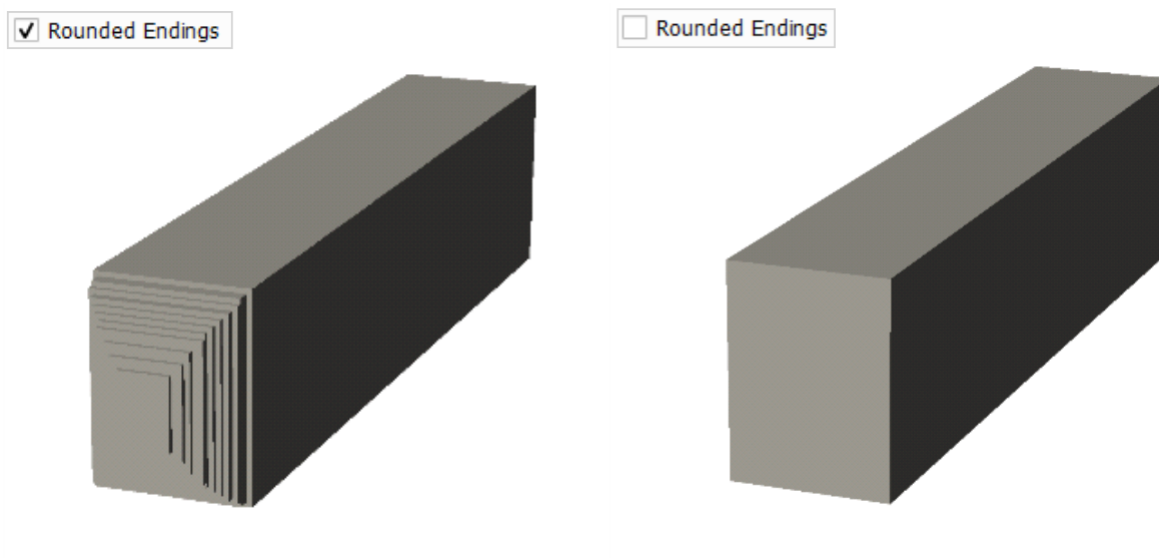
The right column assigns relative density values at these locations. The value **3** at $Z = 0.3$ means that the probability for a fiber center to be located at $Z = 0.3$ is three times higher than at $Z = 0.7$, where the density value is **1**. The fiber density increases and decreases linearly between the given locations in the Z-direction. Therefore, in the following example, the positions where a sharp transition is desired are given twice: once with positive density and once with density of 0.

Observe how, with the values in this table, the gray fibers occupy the area in the middle of the paper sheet ($Z=0.3$ to $Z=0.7$), whereas the yellow fibers' centers are distributed uniformly in it.



Rounded Endings

Short fibers with any cross-section (Circular, Cellulose, Elliptic, or Rectangular) can be created with or without rounded ends by checking or leaving un-checked the **Rounded Endings** box. Observe the variation in the shape of the short rectangular fibers after checking the **Rounded Endings** box.



Orientation Tab

Define how the fibers should be oriented in the domain. Two possible orientations of the fibers in the XY-plane can be selected from the pull-down menu: **Anisotropy** or **Angle Distribution**. Refer to the FiberGeo chapter for a detailed explanation of anisotropy and fiber orientation in the structure's geometry.

Fiber	Orientation	Shape	Torsion
Orientation in Plane: Anisotropy			
Anisotropy in Plane: 1			
Rotation Angle / (°): 0 Edit...			

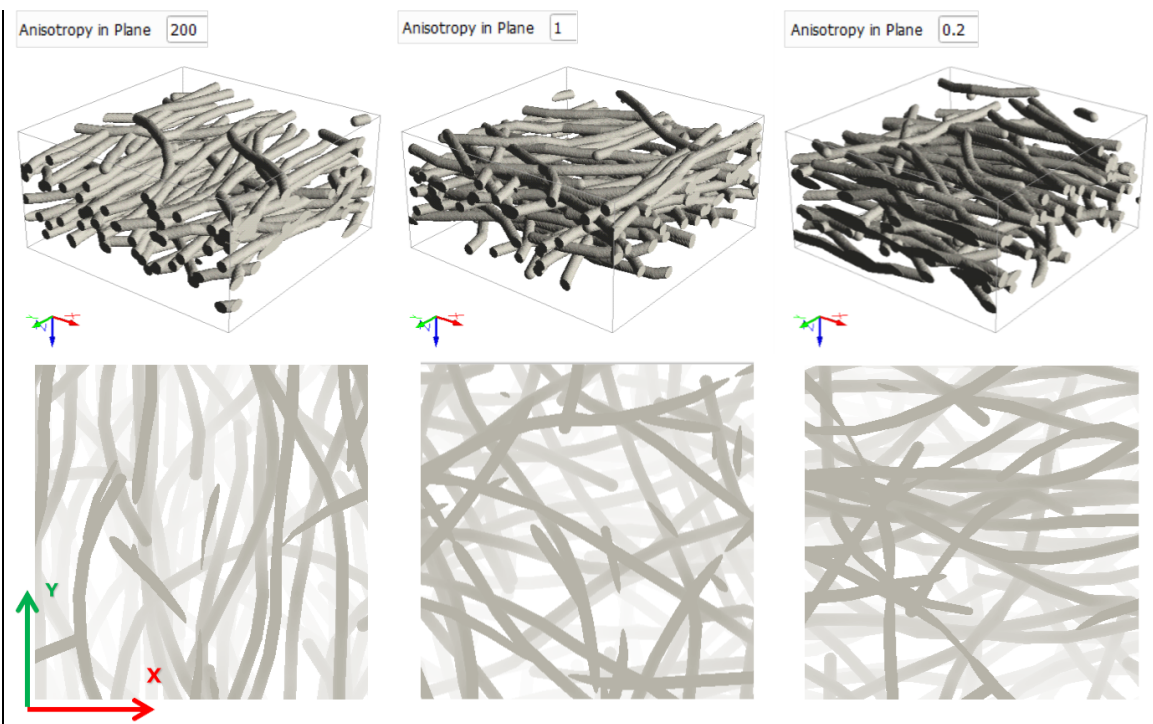
Fiber	Orientation	Shape	Torsion
Orientation in Plane: Angle Distribution			
Orientation Angle / (°): Uniformly in [0,360] Edit...			
Rotation Angle / (°): 0 Edit...			

✓ Orientation in Plane: Anisotropy

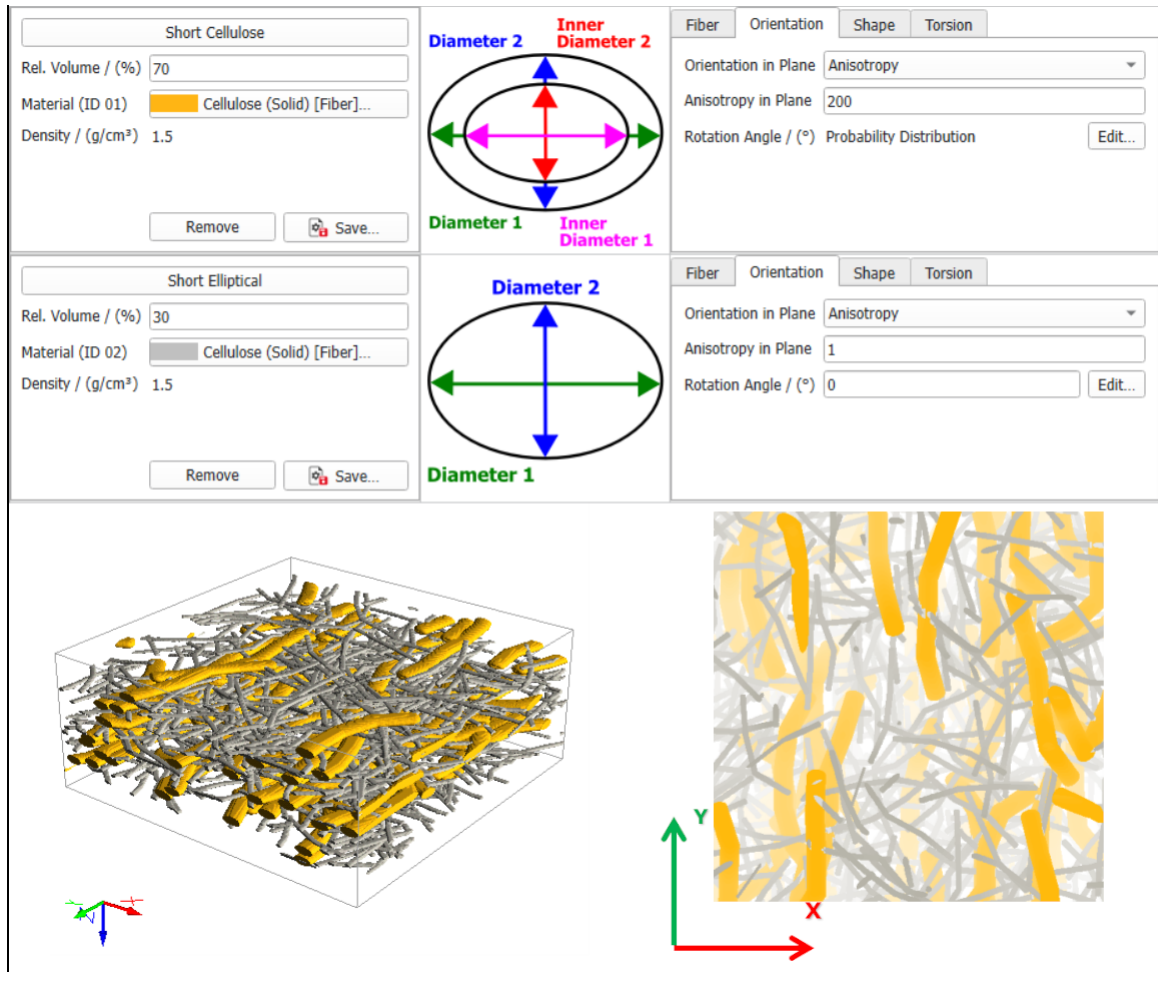
Selecting **Anisotropy**, the desired **Anisotropy in Plane** value can be entered.

Fiber	Orientation	Shape	Torsion
Orientation in Plane: Anisotropy			
Anisotropy in Plane: 1			
Rotation Angle / (°): 0 Edit...			

A value of 1 for **Anisotropy in Plane** corresponds to the isotropic case. In the following examples, all other parameters are left unchanged while the value of the **Anisotropy in Plane** is modified as indicated. For larger anisotropy values the fibers are oriented in Y-direction and for smaller values the fibers are oriented in X-direction.



It is possible to create paper structures with different fiber types which additionally have different values for their **Anisotropy in Plane**. The following paper structure (500x500x200) of grammage 20 g/m² was created using 70% of 200 μm long yellow cellulose fibers (25 μm x 10 μm , wall thickness 4 μm) with anisotropy in plane of 200, and 30% of 100 μm long gray elliptical fibers (8 μm x 2 μm) with anisotropy in plane of 1.



✓ Orientation in Plane: Angle Distribution

After selecting **Angle Distribution** from the **Orientation in Plane** pull-down menu, the desired **Orientation Angle** of the fibers in the XY plane can be directly set to a **Constant** value or to follow a [distribution](#)⁵⁵ (**Uniformly in interval**, **Gaussian**, **Probability Distribution**, or **Log-Normal**) through the **Edit...** button. For an **Orientation Angle** of 0° the fibers are oriented in X-direction.

Fiber	Orientation	Shape	Torsion
Orientation in Plane		Angle Distribution	
Orientation Angle / (°)		30	Edit...
Rotation Angle / (°)		0	Edit...

In the following examples, all parameters of the randomly curved circular fibers are left unchanged while the value of the **Orientation Angle** is modified as indicated.

1. Fibers have a constant orientation angle of 30°.

Rotation Angle / (°)

GEOdict

☒ Constant

Value / (°)

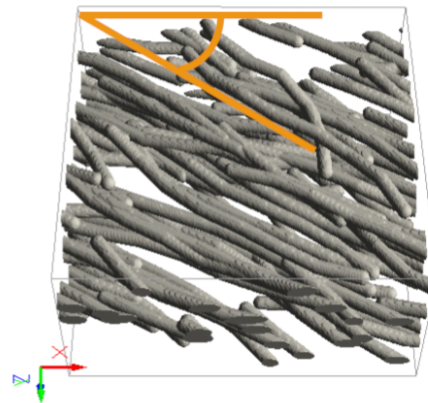
☐ Uniformly in interval

☐ Gaussian

☐ Probability Distribution

☐ Log-Normal

OK Cancel



2. Fibers have an orientation between 45° and 135°.

Rotation Angle / (°)

GEOdict

☐ Constant

☒ Uniformly in interval

Minimum / (°)

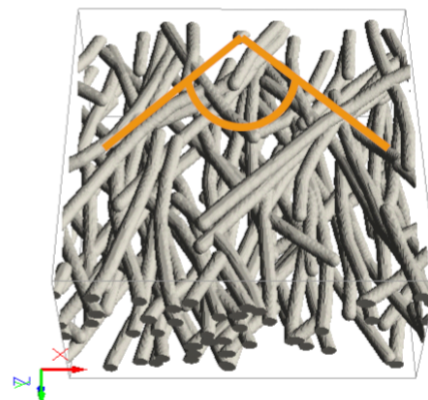
Maximum / (°)

☐ Gaussian

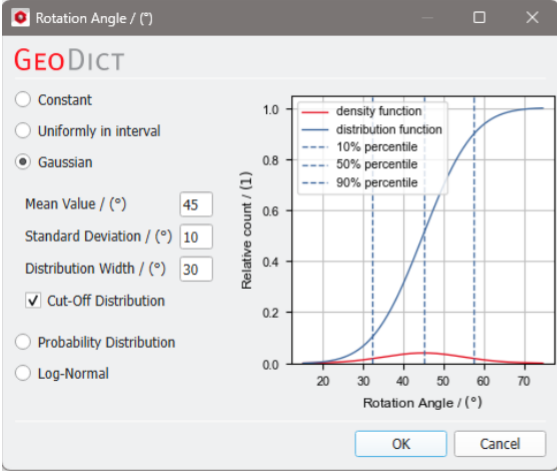
☐ Probability Distribution

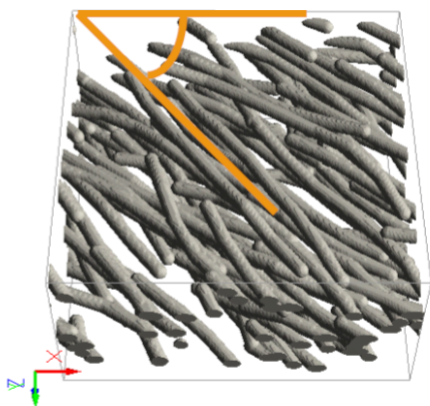
☐ Log-Normal

OK Cancel

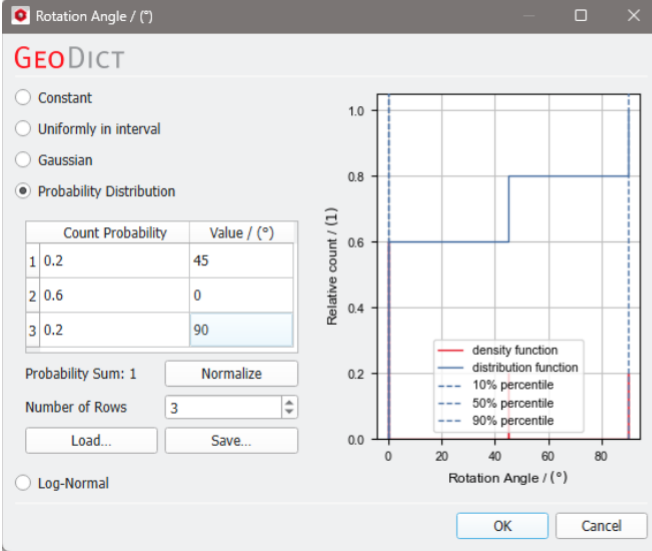


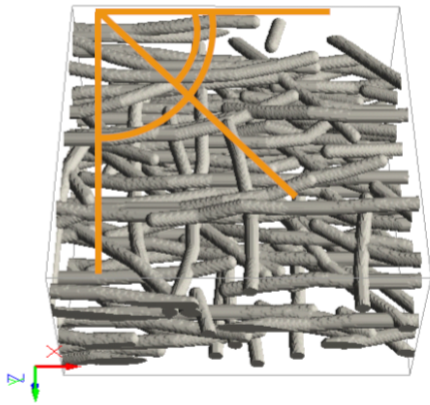
3. Fibers are normally distributed around the mean value 45° with a standard deviation of 10°.





4. The majority of fibers (60%) have an orientation angle of 0°, 20% have 90° angle and another 20% have a 45° angle.

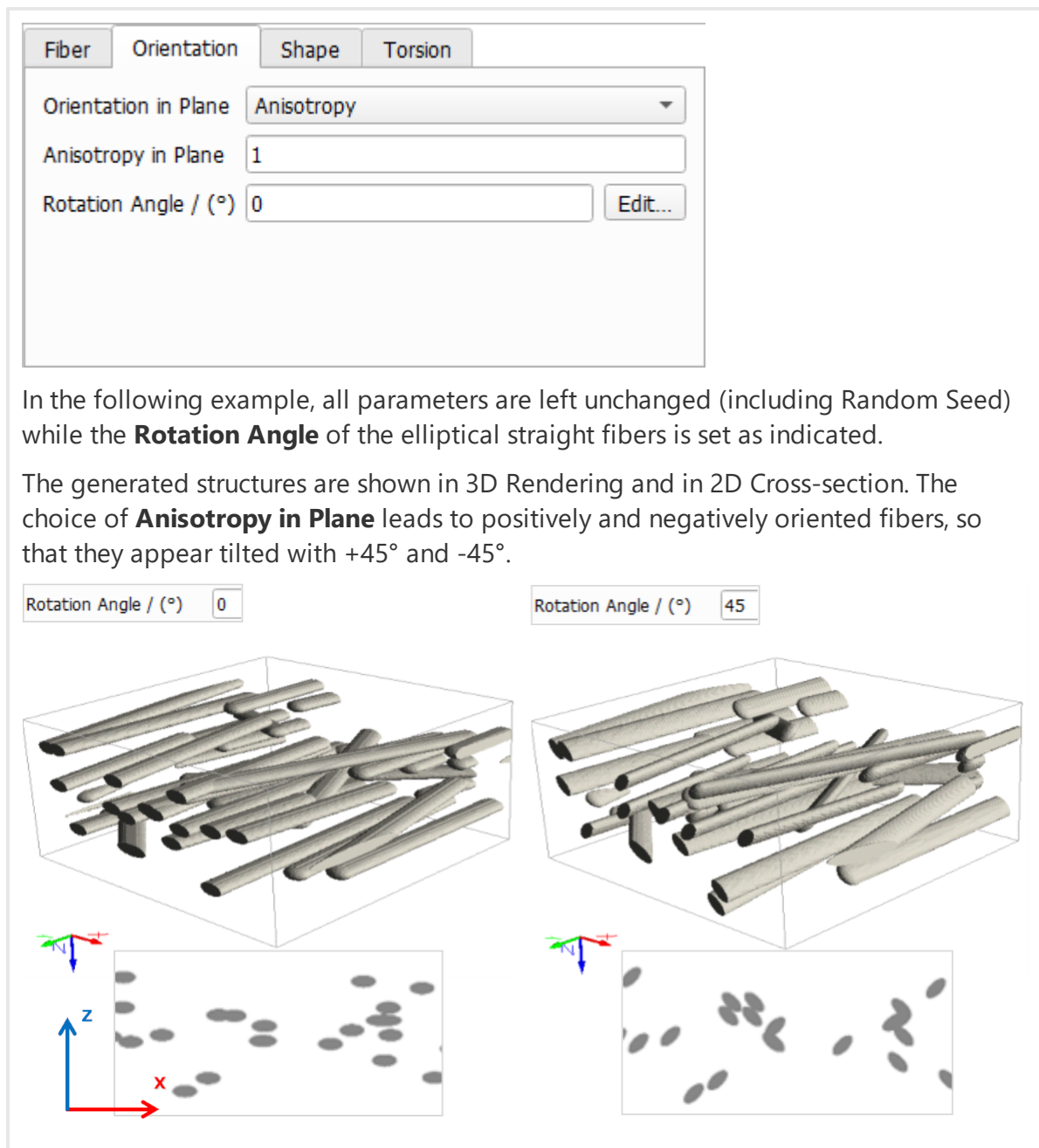




✓ Rotation Angle

The **Rotation Angle** is a measure of the angle the fiber profile has to the XY-plane (i.e., a measure for the rotation of the cross-section). This parameter has no effect if the fibers are circular and straight.

The rotation angle can be set to take a **Constant** value or a [distribution](#)⁵⁵ (**Uniformly in interval**, **Gaussian**, **Probability Distribution**, or **Log-Normal**).

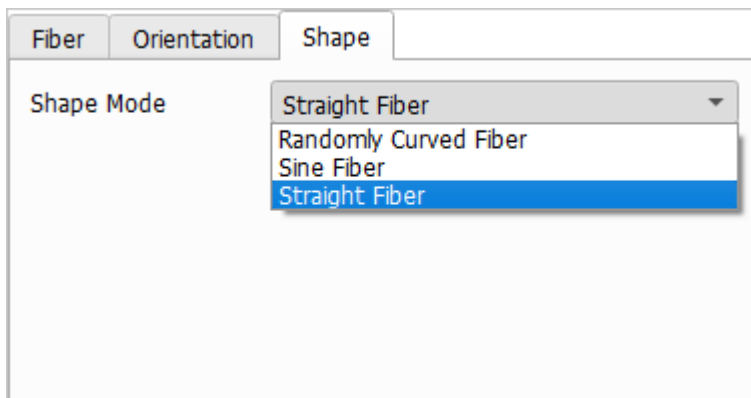


In the following example, all parameters are left unchanged (including Random Seed) while the **Rotation Angle** of the elliptical straight fibers is set as indicated.

The generated structures are shown in 3D Rendering and in 2D Cross-section. The choice of **Anisotropy in Plane** leads to positively and negatively oriented fibers, so that they appear tilted with $+45^\circ$ and -45° .

Shape Tab

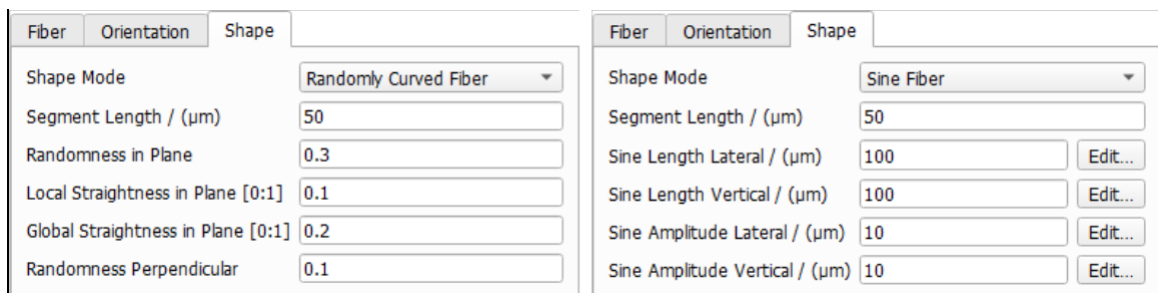
The **Shape Mode** pull-down menu lists the options to define the longitudinal shape of the fibers: **Randomly Curved Fiber**, **Sine Fiber**, and **Straight Fiber**.



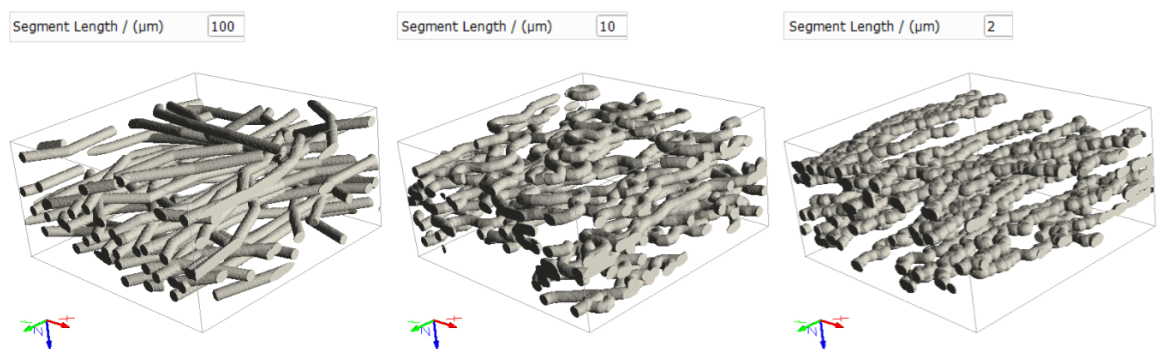
✓ Segment Length

For randomly curved and sine fibers, the **Segment Length** determines the length of the linear parts that build the fiber (finer segments), so that small values lead to well resolved fibers with smooth curving.

A smaller segment length leads to longer computation times when using **Lay-Down Fibers**. A large segment length leads to fibers with long straight segments.



In the following examples, all parameters for the short circular, randomly curved fibers with a length of 1000 μm are left unchanged, while the **Segment Length** varies as indicated.



Straight Fiber

A **Straight Fiber** is straight by definition, so no additional shape parameters are available. To create straight fibers with **Torsion**, for example choose **Randomly Curved Fibers** with zero **Randomness in Plane** and zero **Randomness Perpendicular** as explained in the following.

Randomly Curved Fiber

Randomly Curved Fibers follow a random curve determined by **Randomness in Plane**, **Local Straightness in Plane**, **Global Straightness in Plane**, and **Randomness Perpendicular**.

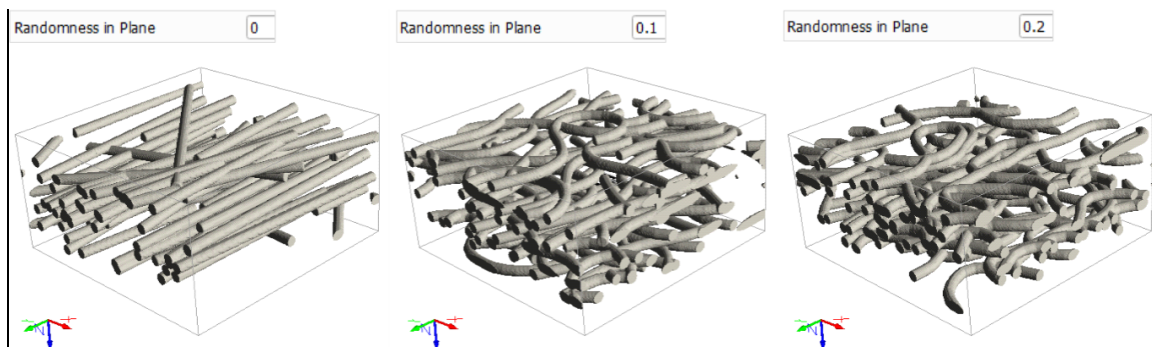
The values of these parameters describe how strongly a fiber may change direction from one segment to the next. The different parameters complement each other, whereby the straightness parameters control the amount of curvature locally or globally and the randomness parameters define the amount of random influences. For a more detailed explanation how the parameters influence the curvature, refer to the FiberGeo chapter.

Fiber	Orientation	Shape
Shape Mode	Randomly Curved Fiber	
Segment Length / (mm)	0.05	
Randomness in Plane	0.1	
Local Straightness in Plane [0:1]	0.1	
Global Straightness in Plane [0:1]	0.2	
Randomness Perpendicular	0.05	

The following examples show the effect of these parameters for short elliptical or circular **Randomly Curved Fibers**. The [segment length](#)⁴⁸ is set to 20 μm for both types of fibers.

