FiberGeo 2015

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Reference

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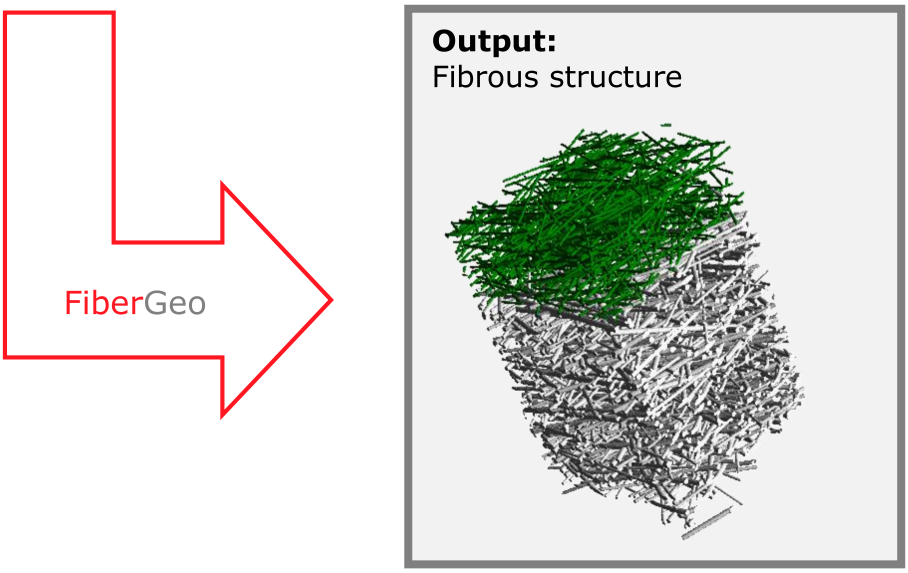
MATH 2 MARKET

GENERATING AND MODELLING FIBROUS STRUCTURES

Starting from random distributions of fibers, FiberGeo creates virtual non-woven and fiber reinforced composites.

To generate fibrous material models, FiberGeo requires the input of fiber material and form, and the desired statistical properties of the resulting structure, such as size, amount of the solid phase, etc. The fibers can be straight or curved, where the profile shape can be varied (circular, elliptical, rectangular, cellulose, etc.). The orientation of fibers and the distribution of fiber parameters can be specified. It is possible to generate structures with prescribed solid volume percentage, prescribed density or prescribed grammage.

Input:
Fiber material and form
Desired structure properties: sample size, solid volume fraction, orientation...



FiberGeo fibrous structures are based on given statistical properties that can be estimated e.g. from 3D images (CT-scan), from 2D images like REM, from certain material properties or from the knowledge of underlying production process. The generated non-woven models are available as 3-dimensional images and as analytical data (*.gad, **GeoDict** analytic data), which can be used to export surface triangulations (stl-files) for CAD-programs.

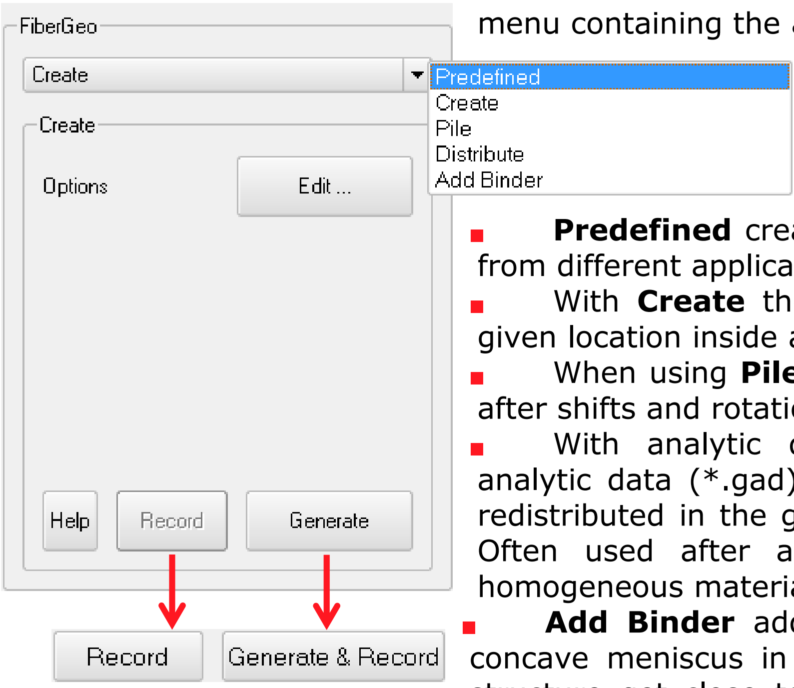
Other material properties like pore-size distribution, flow resistivity (permeability, pressure drop), effective thermal and electrical conductivity, effective elasticity, effective diffusion, filter efficiency, filter capacity, and many more, can be calculated directly on the geometry models, using other GeoDict modules, e.g. PoroDict, ConductoDict, FlowDict, ElastoDict, DiffuDict or FilterDict.

Important application areas are the production of glass fiber and carbon fiber reinforced composites, fibrous insulation materials, gas diffusion layers in fuel cells, filter media, dewatering felts, and many others.

FIBERGEO SECTION

FiberGeo is the default module for the start of GeoDict and allows for the generation of fibrous nonwoven structures. Otherwise, FiberGeo starts when selecting **Modules → FiberGeo** in the Menu bar.

The **FiberGeo** headed section contains a pull-down menu containing the available FiberGeo modes.



- **Predefined** creates some predefined materials from different application areas.
- With **Create** the fibers appear randomly in a given location inside an empty volume.
- When using **Pile** the fibers fall down and settle after shifts and rotations at their final position.
- With analytic data from an initial GeoDict analytic data (*.gad) file, the fibers are taken and redistributed in the given volume using **Distribute**. Often used after a piling step to get a more homogeneous material.
- **Add Binder** adds material in the shape of a concave meniscus in locations where fibers in that structure get close together. This models binder in fibrous structures.

After selecting a mode from the pull-down menu, the necessary parameters can be entered through the corresponding **Options Edit ...** button located in its panel.

Clicking **Generate** at the bottom of the **FiberGeo** section starts the program's generation run. The fibrous structure is created and shown in the **Visualization** area. Macro files are recorded and saved when selecting **Macro → Start Macro Recording...** in the Menu bar. When recording a macro, **Record** becomes active and **Generate** changes to **Generate & Record**.

The modes **Predefined**, **Create**, and **Pile** generate a new fibrous structure or a new structure in the structure currently in memory. The other modes (**Distribute** and **Add Binder**) require a valid initial structure.

For **Create** and **Pile**, a customized **Result File Name (*.gdr)** should be entered to differentiate the results of sets of FiberGeo generations. The resulting *.gdr file will be placed inside the chosen project folder.

When running projects worth archiving, it is useful to save many files with information about the structure generation process. Thus, in addition to the *.gdr file, the project folder may optionally contain a variety of saved files from the FiberGeo run in formats .gdt (GeoDict File), .gad (GeoDict analytic data), .gmc (GeoDict Macro file), and *.gps (GeoDict Project Settings file). Otherwise, the structure model can be saved in .gdt and .gad format by selecting **File → Save Structure as...** in the Menu bar.

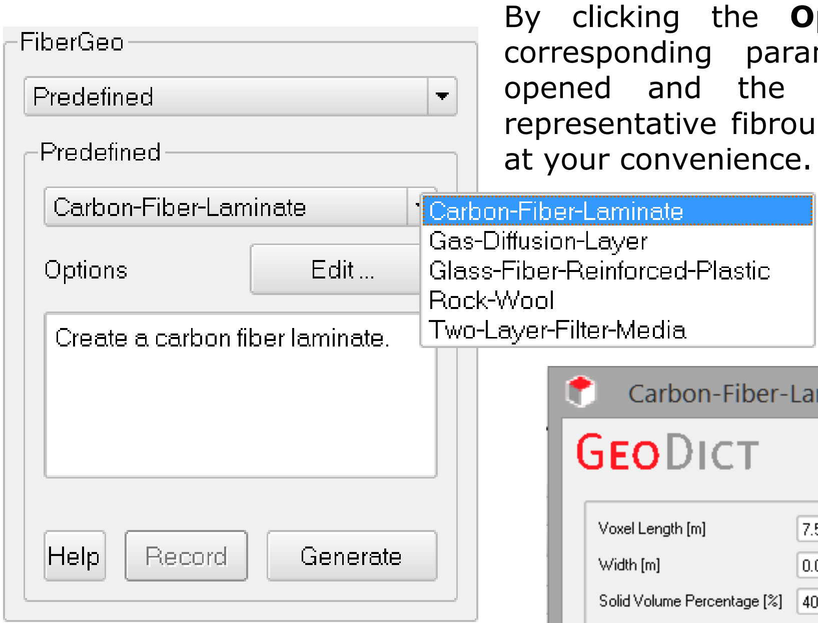
If you save the **Options** dialog boxes parameters into *.gps (**GeoDict** Project Settings) files, you can reload them at will.

Remember to restore and reset your (or GeoDict's) default values through the icons at the bottom of the dialog boxes when needed and/or before every FiberGeo run. Rest the mouse pointer over an icon to see a ScreenTip showing the icon's function.

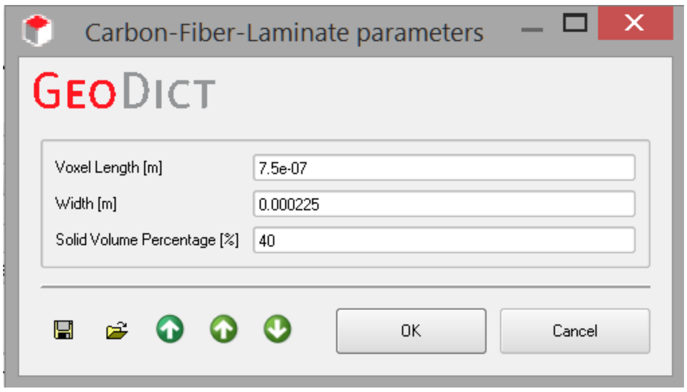
PREDEFINED

When **Predefined** is selected in the **FiberGeo** section, several representative fibrous structures can be chosen from the pull-down menu in the **Predefined** panel. Five predefined fibrous materials are currently available: a Carbon Fiber Laminate, Rock Wool, a Two-Layer Filter Media, a Gas Diffusion Layer (GDL), and a Glass-Fiber Reinforced Plastic (GFRP).

When predefined materials are created, GeoDict macros corresponding to the generation of these five predefined fibrous structures are called and executed. These macros are available in the **FiberGeo** folder in the GeoDict installation folder. They can be opened with a text editor to observe their syntax and the steps involved in the generation, and can also be edited. To add your own predefined materials put the corresponding macros in the described folder and start GeoDict again.



By clicking the **Options Edit...** button, the corresponding parameter dialog box can be opened and the parameters defining these representative fibrous structures may be changed at your convenience.

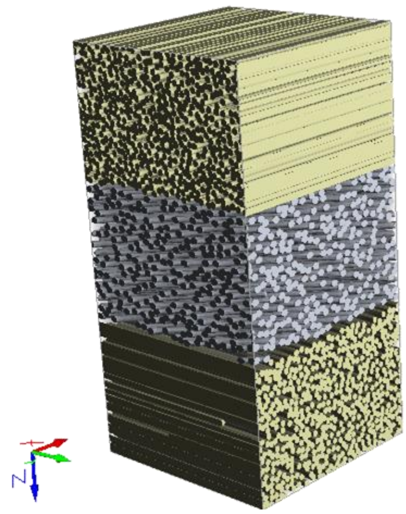


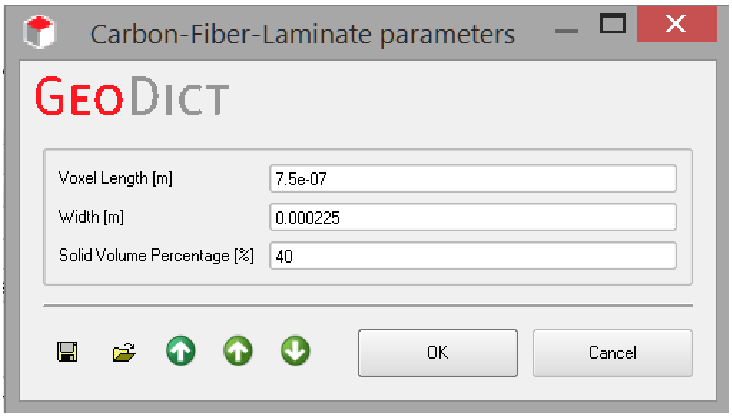
After modifications are done, clicking **Generate** produces the modified predefined fibrous structure.

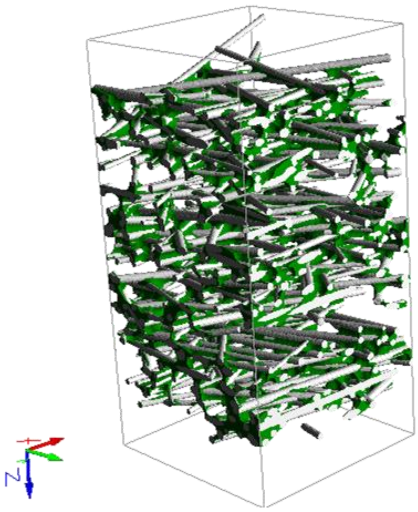
Inside the project folder, a result file (.gdr) and a folder with the same name, containing the analytic data file (.gad) of the fibrous structure, are automatically saved. The .gdr result file can be opened in GeoDict through **File → Open .gdr File…** in the menu bar.

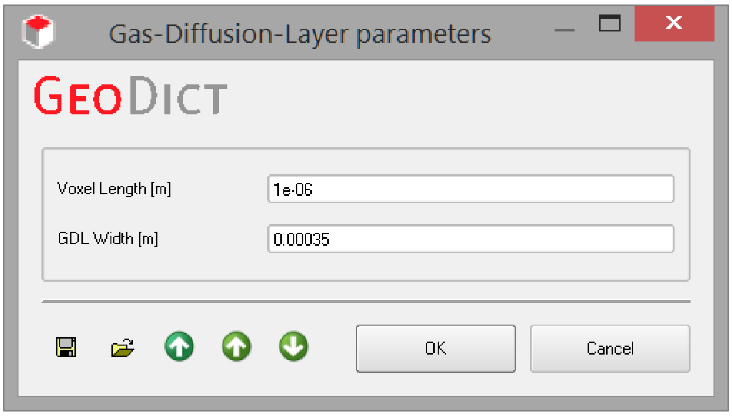
The user can directly access all parameters used for the generation of these predefined structures by clicking the **Load Input Map** button at the bottom, and then selecting **Create** in the FiberGeo section pull-down menu, and clicking the **Option**s **Edit…** button. In this way, all parameter values used for the generation are loaded into the **FiberGeo Create Options** dialog box and can be examined in detail.

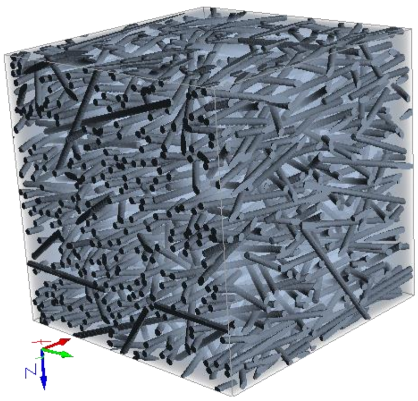
PREDEFINED MATERIALS GALLERY

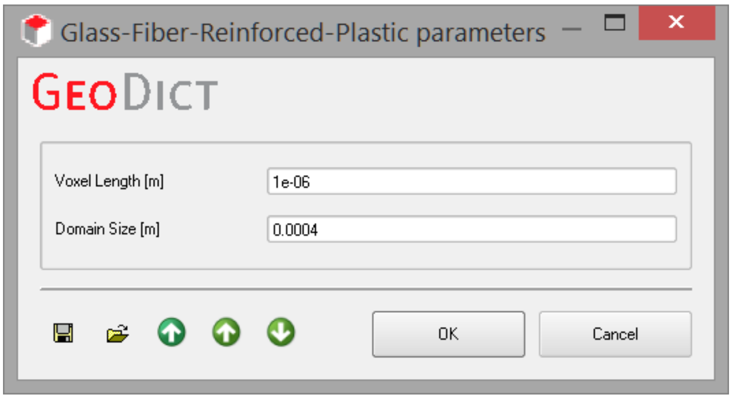


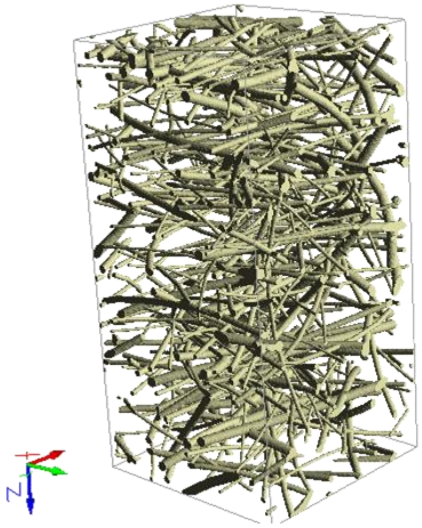


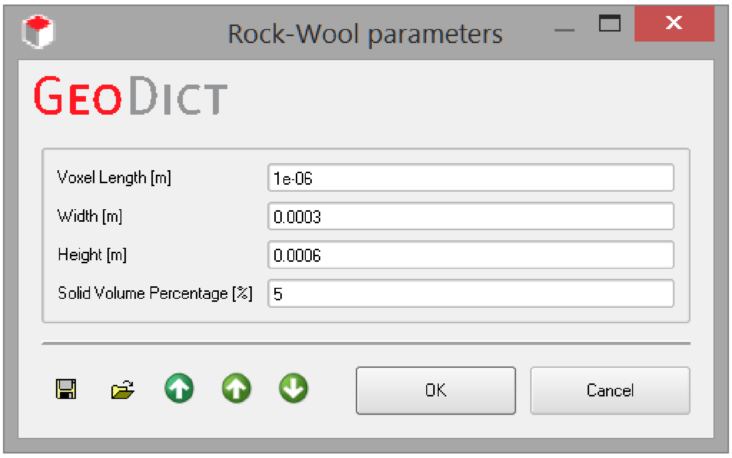


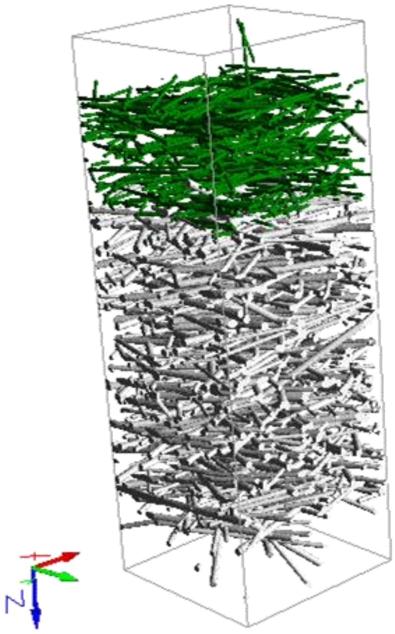


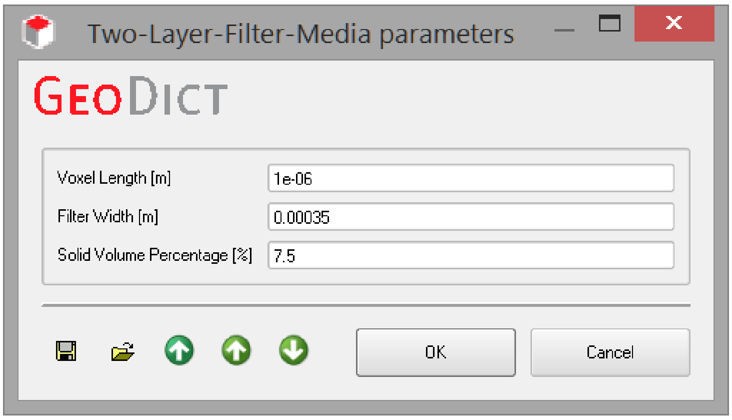






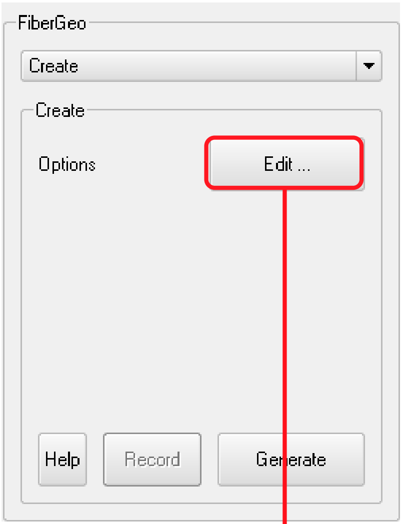

Rock-Wool parameters
GeoDict
Voxel Length [m]
1e-06
Width [m]
0.0003
Height [m]
0.0006
Solid Volume Percentage [%]
5
OK
Cancel




Two-Layer-Filter-Media parameters
GeoDict
Voxel Length [m]
1e-06
Filter Width [m]
0.00035
Solid Volume Percentage [%]
7.5
OK
Cancel

CREATE

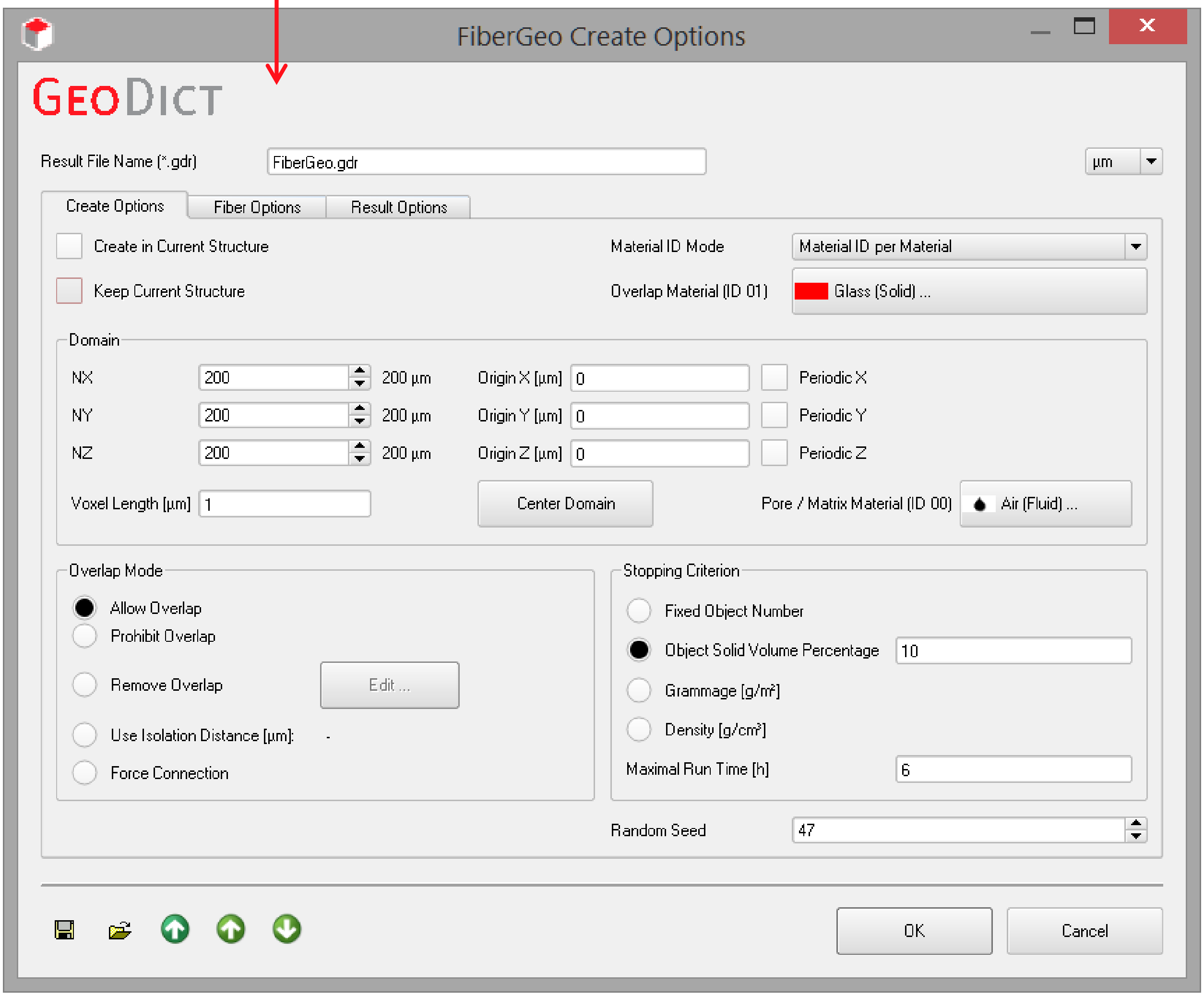
The **FiberGeo Create Options** dialog box opens when clicking the **Options**' **Edit...** button in the FiberGeo section.



At the top left of the **FiberGeo Create Options** dialog box, the name for the files 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 available units (**m**, **mm**, **µm**, **nm**, and **Voxel**) are selectable from the pull-down menu at the top right of the **FiberGeo Create Options** dialog box. When the units are changed, the entered values are adjusted automatically.

The options are organized into **Create Options, Fiber Options**, and **Result Options** accessible through tabs.



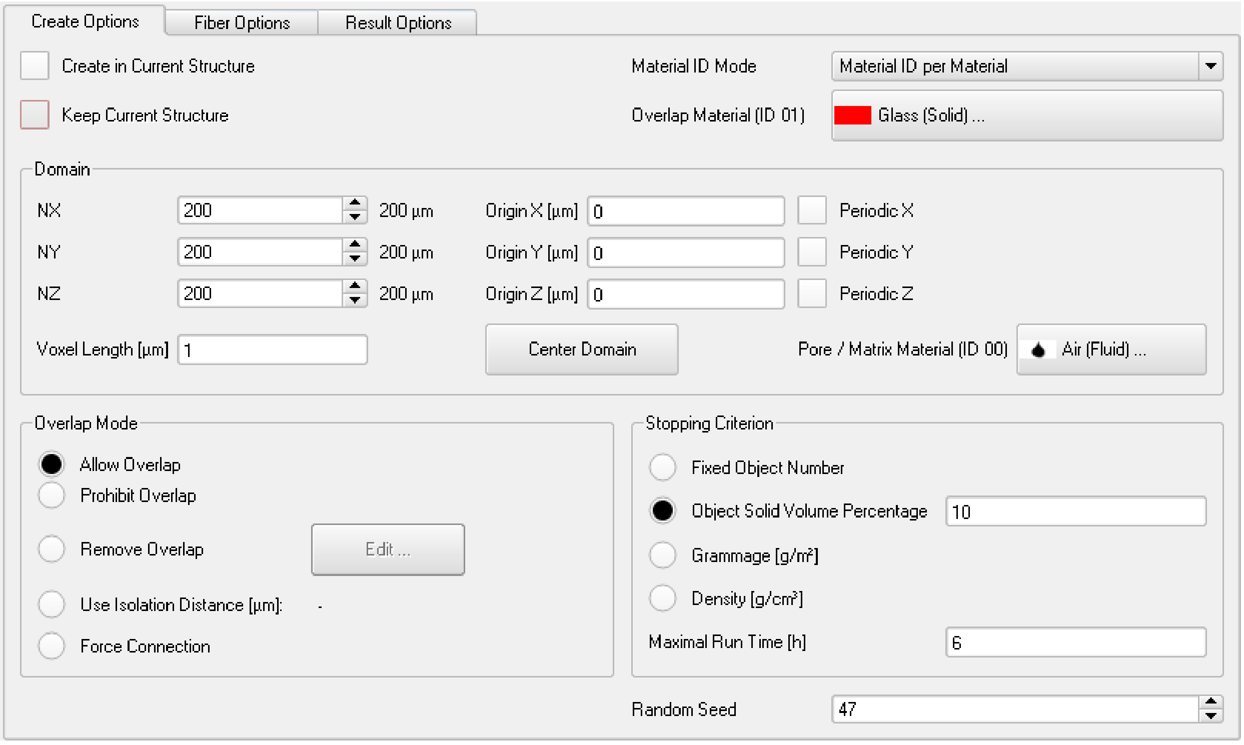
- The **Create Options** determine physical properties of the resulting structure model such as size, position, resolution, and solid volume fraction.

- The **Fiber Options** define the geometrical properties of individual fiber types such as cross-section, length, and orientation. Up to four different material types can be used in one structure.
- The **Result Options** determine if and how the resulting geometry is saved.

As usual, GeoDict does not overwrite the results but automatically appends _no1, _no2, etc. to the result file name if it already exists, unless alternative names are entered. The result files are saved in the chosen project folder (**File → Choose Project Folder**, in the Menu bar).

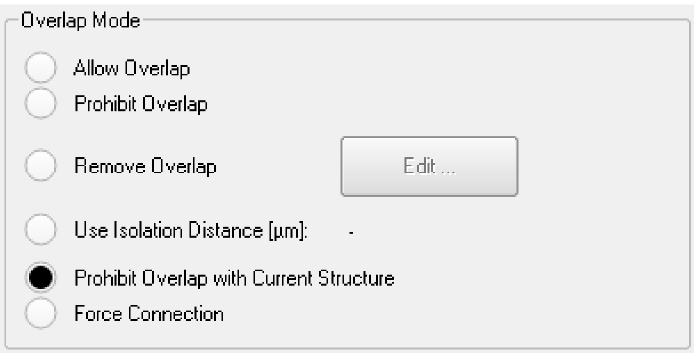
CREATE OPTIONS

The geometric properties of the fibrous structure are entered under the **Create Options** tab. These parameters are grouped into the panels **Domain**, **Overlap Mode**, and **Stopping Criterion**.



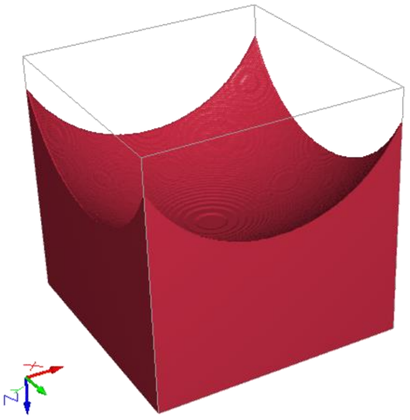
When checking **Create in Current Structure**, the structure currently in memory and showing in the **Visualization** area, is taken into account during the generation of a new structure. Additionally, when **Keep Current Structure** is checked, the structure in memory is kept to be combined with the newly generated fibrous structure.

This feature is used in combination with checking **Prohibit Overlap** or **Prohibit Overlap with Current Structure** (see below, page 16) in the **Overlap Mode** panel.



In this way, complex fibrous models can be achieved. For example, the user can make fibers surround and mold an area previously occupied by a structure that is not kept.

Observe the effect that checking, or leaving un-checked, **Create in Current Structure** and **Keep Current Structure** have during the generation of a fibrous structure.

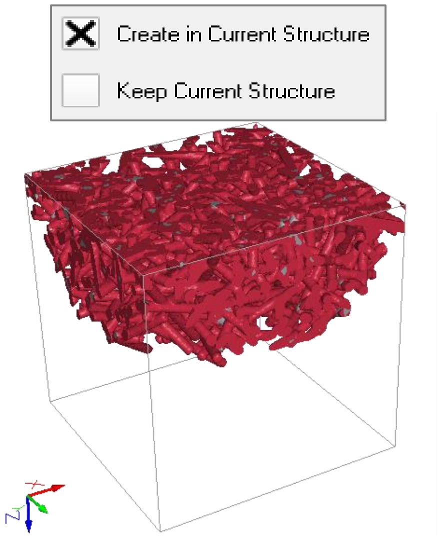


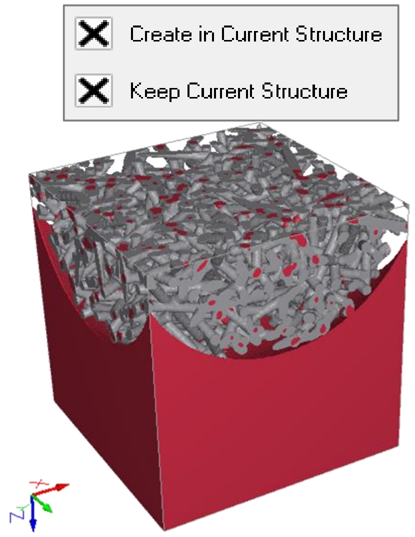
Notice that the parameters grouped under the **Domain** panel, including the voxel length, cannot be modified once the **Create in Current Structure** box is checked, because they are taken from the structure already in memory

A mold is generated and present in memory while polyamide PA-66 fibers are added, not keeping or keeping the mold (current structure). **Prohibit Overlap with Current Structure** is checked to avoid the PA-66 fibers to enter the mold, but the PA-66 fibers can overlap each other.

If additionally, the PA-66 fibers should not overlap each other, the more restrictive **Prohibit Overlap** should be checked instead.

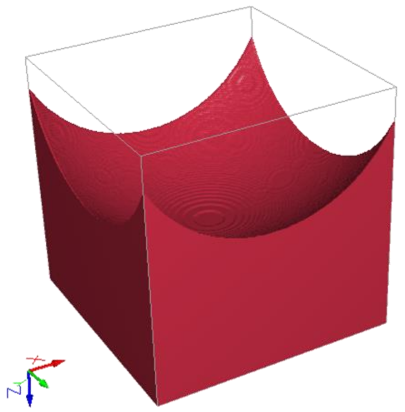
The PA-66 fibers are automatically assigned the material ID 02 when keeping the current structure (with Material ID 01).

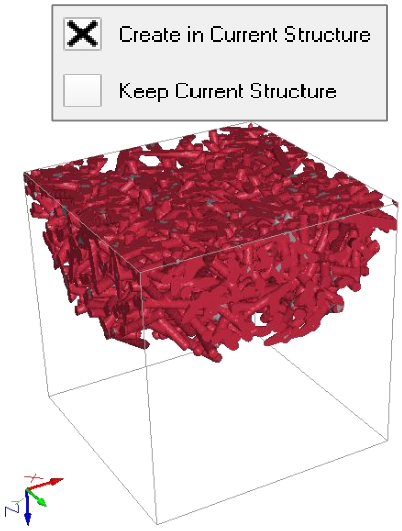


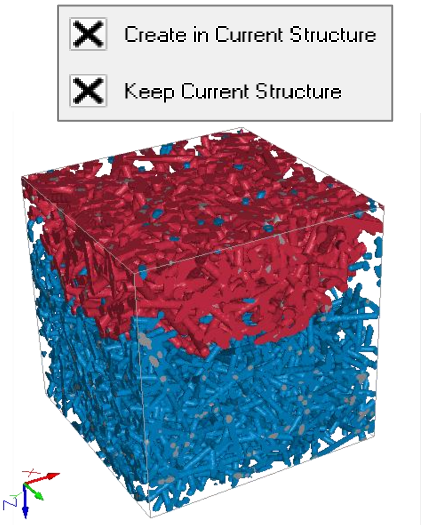


In the following example, the same mold is made and then PA-66 fibers are generated into the mold, which is not kept. Then, the current structure made of PA-66 fibers is kept and PET fibers are generated in the same form that the mold previously had.

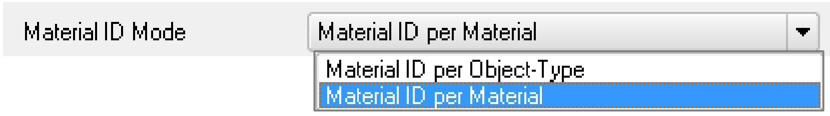
In every step, overlap is prohibited with the current structure but not between the newly generated fibers.







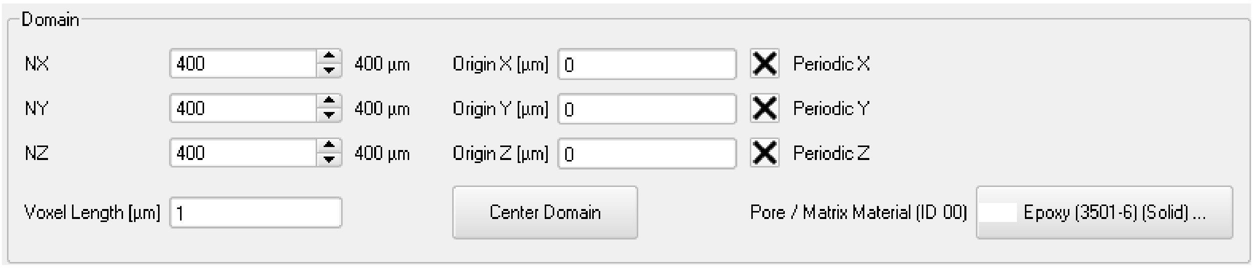
The **Material ID Mode** pull-down menu allows selecting between applying the Material ID based on the materials or the types of objects (fibers) present in the fibrous structure. Assigning a Material ID is part of the GeoDict Material Database concept, in which objects in the structure are ascribed to an individual material (e.g. glass, iron, PET) with specific physical properties.



Overlap Material controls the ID of the material assigned to the regions where fibers of the newly generated structure overlap.

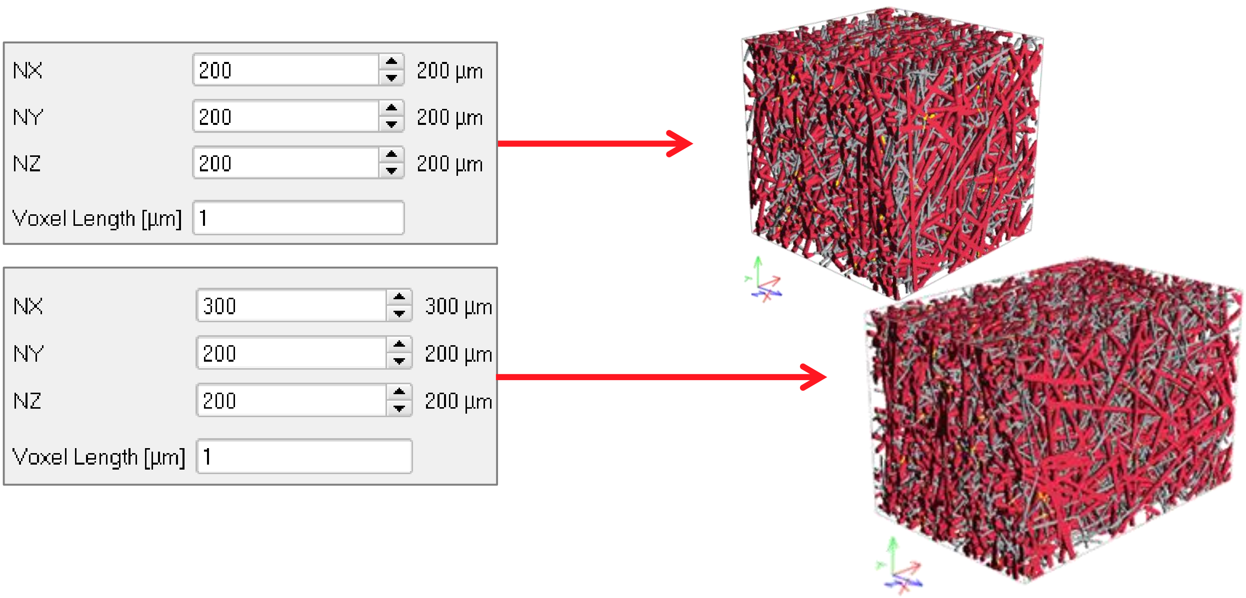
Domain parameters

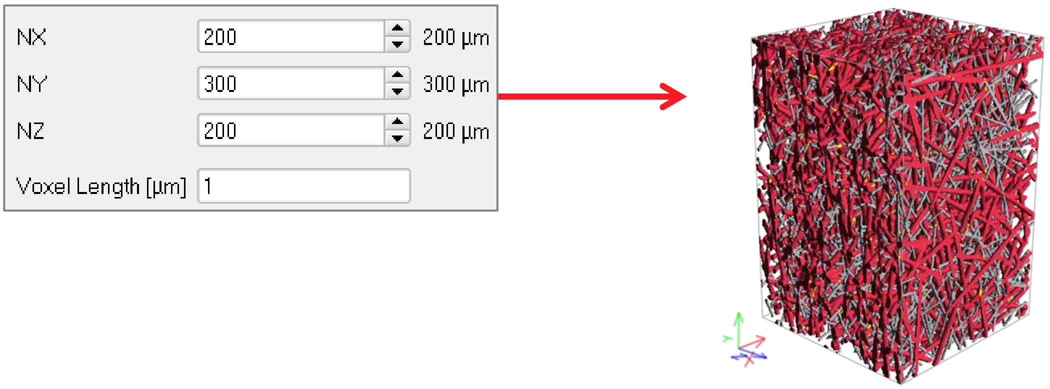
The **Domain** panel contains the parameters defining the structure size (**NX**, **NY,** and **NZ**) in combination with the resolution (**Voxel Length**), as well as the **Origin** parameters, the **Periodicity** check-boxes, the **Center Domain** button, and the **Pore/Matrix Material (ID 00)** pull-down menu.



NX, NY, NZ, and Voxel Length

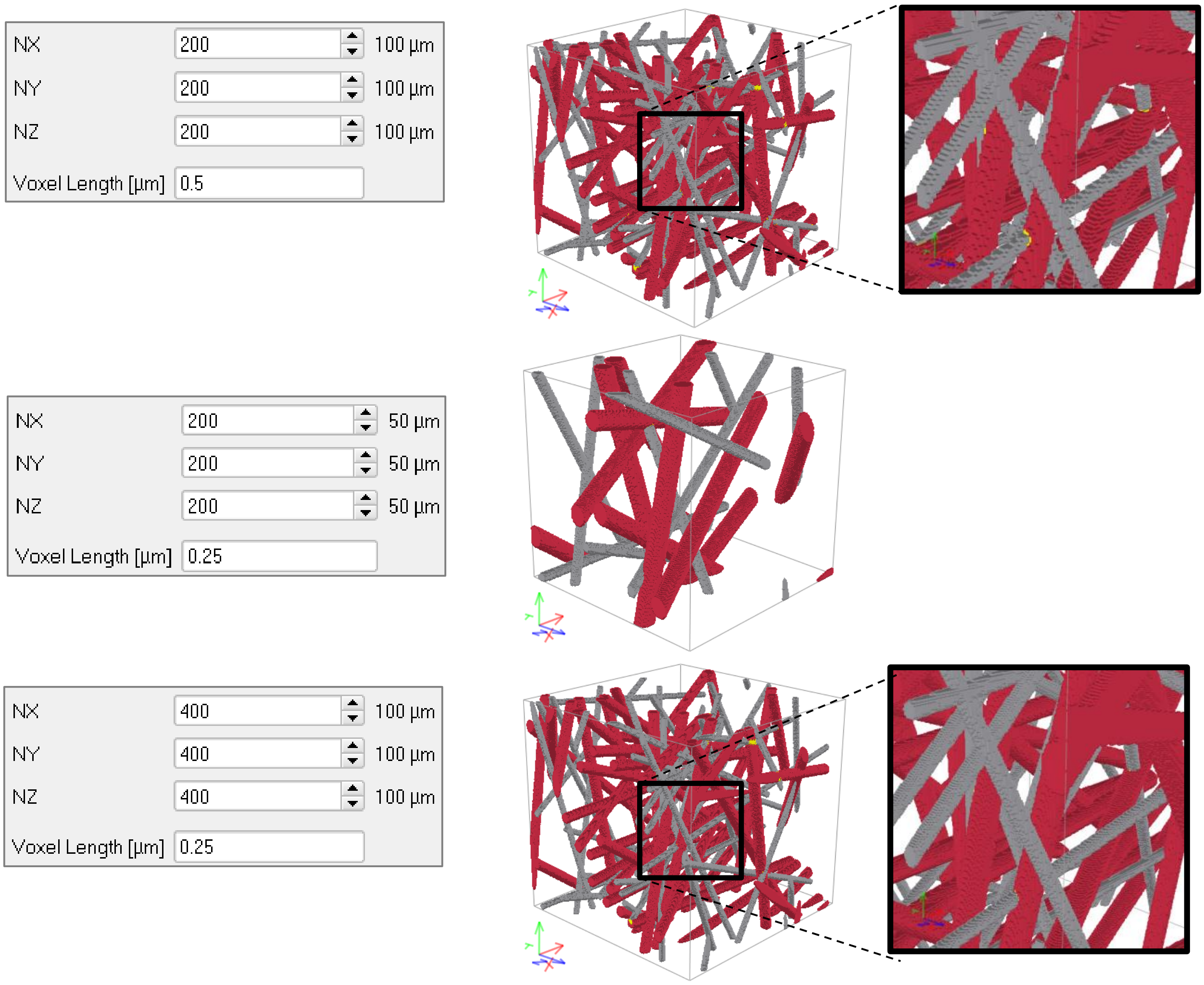
The internal representation of a structure in GeoDict consists of rectangular 3D arrays of equal sized boxes, hereafter called volume elements or **voxels**. **NX**, **NY,** and **NZ** are the number (N) of voxels in X, Y and Z directions. The **Voxel Length** is the size of one voxel in the chosen units. Varying the values for **NX**, **NY**, and **NZ** has the effect of changing the size of the structure in the given direction.





Low values for voxel length result in higher resolution, but also 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.

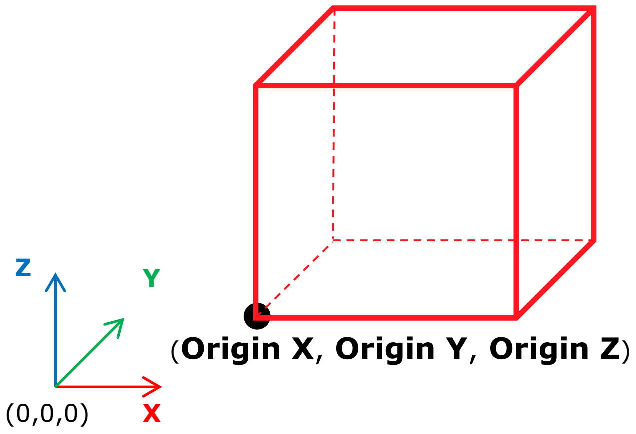
Observe how setting the number of voxels at a constant 200 x 200 x 200 voxels (100 x 100 x 100 µm^3) while decreasing the **Voxel Length** from 0.5 µm to 0.25 µm has the effect of refining the structure by increasing the resolution while decreasing the size of the volume to 50 x 50 x 50 µm^3. By restoring the original size of the volume to 100 x 100 x 100 µm^3 (**NX**=400, **NY**=400, **NZ**= 400), the structure is displayed at higher resolution.



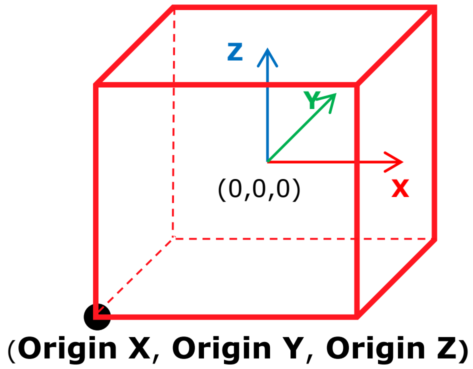
Origin x, Origin y, and Origin z, and Center Domain

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 require that the point with (0, 0, 0) coordinates be located at the lower left corner of the structure. To enter values for **Origin X**, **Origin Y**, and **Origin Z** is interesting in applications that call for exact structure coordinates.