✓ Randomness in Plane

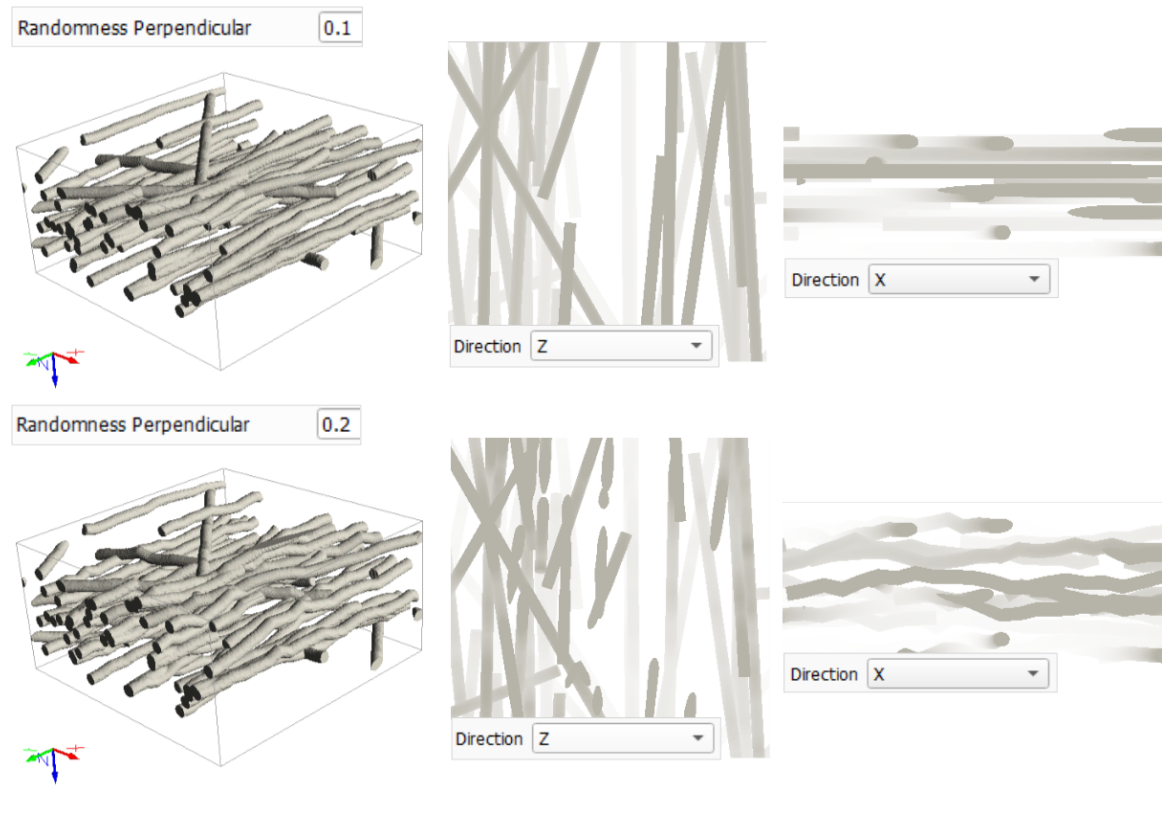
Initially, the **Randomness in Plane** is set to 0, as are all other three randomness parameters. Then, the **Randomness in Plane** is set to 0.1 and finally to 0.2. Too large values of **Randomness in Plane** lead to unrealistic results in this constellation. Observe that using **Randomness in Plane**, the deformation occurs only in the XY-plane and not in the Z-direction.



✓ Randomness Perpendicular

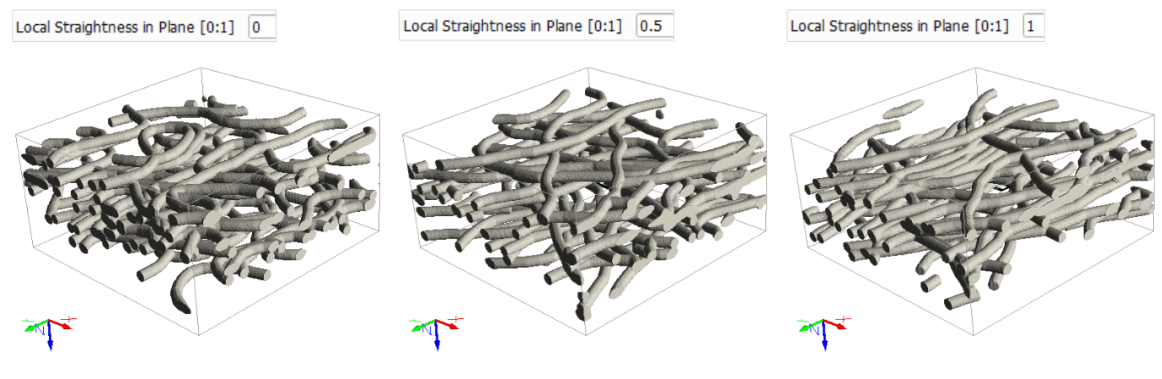
To achieve a deformation in the Z-direction, **Randomness Perpendicular** must be used. A structure created with a higher Randomness Perpendicular value (0.2) is viewed

in 3D Rendering and in 2D Cross-section to show that the deformation occurs in the Z-direction while no deformation can be observed in the XY-plane.



✓ Local Straightness in Plane

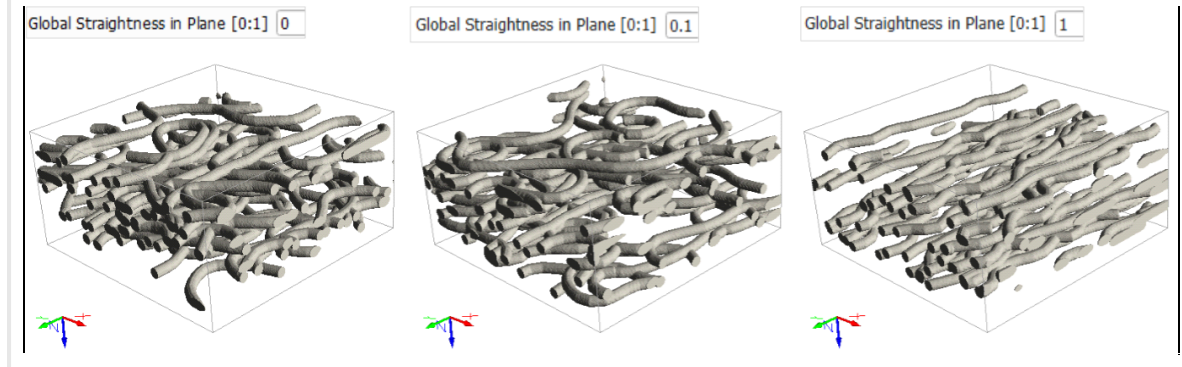
The **Local Straightness in Plane** parameter controls how strongly fibers might change direction from one segment to the next. The values must be chosen between 0 and 1. Observe the effect of increasing the **Local Straightness in Plane** from 0 over 0.5 to 1, while the Randomness in Plane is kept at a constant value of 0.2. The segment length is 20 μm . The fibers appear locally straighter but are globally curved.



✓ Global Straightness in Plane

The **Global Straightness in Plane** parameter controls how strongly the fibers follow their main fiber direction. The values must be chosen between 0 and 1. Observe the

effect of increasing values of **Global Straightness in Plane** (0, 0.1, and 1), while the Randomness in Plane is kept at a constant value of 0.1. The segment length is 20 μm . The fibers appear globally straighter, while they are still locally curved.



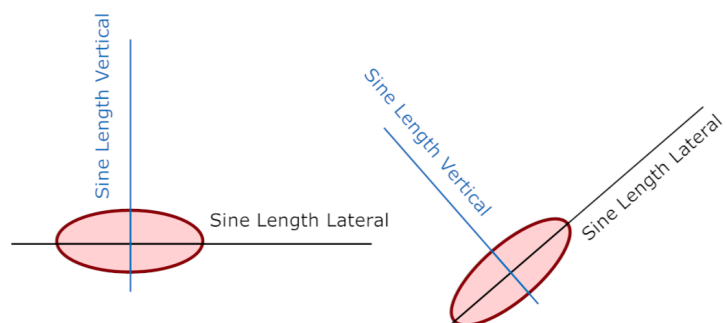
Sine Fiber

Sine (or sinusoidal curved) **Fibers** are following a sinusoidal curve where the length and amplitude parameters can be defined in two perpendicular directions.



The direction of the parameters **Sine Length Lateral**, **Sine Length Vertical**, **Sine Amplitude Lateral**, and **Sine Amplitude Vertical** is depending on the fiber orientation. For elliptical fibers, lateral and vertical describe the directions of the main axes.

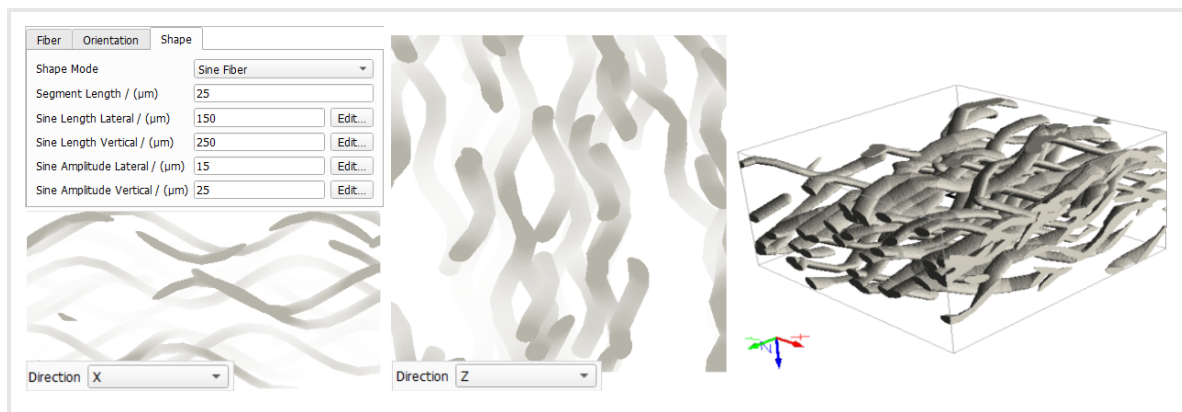
Fiber	Orientation	Shape
Shape Mode	Sine Fiber	
Segment Length / (μm)	50	
Sine Length Lateral / (μm)	100	Edit...
Sine Length Vertical / (μm)	100	Edit...
Sine Amplitude Lateral / (μm)	10	Edit...
Sine Amplitude Vertical / (μm)	10	Edit...



The following examples show the influence of these parameters on sine fibers. The [Segment Length](#) is set to 25 μm ($\frac{1}{4}$ of the sine length).

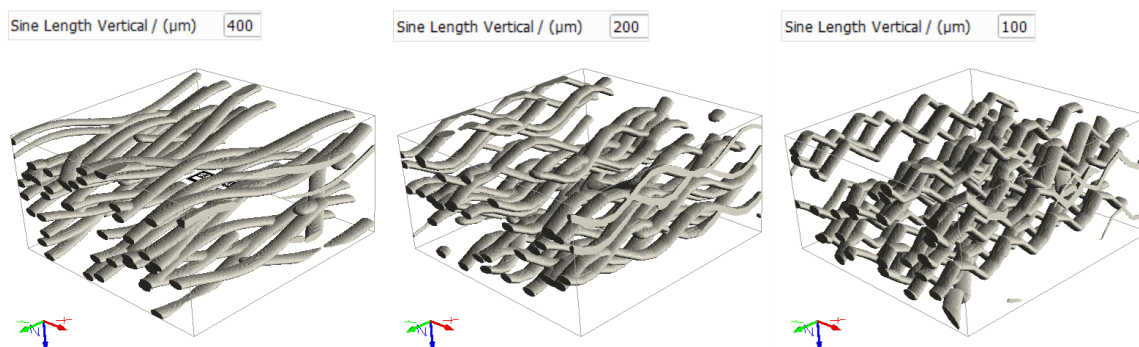
✓ Sine Fibers with lateral and vertical components

Sine fibers with a combination of lateral and vertical components are obtained, for example, with the following values:



✓ Sine Length

Setting higher values of **Sine Length Lateral** and **Sine Length Vertical** produces less sharply bent sine fibers. In the example the segment Length is kept at 25 μm and the lateral sine amplitude is kept at 0 to only apply vertical sine curvature.

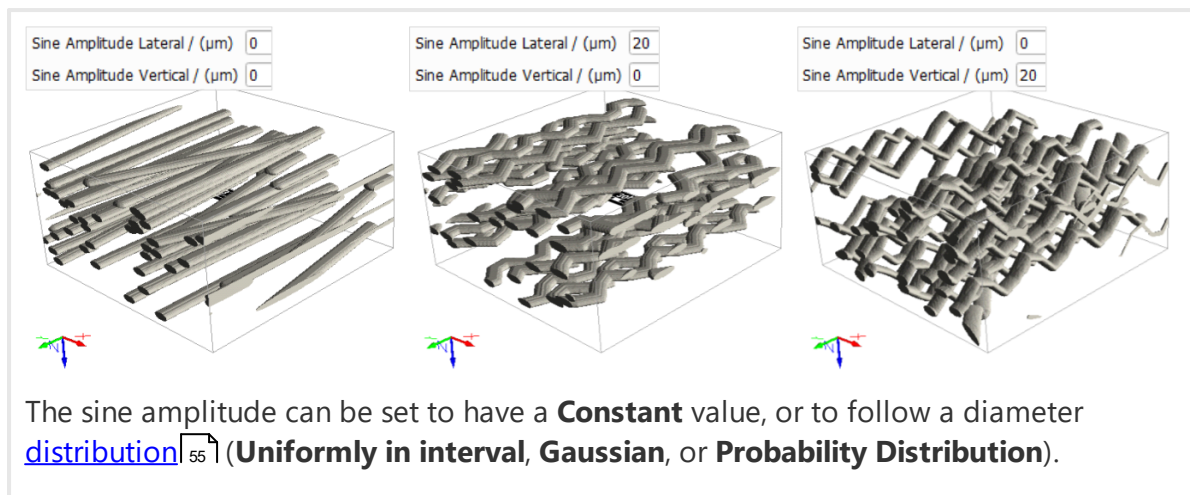


The sine length can be set to have a **Constant** value, or to follow a diameter [distribution](#)⁵⁵ (**Uniformly in interval**, **Gaussian**, or **Probability Distribution**).

✓ Sine Amplitude

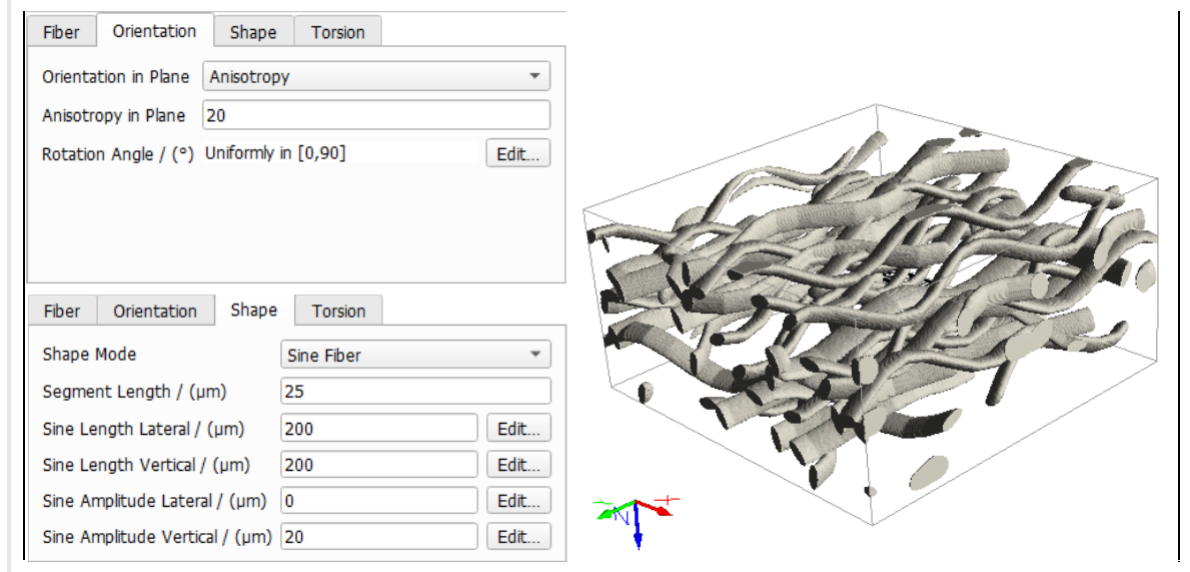
Initially, **Sine Amplitude Lateral** and **Sine Amplitude Vertical** are set to 0 (as are the **Rotation Angle** and the **Torsion Angle**) to produce fibers that are straight. To better observe this effect, the Anisotropy in Plane has been set to 20.

Sine fibers have only a vertical component when the **Sine Amplitude Vertical** takes a value greater than zero, while the **Sine Amplitude Lateral** is 0 μm . Vice versa, they have only a lateral component when the **Sine Amplitude Vertical** is 0 μm and the **Sine Amplitude Lateral** is larger than zero. Setting both amplitude values larger than zero, the fibers have both, a lateral and a vertical component.



✓ Combination with Rotation Angle

Observe the effect of the combination of sine parameters with a **Rotation Angle** that follows a uniform distribution in the interval 0° to 90° . The fibers appear not only curved but also rotated.



Torsion Tab

Randomly curved fibers and sine fibers with elliptical, cellulose, and rectangular cross-section can be twisted to achieve torsion. The **Torsion Angle** defines how strongly the fibers are twisted within the first segment length. The **Maximum Torsion Change** adds a random component by allowing the torsion to change from one segment to the next.

Fiber

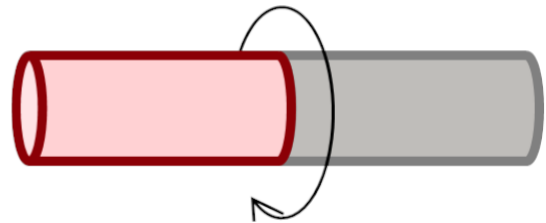
Orientation

Shape

Torsion

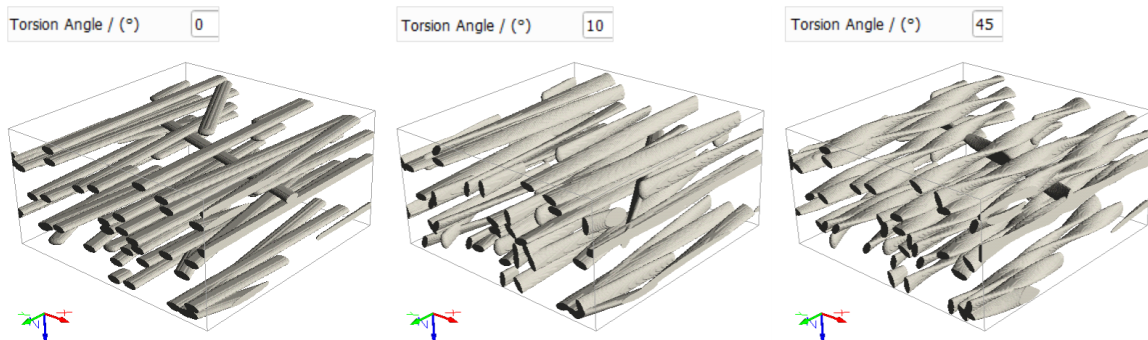
Torsion Angle / (°)
Edit...

Max Torsion Change / (°)



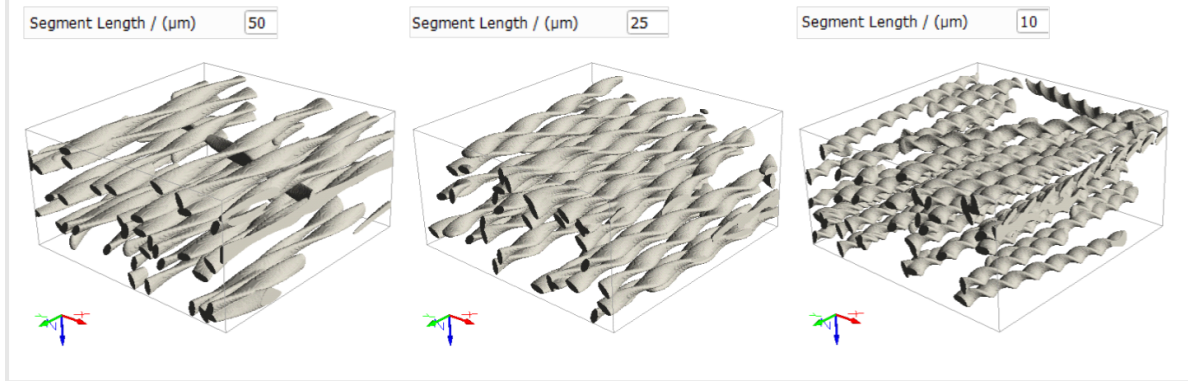
✓ Torsion Angle

The following examples show the effect of varying the **Torsion Angle** on [sine](#)⁵¹ fibers with an elliptical cross-section, with both amplitude values set to 0 to create straight fibers as a base. The torsion angle is set as indicated (0°, 10°, and 45°) while all other parameters are kept unchanged.



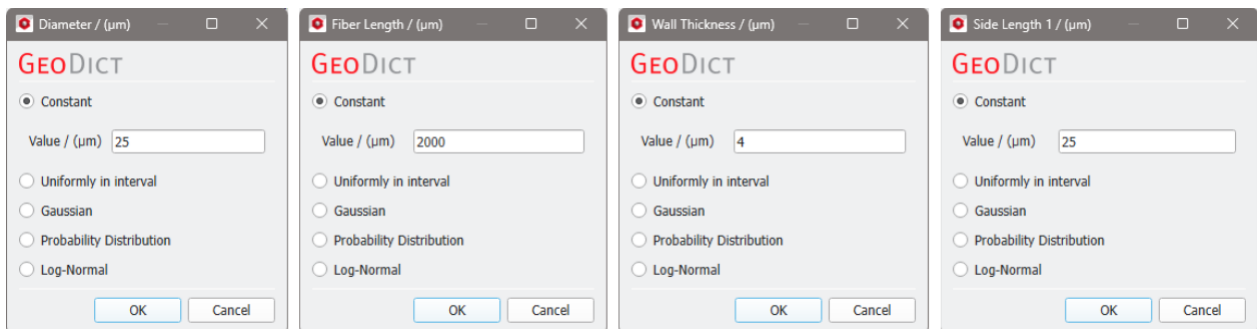
✓ Combination with Segment Length

The association between **Torsion Angle** and **Segment Length** (under the **Shape** tab) can be observed in the following examples where the torsion angle is kept at a constant value of 45° whereas the segment length varies from the default $50\text{ }\mu\text{m}$, to $25\text{ }\mu\text{m}$, and finally to $10\text{ }\mu\text{m}$.



Distribution

Under the **Fiber** tab, the fiber **Diameter**, the **Fiber Length**, the **Wall Thickness**, and the **Side Length** can be set to a **Constant** value, or to follow a **Uniformly in interval** distribution, a **Gaussian** distribution, a user-defined **Probability Distribution**, or a **Log-Normal** distribution.



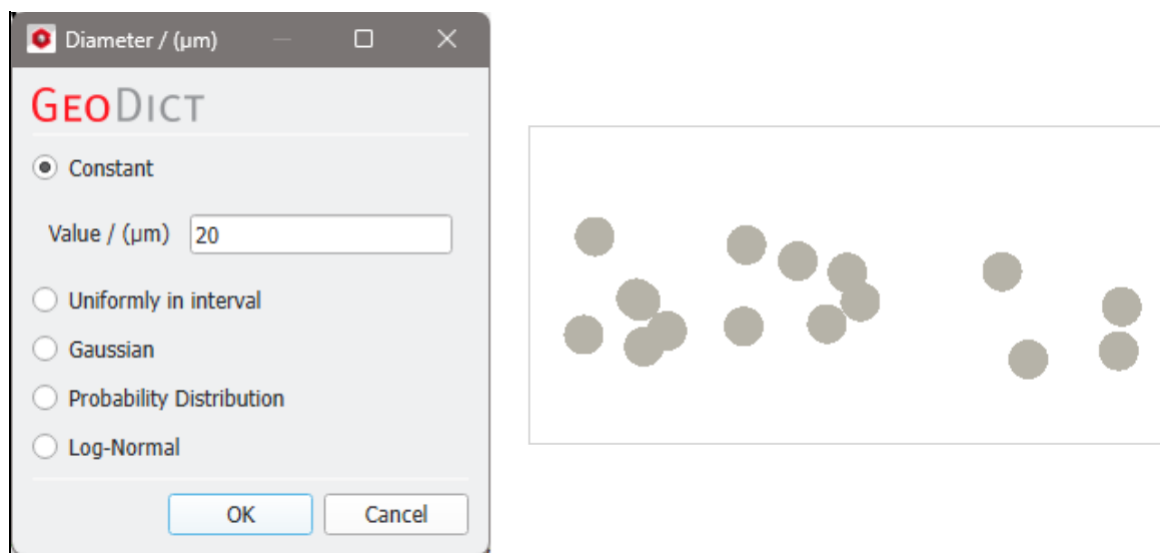
Under the **Orientation** tab, the **Rotation Angle** and the **Orientation Angle** values (for Orientation in Plane → Angle Distribution) can be set to be **Constant**, to follow a **Uniformly in interval** distribution, a **Gaussian** distribution, a user-defined **Probability Distribution**, or a **Log-Normal** distribution.

Except for Circular fibers, under the **Torsion** tab, the **Torsion Angle** value can be set to be **Constant**, to follow a **Uniformly in interval** distribution, or a user-defined **Probability Distribution**.



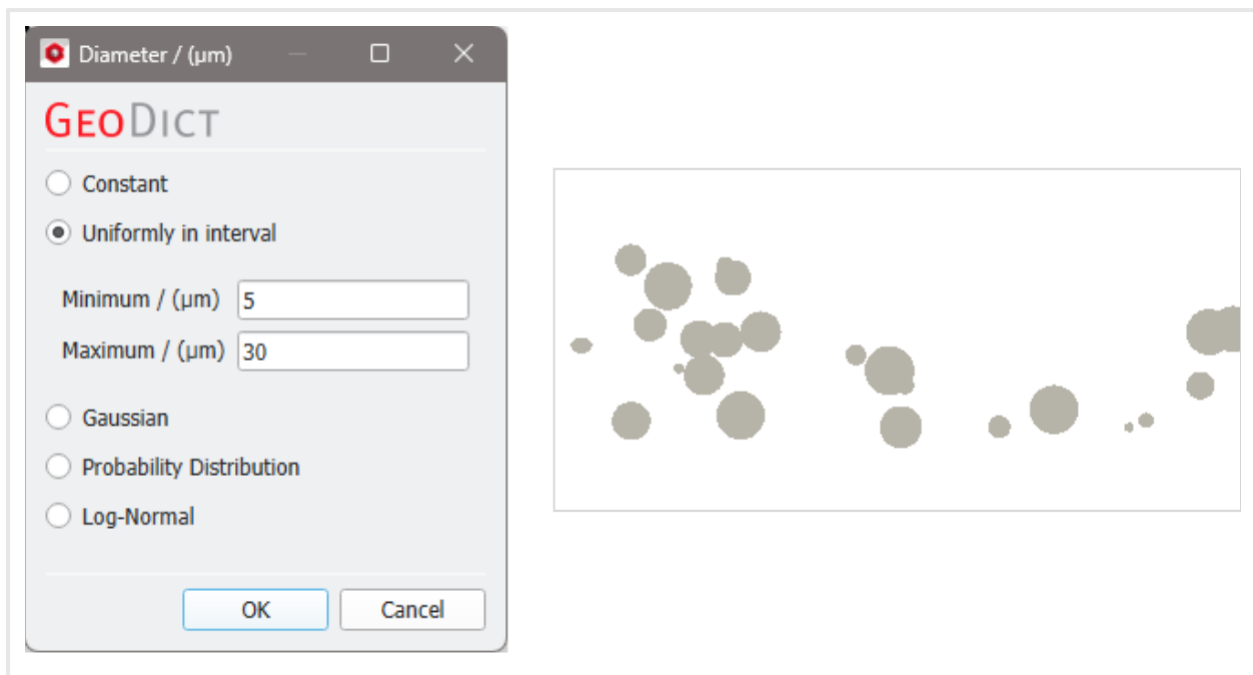
✓ Constant

Observe the effect of choosing the diameter to be **Constant** in the following example with only circular cross-section fibers. The generated structures are shown as 2D cross-section. To better observe the circular cross-section in 2D view, the fibers are all oriented perpendicular to the view direction.



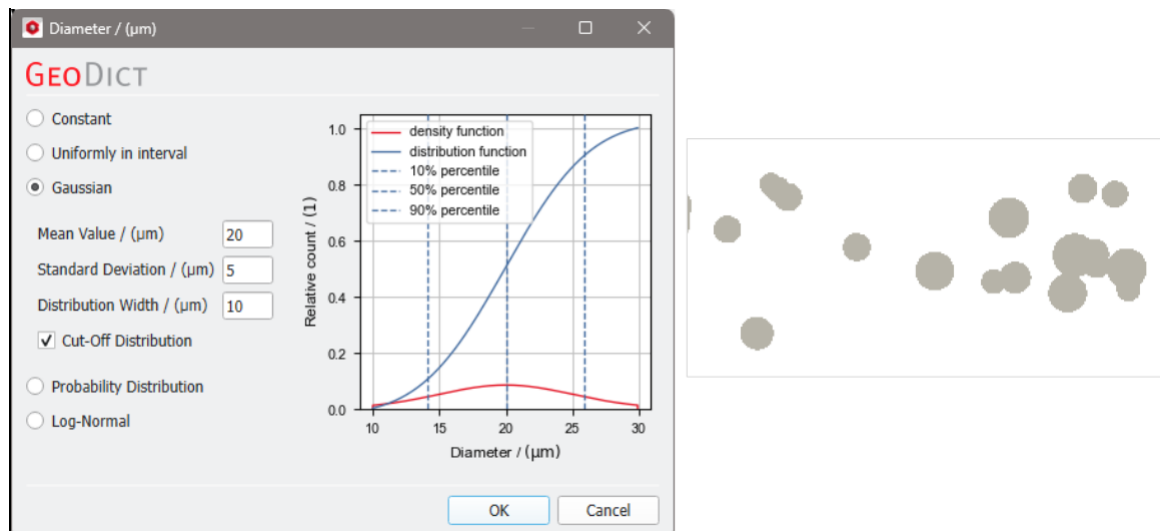
✓ Uniformly in interval

When selecting **Uniformly in interval**, and entering a **Minimum** value and a **Maximum** value, the random diameters are distributed within the given interval and every feasible diameter has the same probability.



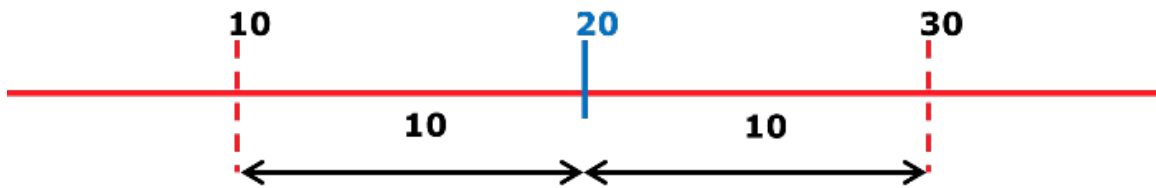
✓ Gaussian

Taking the **Gaussian** distribution, the random diameter, length, or side length values follow a bell-shaped distribution. The values cluster around the entered **Mean Value** but may vary according to the entered **Standard Deviation**.



The value in **Distribution Width** corresponds to the interval on both sides of the mean value limiting the random diameter or angle values that are accepted.

As an example, a **Distribution Width** value of 10 means that the values may vary only - 10 to +10 from the given **Mean Value**.



You can set the parameters so that negative values would be possible. Then, the negative values are ignored and only the range of possible values is generated. For example, a mean value of 20 and a distribution width of 25 would lead to values between 1 and 45.

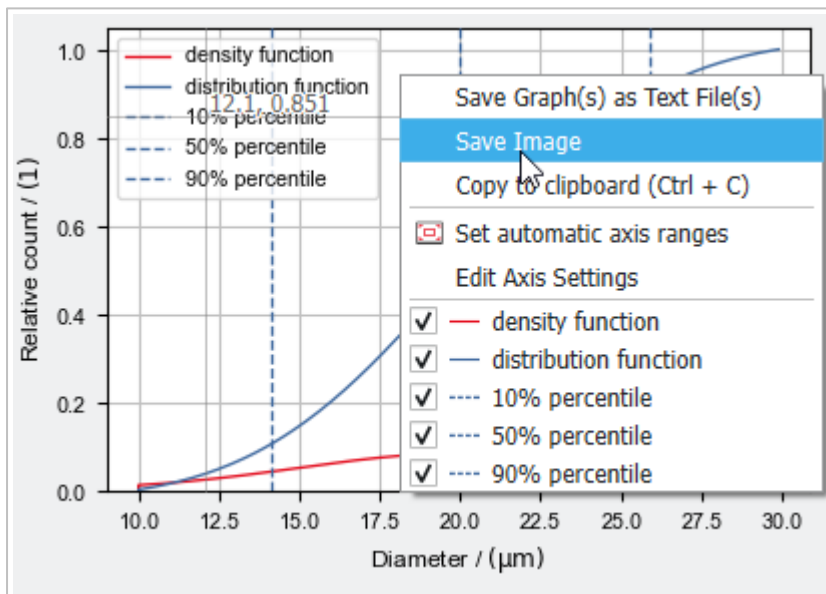
For all distribution options (Gaussian, Probability Distribution and Log-Normal) on the right of the dialog the distribution is visualized in a 2D plot.

The **red** line shows the density distribution defined by Mean Value, Standard Deviation and Distribution Width. It displays how many objects of which diameter will be generated in percent. The **blue** curve shows the cumulative distribution.

The three **dashed blue** lines show the diameter values for 10% percentile, 50% percentile and 90% percentile of the distribution. For example, if the distribution is given for diameters as shown in the screenshot above, on average, 10% of the objects have a diameter smaller than 14 μ m (10% percentile), and 90% of the generated objects have a diameter smaller than 26 μ m (90% percentile). For further explanations, see the [Wikipedia](#) article.

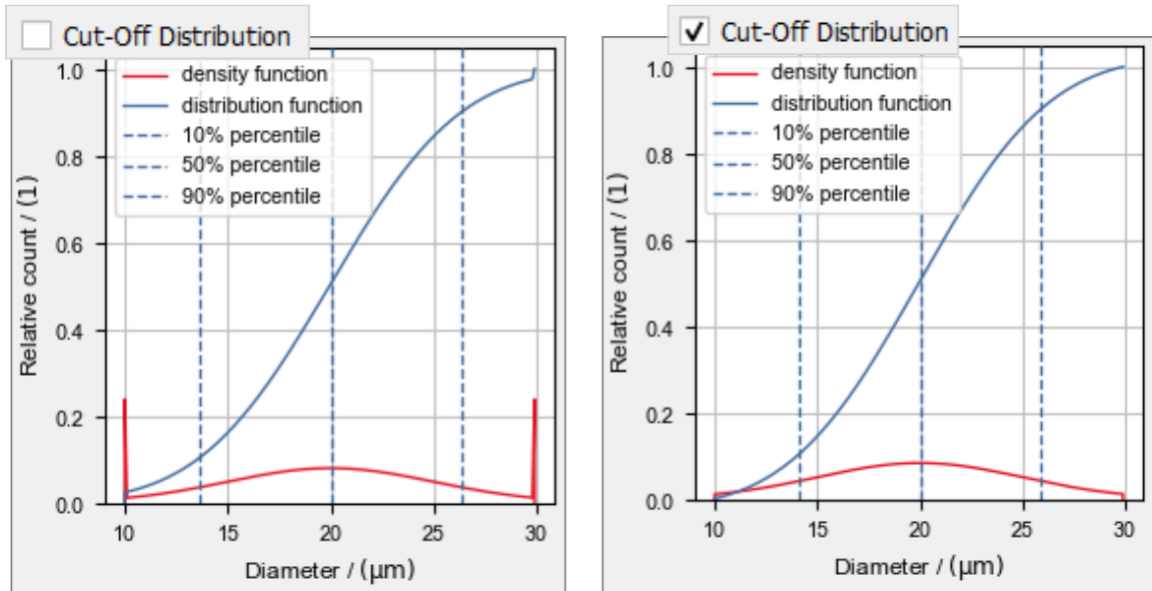
Right-clicking into the plot opens a dialog to **save** the plot or to **Edit the Axis Settings**. Checking or unchecking the checkboxes next to the graph names decides which curves should be displayed.

More information about these options can be found in the [Result Viewer](#) User Guide.

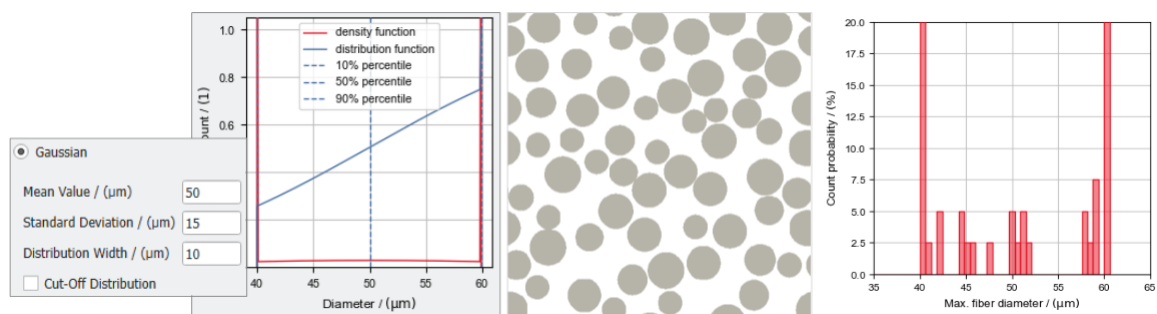


If **Cut-Off Distribution** is checked, the distribution is truncated at the bounds. This means, that all values outside the bounds are dropped and not considered for

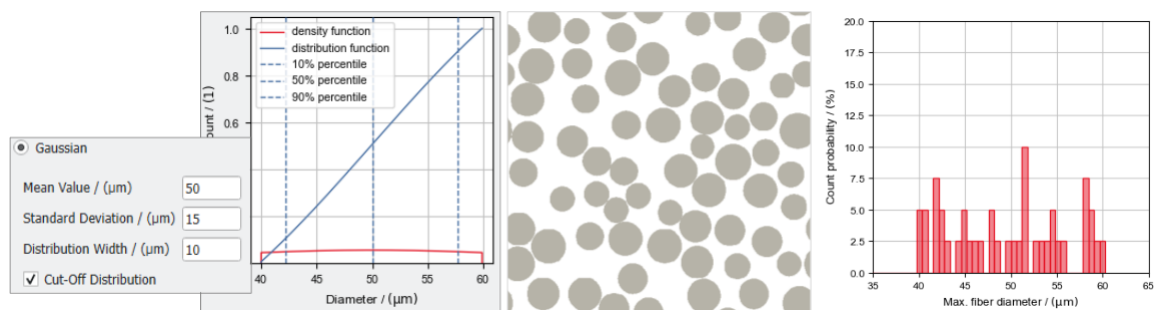
generation. If this option is not checked, then all values that are outside of the bounds are set to be on the distribution bound. Not checking this option leads to an accumulation of values on the bounds.



In the following example, leaving **Cut-Off Distribution** unchecked leads to many objects with diameters of 40 or 60 μm .



In contrast, checking **Cut-Off Distribution** leads to more grains with diameter of 50 μm .



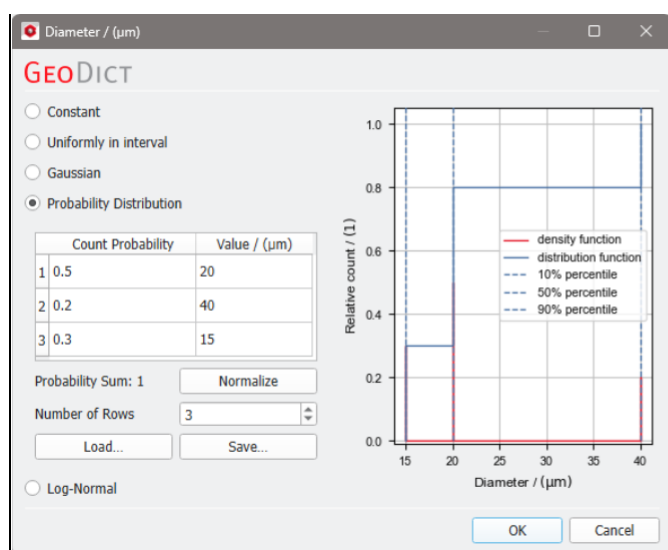
Further details on Gaussian distributions can be found, e.g., on [Wikipedia](https://en.wikipedia.org/wiki/Normal_distribution) on Normal (or Gaussian) distributions.

✓ Probability Distribution

The **Probability Distribution** table allows to enter user-defined probability distributions. The **Number of Rows** can be increased or decreased to enter as many value pairs as desired. The **Value** corresponds to the chosen property, e.g., diameter, length, or angle. The **Count Probability** of the values must lay between 0 and 1 and their sum must be equal to 1.

Especially for large tables, it is useful to observe the value of **Probability Sum**, i.e., the sum of the count probabilities. When the **Probability Sum** is not equal to 1, click the **Normalize** button to automatically round the **Count Probability** values.

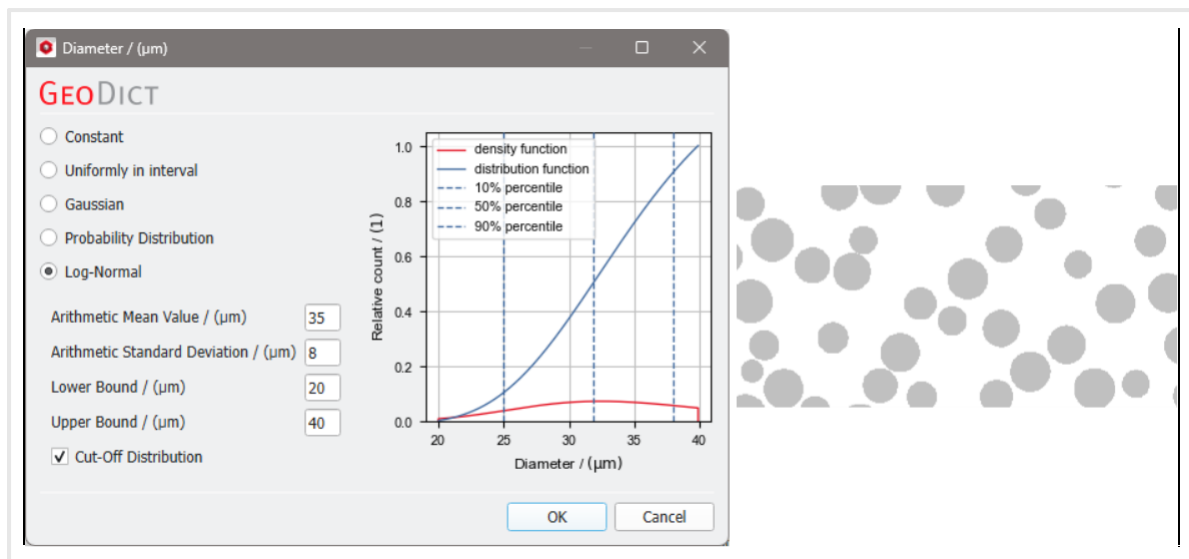
The buttons **Load** and **Save** allow loading a previous probability distribution and saving the current one for later use.



✓ Log-Normal

The **Log-Normal** distribution describes the situation in which the logarithm of the diameter values follows a normal distribution.

The diameter values group around the entered **Arithmetic Mean Value** and scatter according to the entered **Arithmetic Standard Deviation**. The values in **Lower Bound** and **Upper Bound** restrict the possible values that the random diameters can take to the given interval.



Fiber Overlap

The **Fiber Overlap** tab contains options dealing with how to define the Material ID in locations where materials in the structure overlap. The overlap locations may exhibit other properties than those of the original materials.

Create Options Fiber Options **Fiber Overlap** Result Options

Material ID Mode Material ID per Object-Type

☐ Resolve Overlap

☐ Mark Contact Voxels

Default Overlap Material (ID 02) Cellulose (Solid) [Overlap]...

Number of Overlap Rules 1

	Material ID 1	Material ID 2	Overlap Material ID
1	01 Cellulose (Solid)	01 Cellulose (Solid)	01 Cellulose (Solid)

✓ Material ID Mode

Through the **Material ID Mode**, select between applying the Material ID based on the materials or the types of objects present in the structure.

Material ID Mode Material ID per Object-Type

Material ID per Object-Type

Material ID per Material

✓ Resolve Overlap

If **Resolve Overlap** is checked, the overlap of objects is not assigned to a new Material ID. Instead, the water-shed algorithm is used to decide which of the overlap voxels belongs to which object in a post-processing step. Thus, each overlap voxel is assigned

to one specific object. This option needs more memory and a longer run-time.

In detail, the **Resolve Overlap** algorithm starts with computing a distance map for the overlap voxels, i.e., it computes the distance to the next object for each overlap voxel. On this distance map the watershed algorithm is run using all voxels belonging to an object as seeds. There, all voxels contained in the same object have the same Material ID. Thus, the overlap area is filled with the object IDs according to the distance map.

To mark the contact voxels between the objects with a separate Material ID, select **Mark Contact Voxels** and choose a **Contact Material** from the **Material Database**.

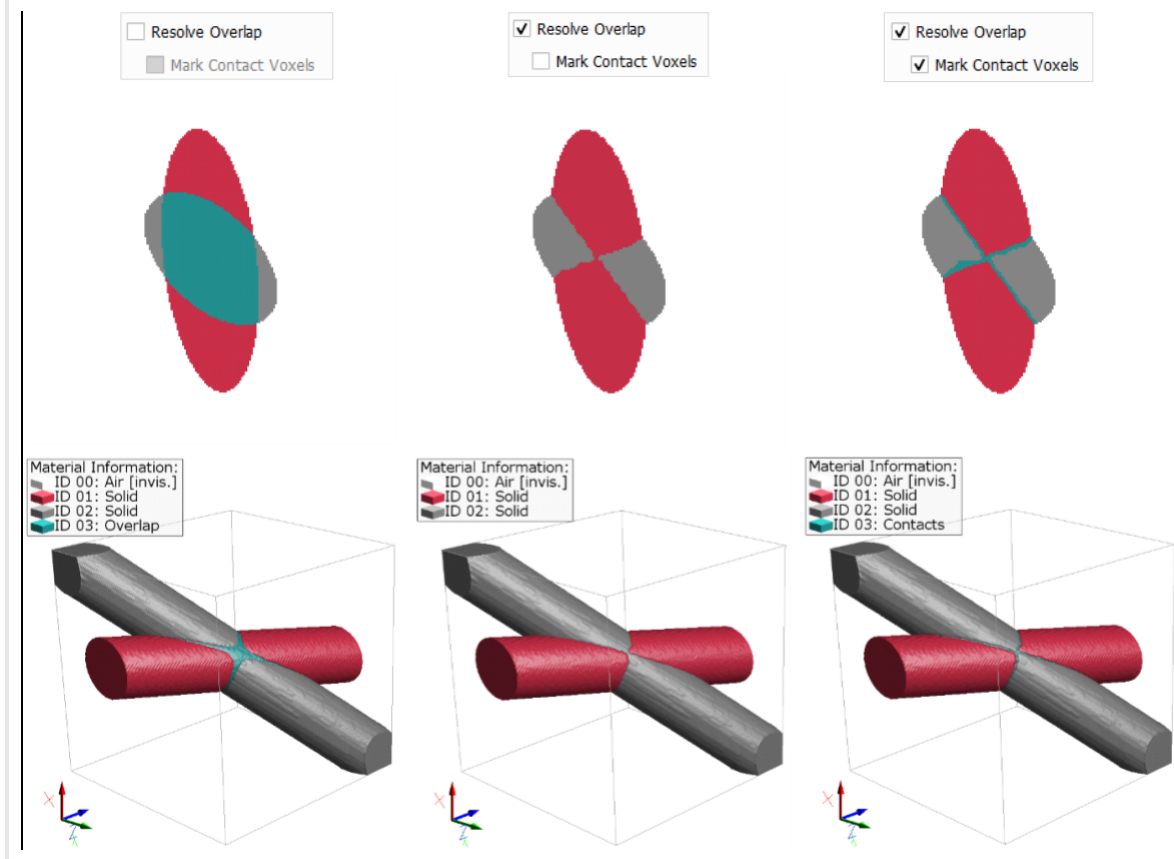
The voxels, where two or more objects IDs meet, are marked as contact voxels, by reassigning them with a new Material ID. Thus, the layer of contact voxels always has a thickness of two voxels.

☒ **Resolve Overlap**

☒ **Mark Contact Voxels**

Contact Material (ID 03) Contact (Solid)...

In the following observe the resulting Material IDs for the overlap for not resolved, resolved and resolved overlap with marked contact voxels, while all other settings are kept the same.



Overlap Rules and Default Overlap Material

Default Overlap Material controls the material assigned to the regions where objects of the generated structure overlap and is only available if [Resolve Overlap](#)⁶¹ is disabled. The Material ID of these regions is chosen by default as the next available Material ID. The material can be changed by clicking on the button.

Overlap rules can be set to control how the overlap between Material IDs should be handled in the structure. You can set up to 100 rules by selecting a number in the box for **Number of Overlap Rules**, and then define these rules in the panel below.

The materials shown in the panel (as buttons or pull-down menu) correspond to the materials selected under the **Fiber Options** tab.

For example, you simulate a structure made of plastic fibers that melt together using a negative **isolation distance** as a **Generation and Overlap Mode** under the **Create Options** tab. Then, you can set up a rule that defines what happens with the Material ID at the melting location.

In the example shown below, three rules have been defined: The overlap of objects with Material ID 1 (dark red) will be assigned to ID 3 (turquoise). The overlap of objects with Material ID 2 (gray) will be assigned to ID 4 (blue) and the overlap of ID 1 and ID 2 will be assigned to ID 5 (purple). For all other possible overlap cases, the **Default Overlap Material ID** is applied.

Number of Overlap Rules

	Material ID 1	Material ID 2	Overlap Material ID
1	01 Glass (Solid) ▾	01 Glass (Solid) ▾	03 Glass (Solid) ▾
2	02 Glass (Solid) ▾	02 Glass (Solid) ▾	04 Solid ▾
3	01 Glass (Solid) ▾	02 Glass (Solid) ▾	05 Solid ▾

✓ Overlap Results

Note, that the results for volume in the resulting report do not change for different overlap rules, as the values are computed before the post-processing is applied.

In the three examples given for **Resolve Overlap**, the **Absolute object distribution** is shown below.

Absolute object distribution:

	Count	Volume / (%)	Grammage / (g/m ²)	Density / (g/cm ³)	Weight / (%)
Total	realized: 2 target: 2 error: 0.00	realized: 11.09 target: --- error: ---	realized: --- target: --- error: ---	realized: --- target: --- error: ---	realized: --- target: --- error: ---
Object type 1	realized: 1 target: 1 error: 0.00	realized: 4.42 target: --- error: ---	realized: --- target: --- error: ---	realized: --- target: --- error: ---	realized: --- target: --- error: ---
Object type 2	realized: 1 target: 1 error: 0.00	realized: 6.68 target: --- error: ---	realized: --- target: --- error: ---	realized: --- target: --- error: ---	realized: --- target: --- error: ---

For the volume percentages of the final structure, refer to the **Statistics** in the left of the GeoDict main window. Either just hover over the statistics bar or unfold the Statistics section in the project status panel below.

Here, the volume statistics are shown for the example with default overlap rules. The red fiber has 3.55% of the volume, the gray fiber has 5.81% and the overlap 1.73%.

In the result file the overlap volume is proportionally added to the volume of the overlapping fibers. Here, the red fiber obtains $3.55\% + (1.73/2)\% = 4.415\%$. Rounded, this results in the 4.42% shown in the report.

88.9		Statistics for 3D Geometry	
C:/User Guide		GAD Objects 3D: 2	
Structure (200x200x200, 1 µm)			
GAD Objects (2)			
Statistics			
3D			
GAD Objects : 2			
Material IDs			
00 88.91 % (7112422 Voxel)			
01 3.55 % (284224 Voxel)			
02 5.81 % (465160 Voxel)			
03 1.73 % (138194 Voxel)			

	Volume %	Voxel Number
Material ID00	88.91	7112422
Material ID01	3.553	284224
Material ID02	5.815	465160
Material ID03	1.727	138194
Porosity	88.91	7112422
Air	88.91	7112422
Solid Volume	11.09	887578
Manual 1	3.553	284224
Manual 2	5.815	465160
Manual 3	1.727	138194



Result Options

The generated structure is always saved as a **GeoDict structure file (*.gdt)** (GeoDict binary data). The file is placed in an automatically created result folder inside the chosen project folder (**File** → **Choose Project Folder...** in the menu bar).

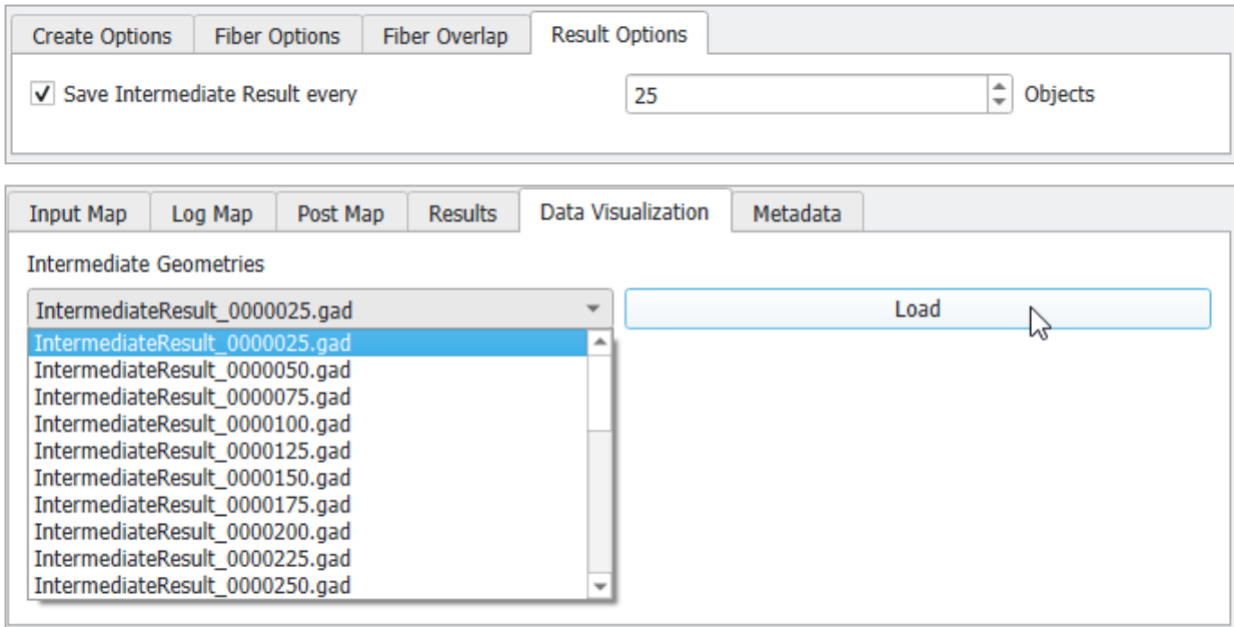
The result file as well as the result folder take the name entered as **Result File Name (*.gdr)** at the top of the dialog.

An additional option to save the generated structure data is to check **Save Intermediate Result every** and enter a number of **Objects** in the box. As objects are added to the structure during the generation, an intermediate result file is saved each time the number of placed

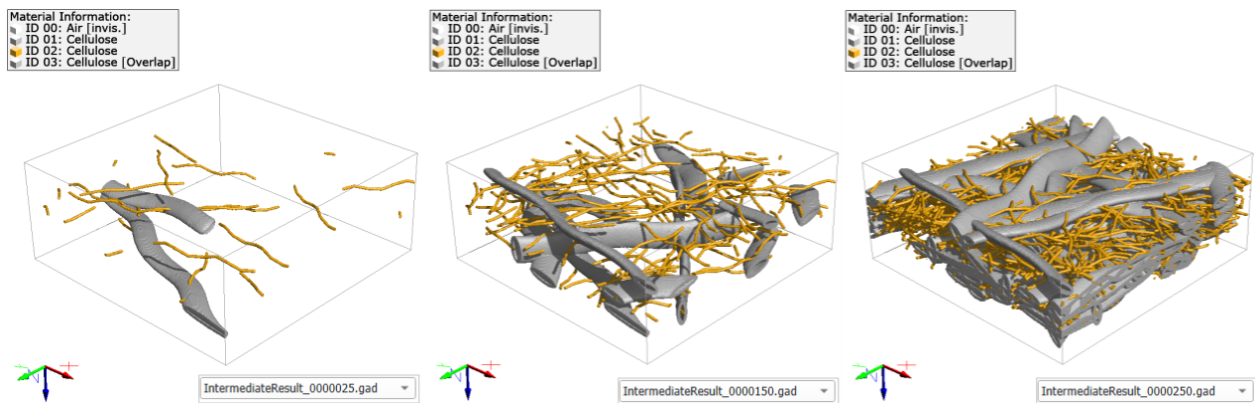
objects reaches a multiple of the entered value.