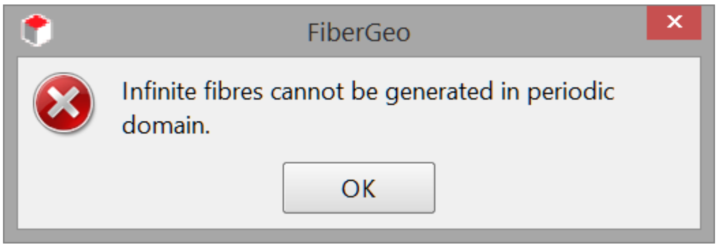
When clicking the **Center Domain** button, the origin is placed so that the point with (0, 0, 0) coordinates lies in the center of the structure.



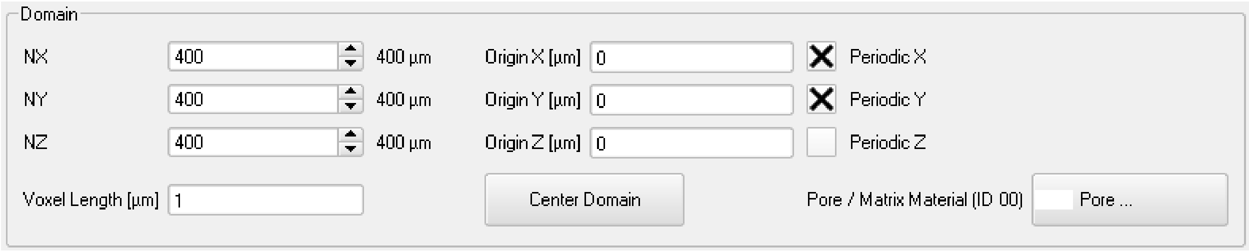
Periodicity

Periodicity is understood as the periodical repetition of the structure in space. Checking the **Periodic X**, **Periodic Y**, and **Periodic Z** boxes allows the generation of structures which are periodic in one or several directions. Periodicity has the effect that the fibers ending on one side of the volume reappear in the opposite side, so that when several volumes with periodic fibers are combined, the structure emerges as a repetitive complex.

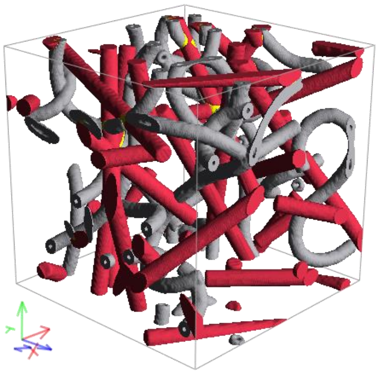
An error message displays when trying to generate a periodic structure with **fibers that are longer than the structure size**. It is required that the fiber length be shorter than or equal to the structure size.



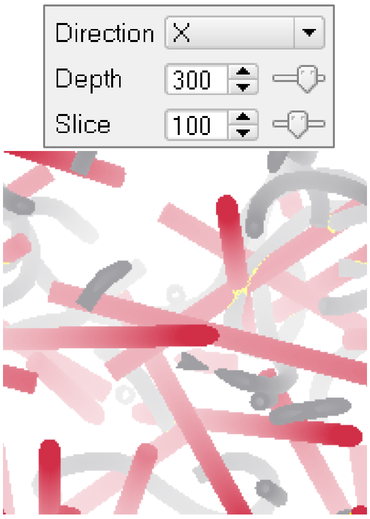
Observe the effect of checking the **Periodic X** and **Periodic Y** boxes, but leaving un-checked the **Periodic Z** box, has on the periodicity of a generated fibrous structure.

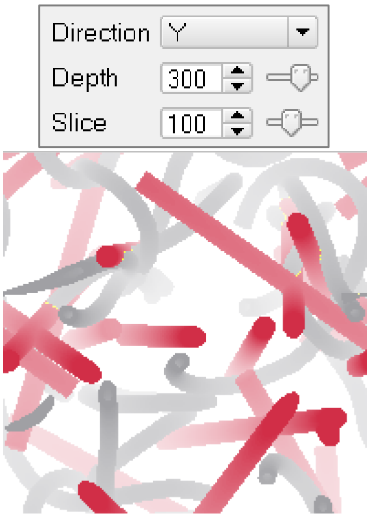


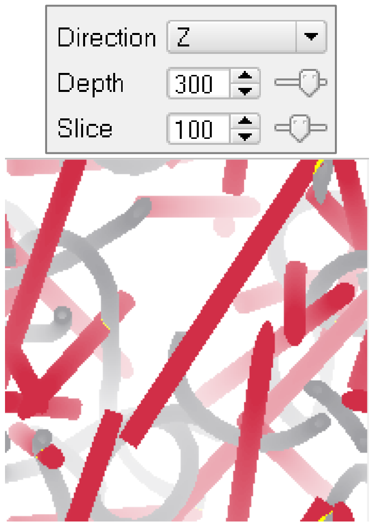
View → 3D Rendering



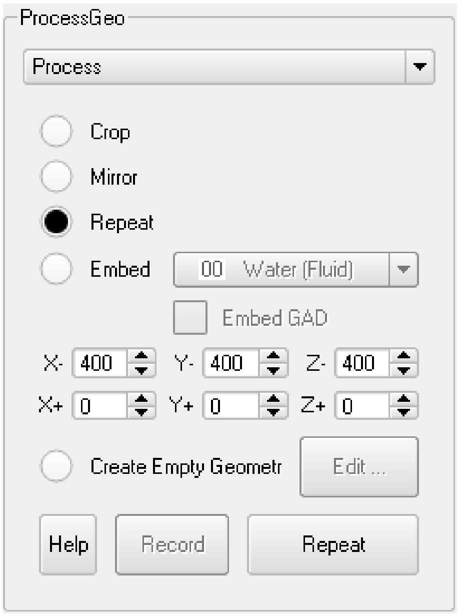
View → 2D Cross Section

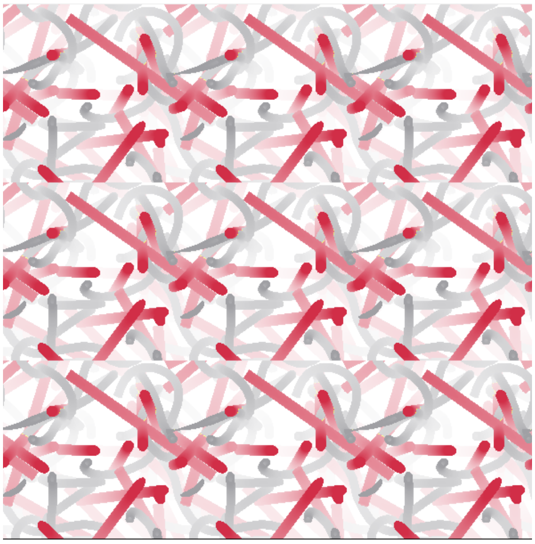




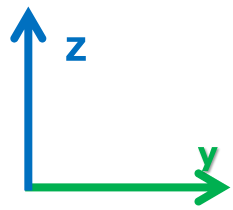


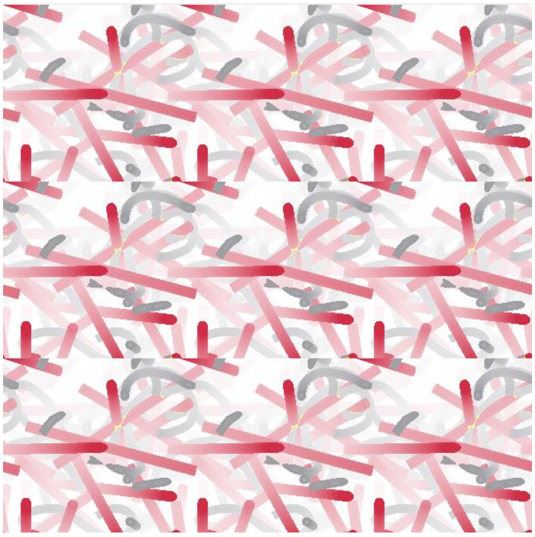
The effect is readily observed when repeating the sample structure through **Modules → ProcessGeo** (Repeat: X- 400 voxels, Y- 400 voxels, and Z- 400 voxels) and viewing it again from the three directions. In the directions checked as periodic (X and Y), the fibers connect to each other across the repeated samples. In the direction checked as non-periodic (Z), the fibers end at the edge of the sample.



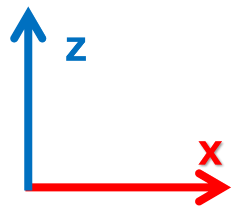


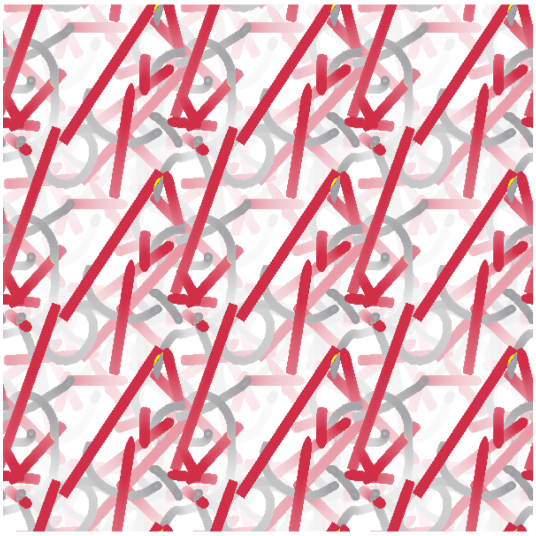
Observe the periodicity in the Y-direction, with unit cells passing smoothly into each other, and no periodicity in Z-direction, with unit cells appearing disconnected.



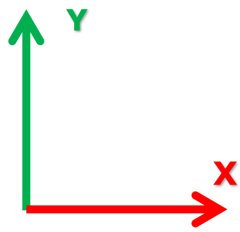


Observe the periodicity in X-direction, with unit cells passing smoothly into each other, and no periodicity in Z-direction, with unit cells appearing disconnected.





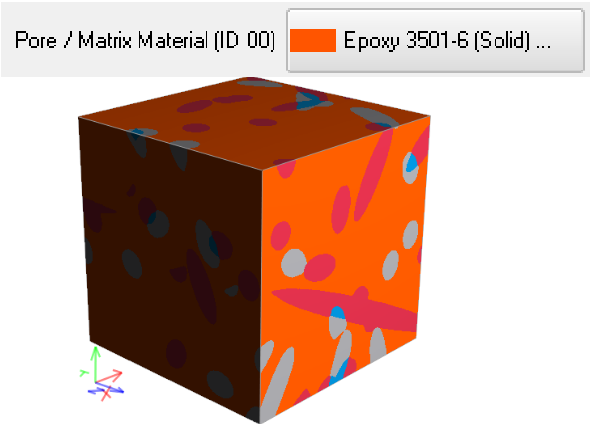
Observe the periodicity in the X- and the Y-directions, with unit cells passing continuously into each other in both directions.

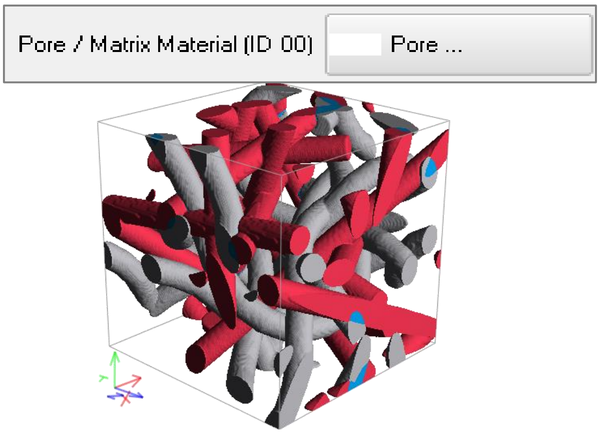


Pore/Matrix Material

Choose the material of the pore space or the matrix around the fibers from the pull-down menu.

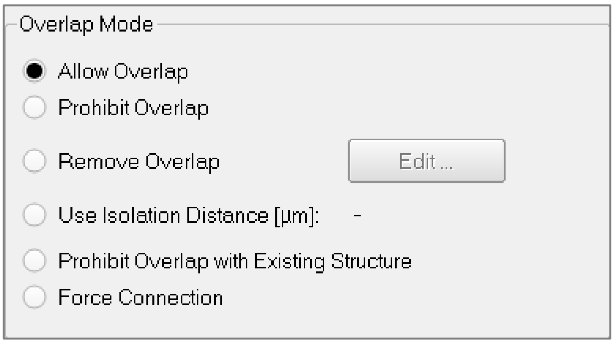
When the material is chosen to be **Pore**, the fibers are embedded in empty pore space. Otherwise, the material filling the matrix can be chosen to be a **Solid**, **Porous**, or **Fluid** in which the fibers are embedded.

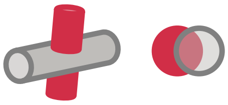


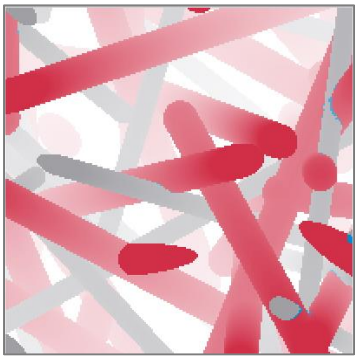


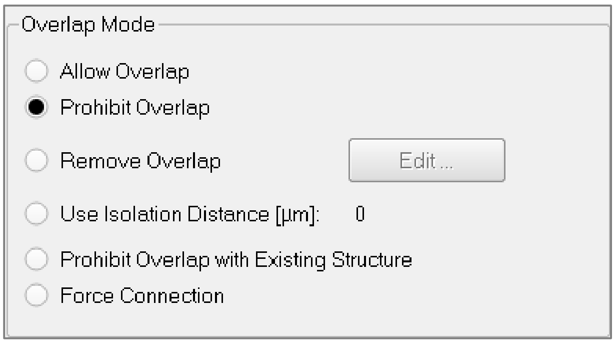
Overlap Mode

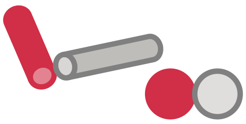
The options in the **Overlap Mode** panel control the relative position among fibers or with the structure currently in memory. It is possible to choose **Allow Overlap**, **Prohibit Overlap**, **Remove Overlap**, **Use Isolation Distance**, **Prohibit Overlap with Existing Structure**, or **Force Connection**. Fibers may overlap when **Allow Overlap** is selected. Fibers may touch but not overlap when the **Prohibit Overlap** is selected.

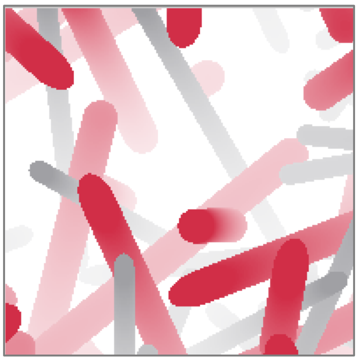


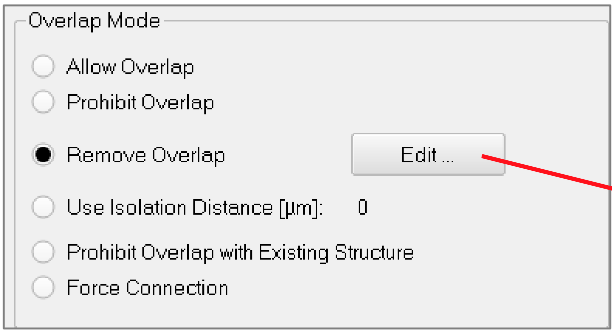


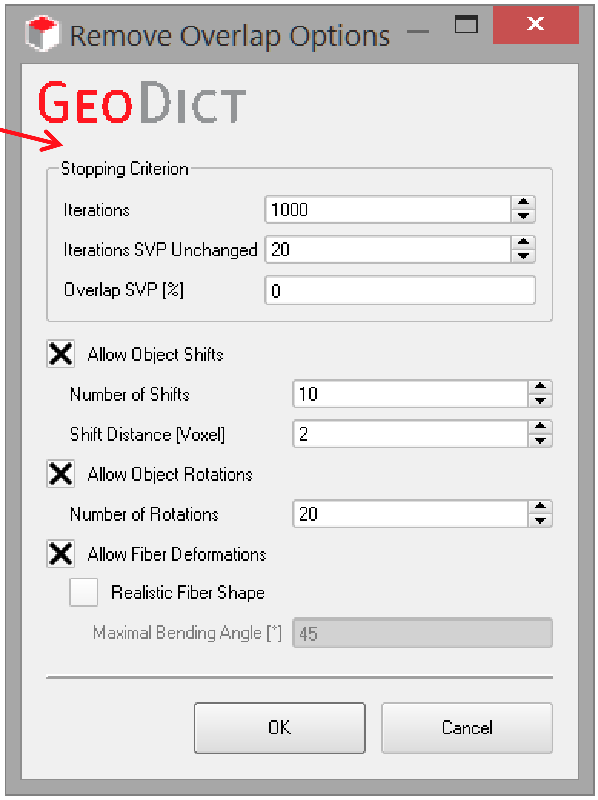








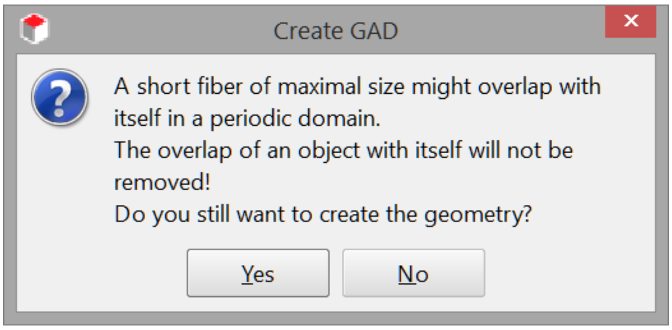




Checking **Remove Overlap** eliminates existing overlaps after the generation step. The user should take into account that:

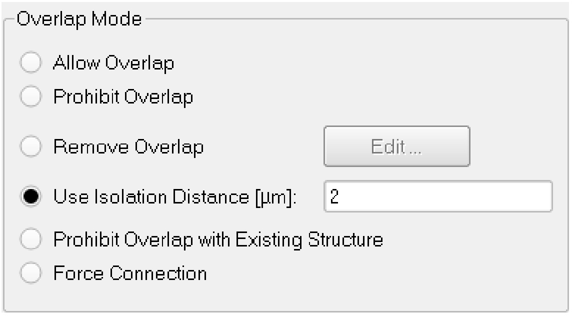
- Overlaps can be removed only from periodic structure models. The statistical properties might change slightly.

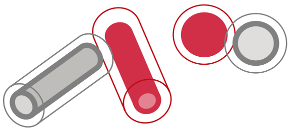
- Overlaps cannot be removed in a periodic domain if fibers are longer than the domain. Such fibers might overlap with themselves and the overlaps cannot be removed. In this case, an error message appears.

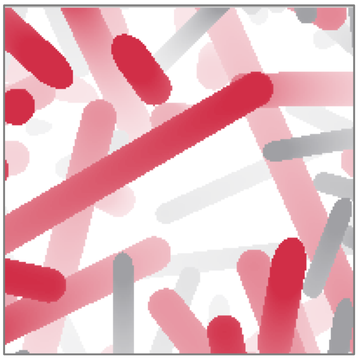


The way in which the overlap removal occurs can be controlled through the **Remove Overlap Options**. Set parameters such as the final **Overlap SVP** allowed and after how many iterations the removal should stop, or whether the removal should be done by shifting, rotating, or deforming the fibers, etc.

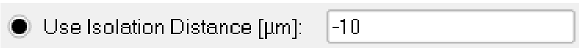
By selecting **Use Isolation Distance,** and inserting a positive value, the gaps between fibers have at least this preset distance.

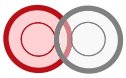


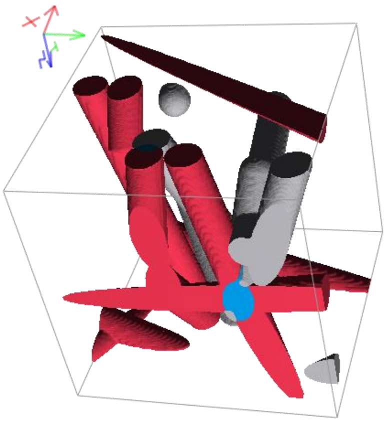




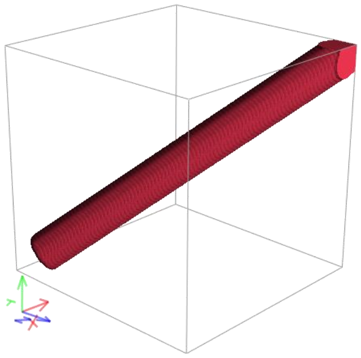
When the **Use Isolation Distance** is set to negative values (e.g. -10 µm), the effect is that the fibers may overlap with maximally 10 µm (showing in a different color which here is blue). Negative values of isolation distance are useful to model synthetic fibers that melt, or natural fibers that deform at touching points, during the generation of the structure. Then, the distance between the centers of the fibers is less than the sum of the two diameters.

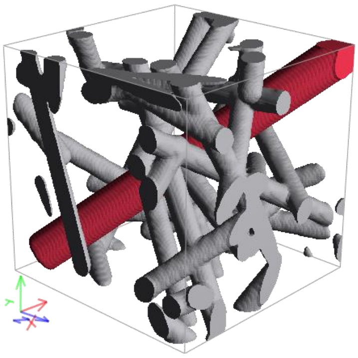




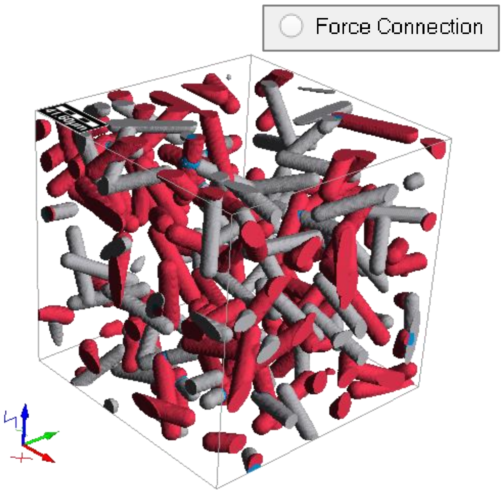


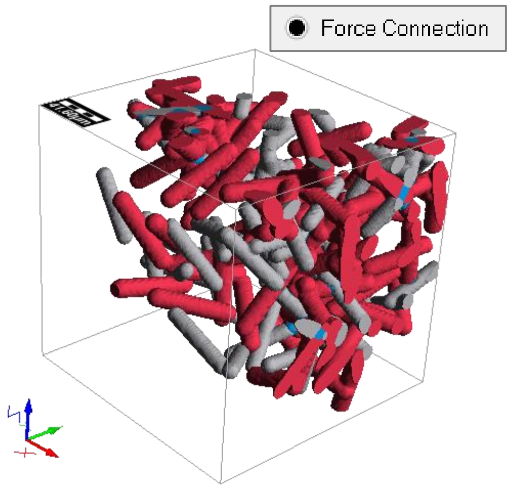
When choosing **Prohibit Overlap with Current Structure** (and checking Create in Current Structure), the fibers in the newly generated structure are allowed to intersect with each other but not with those of the already existing structure. Observe this effect in a structure with one fiber (red) over which a new structure with thinner grey fibers is generated. Whereas the gray fibers overlap with each other, they do not overlap with the pre-existing red fiber.





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

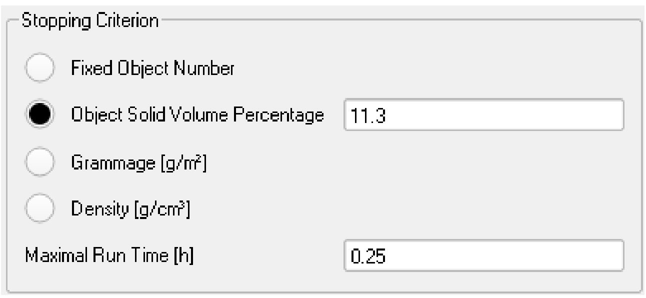




The algorithm under **Allow Overlap** is fast, especially for big structures and, in most cases, leads to excellent results. In contrast, choosing **Prohibit Overlap**, **Use Isolation Distance**, or **Prohibit Overlap with Existing Structure**, when combined with high fiber solid volume percentages (low porosity), may lead to prolonged generation time to achieve high resolutions in big structures.

Stopping Criterion

The **Stopping Criterion** panel parameters control whether the generation process should be continued or the material is "ready".



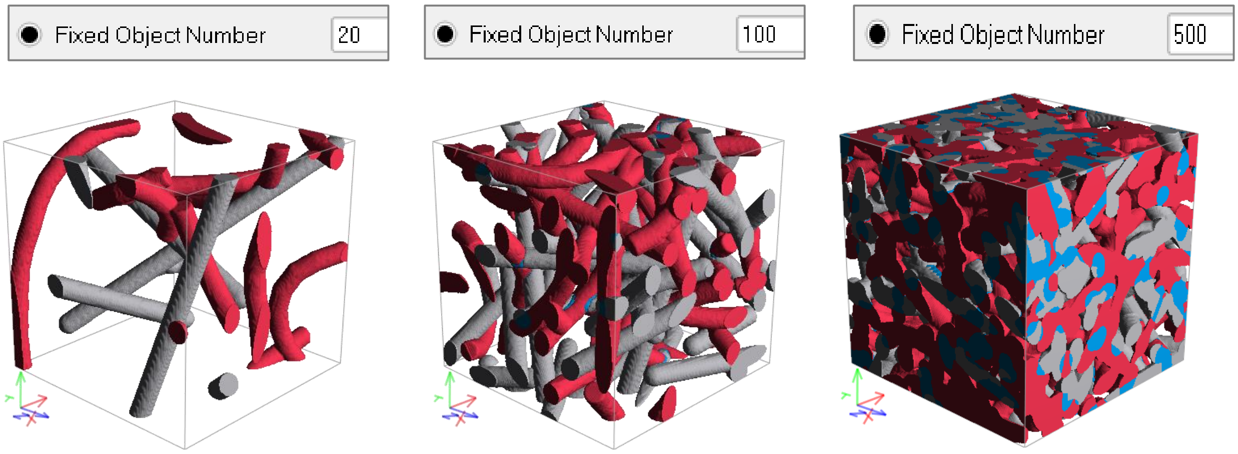
It is possible to choose between simulation parameters such as **Fixed Object Number** or macroscopic properties like **Object Solid Volume Percentage**, **Grammage (g/m²)**, or **Density (g/cm³)**.

Additionally, entering the **Maximal Run Time (h)** the process is stopped even when the desired Object Solid Volume Percentage cannot be achieved.

Fixed Object Number

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

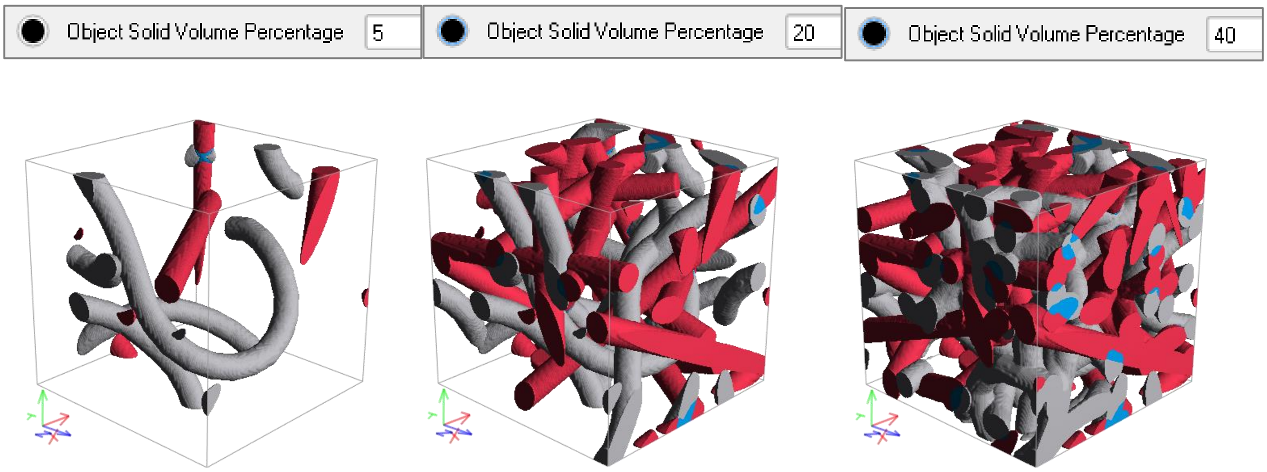
Observe the effect of setting a fixed number of objects (20, 100, or 500) as stopping criterion, for the generation of a structure with two fiber types. All other parameters are left untouched, including the default **Allow Overlap**. Note how the overlapping of fibers, shown in blue, increases with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



Object Solid Volume Percentage

Object Solid Volume Percentage (SVP) determines the fraction of the total volume in percent that the fibrous structure should have. Accepted values range from 0 to 100. For example, a structure with **Object Solid Volume Percentage** of 40 consists of 40% fibers and 60% void space. Porosity is defined as (1 – SVP).

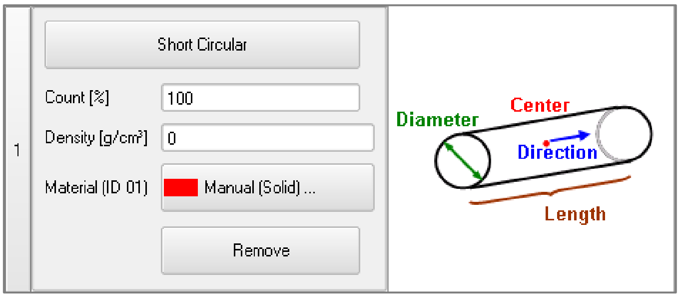
Observe the difference in a structure when varying the solid volume percentage from 5%, to 20% and finally to 40%, while all other parameters are left unchanged.



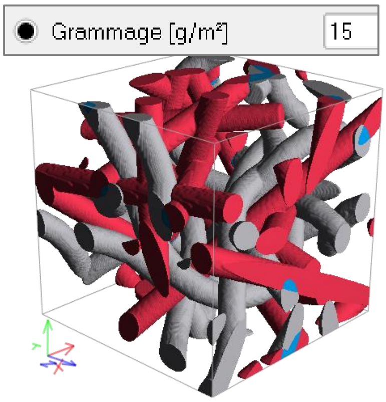
Grammage

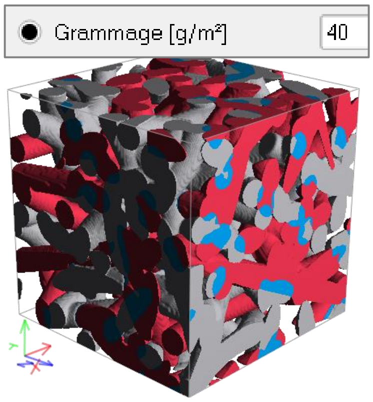
The **Grammage** (g/m²) determines the weight per area of the resulting fibrous structure and works in a similar way to the Solid Volume Percentage.

When **Grammage** is checked as stopping criterion under the **Create Options** tab, the **Density** (g/cm³) of the fiber material(s) has to be entered in each of the fiber panels under the **Fiber Options** tab.



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

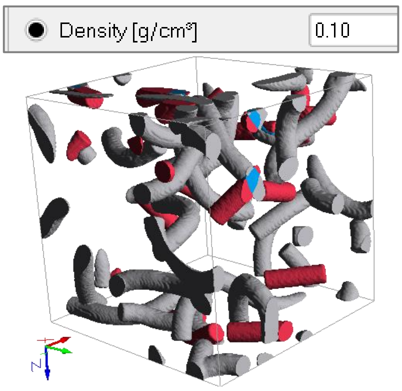


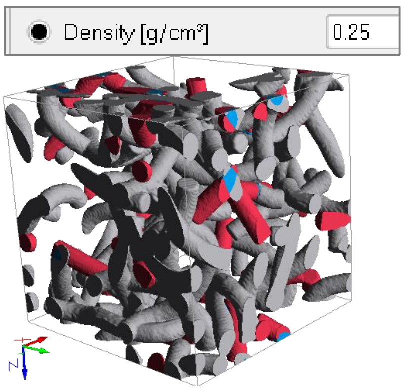


Density

The **Density** (g/cm³) also determines the weight of the resulting fibrous structure and works in a similar way to the **Object Solid Volume Percentage** and the **Grammage**.

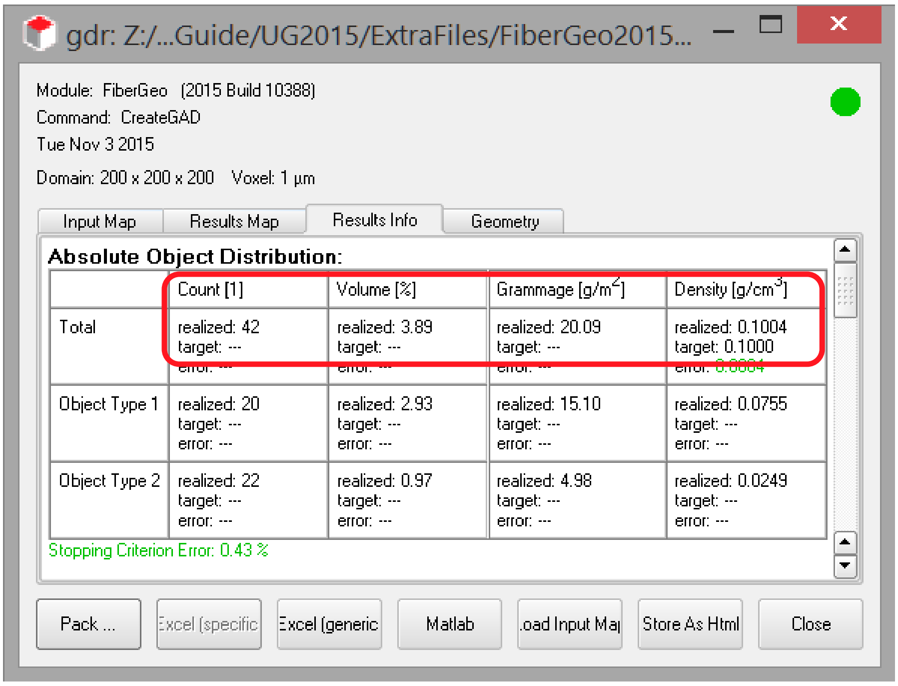
Observe the effect of increasing the density from 0.10 g/cm³ to 0.25 g/cm³, whereas all other parameters are left unchanged.





The correspondence of values between **Fixed Object Number**, **Solid Volume Percentage**, **Grammage**, and **Density** can be observed in the generation result file under the Result Info tab.

In this example a **Density** of about 0.10 g/cm³ corresponds to a **Fixed Object Number** (Count) of 42, a **SVP** (Volume) of 3.89% and a **Grammage** of 20.09%.



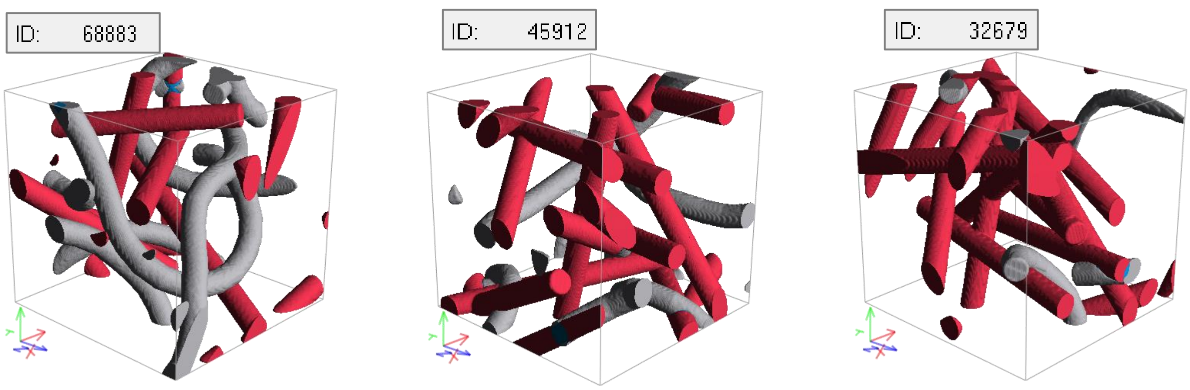
Maximal Run Time

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

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 in the visualization area, as shown by the ID number in the Status section. **Random Seed** is a non-negative integer number.

Varying the **Random Seed** allows generating different samples of the same fibrous structure for a series of experiments. In the following examples, all parameters are unchanged while the random seed automatically increases with every generation run (45, 46 and 47).



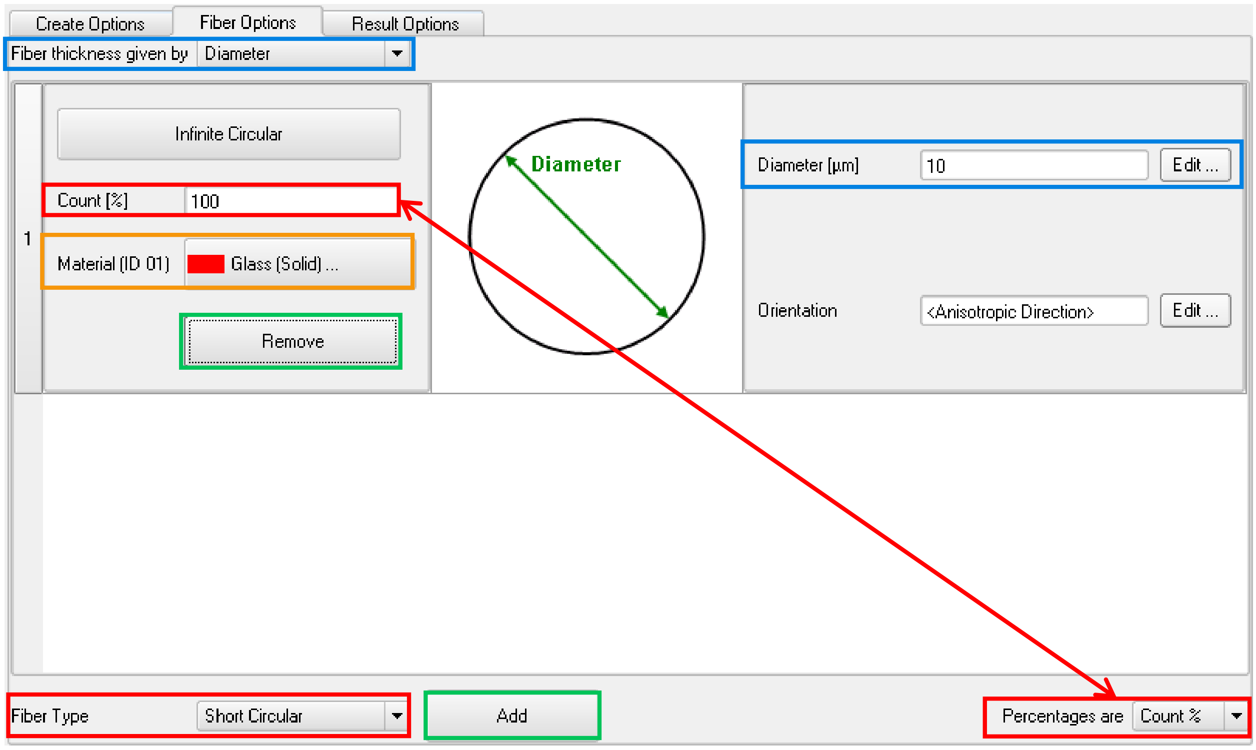
Fiber Options

All fiber options listed here can be separately set for each fiber type and these assorted fibers may coexist within the same structure. Thus, the possibilities to create a myriad variations of fibrous structures are endless.

The fibers available for the generation of fibrous structures are organized and listed in panels. For all fibers, the left column of the panel contains the name of the fiber type, the fiber percentage in the structure as **Count**, **Volume** or **Weight**, and the fiber **Material**.

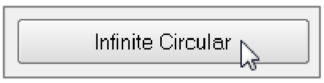
The middle column shows a drawing of the main geometrical properties of this fiber type.

In the right column, the geometrical properties or defining parameters of the particular fiber type can be entered. These geometrical properties include diameter, orientation, length, position, longitudinal deformation parameters (curved fibers), etc.



Infinite Circular is the default **Fiber Type**. At the bottom left of the dialog box, clicking **Add** inserts other fiber types chosen from the **Fiber Type** pull-down menu (Short Circular, Curved Cellulose, Infinite Hollow, etc.). Unwanted fiber types can be discarded when clicking **Remove** in the left panel 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 move up and down the list of chosen fiber types.



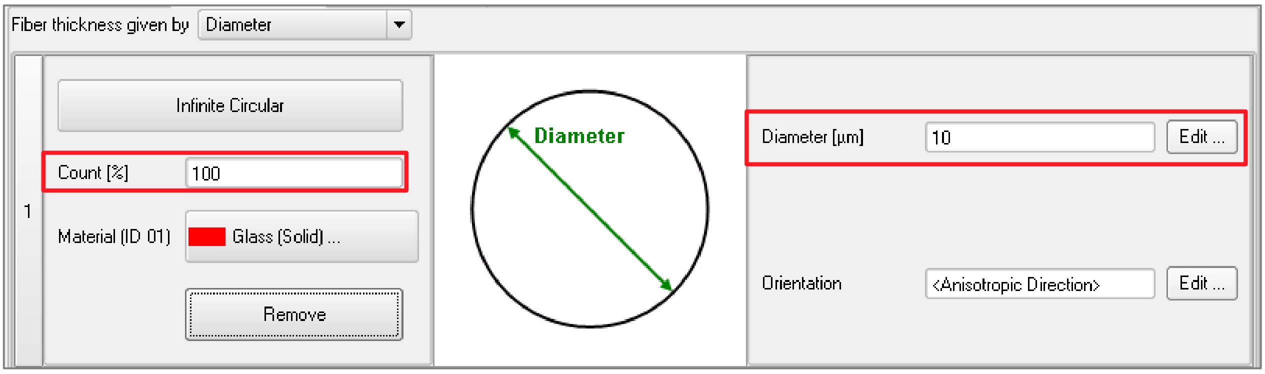
Fiber thickness

Whether the Fiber Thickness is given by **Diameter** or **Dtex** (decitex: textile unit of measure of fiber weight, 1 Dtex= 1 g/10000 m) is chosen from the pull-down menu.

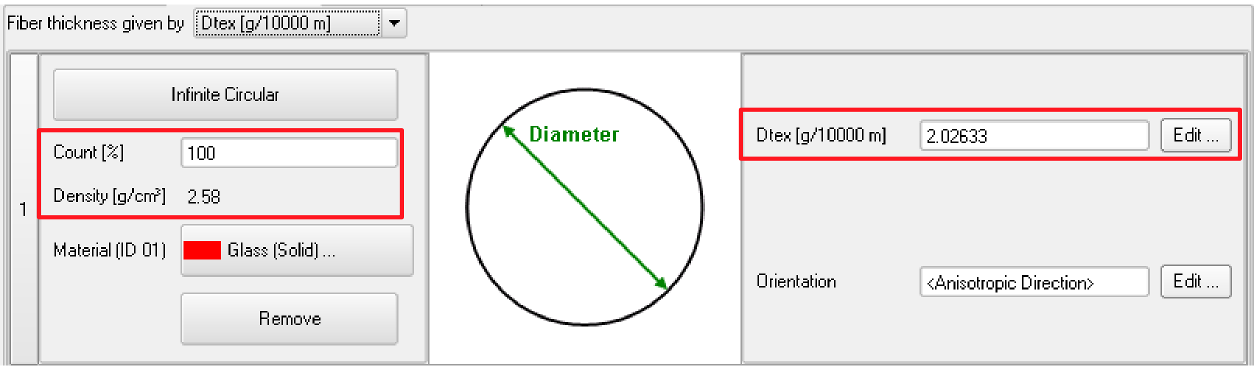
The fiber parameters in the panels are automatically adjusted depending on this choice.

The use of **Dtex** requires knowing the material density in g/cm^3.

If the choice of **Fiber thickness given by** all diameter values is changed, all fields are automatically recalculated.



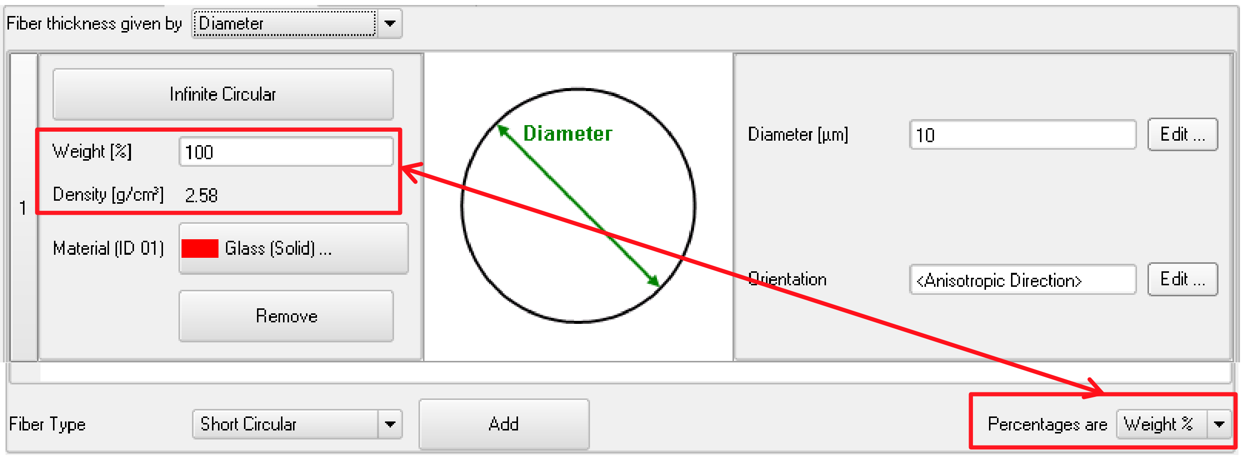
Unless changed, a default density value is used when Dtex is chosen in the pull-down menu.



FIBER TYPE PERCENTAGE AS COUNT, VOLUME, OR WEIGHT

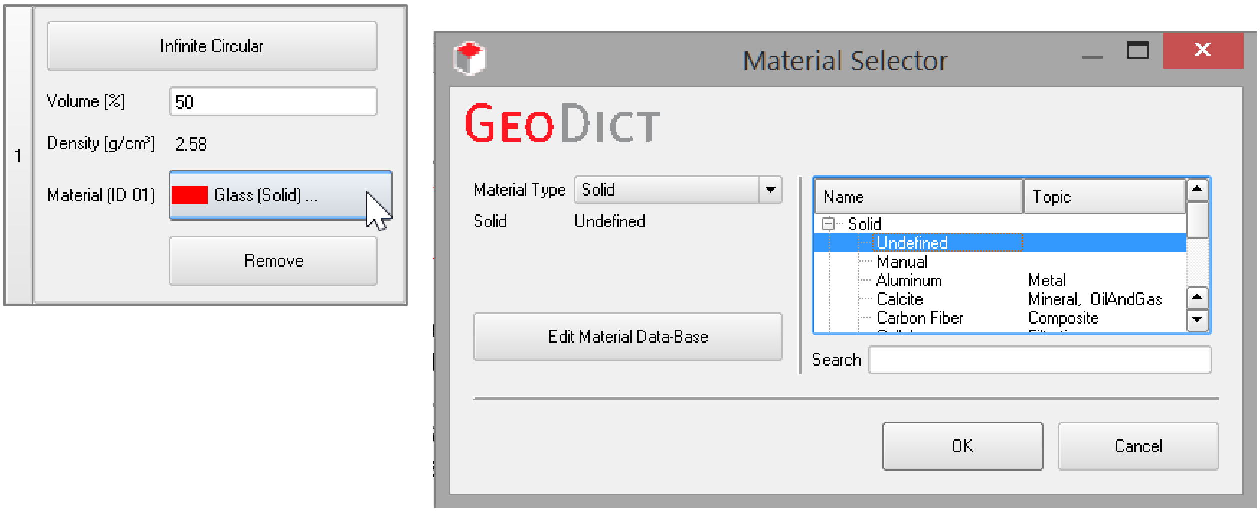
The fiber type percentage can be specified as **Count %**, **Volume %** and **Weight %** as selected from the pull-down menu at the bottom right of the dialog box.