This option may be interesting when studying the properties of a series of structures with increasing density.

After running the generation, the intermediate geometries can be found as ***.gad** analytic files in the result folder and can be loaded directly from the **Result Viewer** of the *.gdr result file.



Below find an example for the creation of 250 fibers. Observe how more and more fibers are added.



1.1.2 Results

The generated structure is shown in the visualization area. Learn more about visualization in GeoDict in the **Visualization** chapter.

The result file is automatically opened in the Result Viewer and shows structure statistics in the **Results-Report** and **Results-Plot** tabs. Additionally, it offers 3D **Data Visualization** options depending on the generation settings. Find more information on GeoDict result files in the **Result Viewer** chapter.

Results

✓ Report

The first two tables show the **Absolute** and **Relative object distribution** for all object types.

Input Map

Log Map

Post Map

Results

Data Visualization

Metadata

Report

Plots

Map

Absolute object distribution:

	Count	Volume / (%)	Grammage / (g/m ²)	Density / (g/cm ³)	Weight / (%)
Total	realized: 1794 target: --- error: ---	realized: 34.99 target: 35.00 error: -0.01	realized: --- target: --- error: ---	realized: --- target: --- error: ---	realized: --- target: --- error: ---
Object type 1	realized: 992 target: --- error: ---	realized: 17.47 target: 17.50 error: -0.03	realized: --- target: --- error: ---	realized: --- target: --- error: ---	realized: --- target: --- error: ---
Object type 2	realized: 801 target: --- error: ---	realized: 17.52 target: 17.50 error: 0.02	realized: --- target: --- error: ---	realized: --- target: --- error: ---	realized: --- target: --- error: ---

Stopping criterion error: -0.016 %

Relative object distribution:

	Count / (%)	Volume / (%)	Weight / (%)
Object type 1	realized: 55.35 target: --- error: ---	realized: 49.93 target: 50.00 error: -0.14%	realized: --- target: --- error: ---
Object type 2	realized: 44.65 target: --- error: ---	realized: 50.07 target: 50.00 error: 0.14%	realized: --- target: --- error: ---

Maximal probability error: 0.14%

Afterwards follows a section regarding the overlap between different object types.

Overlap Information:

Overlap of objects of different type: 3.94526 %

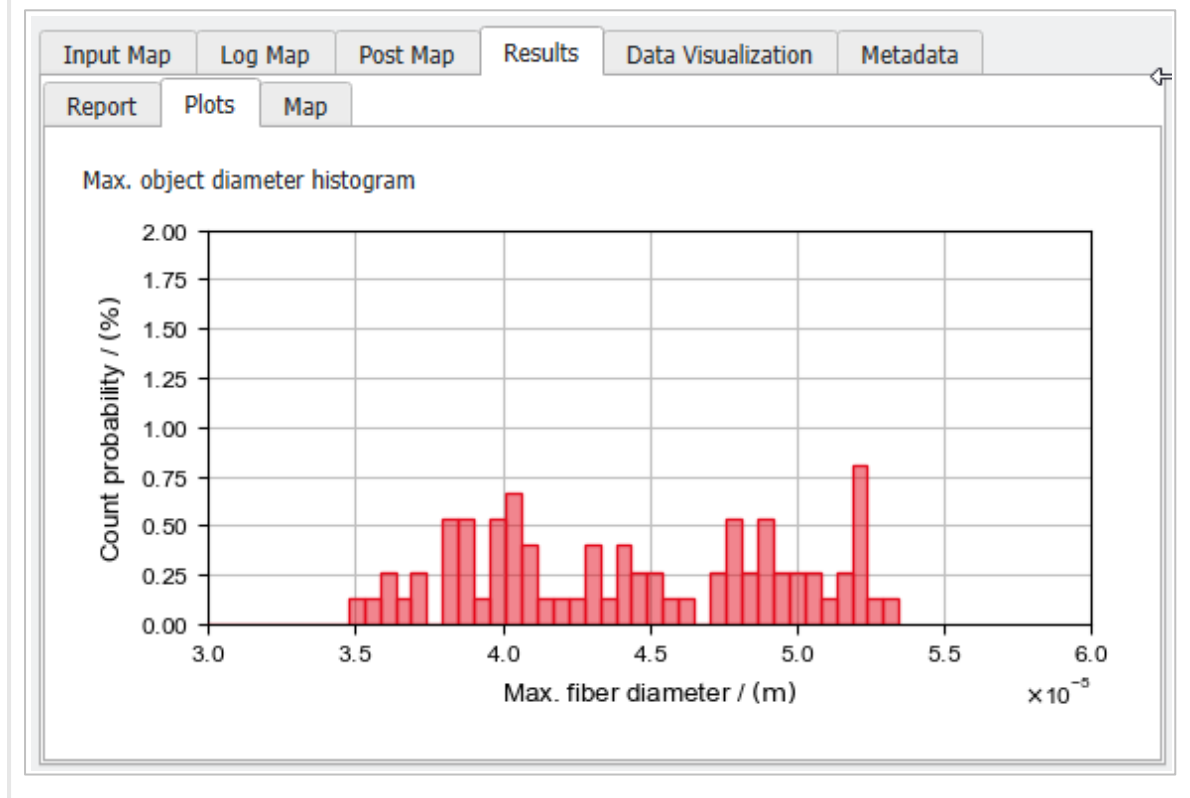
(This overlap may be handled in the geometry post-processing, by the specified overlap rules or by resolve overlap. Both options may change the object type volume fractions.)

Then, the realized, the target, and the error direction tensors for all object types are given. Find below different examples of the direction tensors with isotropic orientation, anisotropy parameters, or orientation tensors.

Direction-tensor object type 1:	Direction-tensor object type 1:	Direction-tensor object type 1:																																																																																	
Anisotropy 1: Target 1.000 Anisotropy 2: Target 1.000 Realized direction tensor: <table> <tr><td>0.3320</td><td>0.0036</td><td>0.0084</td></tr> <tr><td>-</td><td>0.3338</td><td>-0.0036</td></tr> <tr><td>-</td><td>-</td><td>0.3342</td></tr> </table> Target direction tensor: <table> <tr><td>0.3333</td><td>0.0000</td><td>0.0000</td></tr> <tr><td>-</td><td>0.3333</td><td>0.0000</td></tr> <tr><td>-</td><td>-</td><td>0.3333</td></tr> </table> Error tensor: <table> <tr><td>-0.14%</td><td>0.36%</td><td>0.84%</td></tr> <tr><td>-</td><td>0.05%</td><td>-0.36%</td></tr> <tr><td>-</td><td>-</td><td>0.09%</td></tr> </table>	0.3320	0.0036	0.0084	-	0.3338	-0.0036	-	-	0.3342	0.3333	0.0000	0.0000	-	0.3333	0.0000	-	-	0.3333	-0.14%	0.36%	0.84%	-	0.05%	-0.36%	-	-	0.09%	Anisotropy 1: Target 100.000 Anisotropy 2: Target 1.000 Realized direction tensor: <table> <tr><td>0.5026</td><td>-0.0276</td><td>-0.0003</td></tr> <tr><td>-</td><td>0.4970</td><td>0.0000</td></tr> <tr><td>-</td><td>-</td><td>0.0004</td></tr> </table> Target direction tensor: <table> <tr><td>0.4998</td><td>0.0000</td><td>0.0000</td></tr> <tr><td>-</td><td>0.4998</td><td>0.0000</td></tr> <tr><td>-</td><td>-</td><td>0.0004</td></tr> </table> Error tensor: <table> <tr><td>0.28%</td><td>-2.76%</td><td>-0.03%</td></tr> <tr><td>-</td><td>-0.28%</td><td>0.00%</td></tr> <tr><td>-</td><td>-</td><td>0.00%</td></tr> </table>	0.5026	-0.0276	-0.0003	-	0.4970	0.0000	-	-	0.0004	0.4998	0.0000	0.0000	-	0.4998	0.0000	-	-	0.0004	0.28%	-2.76%	-0.03%	-	-0.28%	0.00%	-	-	0.00%	Realized direction tensor: <table> <tr><td>0.8080</td><td>0.0029</td><td>-0.0074</td></tr> <tr><td>-</td><td>0.0934</td><td>0.0000</td></tr> <tr><td>-</td><td>-</td><td>0.0986</td></tr> </table> Target direction tensor: <table> <tr><td>0.8000</td><td>0.0000</td><td>0.0000</td></tr> <tr><td>-</td><td>0.1000</td><td>0.0000</td></tr> <tr><td>-</td><td>-</td><td>0.1000</td></tr> </table> Error tensor: <table> <tr><td>0.80%</td><td>0.29%</td><td>-0.74%</td></tr> <tr><td>-</td><td>-0.66%</td><td>0.00%</td></tr> <tr><td>-</td><td>-</td><td>-0.14%</td></tr> </table>	0.8080	0.0029	-0.0074	-	0.0934	0.0000	-	-	0.0986	0.8000	0.0000	0.0000	-	0.1000	0.0000	-	-	0.1000	0.80%	0.29%	-0.74%	-	-0.66%	0.00%	-	-	-0.14%
0.3320	0.0036	0.0084																																																																																	
-	0.3338	-0.0036																																																																																	
-	-	0.3342																																																																																	
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-	-	-0.14%																																																																																	

Plots

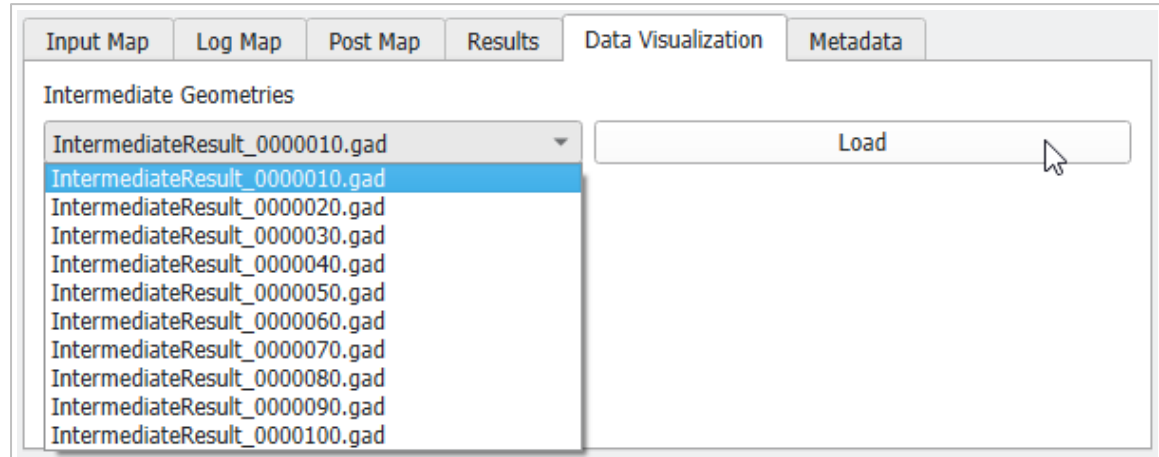
A plot showing the fibers' maximum diameter distribution is shown.



Data Visualization

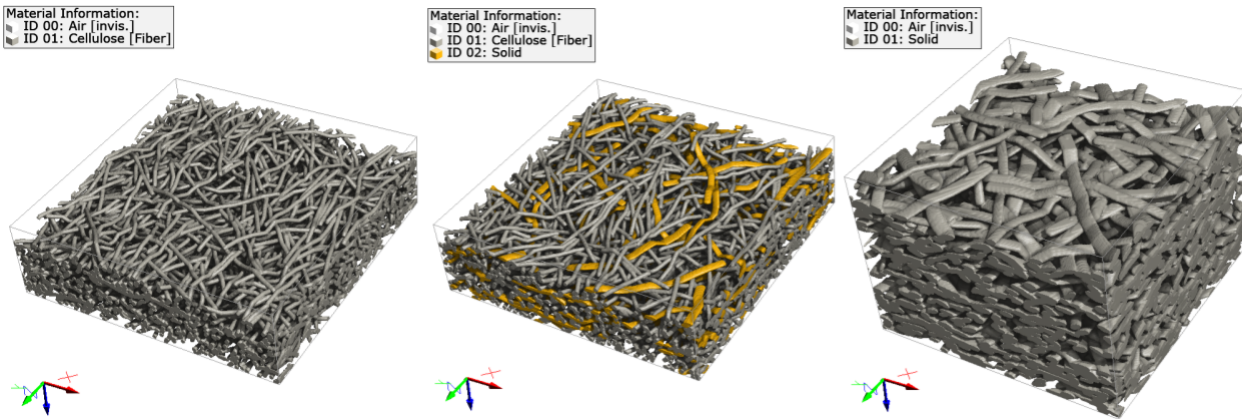
Intermediate Geometries

When selecting **Save Intermediate Results every # Objects** under the **Result Options** tab, you can open the intermediate geometry files (*.gad) after selecting them in the pull-down menu.



1.2 Lay-Down Cellulose Fibers

Using Lay-Down Cellulose Fibers you can form a new paper structure by a lay-down process. With the selection of **Lay-Down Cellulose Fibers** from the **PaperGeo** section pull-down menu, fibers fall from their initial positions during the paper generation and form a paper structure.



The Lay-Down Cellulose Fibers command:

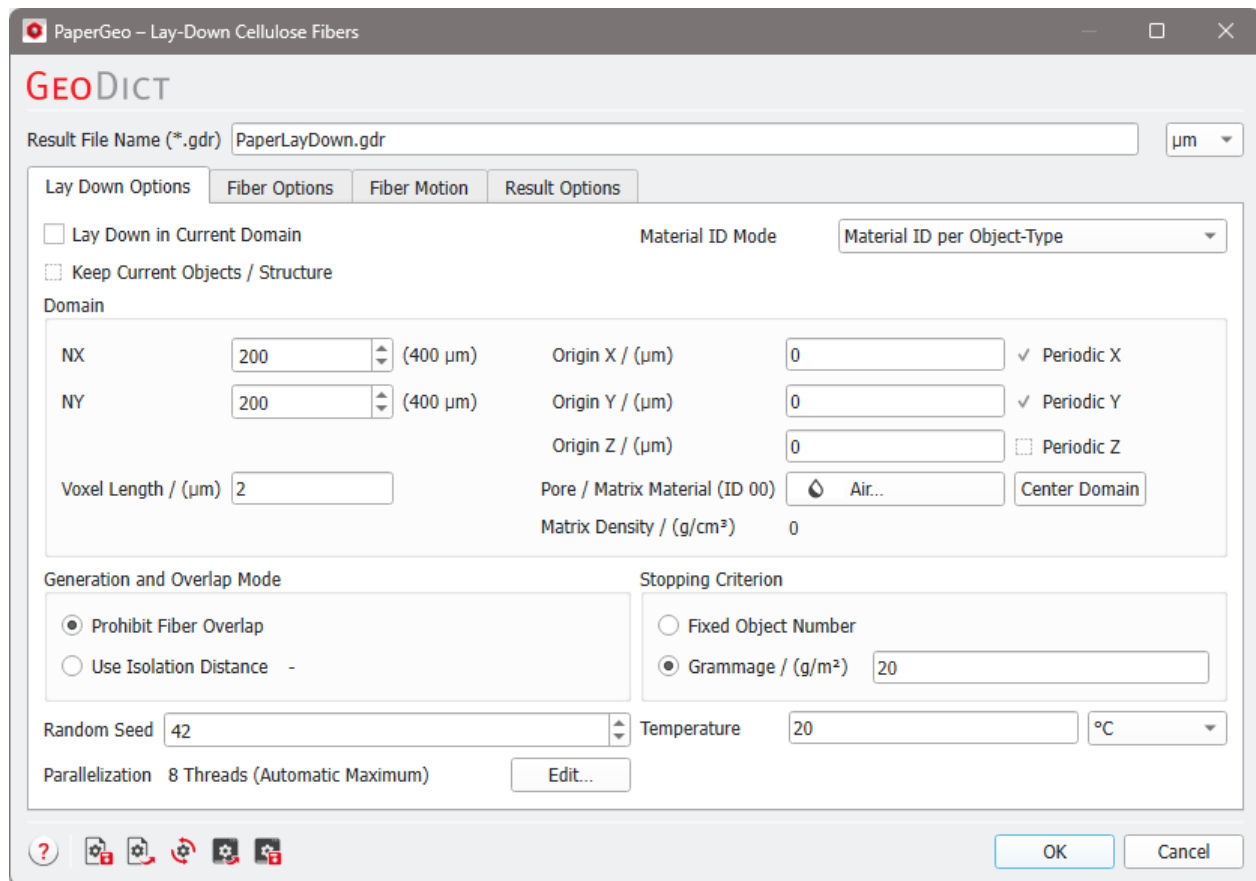
- [Options](#)⁶⁹
Set the parameters for your paper lay-down.
- [Results](#)⁸³
Inspect the result file in the result viewer.

1.2.1 Options

At the top left of the dialog, the name for the file containing the generation results can be entered in the **Result File Name (*.gdr)** box. The default name can be kept, or a new name can be chosen, fitting the current project.

The result files are saved in the chosen project folder (**File** → **Choose Project Folder**, in the **Menu bar**). If a GeoDict result file (*.gdr) with the given name already exists in the project folder, a warning message is shown at the start of the creation process. You can either decide to rename the chosen file name to a new one, to cancel the generation process, to overwrite or to back up the old file. When nothing is selected, GeoDict uses the **Back-Up** option after a waiting time.

The available units (m, cm, mm, μm , nm and Inch) are selectable from the pull-down menu at the top right of the dialog. When the units are changed, the entered values are adjusted automatically.



The options are organized into tabs:

- [Lay Down Options](#)⁷¹
Determine general properties of the resulting paper model such as size, resolution, and the stopping criterion for the generation.
- [Fiber Options](#)⁷⁹
Define the geometrical properties of the individual fiber types such as cross-section, length, and orientation. Up to seven different fiber types can be used in one paper structure.
- [Fiber Motion](#)⁸¹
Control the way the fibers are laid down (initial fiber positions and their movements to the final position).
- [Result Options](#)⁸²
Determine how the result files are saved.



Opens the corresponding User Guide section.



Saves the settings to a GeoDict settings file (*.gps).



Loads the settings from a GeoDict settings file (*.gps) or a GeoDict result file (*.gdr).



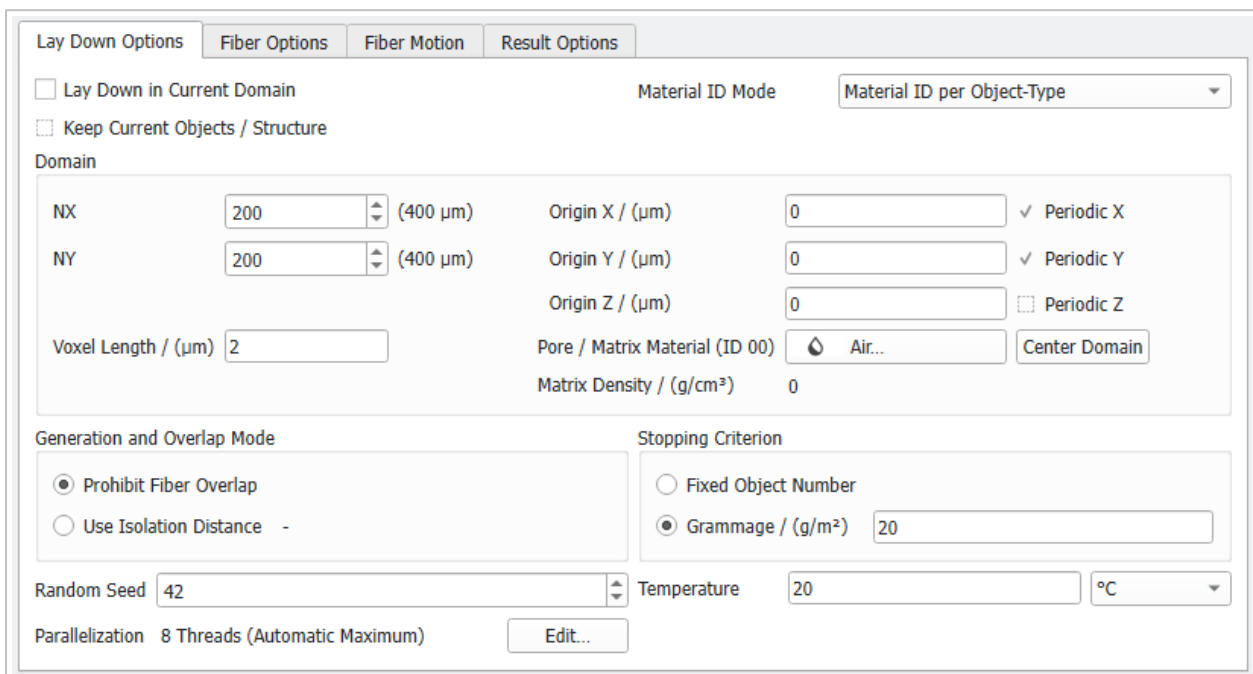
Resets all parameter settings to the built-in default settings.

-  Resets all parameter settings to the saved start-up settings.
-  Saves the current parameter settings as start-up settings.

Each option is explained by a tooltip which appears when resting the mouse over the icon.

Lay Down Options

The general parameters of the paper structure are entered through the **Lay Down Options** tab, and are grouped into **Domain**, **Generation and Overlap Mode**, and **Stopping Criterion** panels and six single options. The three single options in the top control specific **Structure Options**. The other three at the bottom control **General Options**.

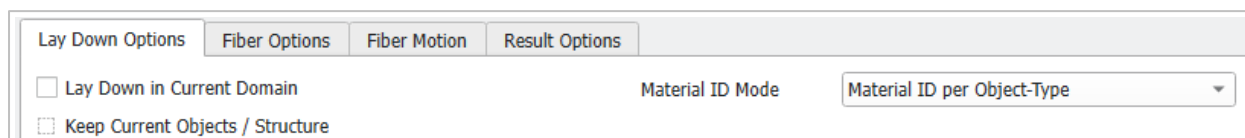


The parameters are organized in the following groups:

- [Structure Options](#)⁷²
Lay-down in a current domain and keep current objects or the structure.
- [Domain](#)⁷³
Define the domain parameters, such as resolution, periodicity, and matrix material.
- [Generation and Overlap](#)⁷⁶
Decide about prohibiting overlap or defining an isolation distance.
- [Stopping Criterion](#)⁷⁶
Define according to which criteria the lay-down should be stopped.
- [General Options](#)⁷⁷
Define the temperature, the random seed, and the number of parallel processes.

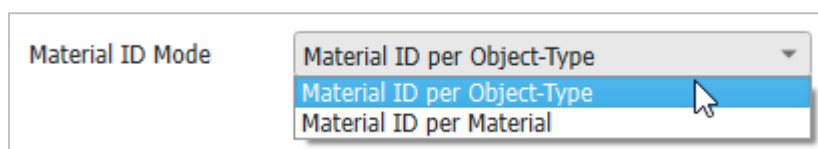
Structure Options

Define the structure options **Material ID Mode**, **Lay Down in Current Domain**, and **Keep Current Objects / Structure**.



Material ID Mode

The **Material ID Mode** pull-down menu allows selecting between applying the Material ID based on the materials or the types of objects (fibers) present in the fibrous structure.



Assigning a **Material ID** is part of the GeoDict Material Database concept, in which objects in the structure are ascribed to an individual material (e.g., glass, cellulose, PET) with specific physical properties.

If selecting **Material ID per Object-Type**, every object type selected under the **Fiber Options** tab is assigned to a different Material ID. Otherwise, the chosen material defines the Material ID. Consider for example four fiber types are chosen, where two of them should be of material cellulose and two should be manual. Then, with **Material ID per Material** selected, the resulting paper structure consists of only two solid Material IDs.

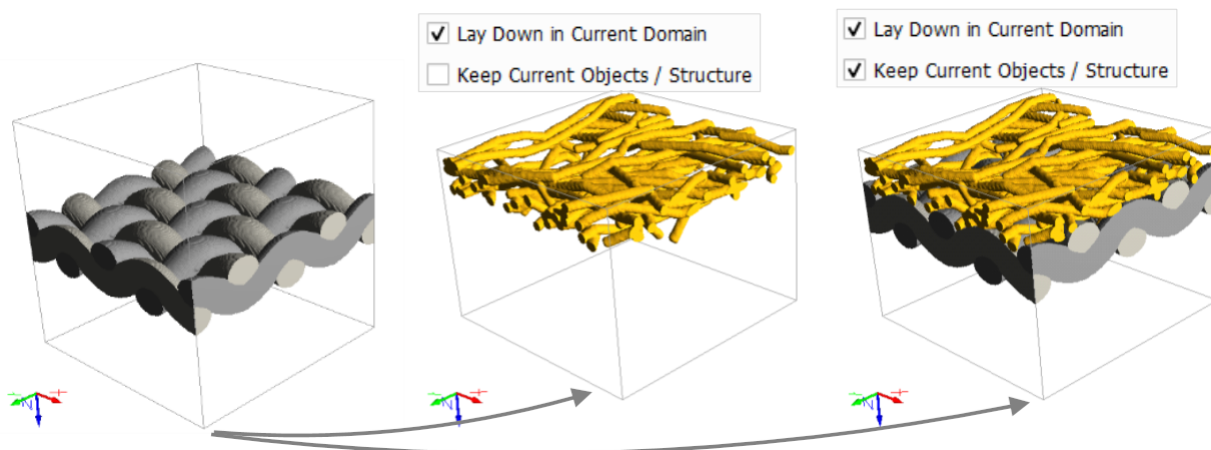
Lay-Down in Current Domain and Keep Current Objects / Structure

When checking **Lay Down in Current Domain**, the parameters of the domain currently in memory are used for the generation of a new structure. Additionally, when **Keep Current Objects / Structure** is checked, the structure in memory is kept and combined with the newly generated paper structure.

Observe the effect that **Create in Current Domain** and **Keep Current Objects / Structure** have on the generation of a paper structure. A woven structure is already in memory (left image) and fibers are laid down in the Z+ direction.

When **Lay Down in Current Domain** is checked but **Keep Current Objects / Structure** is left unchecked (middle image), the yellow fibers fall on the weave, but the weave is deleted after the lay-down operation.

When **Lay Down in Current Domain** and **Keep Current Objects / Structure** are both checked (right image), the gray woven structure is kept, and the yellow fibers are laid over it.



Notice that the domain parameters cannot be modified when **Lay Down in Current Objects / Structure** is checked, because they are kept from the structure already in memory.

Lay Down in Current Domain and **Keep Current Objects / Structure** are useful tools when generating paper structures that are composed by several parts or layers. The previously generated structure is kept, and then, other layers or parts of the structure are added. The size of the final layered structure in the lay-down direction is adjusted automatically.

Domain

The **Domain** panel contains the parameters defining the structure size (**NX**, **NY**) in combination with the resolution (**Voxel Length**), as well as the **Origin** parameters, the **Periodicity** check boxes, the **Center Domain** button, and the **Matrix Material** pull-down menu.

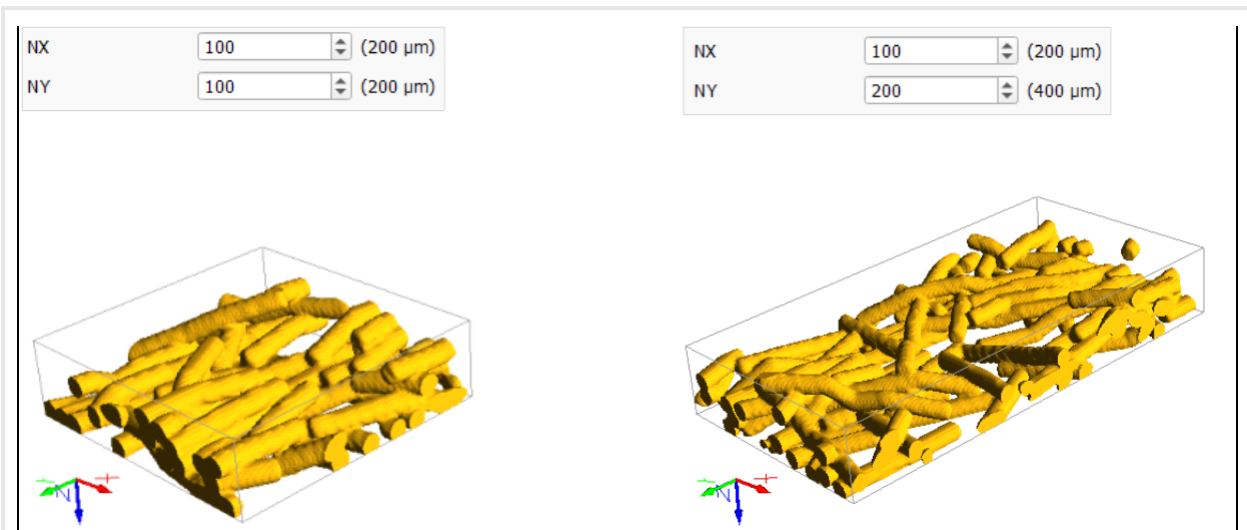
As indicated in the example in the topic [Structure Options](#)⁷², when **Lay Down in Current Domain** is unchecked, the size of the domain in Z-direction (paper thickness) is determined by the thickness of the laid-down fiber structure.