Note that, if the **Weight** option is chosen, the default material density is given even when **Diameter** is selected in the **Fiber thickness given by** pull-down menu.

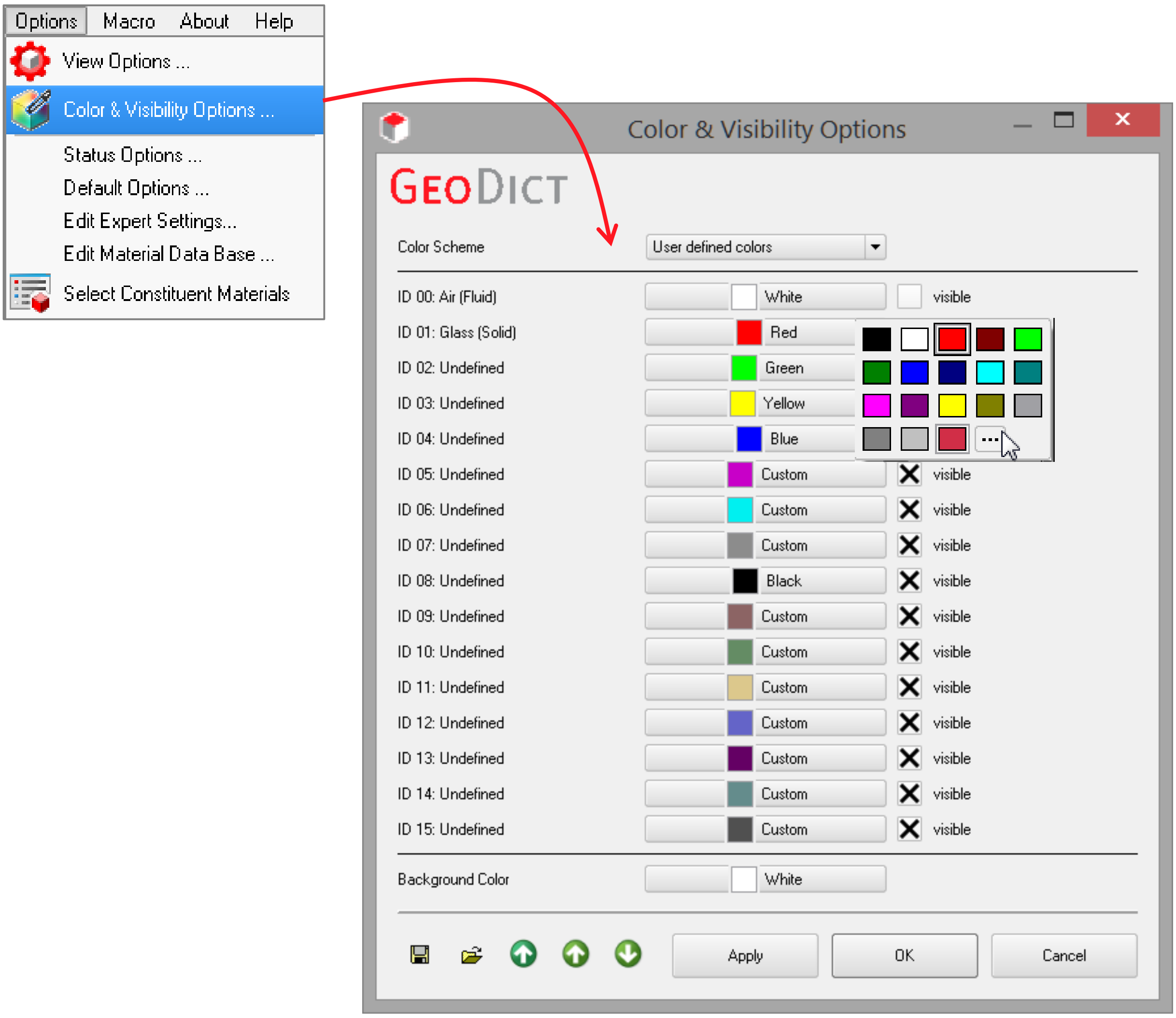


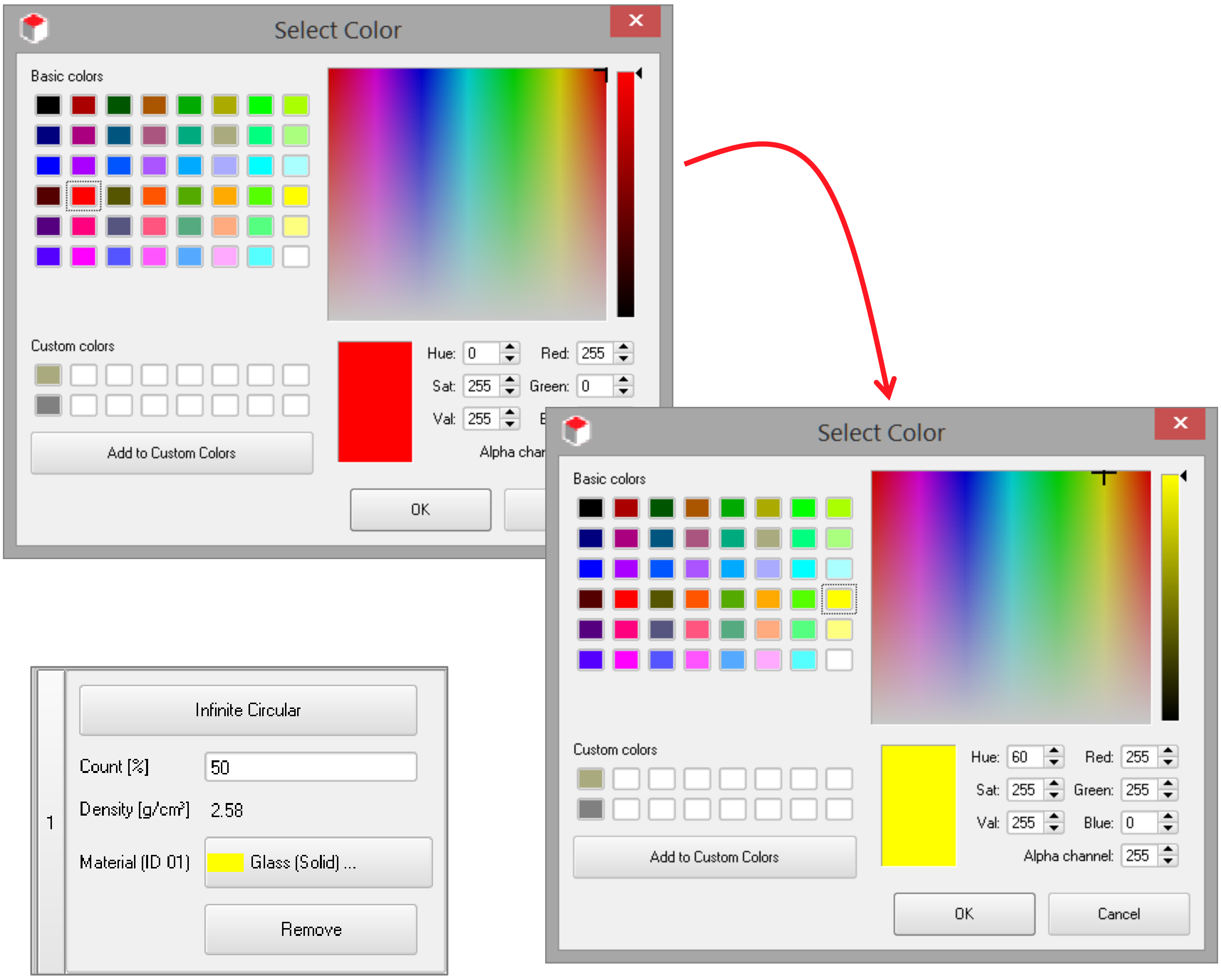
Material

Material designates the constituent material assigned to the fiber type used in the fibrous 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, **Undefined** or **Manual** should be chosen.



To match realistic material colors for visualization in a certain application, the default **Material** colors can be changed through **Options** → **Color & Visibility Options** in the Menu bar.





Fiber Type

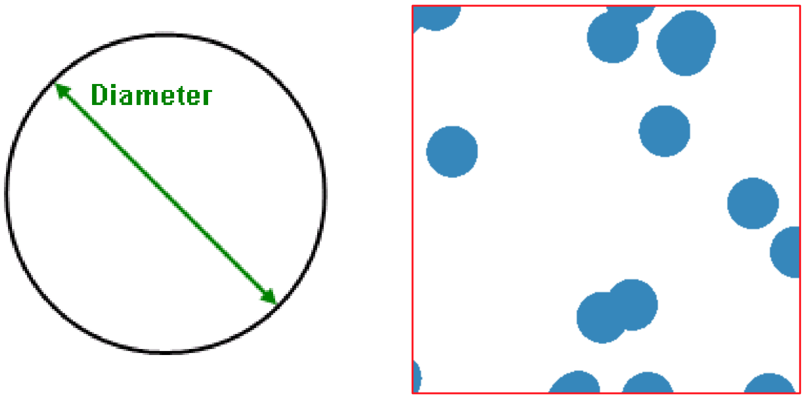
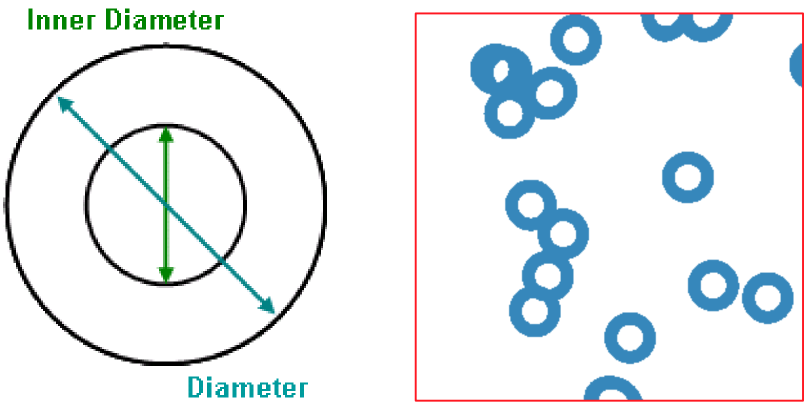
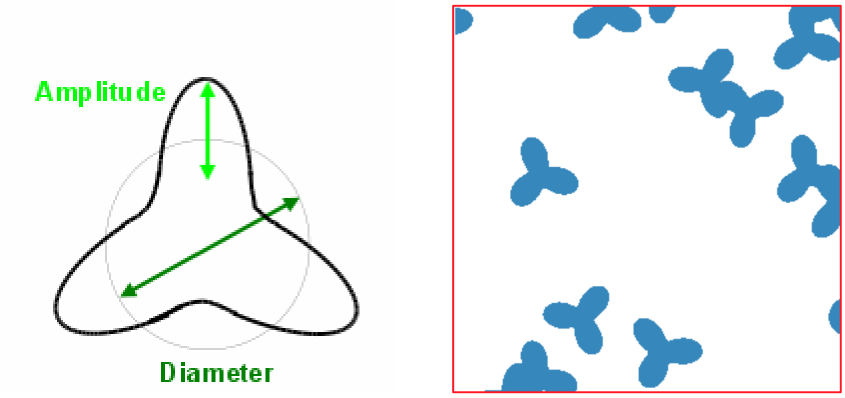
The **Fiber Type** is selected from the pull-down menu at the lower left under the **Fiber Options** tab. After selecting, click **Add** to include this fiber type. If the wrong fiber type has been added, discard it by clicking **Remove**.

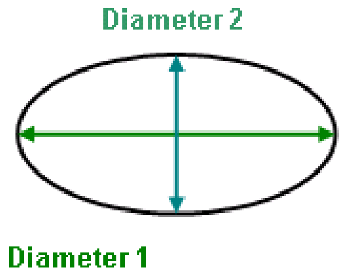
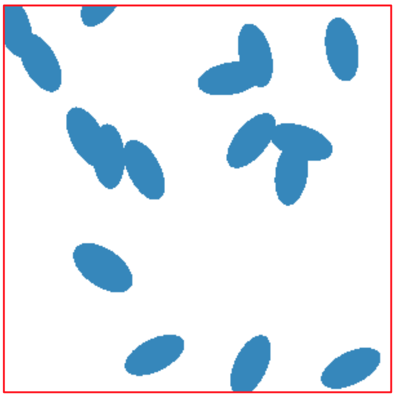
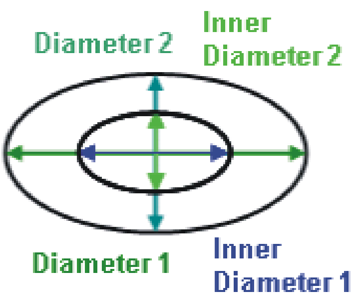
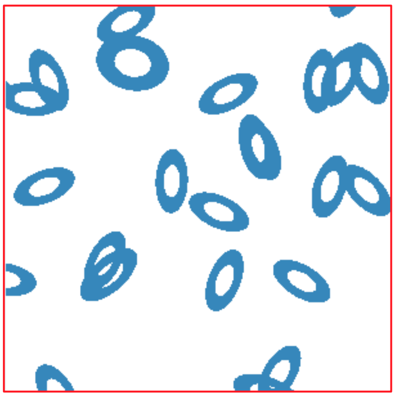
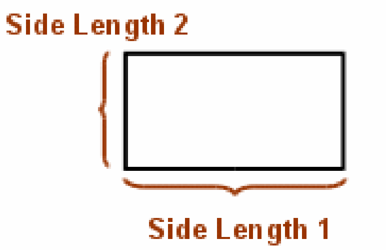
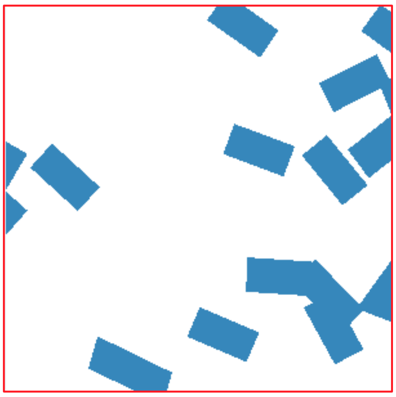
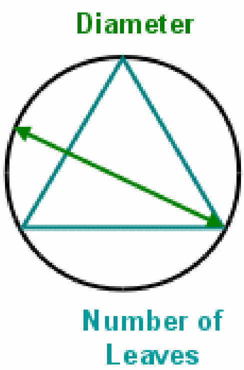
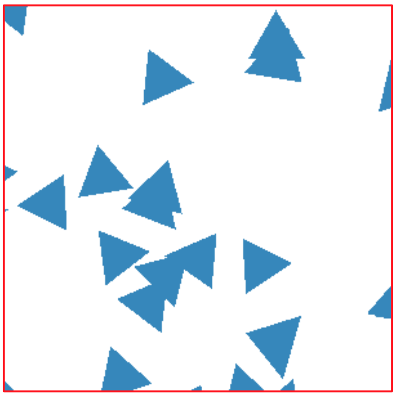
The following combinations of fiber cross-section with fiber length and fiber shape are available:

	Short		Infinite		Curved
		Bundle		Bundle	
Circular	Short Circular	Bundle Short Circular	Infinite Circular	Bundle Infinite Circular	Curved Circular
Hollow	Short Hollow		Infinite Hollow		Curved Hollow
Rosetta	Short Rosetta		Infinite Rosetta	Bundle Infinite Rosetta	Curved Rosetta
Elliptical	Short Elliptical	Bundle Short Elliptical	Infinite Elliptical	Bundle Infinite Elliptical	Curved Elliptical
Cellulose	Short Cellulose		Infinite Cellulose		Curved Cellulose
Rectangular	Short Rectangular		Infinite Rectangular		Curved Rectangular
Angular	Short Angular		Infinite Angular		Curved Angular
Arbitrary	Short Arbitrary		Infinite Arbitrary		Curved Arbitrary

Fiber cross-section

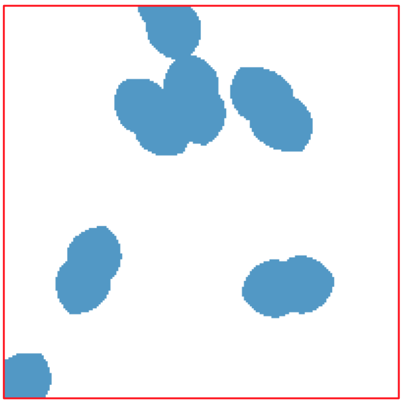
A drawing of the fiber cross-section is shown in the center column of each fiber type panel. The available fiber cross-sections and their defining parameters are:

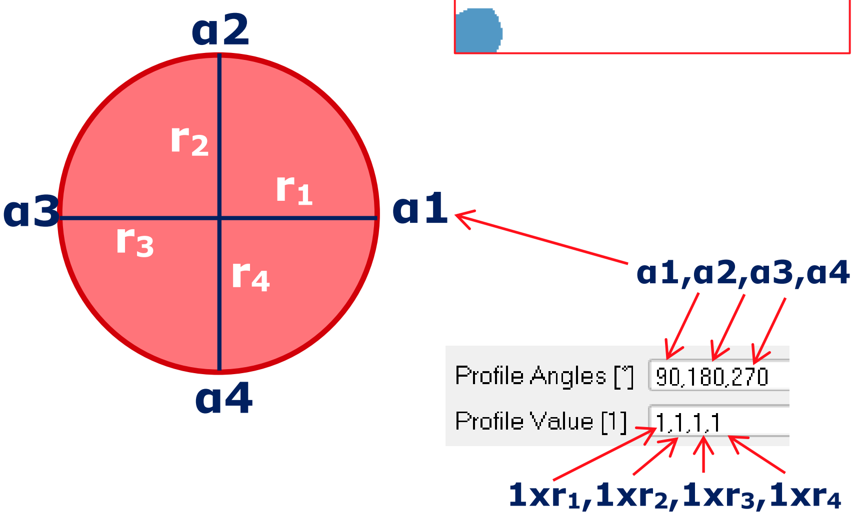
<table>
<tr><th>Cross-section</th><th>Defining parameters</th></tr>
<tr><td>Circular

</td><td>Diameter [µm]</td></tr>
<tr><td>Hollow

</td><td>Diameter [µm]
Inner Diameter Fraction</td></tr>
<tr><td>Rosetta

</td><td>Diameter [µm]
Amplitude Fraction
Number of Leaves</td></tr>
<tr><td colspan="2">Radius (phi)=Diameter/2 • (1 - AmplitudeFraction • sin(NumberOfLeaves • phi)
where phi in [0,2\pi] is the angle in the cross-sectional plane and the Diameter value is the average of the minimal and maximal radius.</td></tr>
</table>

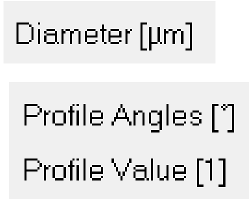
Elliptical  	Diameter 1 [µm] Aspect Ratio
Cellulose  	Diameter 1 [µm] Aspect Ratio Inner Diameter Fraction
Rectangular  	Side Length 1 [µm] Aspect Ratio
Angular  	Diameter [µm] Number of Leaves

Arbitrary

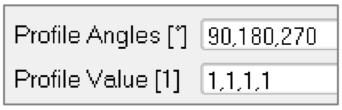
Complex cross-sections are obtained by varying the Profile Angles and the Profile Values at these angles (Profile Value x cross-section radius, e.g. $1xr_1$).
Note that the Profile Angle α1 is not shown and is always 0°. Here:

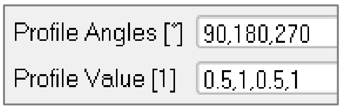


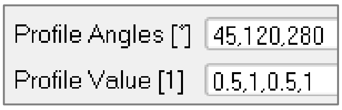




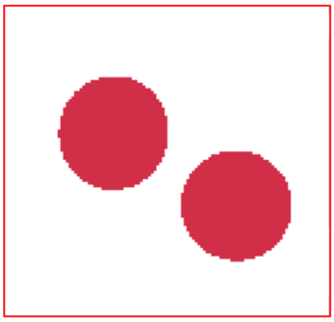
For example, with a diameter of 10 µm, the following cross-section is obtained by applying the indicated profile angles and profile values:

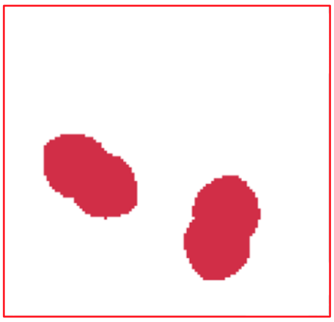


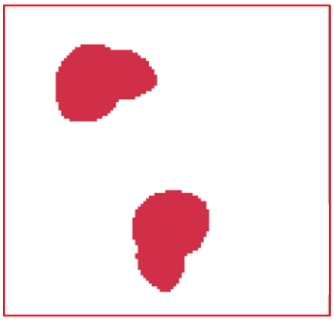


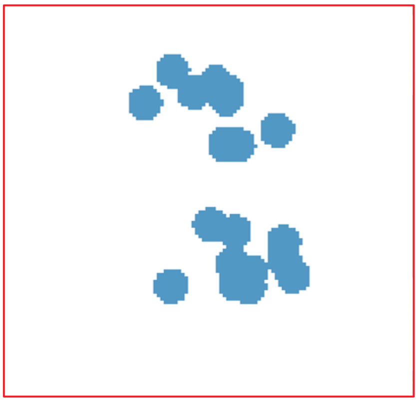


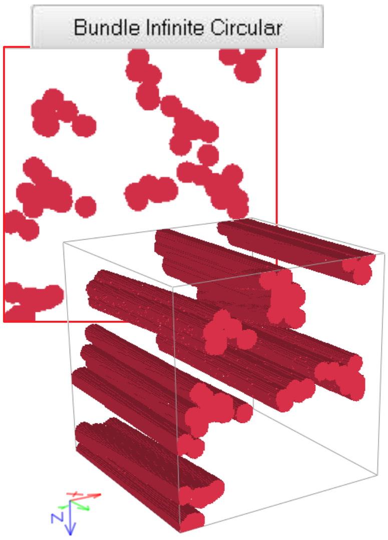
$1 \times r_1 \rightarrow 5$ µm at 0°	$0.5 \times r_1 \rightarrow 2.5$ µm at 0°	$0.5 \times r_1 \rightarrow 2.5$ µm at 0°
$1 \times r_2 \rightarrow 5$ µm at 90°	$1 \times r_2 \rightarrow 5$ µm at 90°	$1 \times r_2 \rightarrow 5$ µm at 45°
$1 \times r_3 \rightarrow 5$ µm at 180°	$0.5 \times r_3 \rightarrow 2.5$ µm at 180°	$0.5 \times r_3 \rightarrow 2.5$ µm at 120°
$1 \times r_4 \rightarrow 5$ µm at 270°	$1 \times r_4 \rightarrow 5$ µm at 270°	$1 \times r_4 \rightarrow 5$ µm at 280°

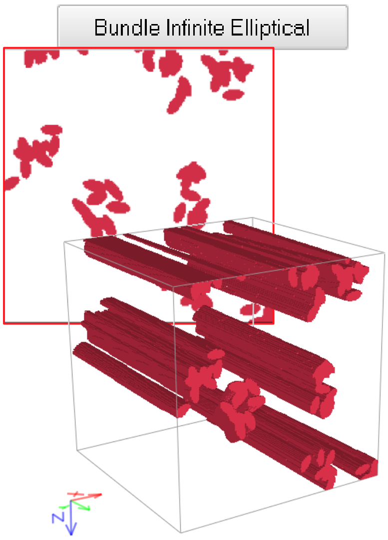


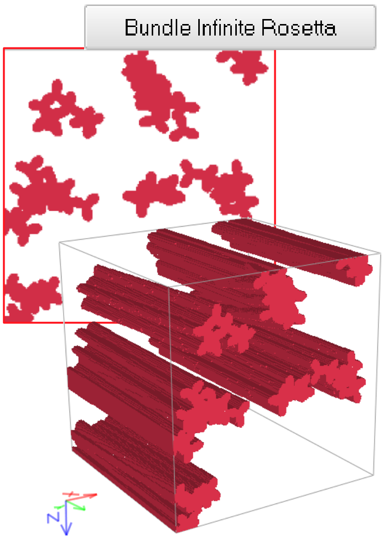




Bundle Circular, elliptical or rosetta cross-sectioned, short or infinite, fibers are clumped together forming bundles. The compaction of the bundles is given by the bundle diameters, the bundle profile angle and the number of fibers in it. Fibers in the bundle are defined by their diameter(s). 	Bundle Diameter 1 [µm] Bundle Diameter 2 [µm] Profile Angle [°] Number of Fibers Diameter [µm]

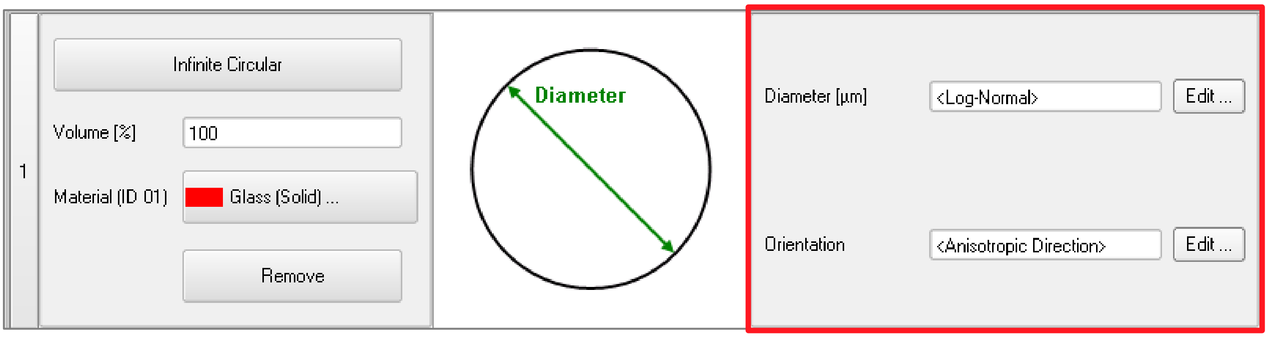






Fiber Parameters

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

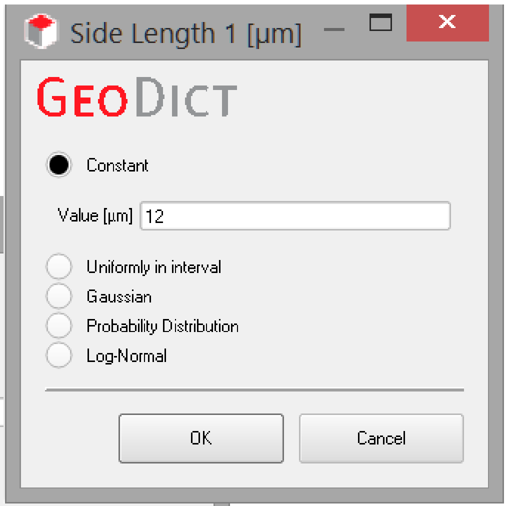


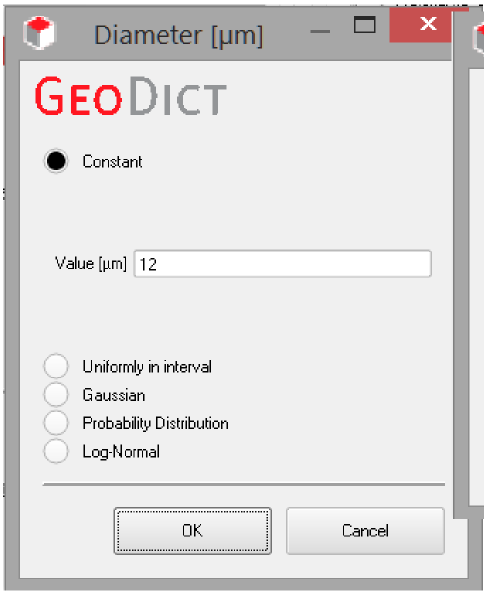
Some fiber parameters can only be set for some fiber types, such as the selections under the **Curl** tab or the **Torsion** tab for Elliptical, Cellulose, Rectangular, or Angular cross-section fibers. The fiber length can only be set for finite (**Short** or **Curved**) fibers but not for **Infinite** fibers.

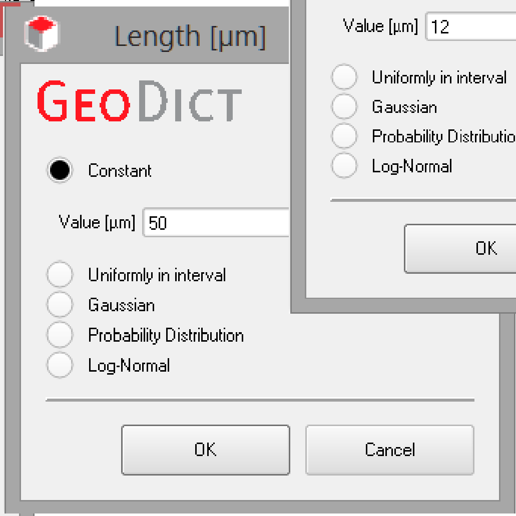
Constant values or Distributions of parameters

The defining parameters can be entered in the dialog boxes which open when clicking the corresponding **Edit...** buttons.

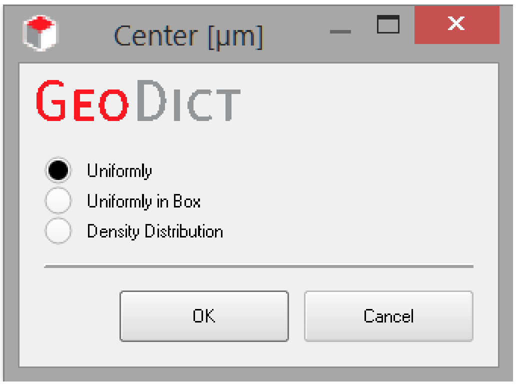
The fiber **Diameter**, the **Length**, and the **Side Length** can be set to a **Constant** value, or to follow a certain distribution (**Uniformly in interval**, **Gaussian**, **Probability Distribution**, or **Log-Normal**).





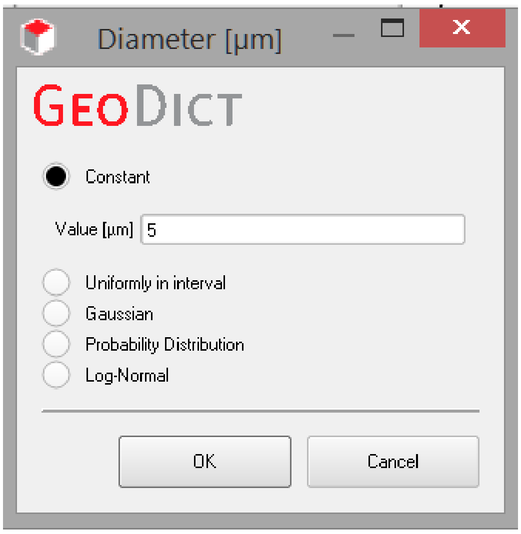


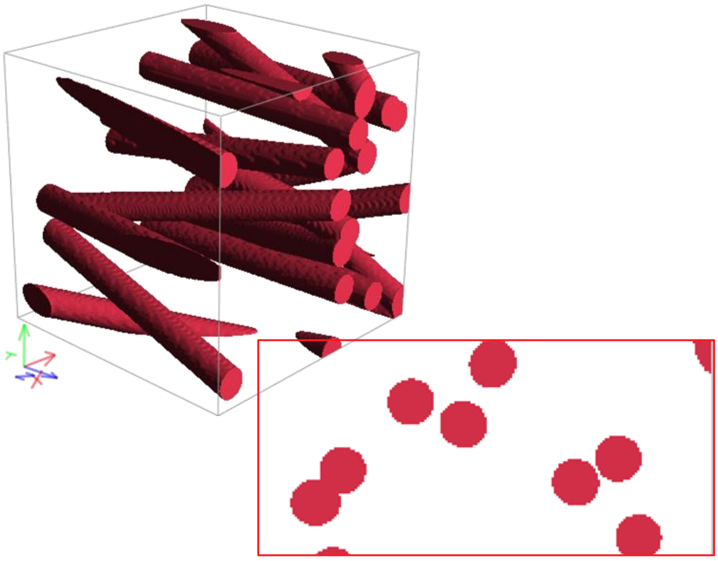
The **Center**, for short and curved fibers (not for infinite), can be set to distribute **Uniformly**, **On current structure**, **Uniformly in Box**, or to follow a **Density Distribution**. These distributions are explained in detail below (see pages 47-51, **Fiber Parameters** → **Center**).

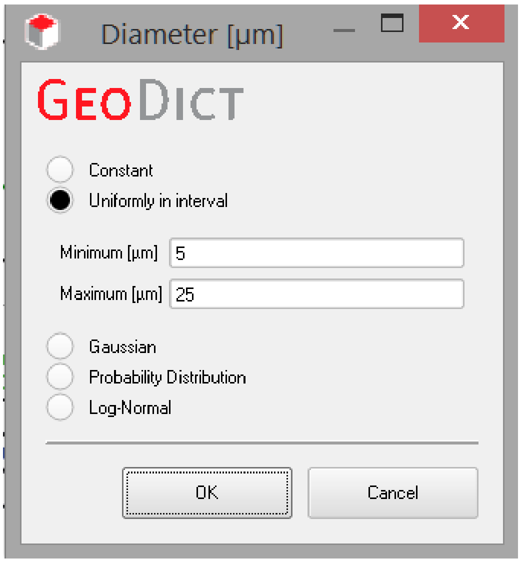


The **Torsion Start Angle** value (for Curved Elliptical, Curved Cellulose and Curved Rectangular cross-sections) can be set to be **Constant**, to distribute **Uniformly in interval**, or to follow a **Probability Distribution**.

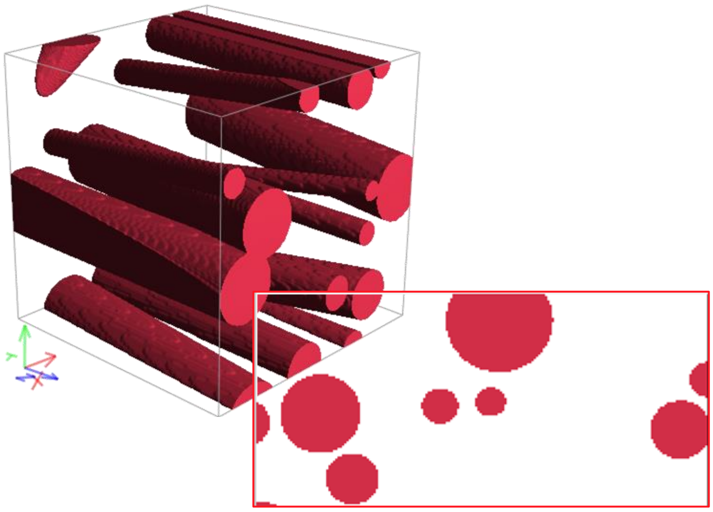
Observe the effect that the **Diameter** options (as shown in the dialog boxes) have on the generated structure with infinite circular cross-section fibers. The generated structures are shown as 3D Rendering and as 2D Cross-section.







When selecting **Uniformly in interval**, and entering a **Minimum** value and a **Maximum** value, the random diameter, length, side length or angle value will take a continuous range of values within this interval.

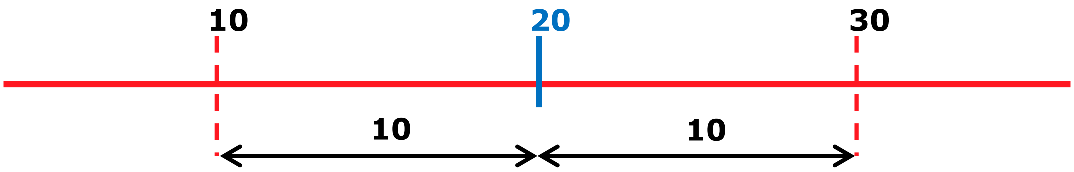


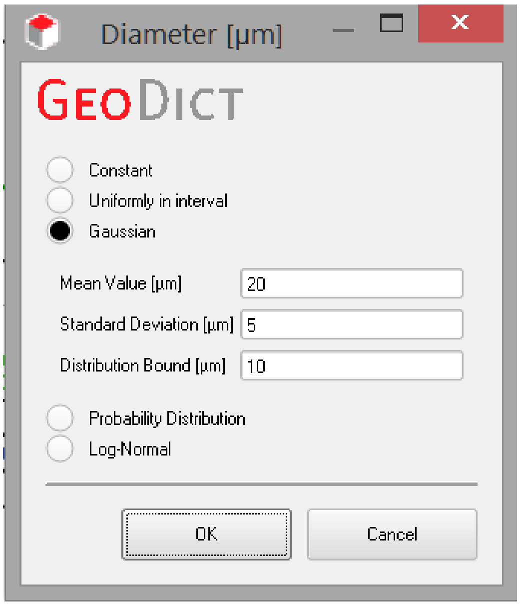
Taking the **Gaussian** distribution, the random diameter, length, or side length values follow a bell-shaped distribution. The diameter and length values cluster around the entered **Mean Value**, but may vary according to the entered **Standard Deviation**.

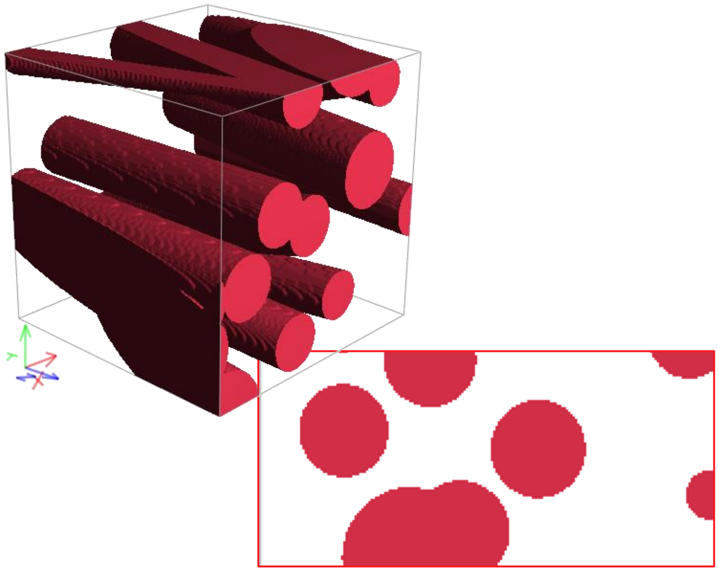
The value in **Distribution Bound** corresponds to the period on both sides of the mean value limiting the random diameter or angle values that are accepted. For diameters, a **Distribution Bound** value of 10 µm means that diameter values may vary only -10 µm to +10 µm from the given **Mean Value**.

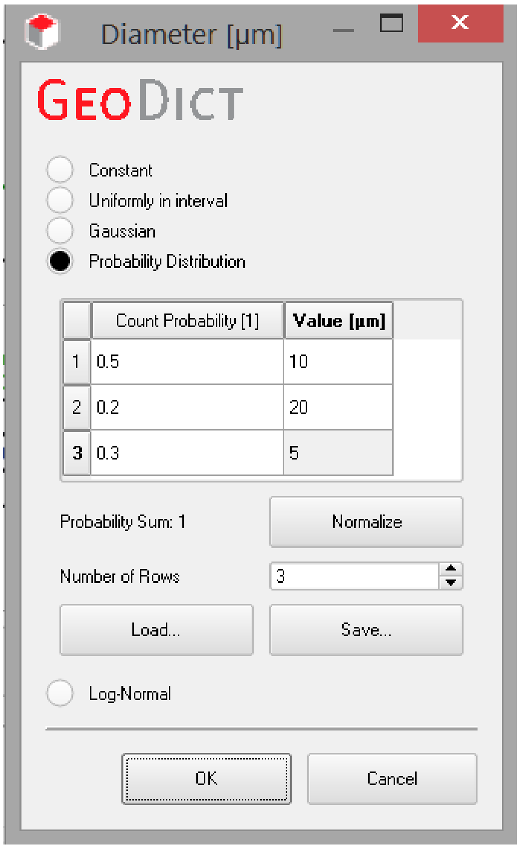
The parameters must be set so that no negative values are possible. For example, a diameter mean value of 20 µm and a distribution bound of 25 µm would lead to an error message appearing, as the diameter would reach a value less than zero.

Further details on Gaussian distributions can be found e.g. on the Wikipedia page on Normal (or Gaussian) distributions.



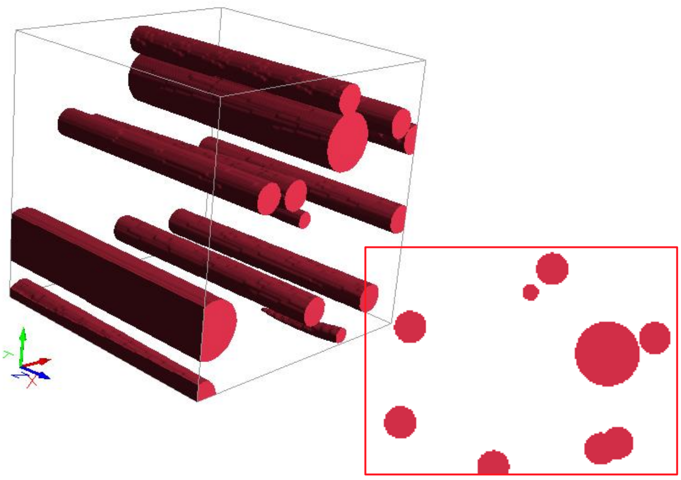






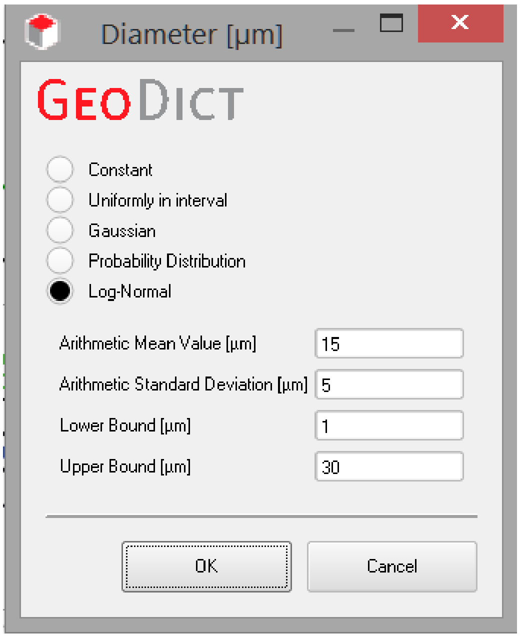
The **Probability Distribution** table describes the probability of a random diameter, length, or angle taking certain values. The **Number of Rows** can be increased or decreased to enter as many diameter, length, or angle **Values** and their **Count Probability**, between 0 and 1.

For large tables, it is useful to observe the value of **Probability Sum**. It corresponds to the adding up of the count probabilities. When the **Probability Sum** is not equal to 1, click the **Normalize** button to automatically round up the **Count Probability** values.

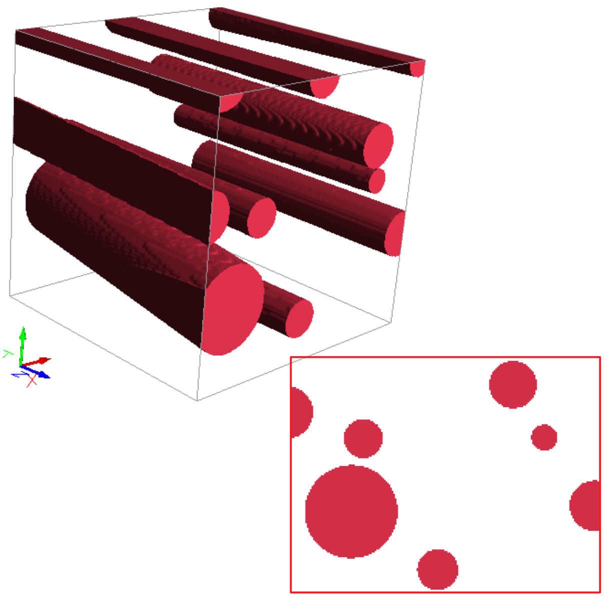


The buttons **Load** and **Save** allow loading a previous probability distribution and saving the current one for later use.

The **Log-Normal** distribution (only available for **Diameter**) describes the situation in which the random diameter values grow or decrease exponentially, following a logarithm that is normally distributed.



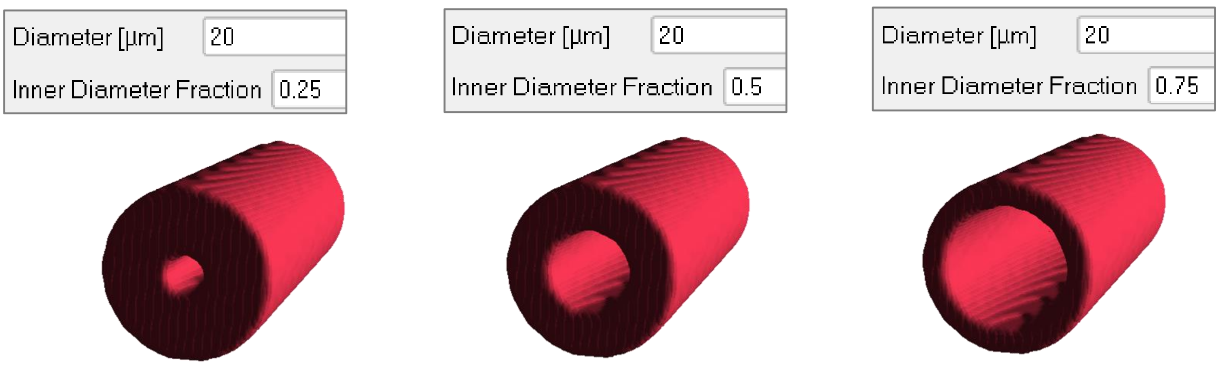
The diameter values will group around the entered **Mean Value**, but may diverge according to the entered **Standard Deviation**. The values in **Lower Bound** and **Upper Bound** restrict the possible values that the random diameters can take to those between them.