The periodicity boxes are always checked for **Lay Down Cellulose Fibers**, because the objects are always laid down periodically.

Domain					
NX	200	(400 μm)	Origin X / (μm)	0	☒ Periodic X
NY	200	(400 μm)	Origin Y / (μm)	0	☒ Periodic Y
			Origin Z / (μm)	0	☐ Periodic Z
Voxel Length / (μm)	2		Pore / Matrix Material (ID 00)	Air...	Center Domain
			Matrix Density / (g/cm^3)	0	

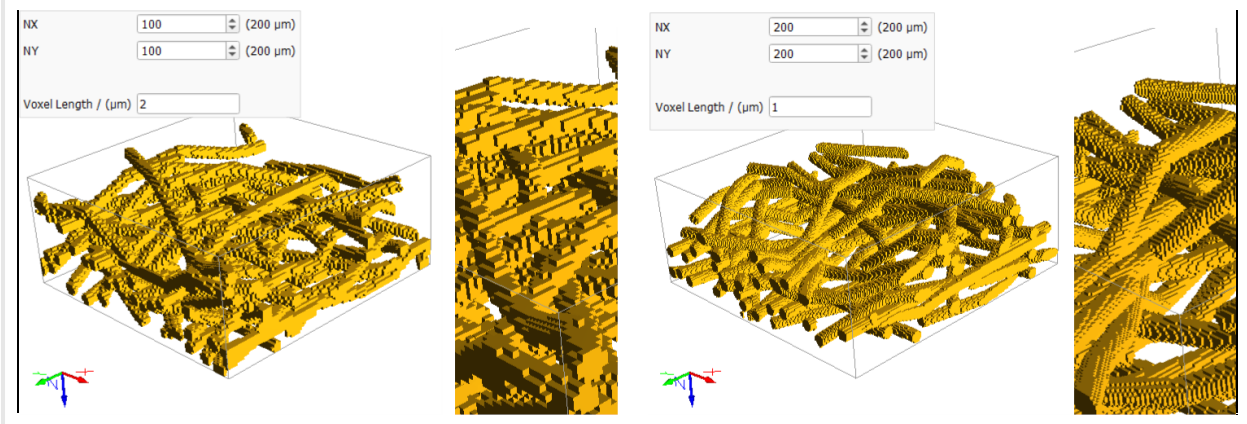
✓ NX, NY, and Voxel Length

In GeoDict, a structure is internally represented by rectangular 3D arrays of equally sized boxes, hereafter called volume elements or **voxels**. **NX** and **NY** are the number (N) of voxels in X and Y directions. Varying the values for NX and NY has the effect of changing the size of the laid down structure in the given direction.



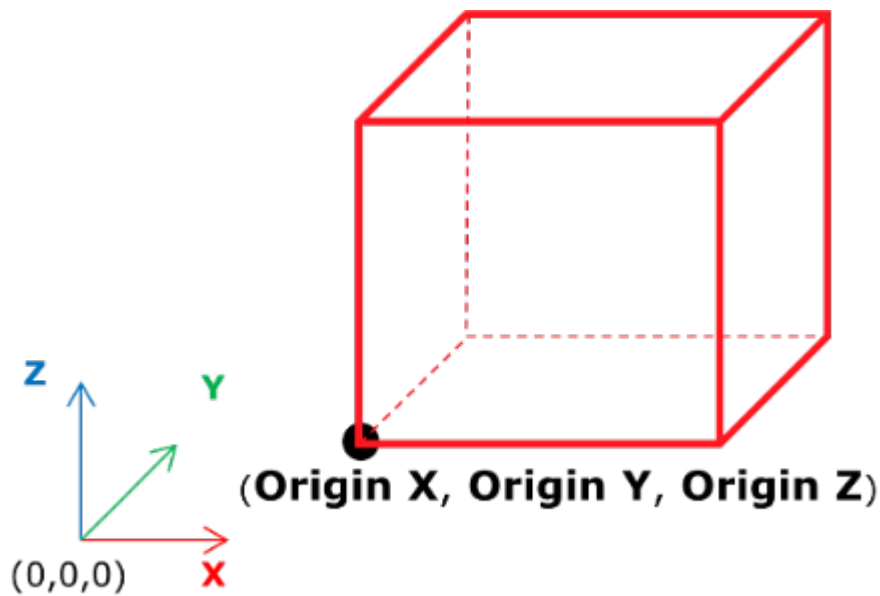
The **Voxel Length** is the size of one voxel in the chosen units. Low values for voxel length in combination with high values for NX and NY result in a higher resolution, but also in a higher computational time. After setting the values of NX, NY, and Voxel Length, the physical structure size is automatically displayed in the chosen units.

Observe how keeping the structure size a constant $200\ \mu\text{m} \times 200\ \mu\text{m}$ (grammage $15\ \text{g/m}^2$) while decreasing the Voxel Length from $2\ \mu\text{m}$ to $1\ \mu\text{m}$ has the effect of refining the laid down fibers by increasing the resolution. Since the voxel length has decreased to half, the size of the structure is kept by doubling the **NX** and **NY** values from 100 to 200.

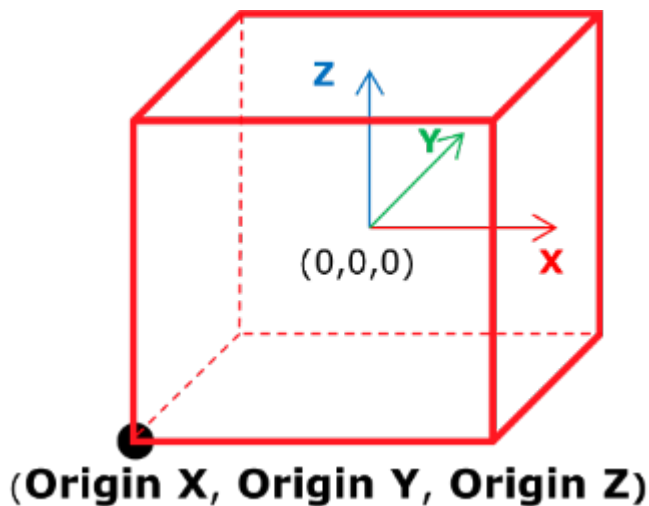


✓ Origin X, Origin Y, Origin Z, and Center Domain

The **Origin X**, **Origin Y**, and **Origin Z** parameters, together with the **Center Domain** button, determine the placement of the structure in the physical space. Zero values for Origin X, Origin Y, and Origin Z mean that the point with (0, 0, 0) coordinates is located at the lower left corner of the structure.



When clicking the **Center Domain** button, the (0, 0, 0)-point is set to the center of the structure as shown below.



✓ Periodicity

Structures generated by laying-down cellulose fibers are, by default, periodic in the X- and Y-directions, but cannot be made periodic for the direction from which they fall (Z-direction). More details on periodicity are explained for the [Create Options Domain](#)¹⁴ parameters.

✓ Pore / Matrix Material and Matrix Density

Choose the material of the matrix around the fibers from the material selector, as explained for the [Create Options Domain](#)¹⁶.

Generation and Overlap

The options in the **Generation and Overlap Mode** panel control the relative position among the fibers in the generated structure (or with the objects of the structure currently in memory).

Generation and Overlap Mode

☒ Prohibit Fiber Overlap

☐ Use Isolation Distance -

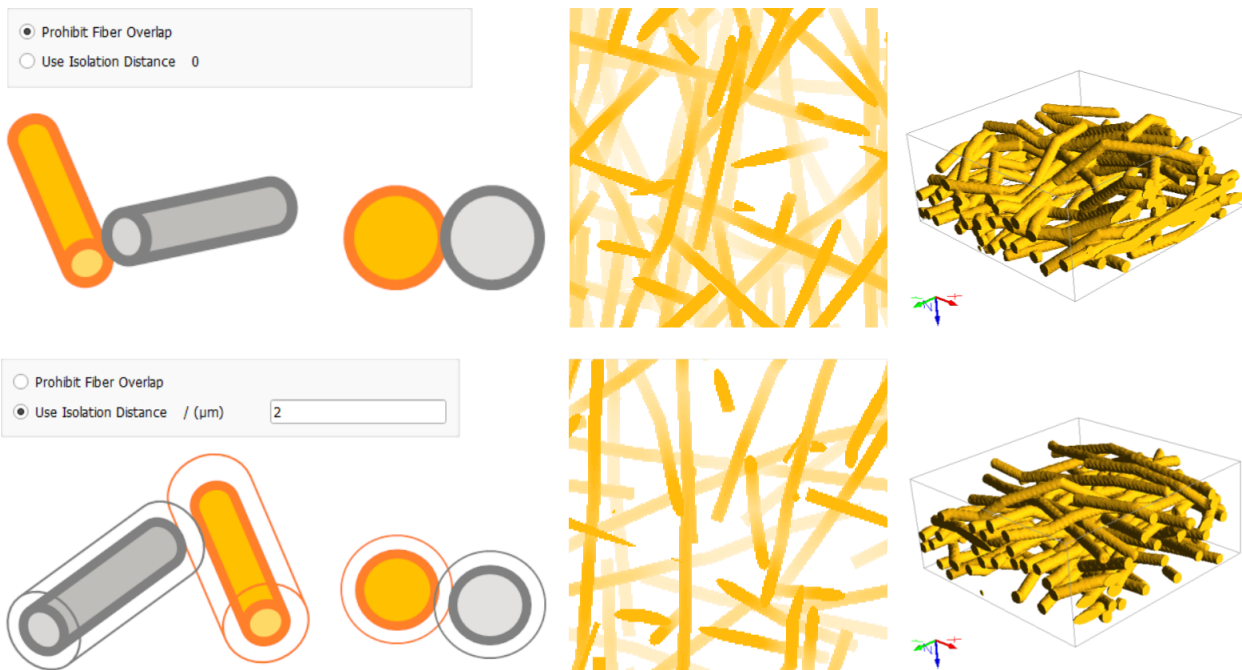
Fibers may touch (but not overlap) when **Prohibit Fiber Overlap** is selected.

Fibers may not touch when **Use Isolation Distance** is selected, and a positive value is entered. Then, the gaps between fibers have at least this preset distance.



Note! The choice of **Use Isolation Distance** may lead to long computation times when working with large structures and/or small segment lengths for the fibers. How to control the segment length is described in the topic [Shape Tab](#)⁴⁸.

When choosing a negative isolation distance, fibers can overlap by this value. This option can be used to simulate fibers that melt together, or that deform when touching other fibers.



Stopping Criterion

Define after which criteria the lay-down should be stopped. The parameters **Fixed Object Number** and **Grammage**, in the **Stopping Criterion** panel, control whether the pile process should be continued, or the material is "ready". The analysis of the results file (*.gdr file) shows any disparity between the achieved result values and the desired ones.

These options work in the same way as for [Create Cellulose Fibers](#)²³.

Stopping Criterion

☐ Fixed Object Number

☒ Grammage / (g/m²)

When **Fixed Object Number** is chosen as stopping criterion, PaperGeo places the given number of fibers in the structure and then the generation stops.

The **Grammage / (g/m²)** determines the weight of the resulting paper/cellulose structure.

When **Grammage** is checked as stopping criterion, the **Density / (g/cm³)** of the fiber material(s) can be seen in the materials panels under the **Fiber Options** tab or must be entered if **Manual** instead of a **Database Material** (such as cellulose) is chosen.

General Options

Define the general parameters temperature, random seed and parallelization.

Random Seed

Temperature °C

Parallelization 8 Threads (Automatic Maximum) [Edit...](#)

Temperature

When **Grammage** (or **Density** or **Object Weight Percentage**) is chosen as **Stopping Criterion**, a temperature can be entered. The temperature is considered for materials with temperature dependent density.

Choose the temperature in Kelvin, Celsius, or Fahrenheit.

Temperature

°C

K

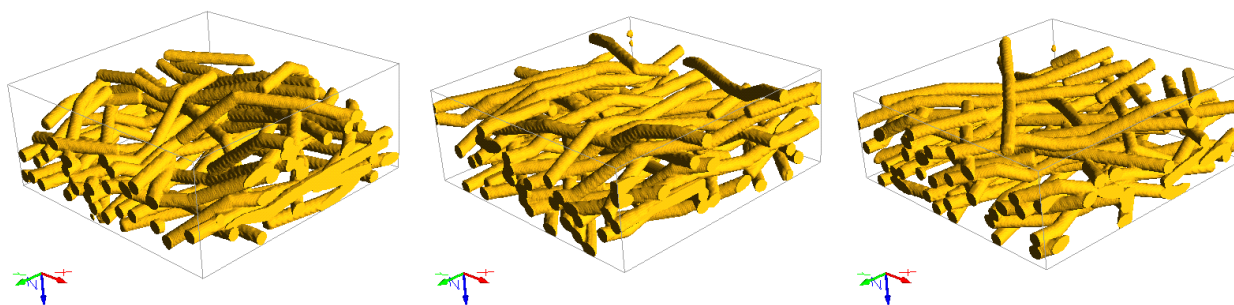
°C

°F

Random Seed

Random Seed initializes the random number generator behind the structure generator. Changing its value produces different sequences of random numbers and hence, different realizations of the specified structure. If all settings are equal, generating with the same **Random Seed** value produces exactly the same structure, as shown by the **Structure ID** number in the Status section. The **Random Seed** is a non-negative integer number, it increases automatically with every generation run.

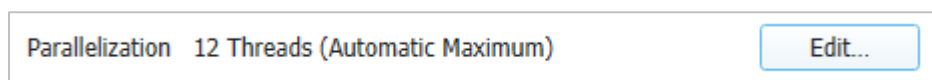
Varying the **Random Seed** allows generating different samples of the same structure for a series of experiments. In the following examples, all parameters are unchanged while the random seed is modified with every generation run.



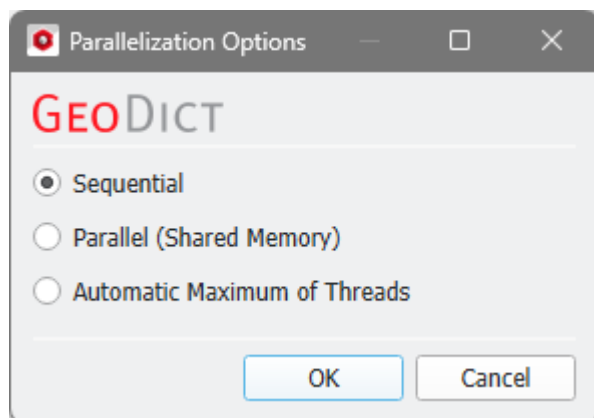
Parallelization

Control how many threads are used for the computation. Parallelization is possible if your license and hardware allow it.

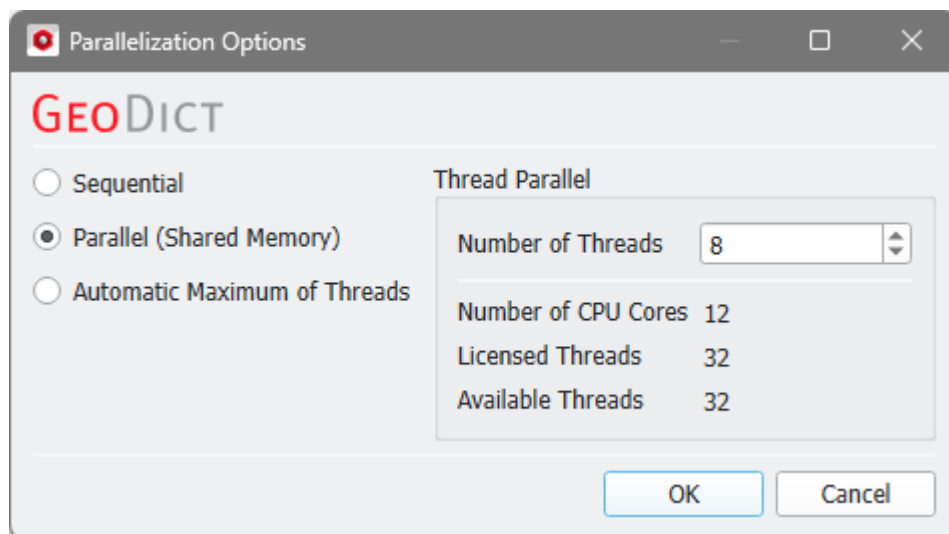
The **Parallelization Options** dialog opens when clicking the **Edit** button and you can choose between **Sequential**, **Parallel (Shared Memory)**, or **Automatic Maximum of Threads**.



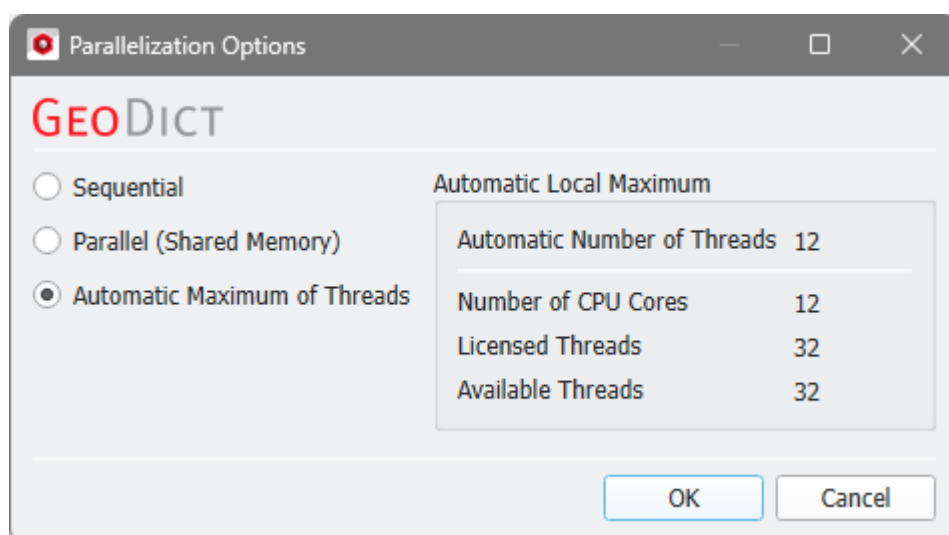
Selecting **Sequential** will not apply parallelization and only one thread is used for the computation.



When **Parallel (Shared Memory)** is selected, the **Number of Threads** can be entered. Below, the **Number of CPU Cores** that the current machine has, the maximum number of **Licensed Threads** and the number of those licensed threads that are available (**Available Threads**) are shown in the dialog. Of course, the maximal number of parallel processes you can use, is the smallest of those three numbers.



If **Automatic Maximum of Threads** is selected, the number of parallel processes is automatically selected for optimal speed, based on the CPU cores and licensed parallel processes.

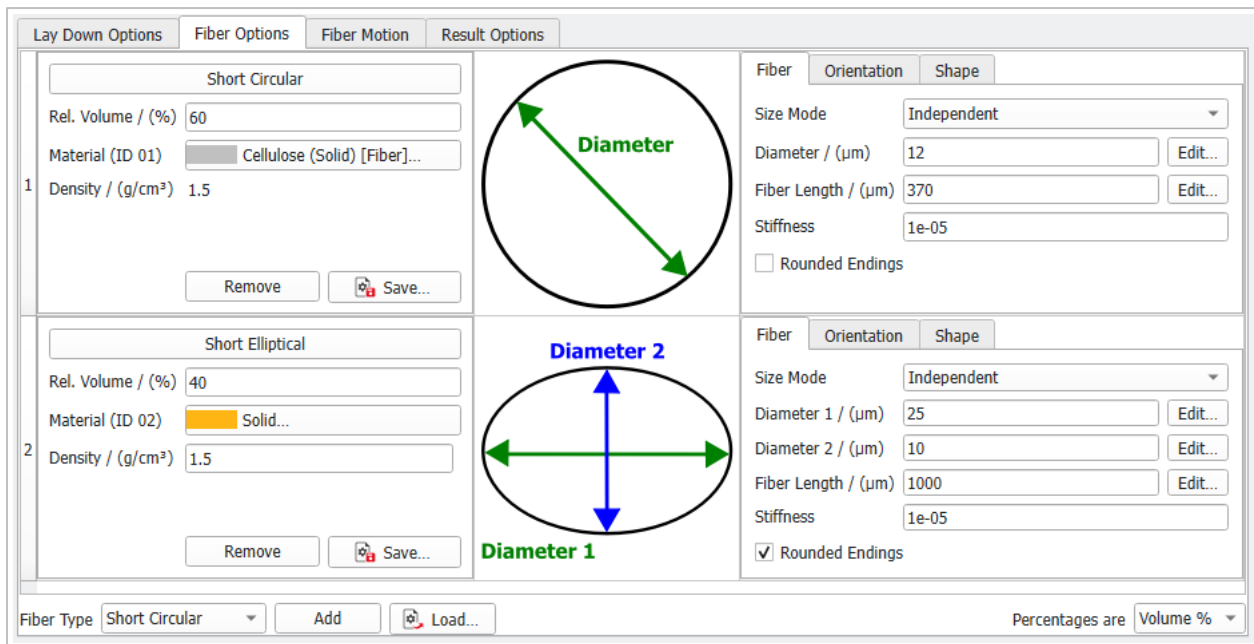


The **Automatic Local Maximum** of processes is automatically selected, which is the minimum of **Number of CPU Cores**, **Licensed Threads**, and **Available Threads**.

Fiber Options

Define the geometrical properties of individual fiber type. The fibers for the generation of paper structures are organized and listed in three columns. In the left one define the [Fiber Type, Percentage and Material](#)^[30] together with it's percentage and material, the center one shows a [cross-section](#)^[33] of the chosen fiber type and in the right one you can edit the [fiber parameters](#)^[35]. In the bottom find the options to choose [additional fiber types](#)^[30] and how the [fiber percentage](#)^[31] should be given.

The fiber list is limited to short fibers of seven different fiber types.



Differences to PaperGeo Create

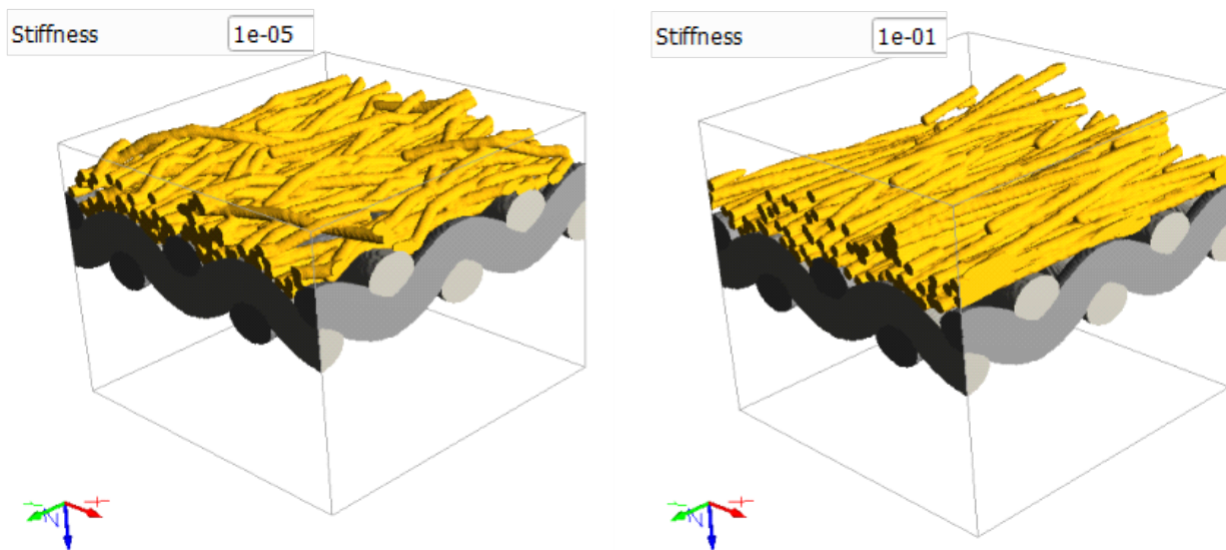
In **PaperGeo Lay-Down**, the center position of the cellulose fibers is a result of the lay-down process and cannot be specified.

An additional parameter in **Lay-Down** is the fiber **Stiffness** to be found under the **Fiber** tab. Values for **Stiffness** can vary from 0 to infinity. A high value indicates a stiff and inflexible fiber, while low values (such as the default 1e-5) indicate a pliable fiber that bends easily over other structures.

As a result of the lack of bending, a paper structure generated by laying down stiff fibers is thicker than a paper structure in which soft fibers are laid down. This side effect provides an additional way to control the thickness of the paper structure.

In the following examples, stiff or soft short-circular randomly curved fibers are laid down over a woven structure. All parameters are unchanged while the fiber **Stiffness** is set as indicated.

Observe that the sheet is thicker, and the domain is larger for the structure on the right, as side-effect of the higher stiffness of the fibers.



Fiber Motion

The **Fiber Motion** parameters, controlling the fibers' movement during the lay-down process, are grouped in the **Lay Down Step** panel.

To refine the result, the available parameters can be used, namely **Number of Shifts**, **Maximum Shift Angle**, **Number of Rotations** per shift, and **Maximum Rotation Angle**.

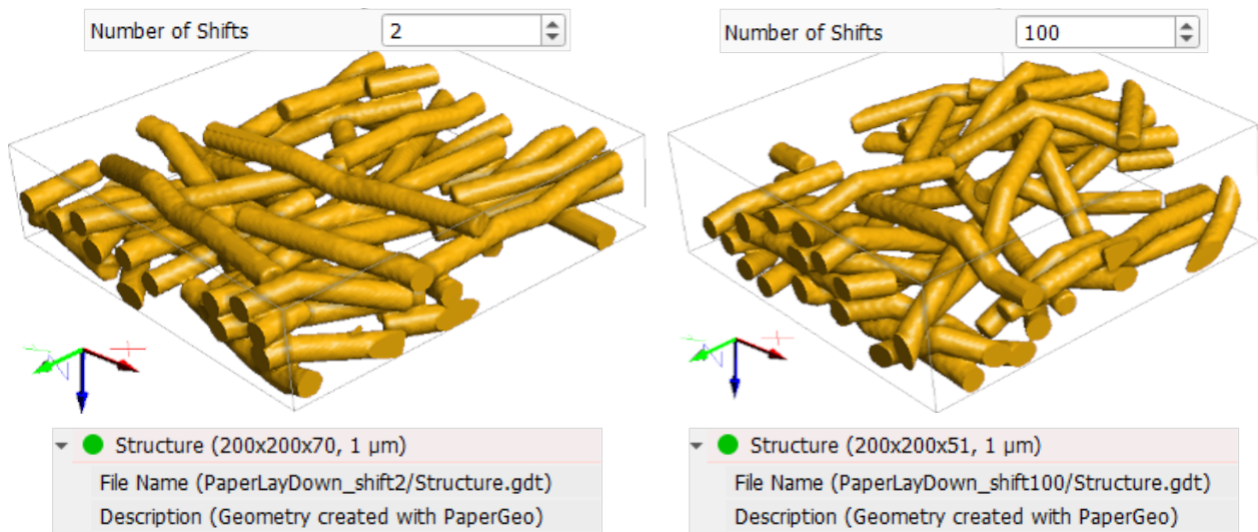
Additionally, falling fibers can be deformed when checking **Deform fibers** and the desired **Number of Deformations** can be entered.