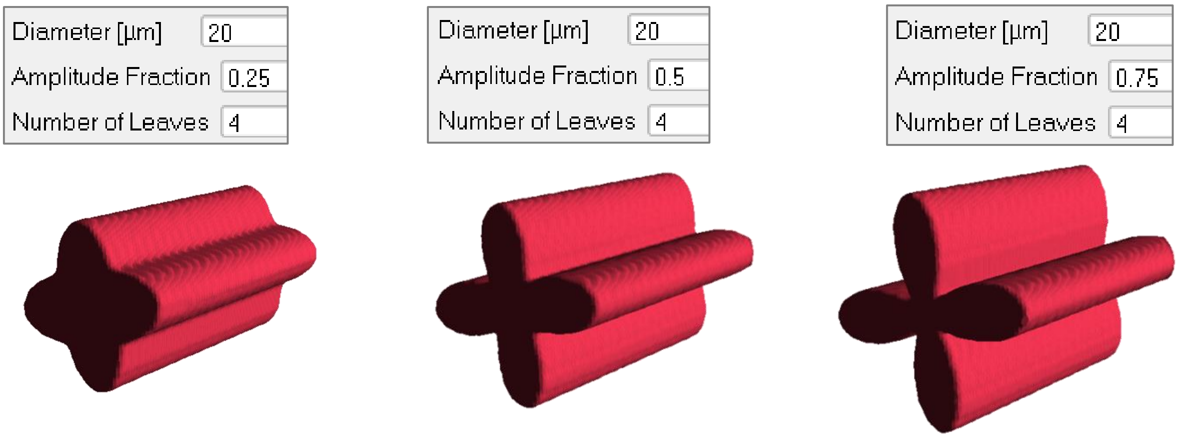
Diameter, Inner Diameter Fraction, Aspect Ratio, and Amplitude Fraction

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 be a **Constant** value, or to follow a diameter distribution (**Uniformly in interval**, **Gaussian**, **Probability Distribution**, or **Logarithmic-Normal**) as indicated above.

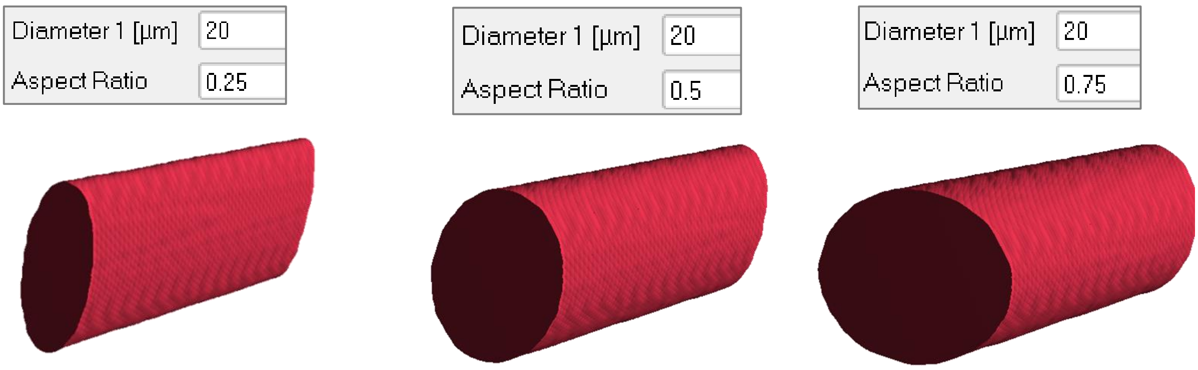
For non-circular fibers, the diameter and other parameters control their shape. For a hollow fiber, the **Inner Diameter Fraction** defines which fraction of the entered (outer) diameter value is to be taken as inner diameter value.



For fibers with Rosetta cross-section, the **Amplitude Fraction** determines the length of the rosetta leaves, whereas the **Number of Leaves** defines how many leaves the rosetta has.

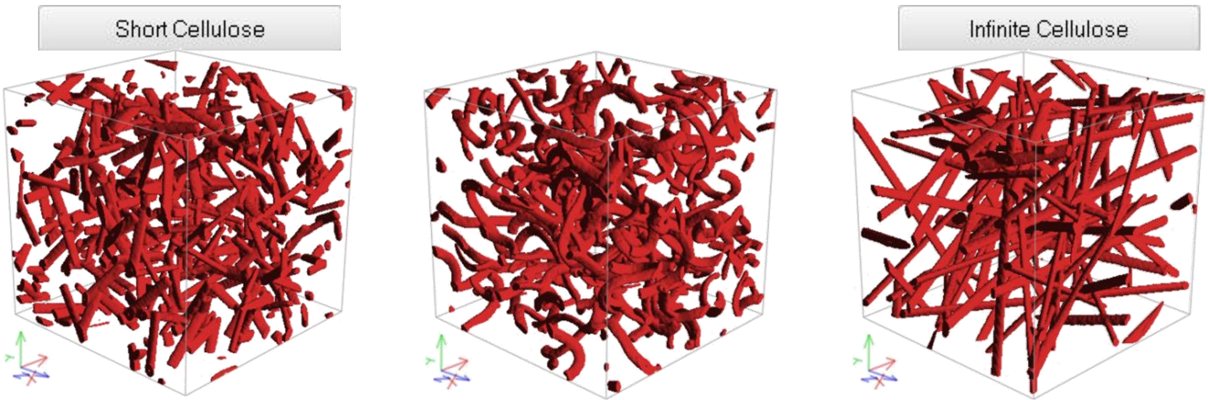


For Elliptical fibers, defined by two dissimilar diameters, the **Aspect Ratio** is the relationship between the longer diameter (Diameter 1) and the shorter diameter (Diameter 2).

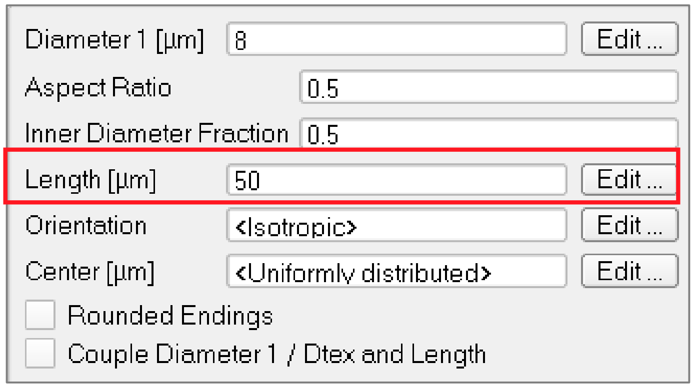


Length and Side Length

Fibers can have **Finite** or **Infinite** length. Finite short fibers (**Short**) are automatically straight and finite long fibers can be curved (**Curved**).



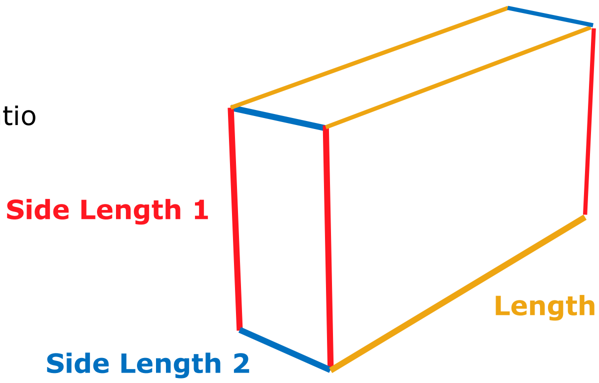
The length of **Short** and **Curved** fibers is editable by clicking on the **Edit...** button and choosing the desired settings in the **Length (µm)** dialog box. The fiber **Length**, and **Side Length**, can be set to take a **Constant** value, or to follow a distribution (**Uniformly in interval**, **Gaussian**, **Probability Distribution**, or **Logarithmic-Normal**).

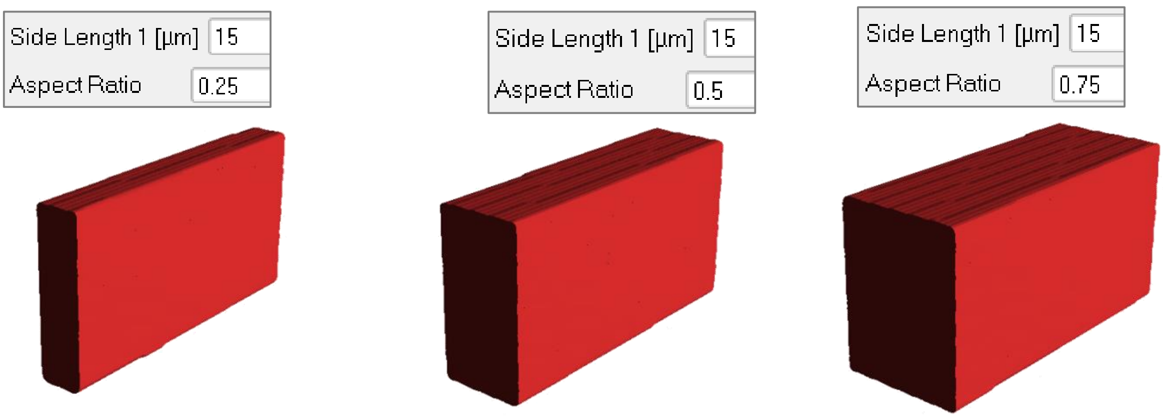


Infinite fibers are straight. Thus, to generate structures with (nearly) infinite length fibers that are curved, choose a curved fiber type and set the fiber length to be much larger than the sample size.

For fibers with rectangular cross-section, the **Side Length 1** and the **Aspect Ratio** can be entered. The relationship between these parameters is like that between Diameter 1 and Aspect Ratio for Elliptical cross-sectioned fiber explained above.

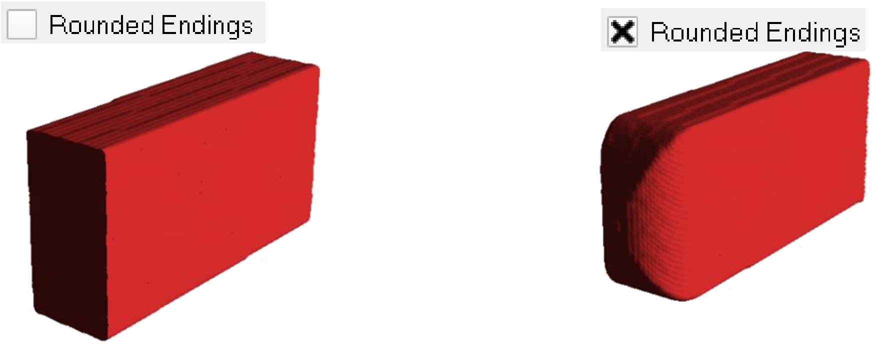
Side Length 2 = Side Length 1 x Aspect Ratio





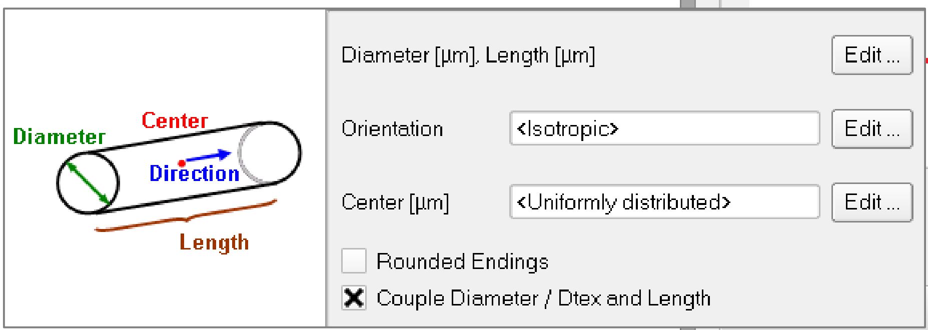
Rounded Endings

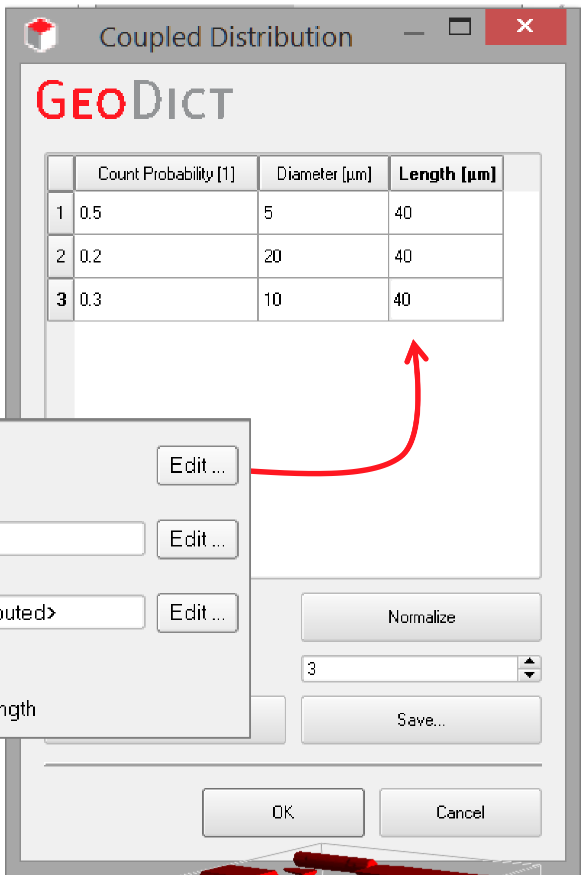
Short fibers with any cross-section (Circular, Hollow, Rosetta, Cellulose, Elliptic, Rectangular and Angular) can be created with or without rounded ends by checking or leaving un-checked the **Rounded Endings** box. Observe the variation in the shape of the short rectangular fibers after checking the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



Couple Diameter (or Side Length)/Dtex and Length

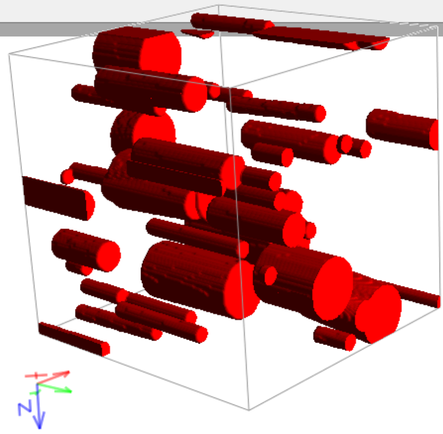
The diameter (or side length)/Dtex and the length of **Short** and **Curved** fibers with any cross-section (Circular, Hollow, Rosetta, Cellulose, Elliptic, Rectangular and Angular) can be coupled by checking the **Couple Diameter/Dtex and Length** or the **Couple Side Length 1/Dtex and Length** box. Clicking the **Edit...** button, the coupling of these parameters is set through values entered in the probability-coupled 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 sizes of short circular fibers which have all the same length of 40 µm but different diameters: 50% with diameter 5 µm, 20% with diameter 20 µm, and 30% with diameter 10 µm.

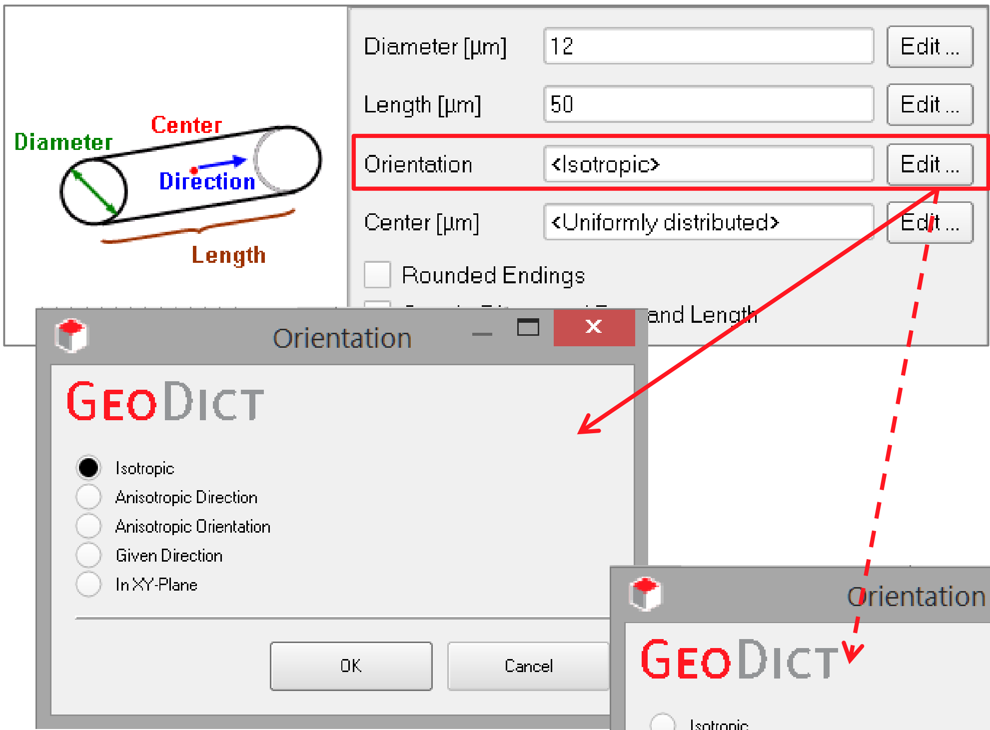


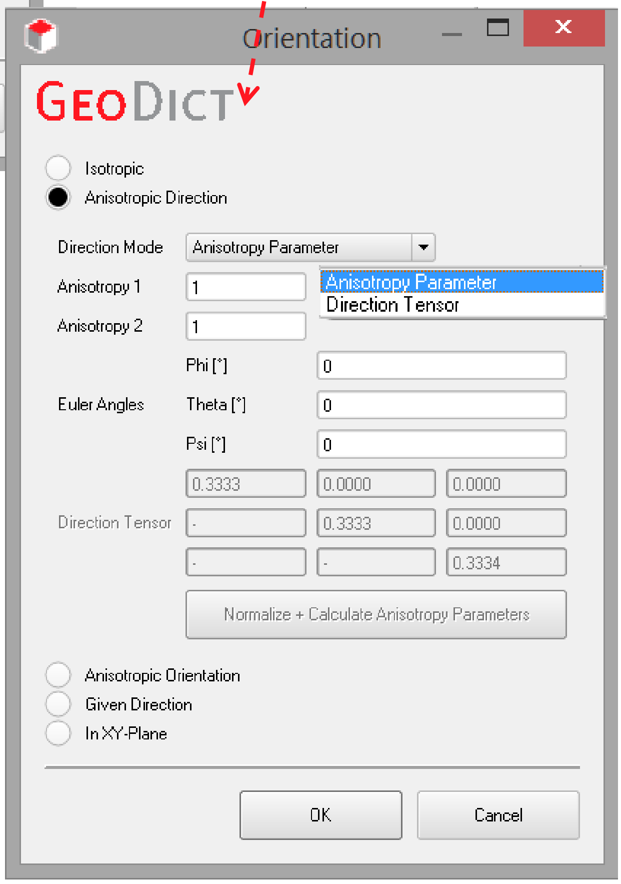
Orientation

The isotropic or anisotropic **Orientation** of a fiber type in a generated structure can be set by clicking the **Edit...** button. The orientation can be separately set for each fiber type so that differently oriented fibers may coexist within the same structure.

In the **Orientation** dialog box, the user defines if fibers should be **Isotropic**, have a certain **Anisotropic Direction**, **Anisotropic Orientation**, or **Given Direction** or be **In XY-Plane**. See how to set the values for Anisotropy 1 and 2 (pages 42-44)

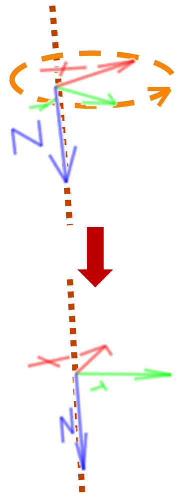
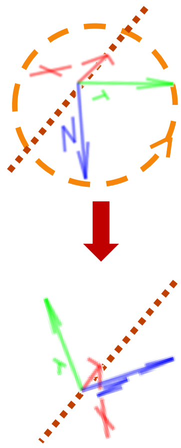
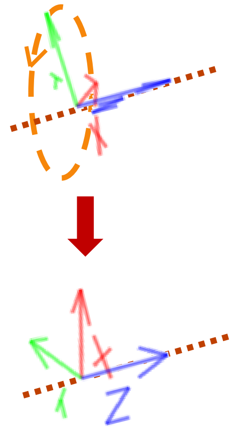
For all fiber types, either with rotationally symmetric cross-section (**Circular** and **Hollow**) or with rotationally asymmetric cross-sections (Rosetta, Elliptical, Cellulose, Rectangular, and Angular), it is possible to control not only the fiber direction but the position of the cross-section with respect to the XY-plane as well (see below, pages 38-39).





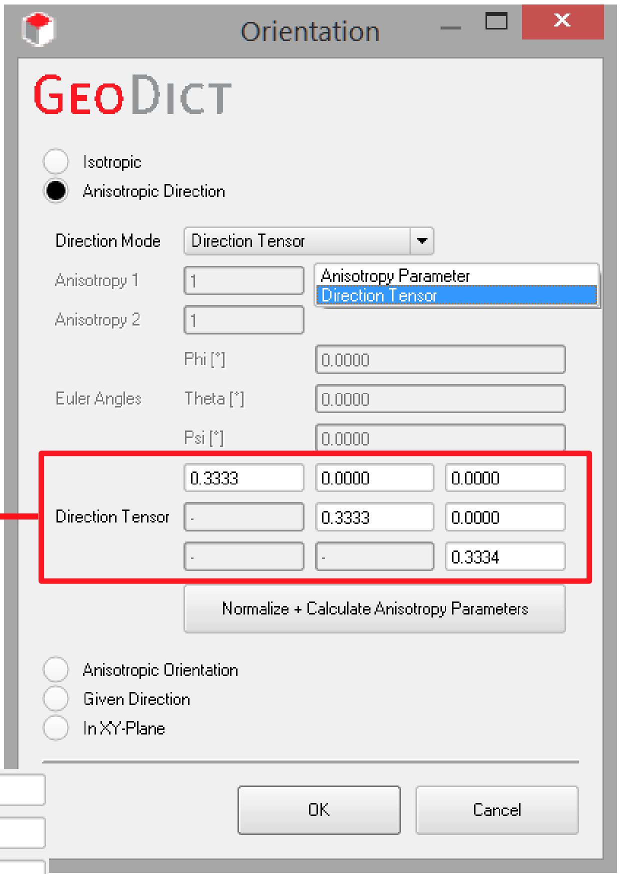
When checking **Anisotropic Direction** and selecting **Anisotropy Parameter** from the **Direction Mode** pull-down menu, the anisotropy values (Anisotropy 1 and Anisotropy 2), as well as the **Phi**, **Theta** and **Psi** Euler Angles for the three dimensional rotation of anisotropic fibers can be defined.

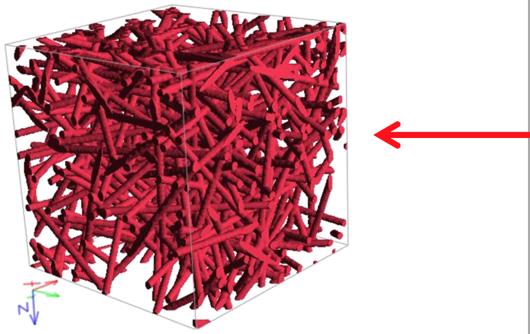
The Euler rotation angles are applied to the fibers during the generation following the order Phi → Theta → Psi.

z axis fixed	new x axis fixed	new z axis fixed
Phi applies rotation about existing z-axis	**Theta** applies rotation about the new x-axis	**Psi** applies rotation about the new z-axis
		

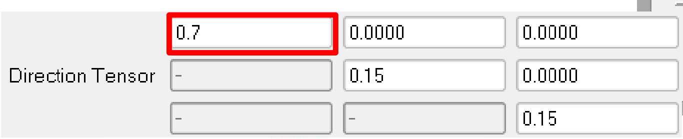
Alternatively, when selecting **Direction Tensor** from the **Direction Mode** pull-down menu, the values for the direction tensor of the anisotropic fibers can be entered.

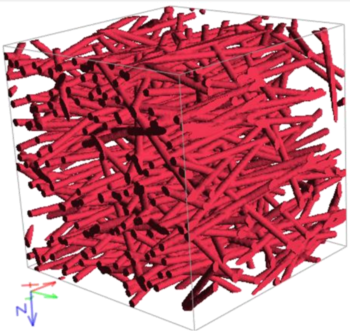
Observe the effect of changing the default values of the isotropic Direction Tensor to obtain anisotropic fibrous structures oriented in the X-, Y-, or Z-Direction.