Lay Down Options	Fiber Options	Fiber Motion	Result Options
Lay Down Step			
Number of Shifts		40	
Maximum Shift Angle / (°)		89	
Number of Rotations		20	
Maximum Rotation Angle / (°)		5	
☒ Deform Fibers			
Number of Deformations		100	

Throughout the lay-down process, the fibers fall and roll to their final location in the paper structure. During the fall, the fibers shift and rotate as many times as defined by the values of **Number of Shifts** and **Number of Rotations** before they come to rest at the bottom of the structure.

Low values for shifts and rotations produce structures with fibers which settle earlier compared to larger values of these parameters, resulting in thicker paper structures. The **Maximum Shift Angle** and **Maximum Rotation Angle** restrict the angle that the objects can adopt during the fall with respect to the lay-down plane.

Observe the effect of setting a high or a low **Number of Shifts** on the final position of fibers and the thickness (Z-direction) of a laid down paper structure.



Result Options

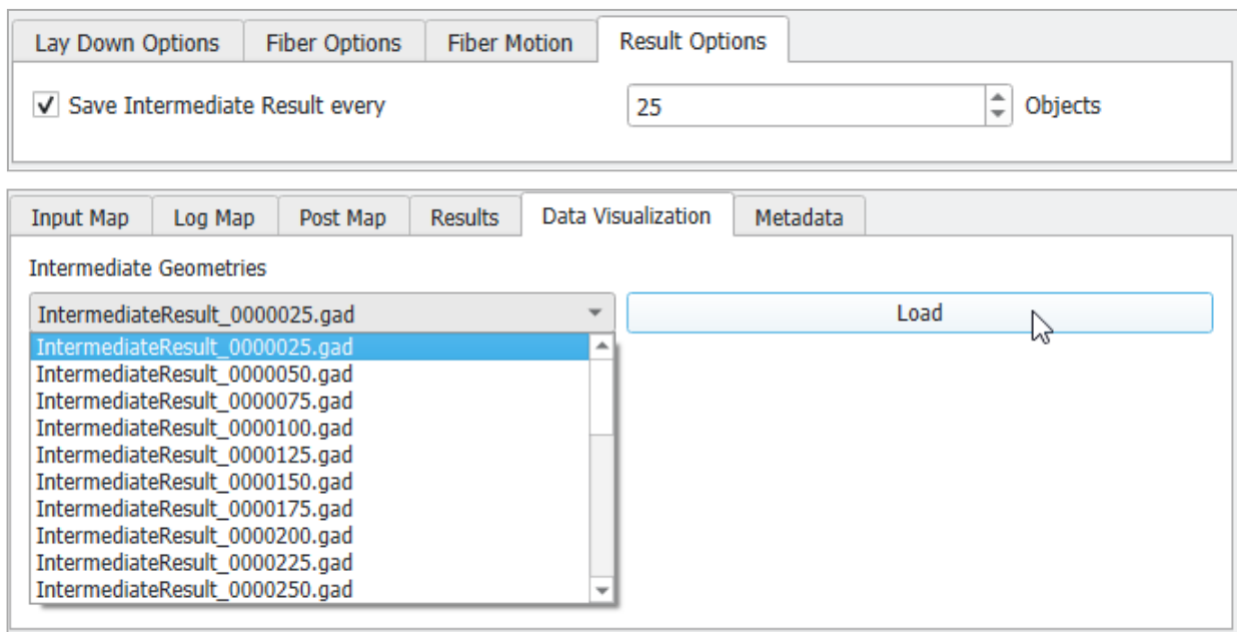
The generated structure is always saved as a **GeoDict structure file (*.gdt)** (GeoDict binary data). The file is placed in an automatically created result folder inside the chosen project folder (**File** → **Choose Project Folder...** in the menu bar).

The result file as well as the result folder take the name entered as **Result File Name (*.gdr)** at the top of the dialog.

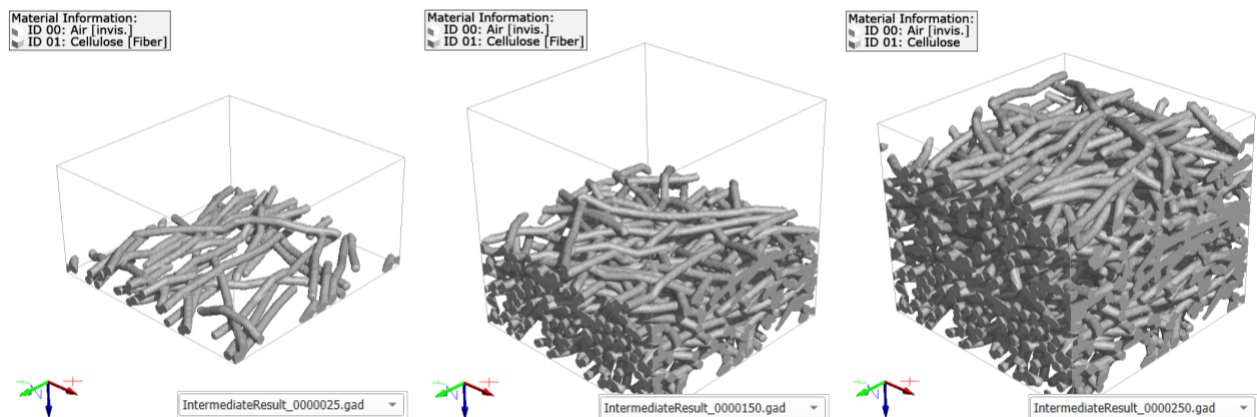
An additional option to save the generated structure data is to check **Save Intermediate Result every** and enter a number of **Objects** in the box. As objects are added to the structure during the generation, an intermediate result file is saved each time the number of placed objects reaches a multiple of the entered value.

This option may be interesting when studying the properties of a series of structures with increasing density.

After running the generation, the intermediate geometries can be found as ***.gad** analytic files in the result folder and can be loaded directly from the **Result Viewer** of the *.gdr result file.



Below find an example for the lay-down of 250 fibers. Observe how more and more fibers are added.



1.2.2 Results

The generated structure is shown in the visualization area. Learn more about visualization in GeoDict in the **Visualization** chapter.

The result file is automatically opened in the Result Viewer and shows structure statistics in the **Results-Report** and **Results-Plot** tabs. Additionally, it offers 3D **Data Visualization** options depending on the generation settings. Find more information on GeoDict result files in the **Result Viewer** chapter.

Results - Report

The first two tables show the **Absolute** and **Relative object distribution** for all object types.

Input Map

Log Map

Post Map

Results

Data Visualization

Metadata

Report

Plots

Map

Absolute object distribution:

	Count	Volume / (%)	Grammage / (g/m ²)	Density / (g/cm ³)	Weight / (%)
Total	realized: 1794 target: --- error: ---	realized: 34.99 target: 35.00 error: -0.01	realized: --- target: --- error: ---	realized: --- target: --- error: ---	realized: --- target: --- error: ---
Object type 1	realized: 992 target: --- error: ---	realized: 17.47 target: 17.50 error: -0.03	realized: --- target: --- error: ---	realized: --- target: --- error: ---	realized: --- target: --- error: ---
Object type 2	realized: 801 target: --- error: ---	realized: 17.52 target: 17.50 error: 0.02	realized: --- target: --- error: ---	realized: --- target: --- error: ---	realized: --- target: --- error: ---

Stopping criterion error: -0.016 %

Relative object distribution:

	Count / (%)	Volume / (%)	Weight / (%)
Object type 1	realized: 55.35 target: --- error: ---	realized: 49.93 target: 50.00 error: -0.14%	realized: --- target: --- error: ---
Object type 2	realized: 44.65 target: --- error: ---	realized: 50.07 target: 50.00 error: 0.14%	realized: --- target: --- error: ---

Maximal probability error: 0.14%

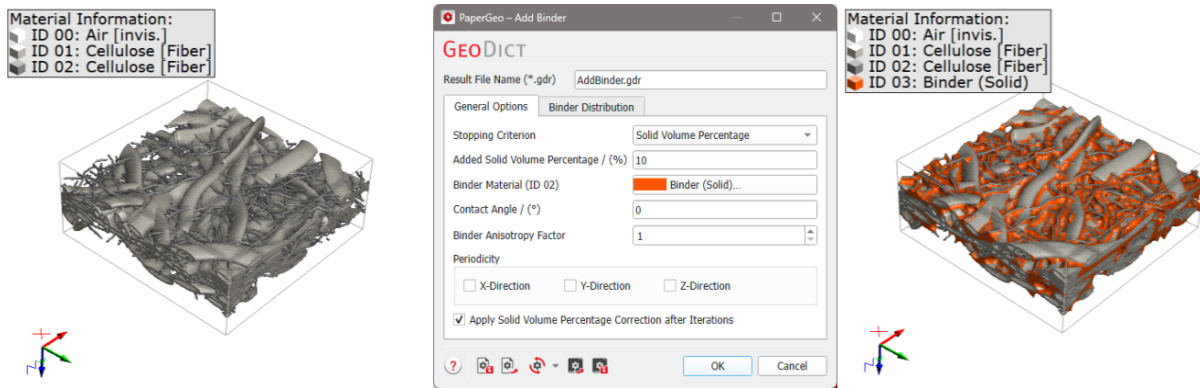
Data Visualization

When selecting **Save Intermediate Results every # Objects** under the **Result Options** tab, you can open the intermediate geometry files (*.gad) after selecting them in the pull-down menu.

Input Map	Log Map	Post Map	Results	Data Visualization	Metadata
Intermediate Geometries					
IntermediateResult_0000010.gad IntermediateResult_0000010.gad IntermediateResult_0000020.gad IntermediateResult_0000030.gad IntermediateResult_0000040.gad IntermediateResult_0000050.gad IntermediateResult_0000060.gad IntermediateResult_0000070.gad IntermediateResult_0000080.gad IntermediateResult_0000090.gad IntermediateResult_0000100.gad			Load		

1.3 Add Binder

To generate realistic models of paper structures, the simulation of binder addition during paper manufacturing is essential. In PaperGeo, the process **Add Binder** reproduces the coating and bonding with binder of paper fibers, filler, and other components, often done to improve structural integrity, water retention, or finish to the paper sheet.



Adding binder to a structure means adding material in the shape of a concave meniscus in the pore space where surfaces in that structure's material get close together. If there is no pore material in the structure, a warning is given.

For hollow objects, such as cellulose fibers, curved cellulose fibers, hollow fibers, curved hollow fibers, and hollow spheres, the algorithm under **Add Binder** needs analytic data (**GAD objects**) to discern that the empty voxels inside the fibers are not part of the pore space. Without analytic data, i.e., when using voxelized models, binder is also added inside the hollow fibers, which is physically inaccurate.

The Add Binder command:

- [Options](#)⁸⁵
Define the Add Binder parameters.
- [Results](#)⁹⁸
View the Add Binder results.

1.3.1 Options

Clicking the **Options' Edit...** button opens the **Add Binder** dialog.

Result File Name (*.gdr) AddBinder.gdr

General Options Binder Distribution

Stopping Criterion Solid Volume Percentage

Added Solid Volume Percentage / (%) 10

Binder Material (ID 02) Binder (Solid)...

Contact Angle / (°) 0

Binder Anisotropy Factor 1

Periodicity

☐ X-Direction ☐ Y-Direction ☐ Z-Direction

☒ Apply Solid Volume Percentage Correction after Iterations

At the top of the **Add Binder** dialog, the name for the file containing the results of adding binding can be entered in the **Result File Name (*.gdr)** box. The default name can be kept, or a new name can be chosen, fitting the current project.

Clicking **OK** in it closes the dialog and returns to the module section. Clicking **Generate** starts the process.

The options are organized into tabs:

- [General Options](#)⁸⁶
Define the binder shape and material.
- [Binder Distribution](#)⁹⁵
Define how the binder should be distributed throughout the domain.

General Options

Define the general options, as the amount of binder to be added, the material and stopping criteria.

General Options

Binder Distribution

Stopping Criterion

Solid Volume Percentage

Added Solid Volume Percentage / (%)

10

Binder Material (ID 02)

Binder (Solid)...

Contact Angle / (°)

0

Binder Anisotropy Factor

1

Periodicity

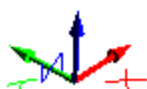
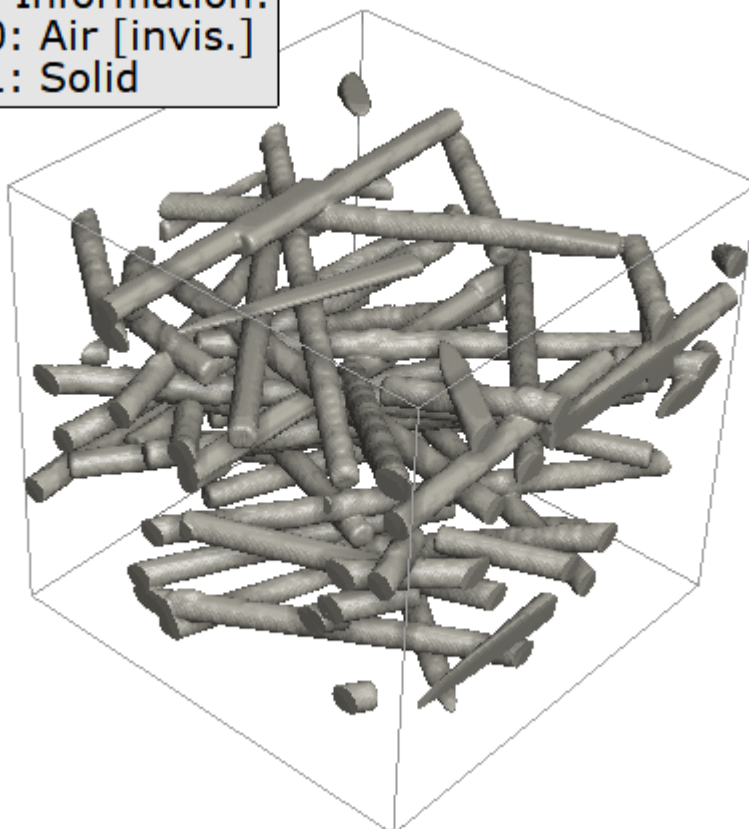
☐ X-Direction
☐ Y-Direction
☐ Z-Direction

☒ Apply Solid Volume Percentage Correction after Iterations

Stopping Criterion

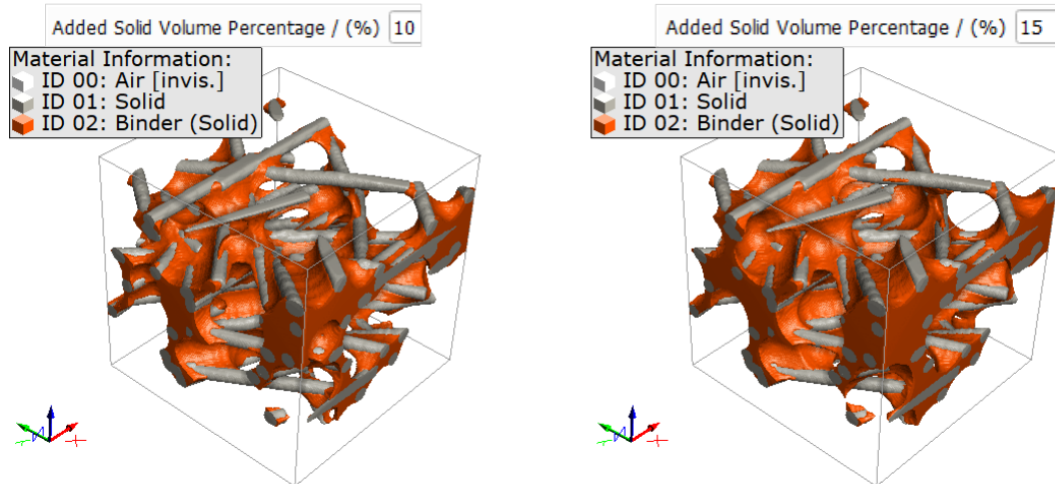
You may choose the most practical stopping criterion when adding binder. The chosen **Stopping Criterion** interrupts the addition of binder when it is reached. The possible stopping criteria are **Solid Volume Percentage**, **Weight Percentage**, and **Grammage**.

Material Information:
 ID 00: Air [invis.]
 ID 01: Solid



☒ Solid Volume Percentage

The process is stopped if the binder volume reaches the desired **Added Solid Volume Percentage**.



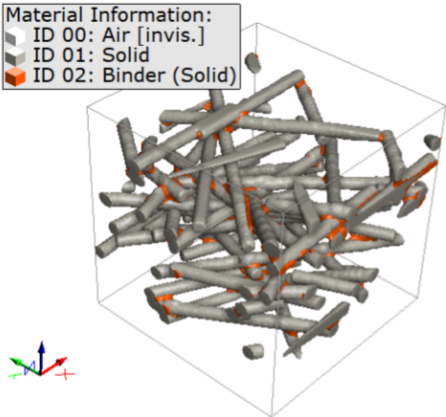
✓ Weight Percentage

The process is stopped if the weight of binder reaches a certain percentage of the weight of material. See [below](#) ⁸⁹ how to select a material for the binder.

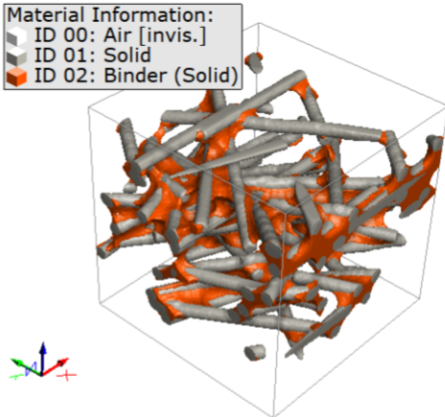
It is necessary to set the density for the structure's material (**Material Density**) and for the binder material (**Binder Density**) both in g/cm³, as well as the desired (weight) percentage of binder material to structure material (**Binder Weight Percentage**, in %). That is, a binder weight percentage of 20 means that there are 20 g of binder added per 100 g of objects in the structure.

Stopping Criterion	Weight Percentage
Binder Weight Percentage / (%)	20
Material Density / (g/cm ³)	1
Binder Material (ID 02)	 Binder (Solid)...
Binder Density / (g/cm ³)	2.70009

In the following example, two types of binder (high density: 5 g/cm³ and low density: 0.5 g/cm³) are added to a structure material with a density of 1.1399 g/cm³. Setting a binder weight percentage of 20% (20 g binder/100 g objects), the amount of binder material deposited is much larger when the binder is less dense.



Stopping Criterion	Weight Percentage
Binder Weight Percentage / (%)	20
Material Density / (g/cm³)	1.1399
Binder Material (ID 02)	Binder (Solid)...
Binder Density / (g/cm³)	5



Stopping Criterion	Weight Percentage
Binder Weight Percentage / (%)	20
Material Density / (g/cm³)	1.1399
Binder Material (ID 02)	Binder (Solid)...
Binder Density / (g/cm³)	0.5

For **Weight Percentage**, when **Manual** or **Undefined** are selected, you must enter the density of the binder (**Binder Density (g/cm³)**). If a material is selected from the database, the **Binder Density** of the binder material is automatically entered. If a manual material is used frequently, it is useful to save it to the material database.

✓ Grammage

The addition of binder stops when the **Added Grammage** (material and binder, g/m²) is reached.

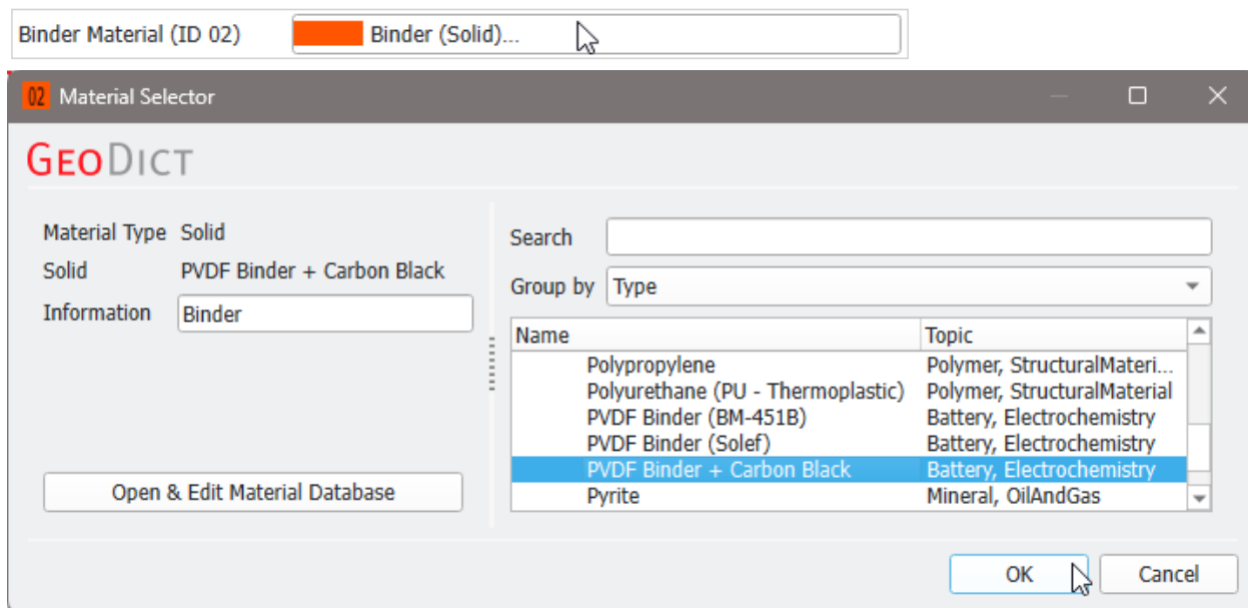
See [below](#) , how to select a material for the binder.

Stopping Criterion	Grammage
Added Grammage / (g/m²)	10
Binder Material (ID 02)	 Binder (Solid)...
Binder Density / (g/cm³)	2.7

For grammage, when manual or undefined are selected, the density of the binder is not automatically taken from the database and you must enter it manually (**Binder Density (g/cm³)**). If a manual material is used frequently, it is useful to save it to the material database.

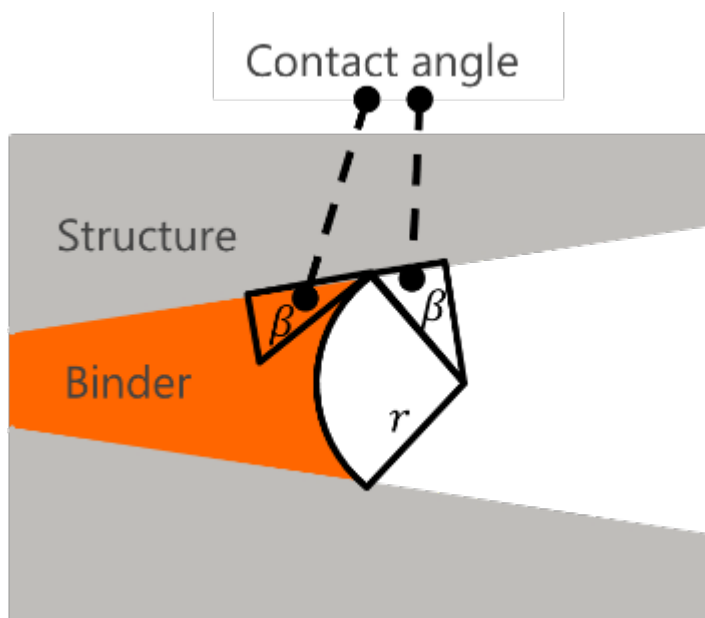
Binder Material

The **Binder Material** is assigned to the next available Material ID, and the appropriate material to be used as binder should be selected from the material database by clicking the button.



Contact Angle

The **Contact Angle** defines the angle in which the binder is deposited in relation to the materials in the structure. Values between 0° and 60° are accepted. When entering values larger than 60°, the value will be changed to 60° automatically. The contact angle helps to optimize and realistically model the addition of binder.



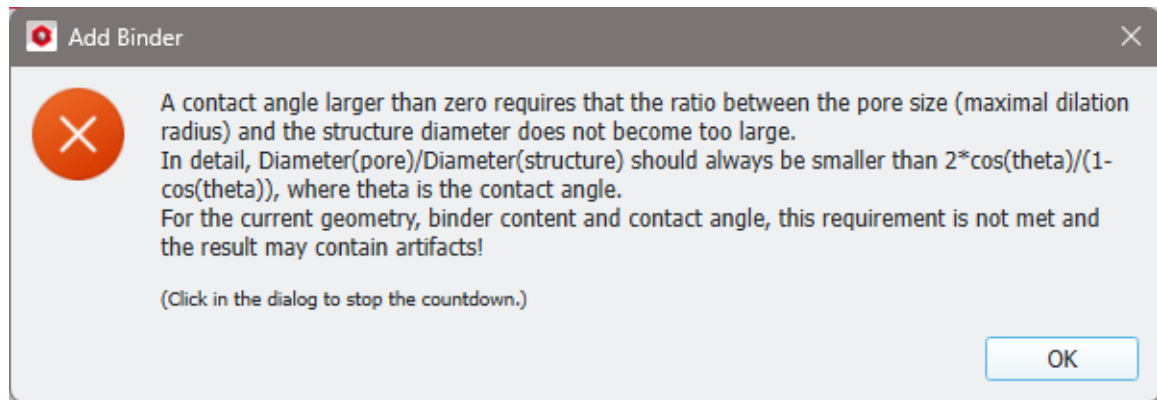
✓ Requirements for large contact angles

The contact angle must fulfill the following requirement:

$$\frac{\text{Diameter(Pore)}}{\text{Diameter(Structure)}} < \frac{2 \cos(\theta)}{1 - \cos(\theta)}$$

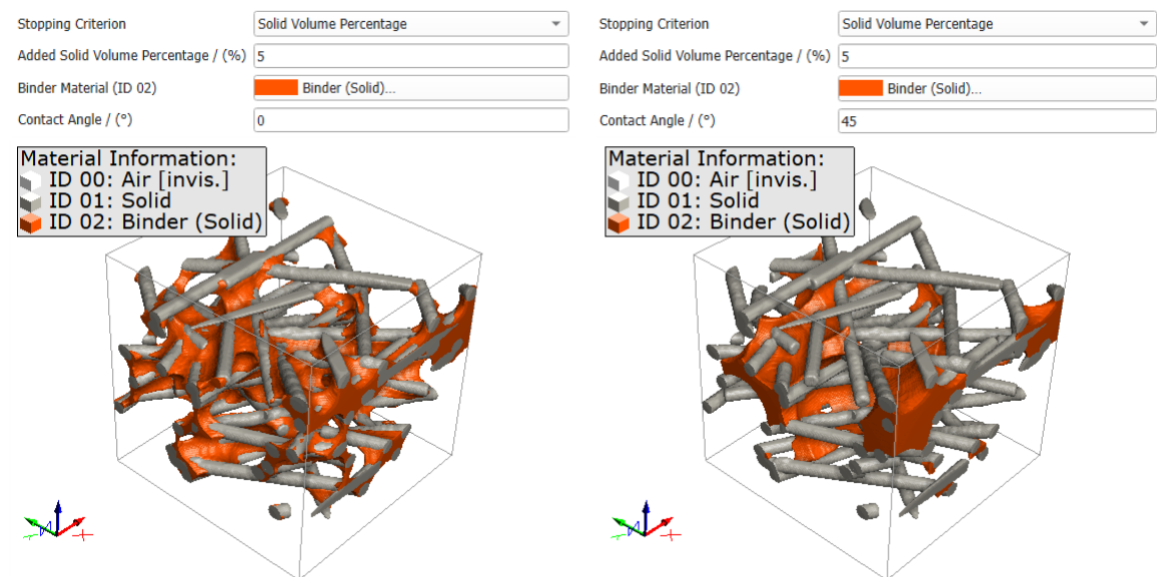
(2) Contact Angle Requirement

where θ is the contact angle and Diameter(Pore) means the maximal dilation radius. If this requirement is not met, a warning message appears. It is recommended to inspect the resulting structure to detect artifacts.



✓ Contact Angle Example

Observe the effect of adding binder with a **Contact Angle** of 0° or 45°.



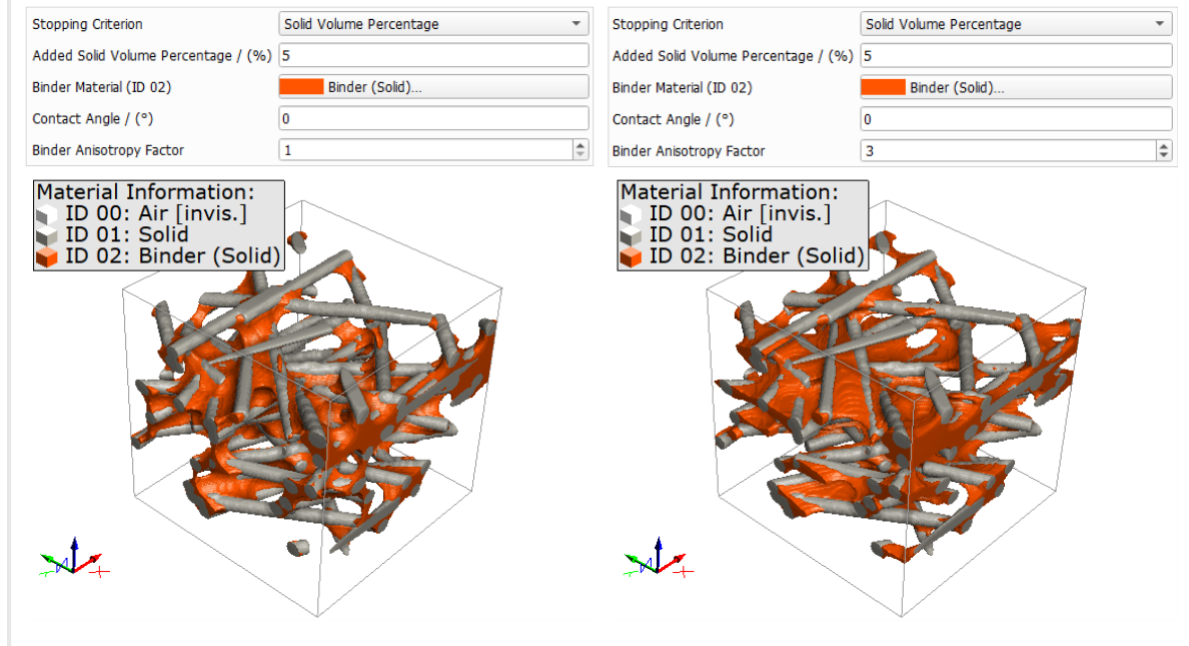
Binder Anisotropy Factor

The **Binder Anisotropy Factor** allows to control the grade of binder anisotropy in the X-Y-plane. If the factor is the default value of 1, the binder is distributed isotropically. By choosing larger values, the binder is distributed in the XY-plane but then, the contact angle value is not

accurate anymore.

✓ Binder Anisotropy Factor Example

Observe the effect of changing the **Binder Anisotropy Factor** from (the default) 1 to 3 when adding binder. With a binder anisotropy factor of 3, the binder is added in the direction of the XY-plane.



Periodicity

When the 3D-structure model is periodic in one or more directions, the binder can be added periodically: in all directions, only in the selected direction (**Periodic X**, **Periodic Y** and/or **Periodic Z**), or non-periodically. Adding binder periodically in certain direction(s) only makes sense if the 3D-structure model is periodic in that/those direction(s).

Periodicity

☐ X-Direction
☐ Y-Direction
☐ Z-Direction

Apply Solid Volume Percentage / Weight Percentage / Grammage Correction after Iterations

The algorithm adds binder until the iteration stops according to the given stopping criterion. Thus, the given value for **Solid Volume Percentage** / **Weight Percentage** / **Grammage** is usually not reached precisely and there are few cases, where the algorithm even does not converge.

If the amount of binder should be reached perfectly, it can be corrected by checking **Apply**

Solid Volume Percentage Correction after Iterations, Apply Weight Percentage Correction after Iterations or **Apply Grammage Correction after Iterations** depending on the chosen stopping criterion.

Selecting this option adds or removes binder surface voxels after the iterations are stopped until the given binder value is reached precisely.



Important! Using the correction feature reduces the **Contact Angle** precision.

General Options Binder Distribution

Stopping Criterion: Solid Volume Percentage

Added Solid Volume Percentage / (%): 5

Binder Material (ID 02): Binder (Solid)...

Contact Angle / (°): 0

Binder Anisotropy Factor: 1

Periodicity

☐ X-Direction ☐ Y-Direction ☐ Z-Direction

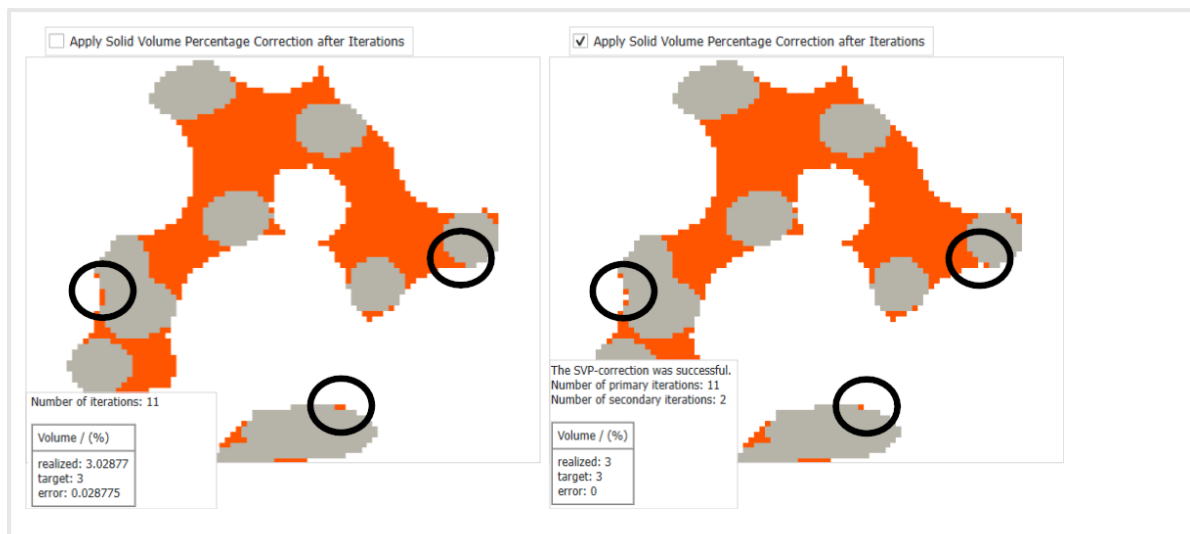
☒ Apply Solid Volume Percentage Correction after Iterations

☒ Apply Weight Percentage Correction after Iterations

☒ Apply Grammage Correction after Iterations

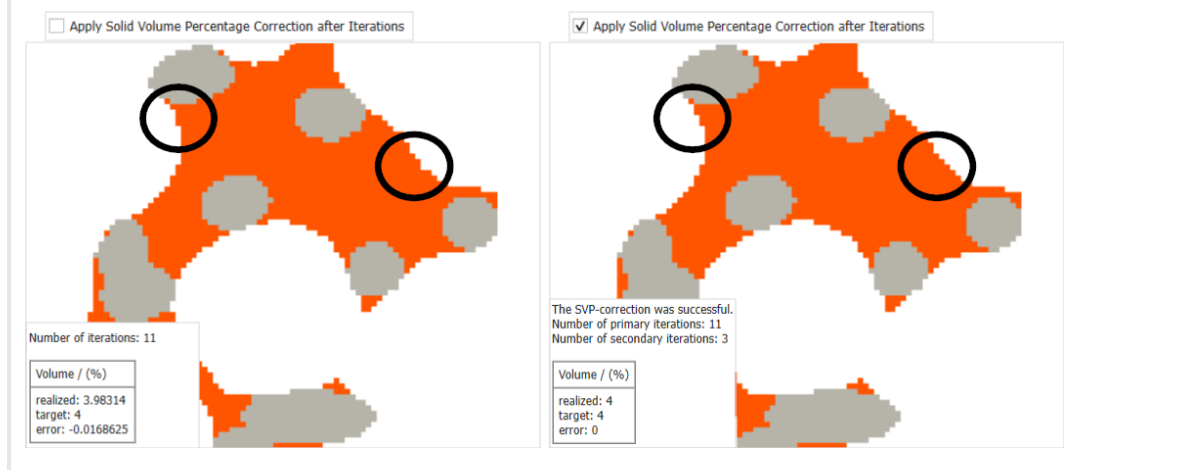
✓ Binder amount larger than target

If the realized amount of binder after the iterations is larger than the target value, voxels are removed from exposed positions, i.e., voxels with only one contact to another binder voxel.



✓ Binder amount smaller than target

In the other case, if the amount of binder is smaller than the target value, the algorithm adds voxels on positions with the most binder voxel neighbors.



✓ Algorithm

In detail, the algorithm applies small dilations and erosions to keep a smooth surface. In detail four steps are performed:

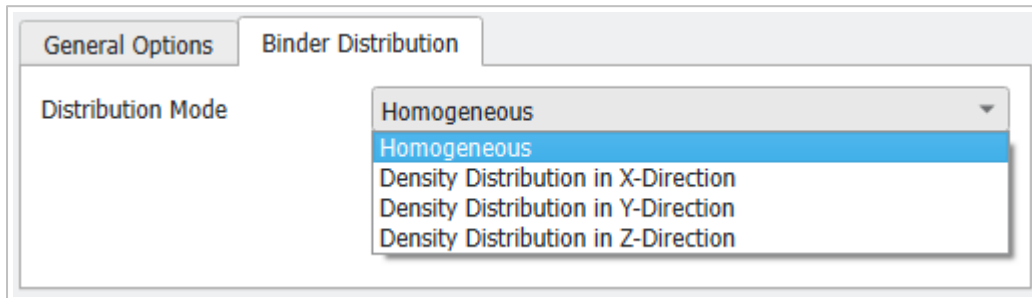
1. First, a voxel-zone at the surface is defined by the smallest possible dilation / erosion.
2. Within this voxel zone the algorithm again applies dilations / erosions. This reduces the voxel zone further.
3. Afterwards only a small surface layer remains that is maximal one voxel thick.
4. These remaining voxels are randomly reassigned.

The random reassignment is done to prevent biased change of the curvature.

Binder Distribution

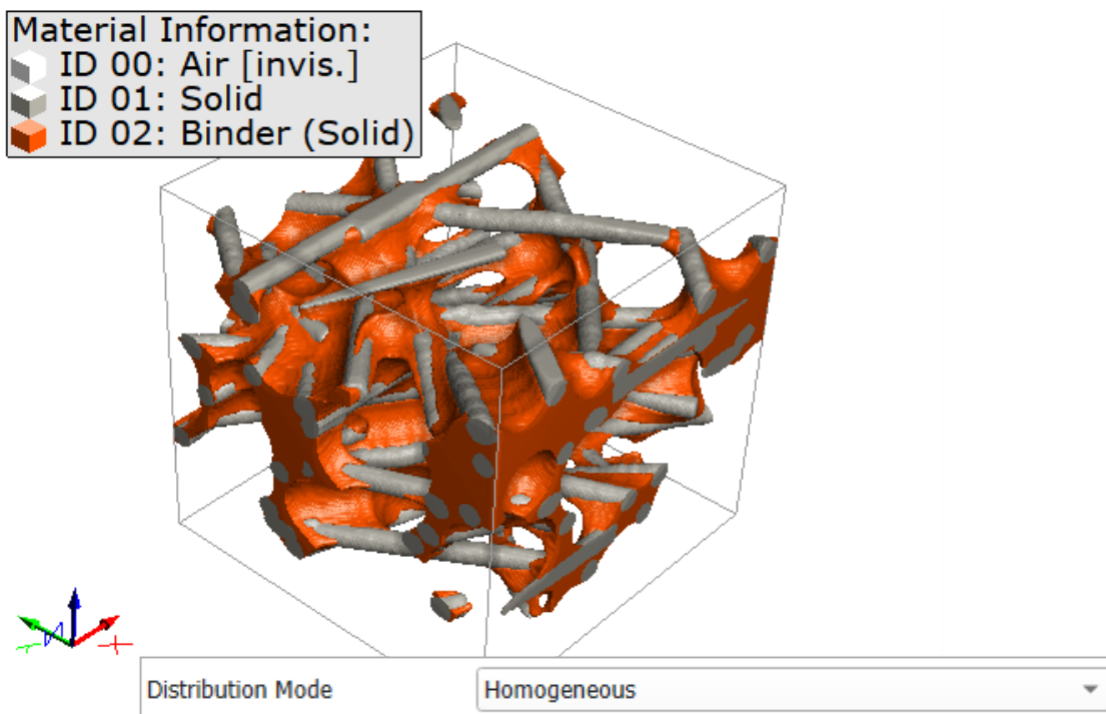
In real life, the process of adding binder to the material is affected by gravity and the viscosity of the binder, leading to inhomogeneous distributions. This effect can be modeled by defining a distribution of the binder under the **Binder Distribution** tab.

The binder either can be distributed homogeneously throughout the domain or follow a distribution in X-, Y- or Z- direction.



Homogeneous

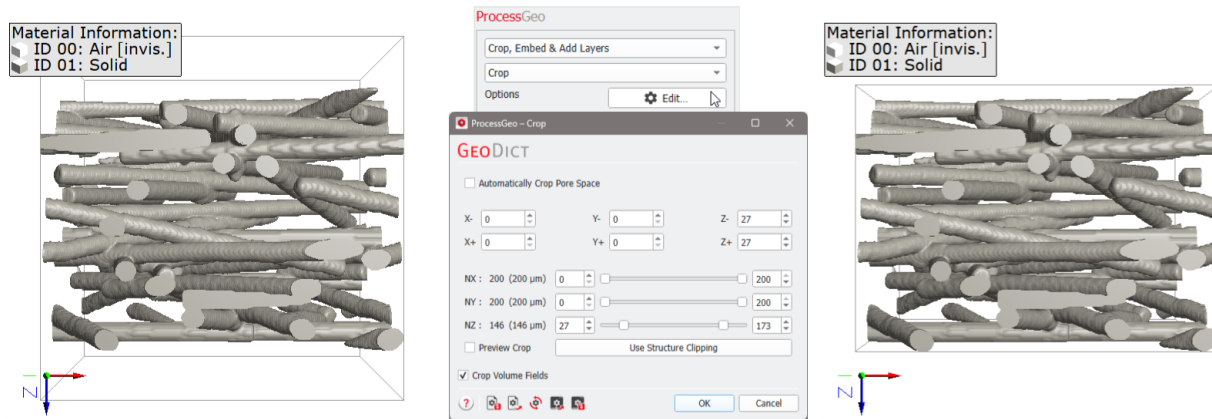
The default distribution is **Homogeneous**, but it can be changed to a **Density Distribution** to allow the modeling of inhomogeneity. For the default case, the binder is distributed homogeneously throughout the domain.



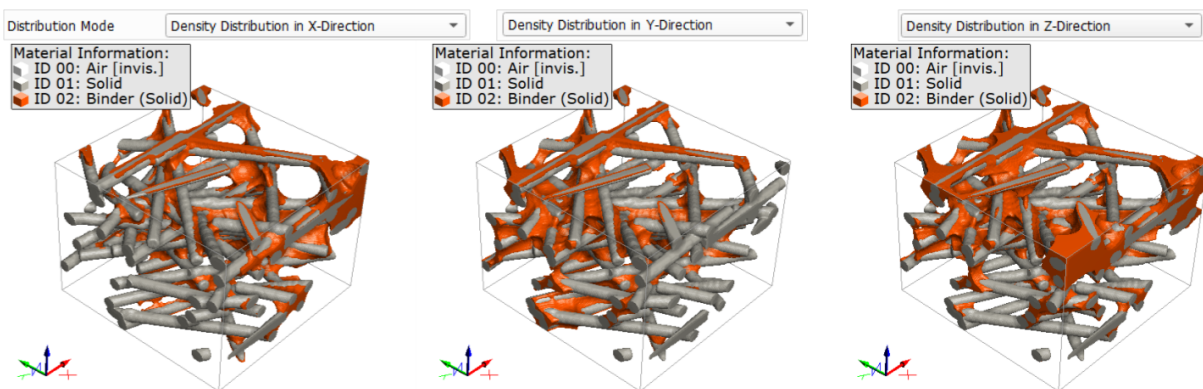
Density Distribution

To model a **Density Distribution**, no inlet or outlet should be left in the structure. If the

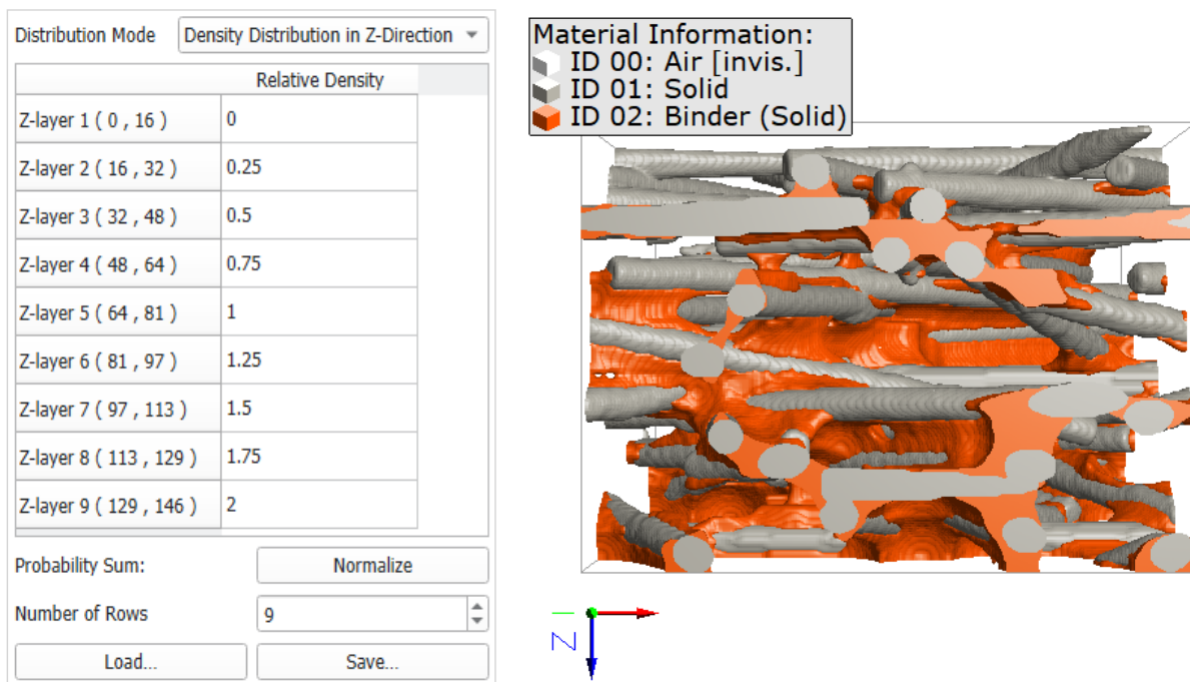
structure has an inlet or outlet in the chosen direction, remove it by cropping with **Model - ProcessGeo - Crop, Embed & Add Layers - Crop**. This is necessary because the algorithm strives to reach the desired binder amount for each sub-segment and will try to add binder in the empty domain. Alternatively, the amount of binder might be set to zero for these segments.



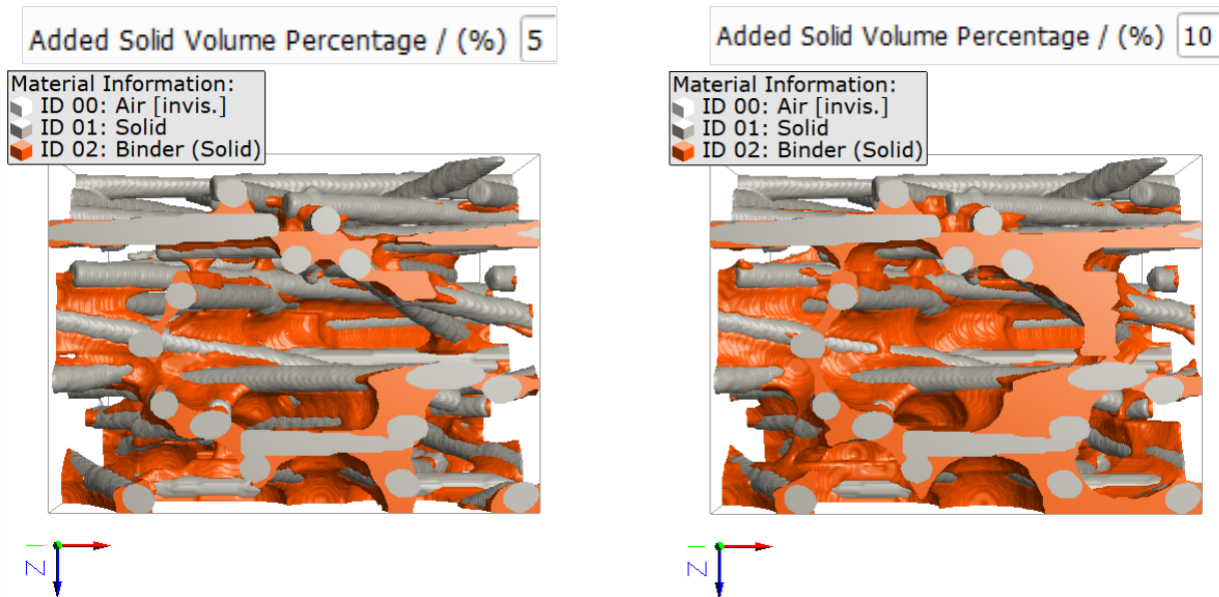
Select the direction for the desired density distribution.



In the examples we consider a density distribution in Z-direction. Then, the **Number of Rows** defines the number of Z-segments. To change the number of segments, change the **Number of Rows** to the number of segments desired.



In each section the binder is generated separately according to the rules defined in the **General Options** tab. The **Added Solid Volume Percentage / (%)** is scaled with the normalized **Relative Density** given in the table of **Binder Distribution**.



The **Binder Distribution** can be entered in form of a ratio in the **Relative Density** table.

In the images below, three different segments are clearly discernible with a binder distribution according to the relative values given in the table.

Distribution Mode: Density Distribution in Z-Direction

Relative Density	
Z-layer 1 (0 , 48)	0.9
Z-layer 2 (48 , 97)	0
Z-layer 3 (97 , 146)	0.1

Probability Sum: 1

Number of Rows: 3

Normalize

90% of the binder is distributed in the Z-layers 0-48.

0% of the binder is distributed in the Z-layers 48-97.

10 % of the binder is distributed in the Z-layers 97-146.

Distribution Mode: Density Distribution in Z-Direction

Relative Density	
Z-layer 1 (0 , 48)	1
Z-layer 2 (48 , 97)	5
Z-layer 3 (97 , 146)	10

Probability Sum: 16

Number of Rows: 3

Normalize

6% of the binder is distributed in the Z-layers 0-48.

31% of the binder is distributed in the Z-layers 48-97.

63% of the binder is distributed in the Z-layers 97-146.

Clicking the **Normalize** button ensures the Relative Density values sum up to one.

Distribution Mode: Density Distribution in Z-Direction

Relative Density	
Z-layer 1 (0 , 48)	1
Z-layer 2 (48 , 97)	5
Z-layer 3 (97 , 146)	10

Probability Sum: 16

Number of Rows: 3

Normalize

→

Distribution Mode: Density Distribution in Z-Direction

Relative Density	
Z-layer 1 (0 , 48)	0.0625
Z-layer 2 (48 , 97)	0.3125
Z-layer 3 (97 , 146)	0.625

Probability Sum: 1

Number of Rows: 3

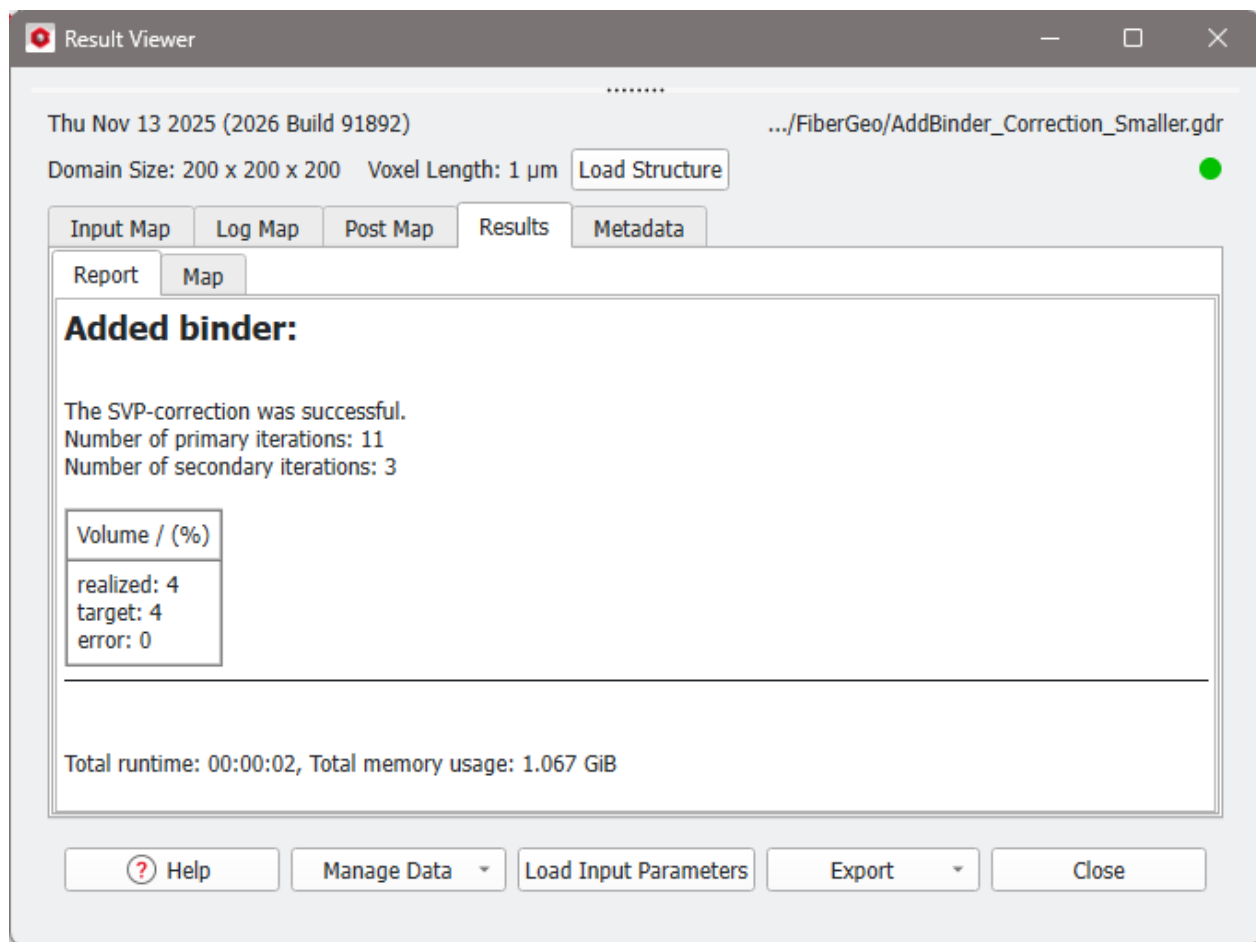
Normalize

With the buttons **Load...** and **Save...** the distribution can be loaded/saved as text file which can be opened with other software as, e.g., Microsoft Excel.

1.3.2 Results

After the binder generation, the new structure with added binder is shown in the visualization area and the result file (*.gdr) is opened in the Result Viewer.

The **Results - Report** tab shows information about the binder generation, as number of iterations, target binder volume and realized binder volume.



If **Weight Percentage** or **Grammage** were selected as **Stopping Criterion**, additionally the realized and target binder weight percentage and grammage are given.

Volume / (%)	Grammage / (g/m ²)	Weight / (%)
realized: 3.46524	realized: 20	realized: 20
target: ---	target: ---	target: 20
error: ---	error: ---	error: 2.59463e-05

If a non-homogeneous binder distribution was defined, the binder volumes additionally are given for each defined layer.

Added binder:

Volume / (%)	Grammage / (g/m ²)	Weight / (%)
realized: 1.27263 target: --- error: ---	realized: 19.9999 target: --- error: ---	realized: 19.9999 target: 20 error: -5.52607e-05

Layer 1

The SVP-correction was successful.

Volume / (%)	Grammage / (g/m ²)	Weight / (%)
realized: 3.62099 target: --- error: ---	realized: 53.9998 target: --- error: ---	realized: 53.9998 target: 54 error: -0.00017705

Layer 2

No binder to add.
The SVP-correction was skipped.

Volume / (%)	Grammage / (g/m ²)	Weight / (%)
realized: 0 target: --- error: ---	realized: 0 target: --- error: ---	realized: 0 target: 0 error: 0

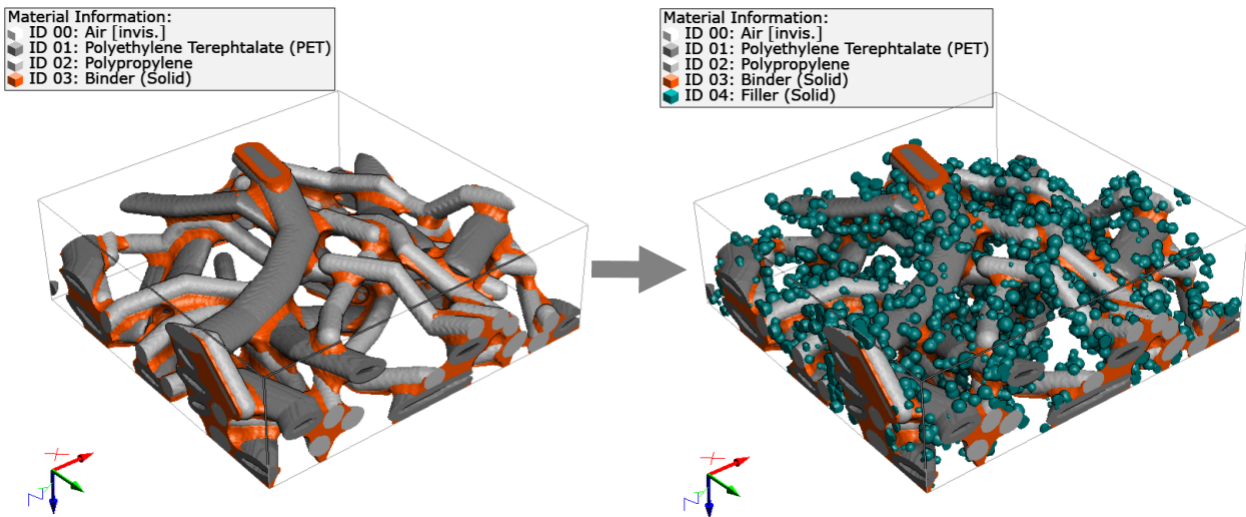
Layer 3

The SVP-correction was successful.

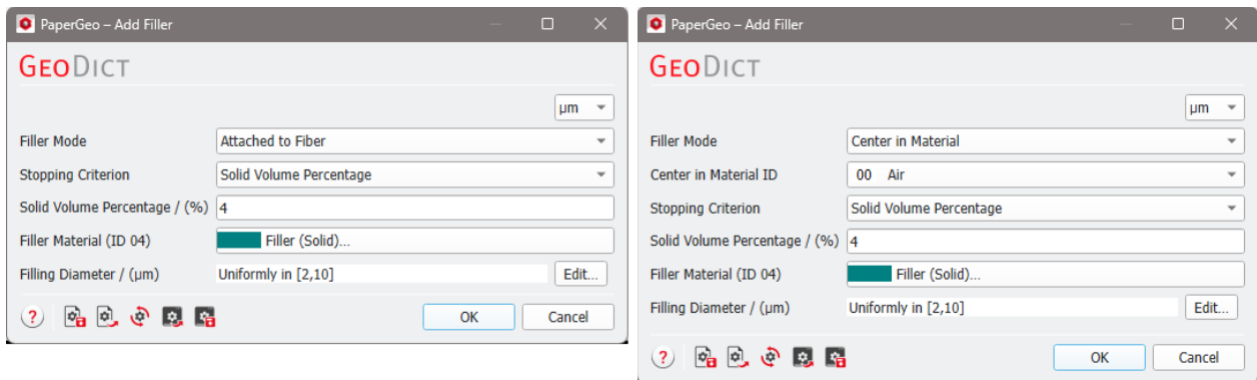
Volume / (%)	Grammage / (g/m ²)	Weight / (%)
realized: 0.196888 target: --- error: ---	realized: 6.00001 target: --- error: ---	realized: 6.00001 target: 6 error: 1.12676e-05

1.4 Add Filler

Add Filler adds spherical particles to coat the paper structure. Fillers are materials added during papermaking to influence the properties of the paper (e.g., dry strength, optical properties, surface smoothness and printability), or to reduce the production costs. Ground or precipitated calcium carbonate (GCC, PCC) is a commonly used filler. Other widely used fillers are china clay (kaolin), titanium dioxide, and talc.



Select **Add Filler** from the pull-down menu and click the **Options' Edit...** button to select parameters for the addition of filler.



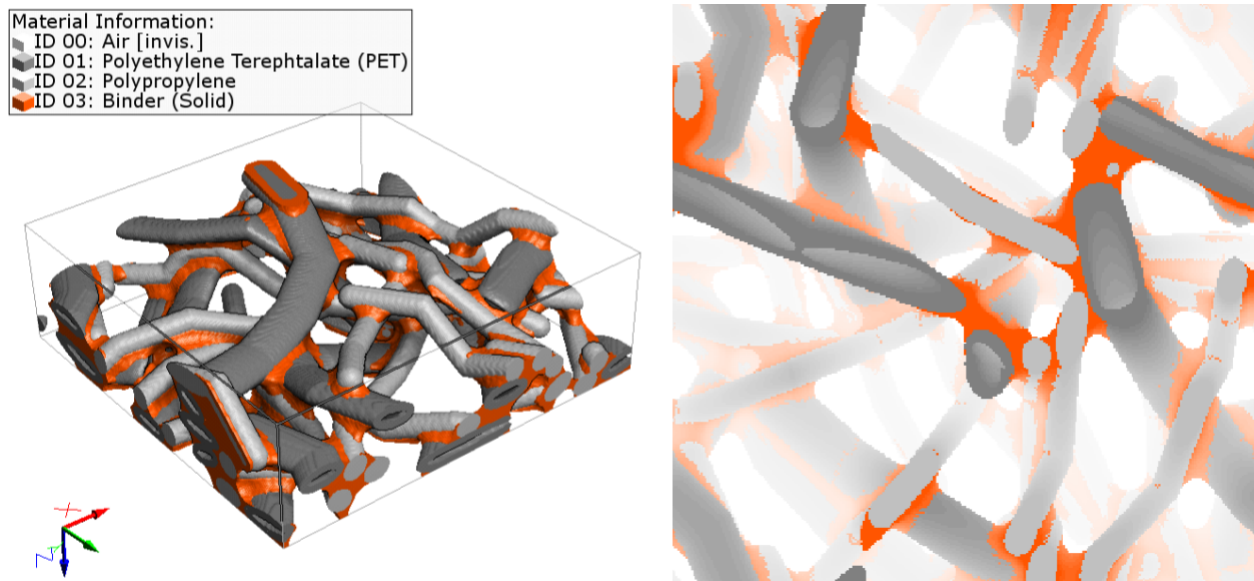
Filler Mode

With **Add Filler**, spherical particles are added to coat the complete structure currently in memory (**Attached to Fiber**) or a single Material ID from the structure can be selected and replaced by the filler particles (**Center in Material**).

Attached to Fiber attaches the spherical particles to all objects present in the structure currently in memory. There is no choice of a specific Material ID to be coated. In other words, the whole structure is coated with the filler.

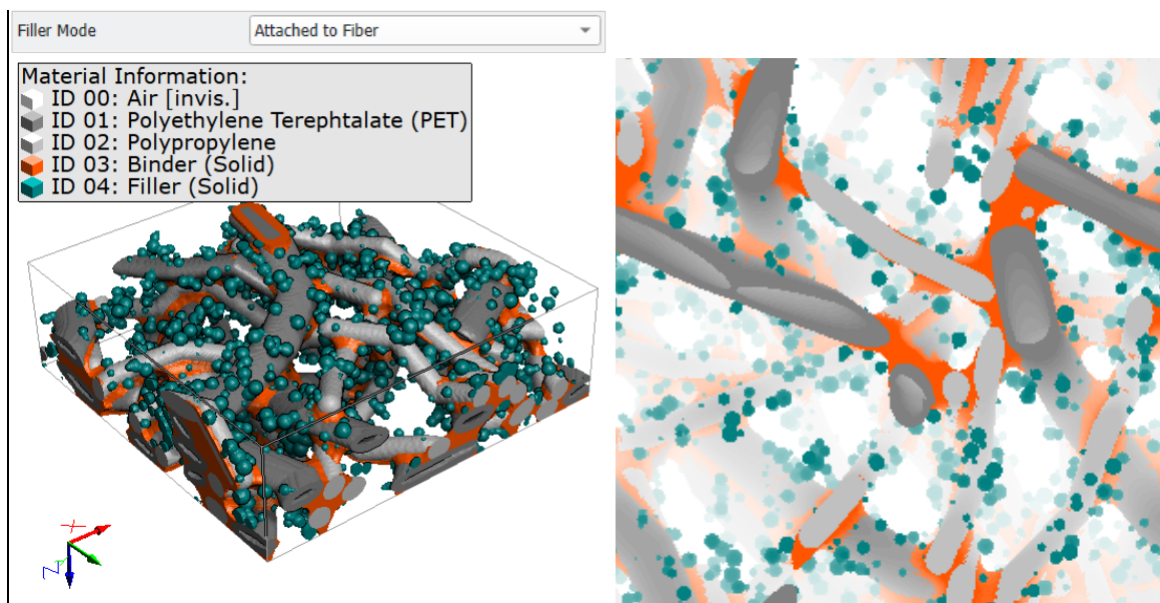
Center in Material replaces the selected Material ID with spherical filler particles.

As an example of adding filler in the two modes, we use a structure with two types of synthetic fibers and added binder to observe the effect of adding filler particles as spheres of between 2 μm and 10 μm diameter:



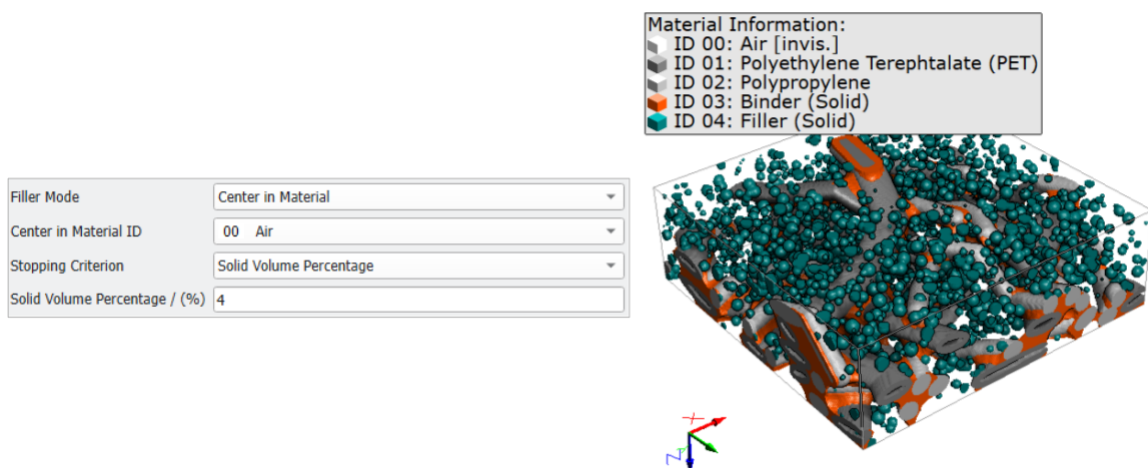
✓ Attached to Fiber

Select **Attached to Fiber** to coat the surface of all materials present including fibers (with Material ID 01 and Material ID 02, in dark gray and light gray) and binder (Material ID 03, in orange).



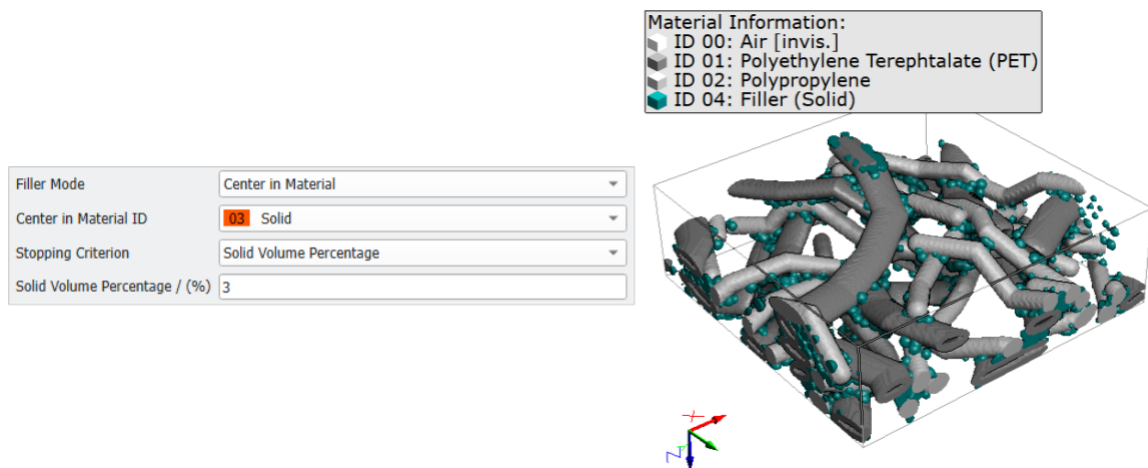
✓ Center in Material

The Material ID of the objects in which to center the spherical particles can be selected from the **Center in Material ID** pull-down menu. Even the pore space filled with a fluid or solid can be selected to be filled.



This option is useful when the filler is to be added only in selected places, for example with the combination of an **Add Binder** and an **Add Filler** step.

Select **Center in Material** and choose the Material ID 03 (which here was the binder, shown in orange) to completely replace this material with filler.



With Center in Material ID, keep in mind that the SVP of the filler must not be (much) higher than the SVP of the material to be replaced. Otherwise, the stopping criterion might be impossible to reach, and the addition of filler ends with an error message.

Material Information:
 ID 00: Air [invis.]
 ID 01: Polyethylene Terephthalate (PET)
 ID 02: Polypropylene
 ID 03: Binder (Solid)

GeoDict Project Status - 3D - Material IDs

Material ID	Volume Percentage (%)	Voxel Count
00	80.61 %	6819959 Voxel
01	6.02 %	509237 Voxel
02	8.32 %	703921 Voxel
03	5.05 %	426883 Voxel

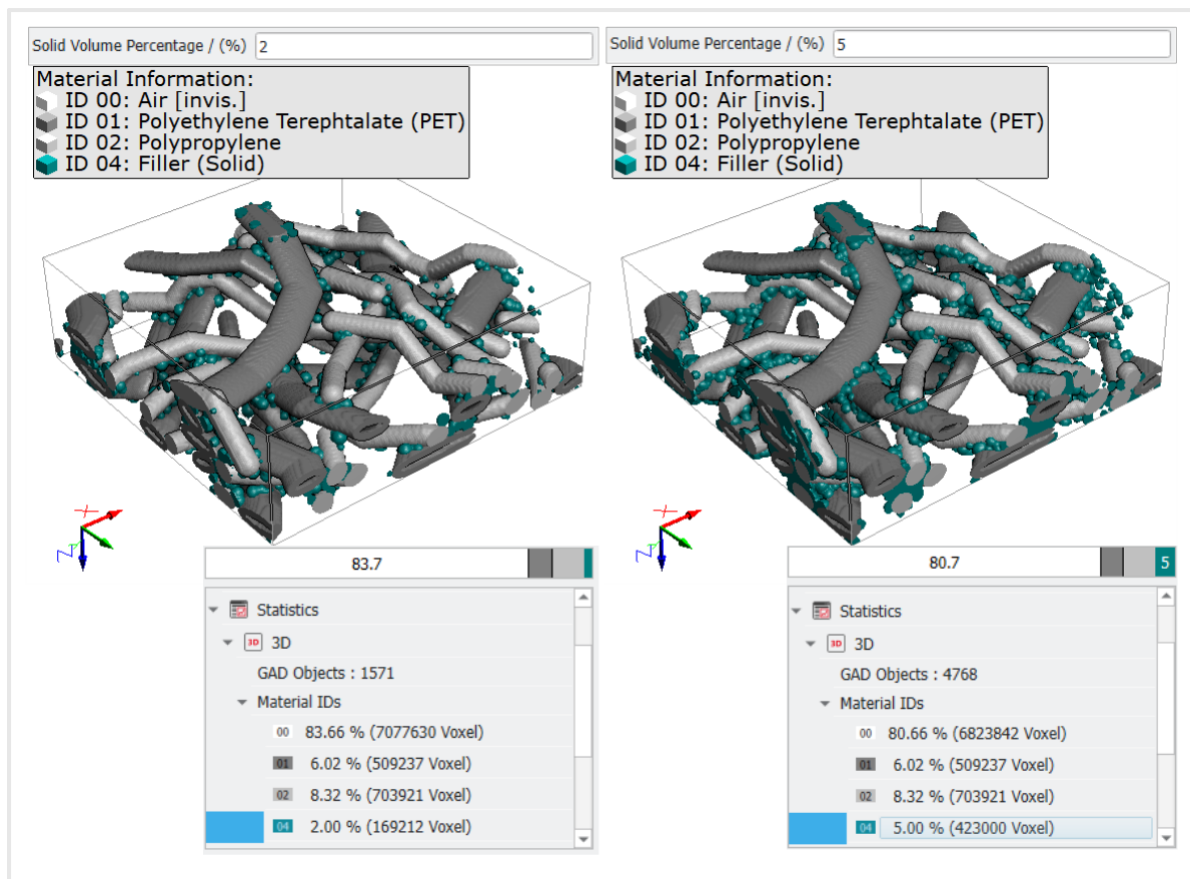
Filler Mode: Center in Material
Center in Material ID: 03 Solid
Stopping Criterion: Solid Volume Percentage
Solid Volume Percentage / (%) 10

Error Dialog:
 Error while executing command "PaperGeo:AddFiller":
 Unable to reach the specified stopping criterion!
 (Click in the dialog to stop the countdown.)

Find the volume percentages for each Material ID on the left-hand side of GeoDict in the **Project Status** section, when unfolding **Statistics - 3D - Material IDs**.

Here, the SVP of the material to be replaced (binder, ID 03) is approximately 5%, so the SVP of filler should not exceed 5%.

Observe the effect of adding 2% and 5% filler to replace the binder in the paper structure, and how this is reflected in the volume percentages of all components of the structure:



Stopping Criterion and Filler Material

As can be seen for [Add Binder](#), a **Stopping Criterion** must be selected to end the addition of filler. The possible stopping criteria are **Solid Volume Percentage** and **Grammage**. For both available criteria define the amount of filler to be added below, either by its volume (**Solid Volume Percentage / (%)**) or by its weight (**Grammage / (g/m²)**).

Stopping Criterion	Solid Volume Percentage	Stopping Criterion	Grammage
Solid Volume Percentage / (%)	2	Grammage / (g/m ²)	10
Filler Material (ID 04)	Filler (Solid)...	Filler Material (ID 04)	Filler (Solid)...
		Filler Density / (g/cm ³)	1.5

For **Grammage**, the **Filler Density / (g/cm³)** defines the specific density of the filler material in g/cm³. For some materials from the GeoDict Material Database, additionally a temperature must be entered.

When **Manual** or **Undefined** are selected as **Filler Material**, the density of the filler is not automatically taken from the GeoDict database, and you must enter it manually (**Filler Density**). If this filler material is regularly used, it can be saved in the material database. For further information, please consider the Material Database chapter.

For example, as the specific density of PCC is about 2.7-2.9 g/cm³ (2700-2900 kg/m³) enter the corresponding value for **Filler Density** in PaperGeo.

✓ **Filler Material**

The **Filler Material** can be selected from the GeoDict Material Database by clicking the button. The filler material is assigned to the next available Material ID, but its color (as well as the color of fibers and binder) can be changed by selecting the **Color & Visibility** tab from the GUI side bar on the right.

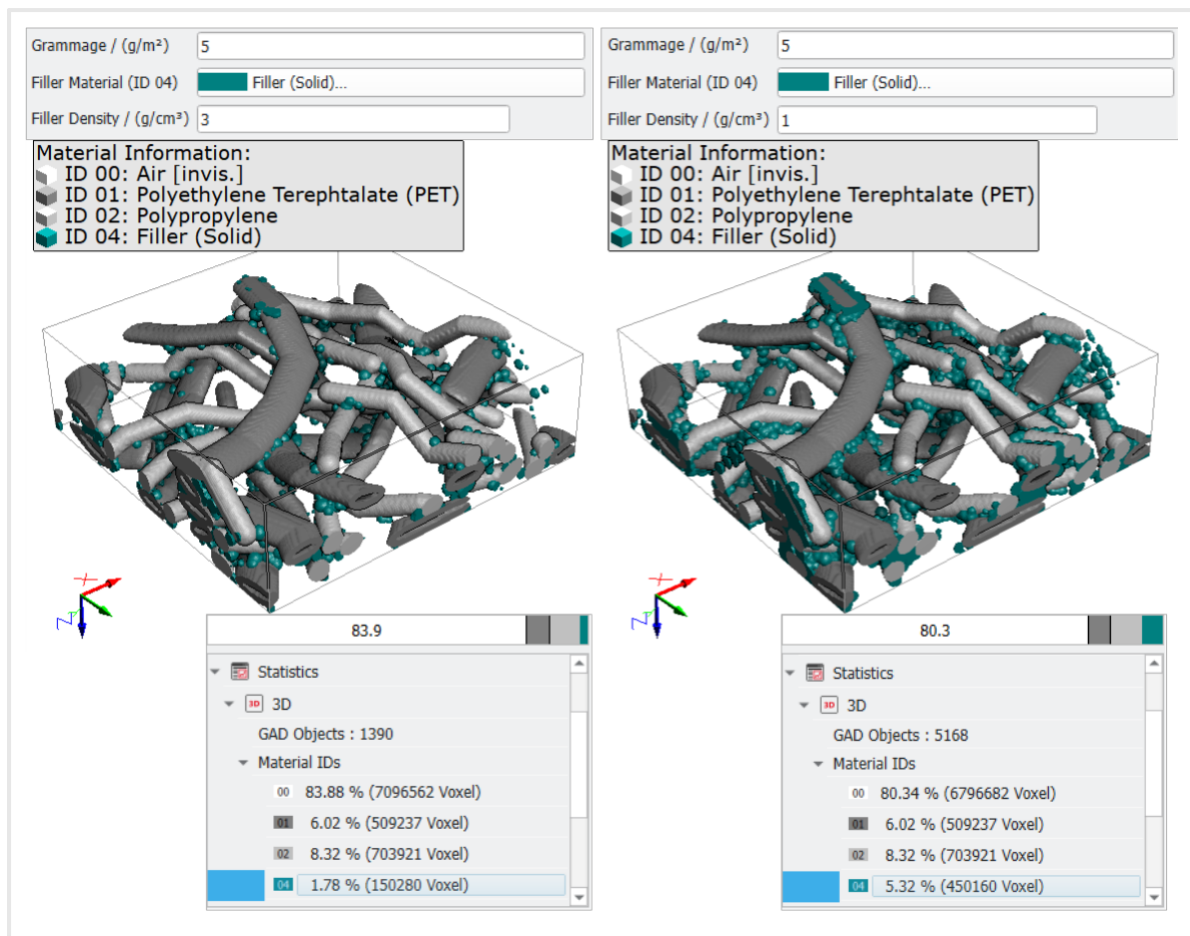
✓ Temperature

For some materials from the database, the **Temperature** must be defined, as density changes according to the temperature.

Stopping Criterion	Grammage	
Grammage / (g/m ²)	10	
Filler Material (ID 04)	Copper (Solid) [Filler]...	
Temperature	20	°C
Filler Density / (g/cm ³)	8.9397957	

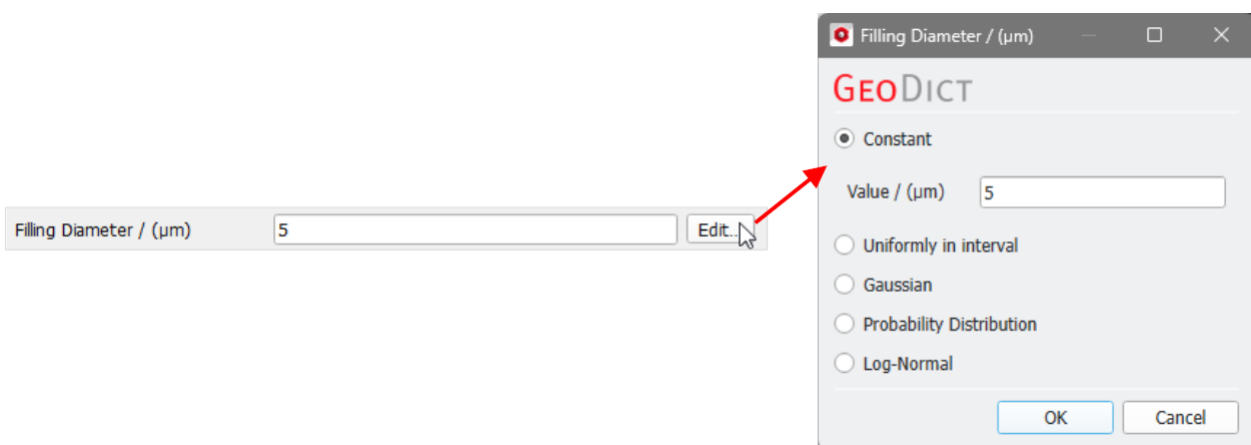
✓ Filler Density

Observe the effect of adding a light (i.e., 1 g/cm³), and a dense filler (i.e., 3 g/cm³) while keeping the **Grammage** of the filler at 5 g/m². Here, the filler is added through **Attached to Fiber**. A larger amount of filler is added to the fiber-binder structure using the lighter filler.

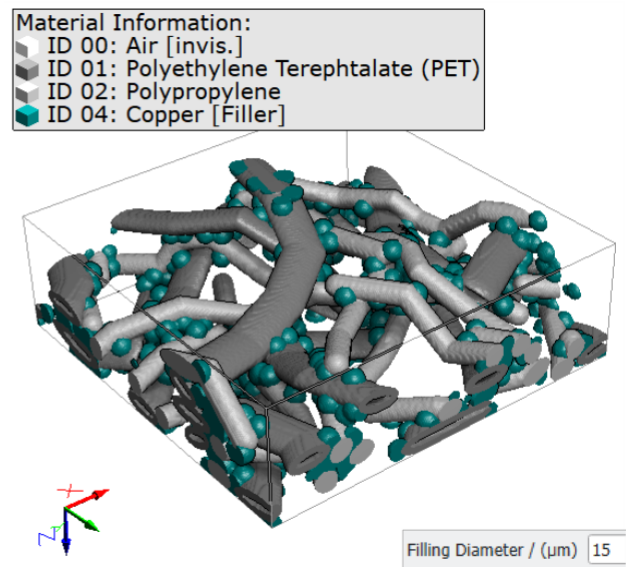
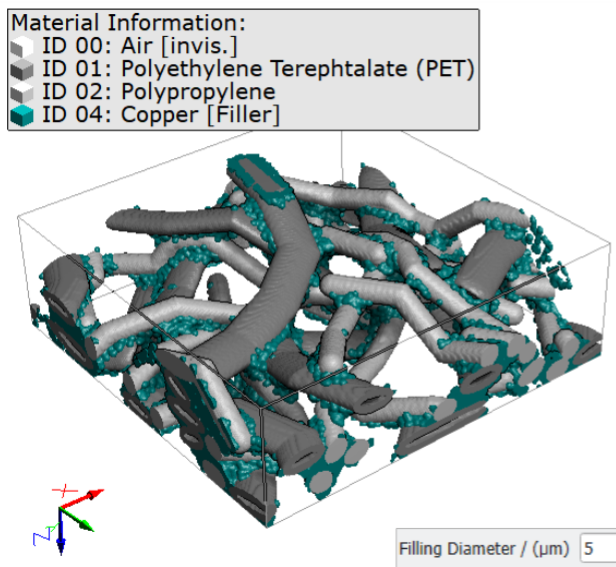


Filling Diameter

The **Filling Diameter** of the spherical particles can be set after clicking the **Edit...** button. The diameter of the particles can be **Constant** or follow one of several [distributions](#) (Uniformly in interval, Gaussian, user-defined Probability Distribution, or Log-Normal).



Observe the filler particles when the diameter is set to a constant value of 5 µm and then, a constant value of 15 µm.



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