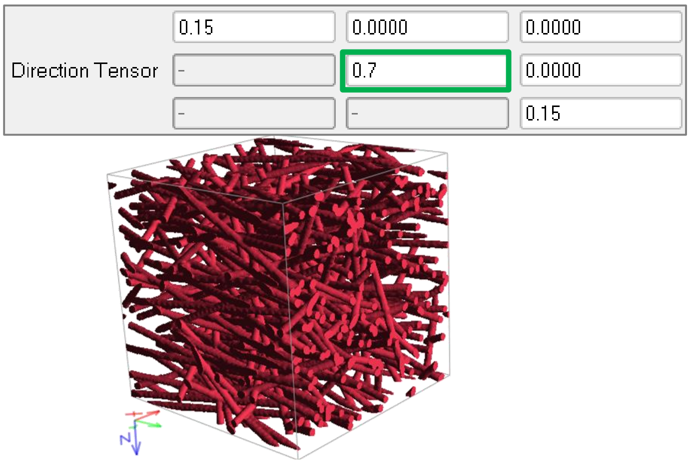


X-direction

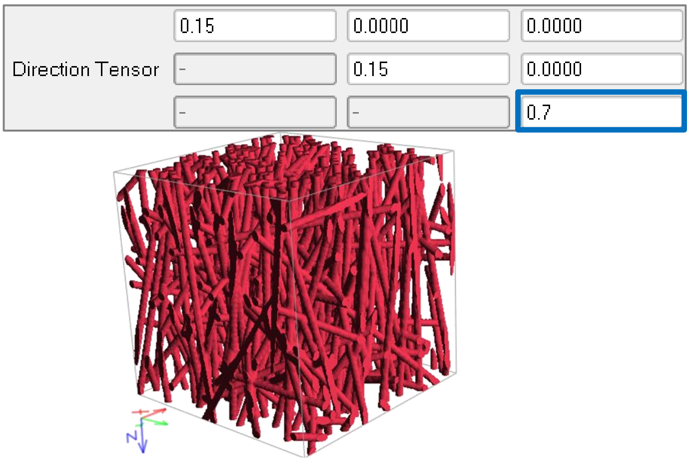




Y-direction



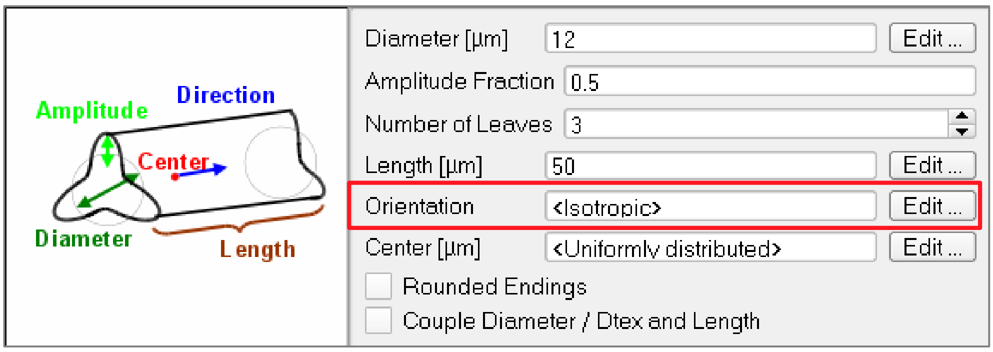
Z-direction

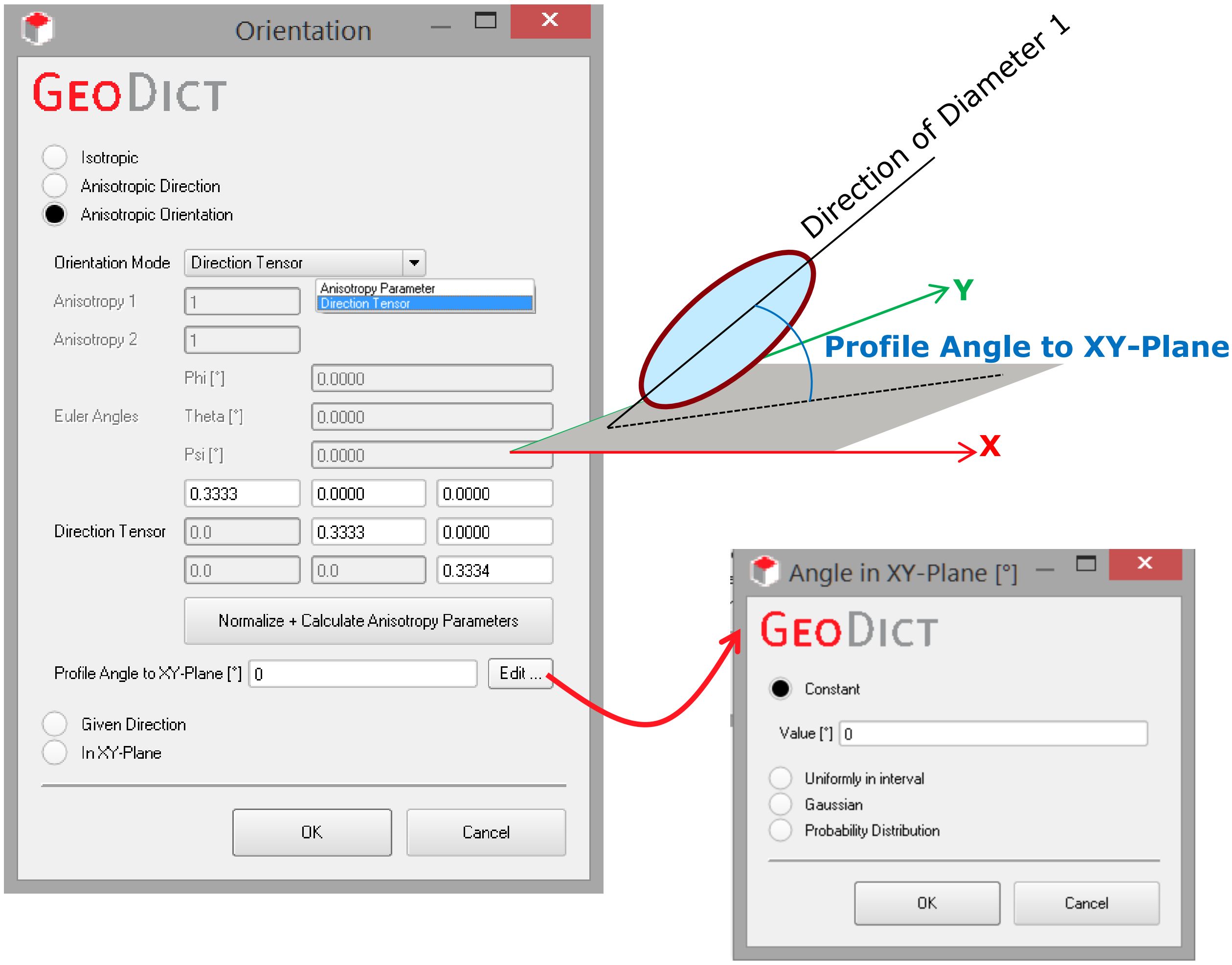


Clicking the **Normalize + Calculate Anisotropy Parameters** button, the adjusted values are entered in the direction tensor and the Anisotropy 1 and Anisotropy 2 boxes.

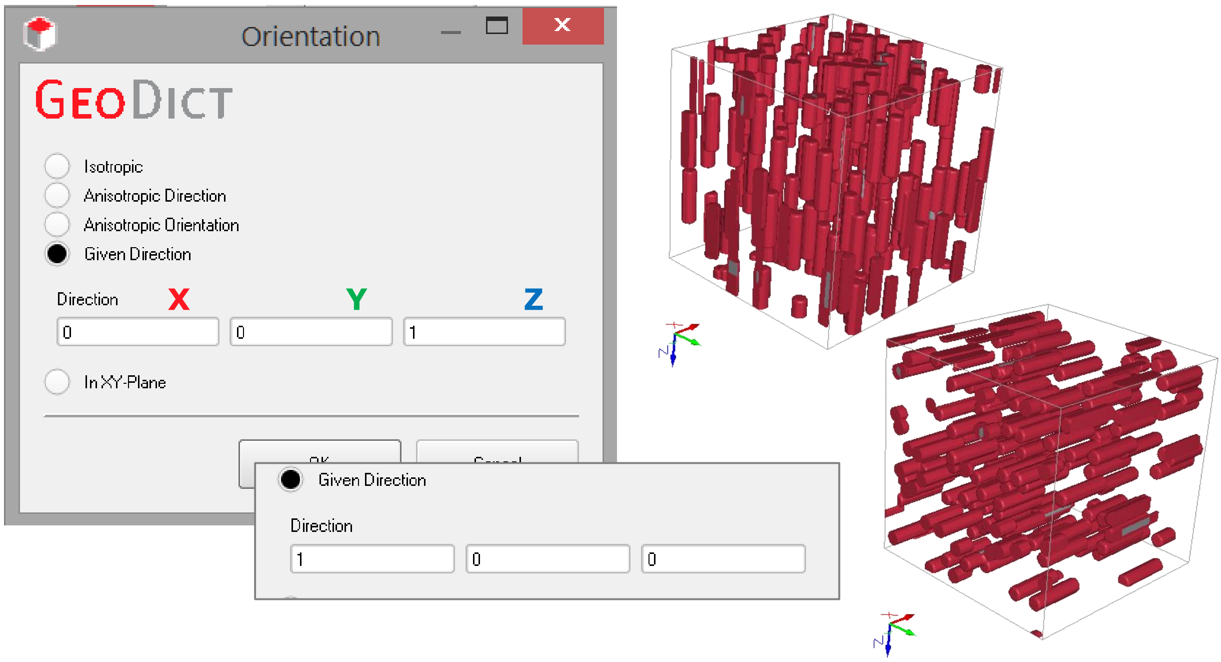
To control not only the fiber direction but the position of the cross-section with respect to the XY-plane as well, check **Anisotropic Orientation** and select either **Anisotropy Parameter** or **Direction Tensor** from the **Orientation Mode** pull-down menu.

The angle between the fiber cross section axis and XY-plane can be entered in the **Profile Angle to XY-Plane** box. For more details and examples, see below, page 43).

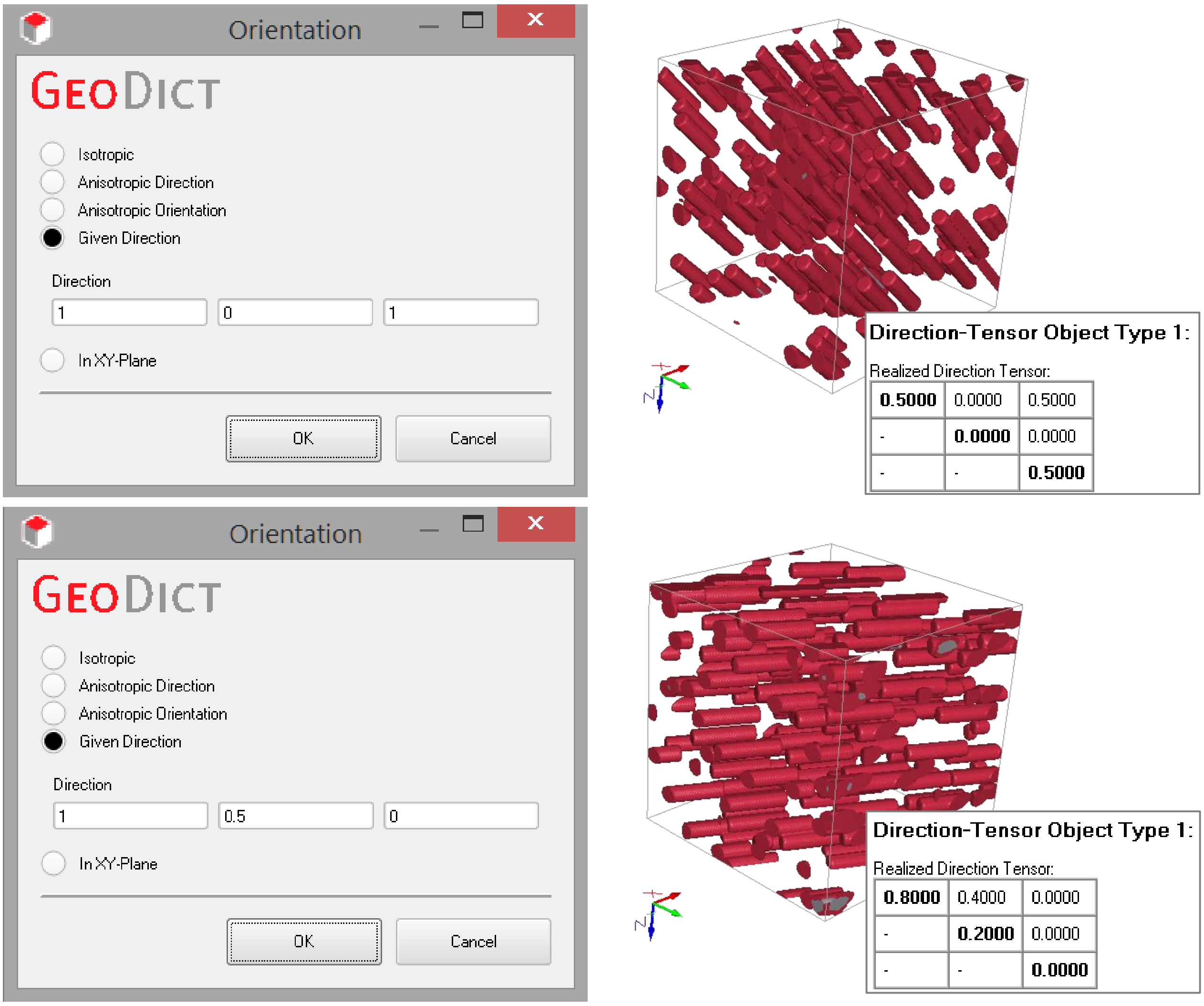




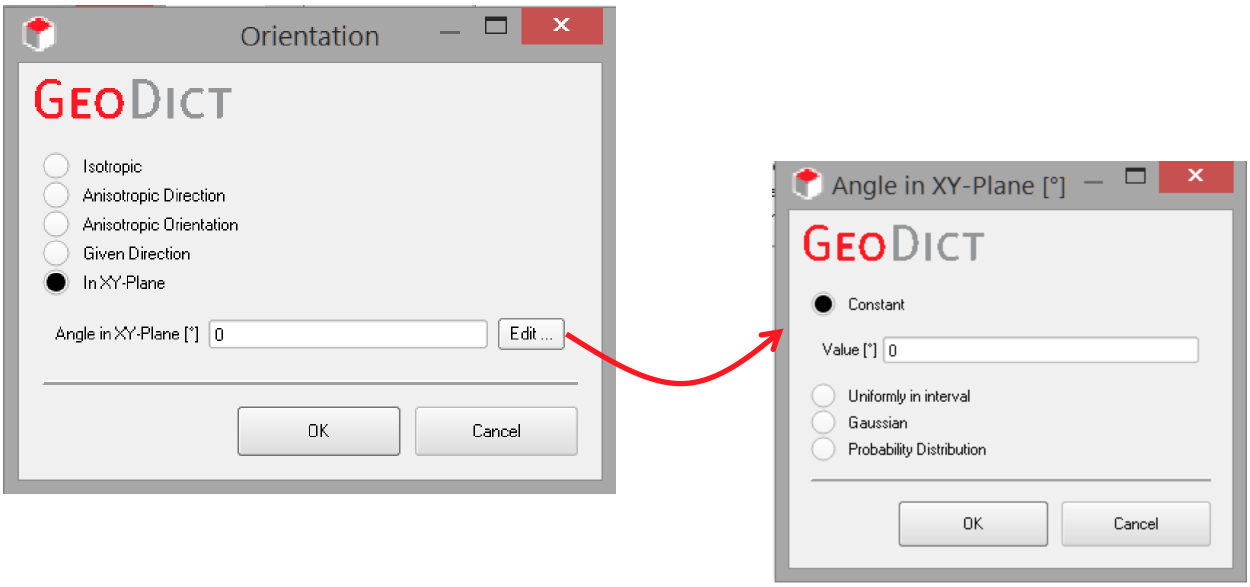
By checking **Given Direction**, the direction of all fibers present in the generated structure is given by the values are entered in the boxes. The strength of the orientation is relative to the entered values, so that 0, 0, 1 means that all fibers follow the Z-direction, and 1, 0 ,0 means that all fibers follow the X-direction.



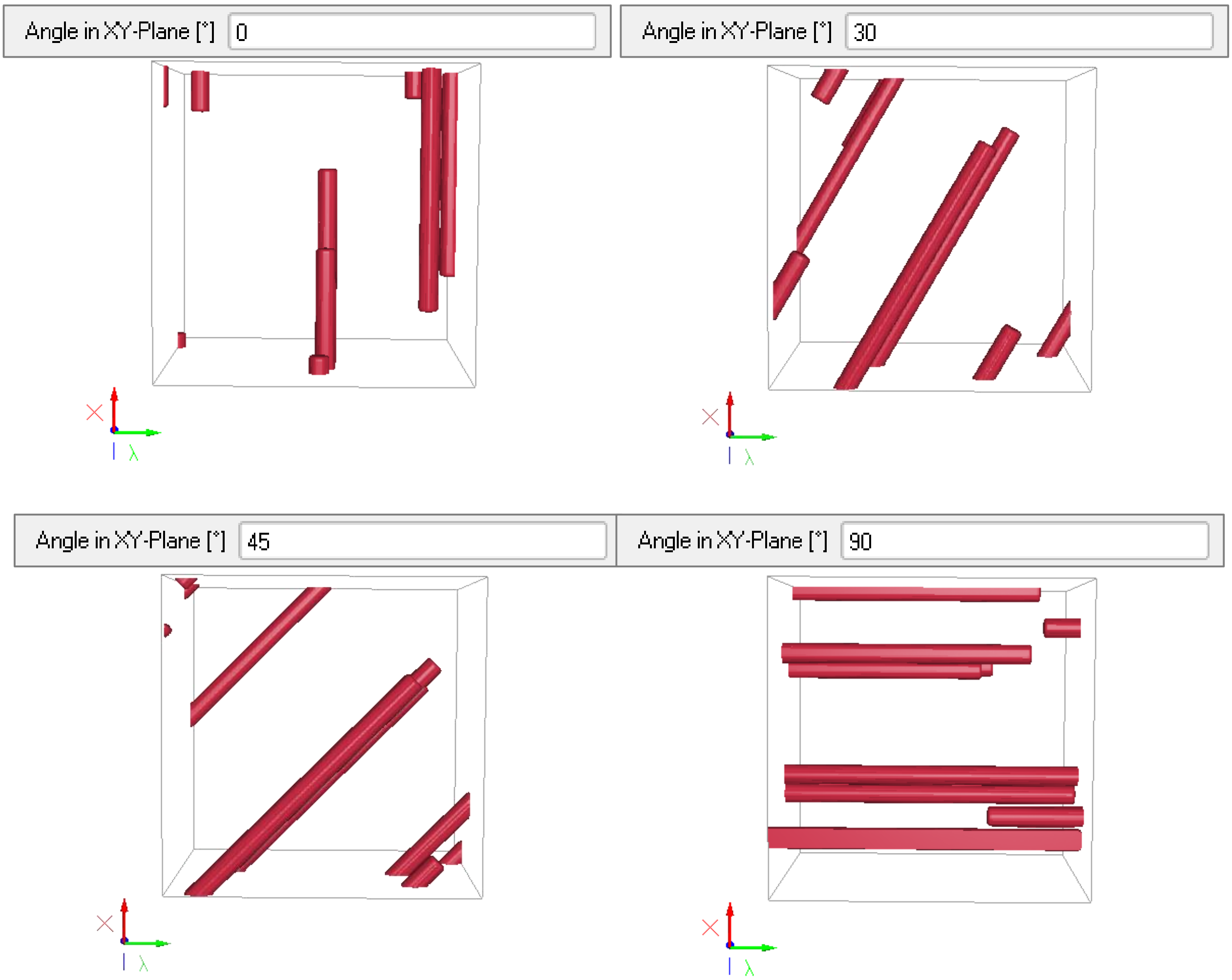
Entering values for more than one direction is possible, and the direction of the fibers is given by the relative value of the components. For example:



After checking **In XY-Plane**, the user can set the angle of the fibers main axis in the XY-Plane. This is similar to setting the **Profile Angle to XY-Plane**, but in this case, the fibers lay on the XY-Plane and their main axis orientation in relation to the X-direction is controlled by the entered value.



For example, enter 0°, 30°, 45°, or 90°, to obtain the following fiber orientations in the XY-Plane:

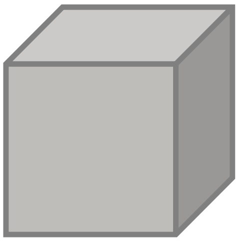


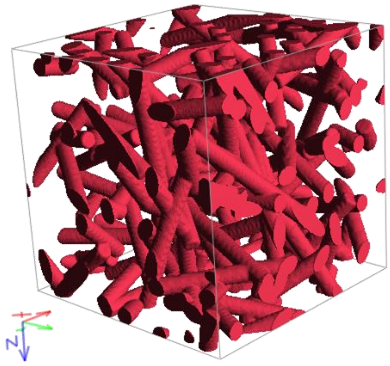
Selecting Anisotropy values

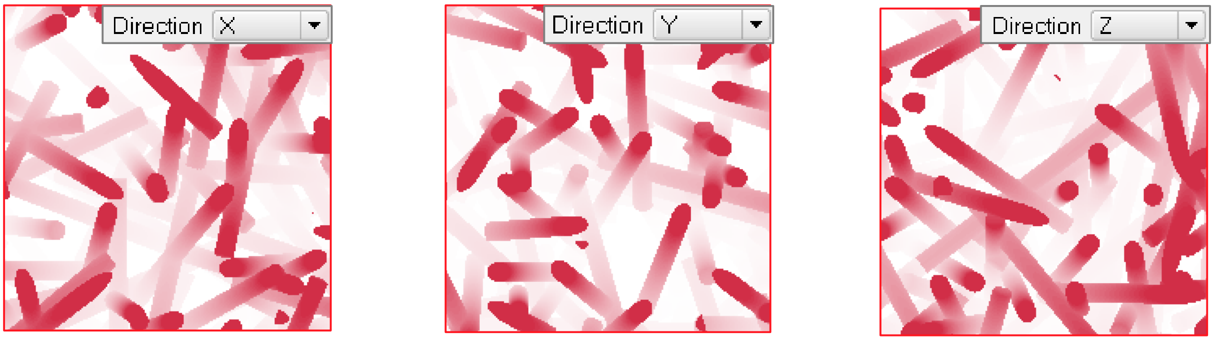
The values for Anisotropy 1 and Anisotropy 2 define the orientation of the fibers in fibrous structures generated with FiberGeo in the following manner:

Anisotropy 1 = Anisotropy 2 = 1 (Isotropic material)

When the structure is examined in 2D Cross-section View, all directions are similar and none is preferred.

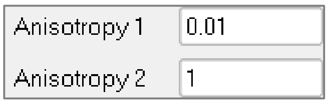


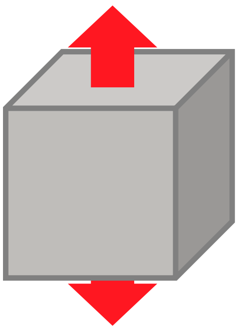


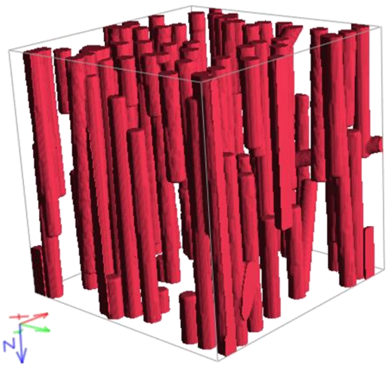


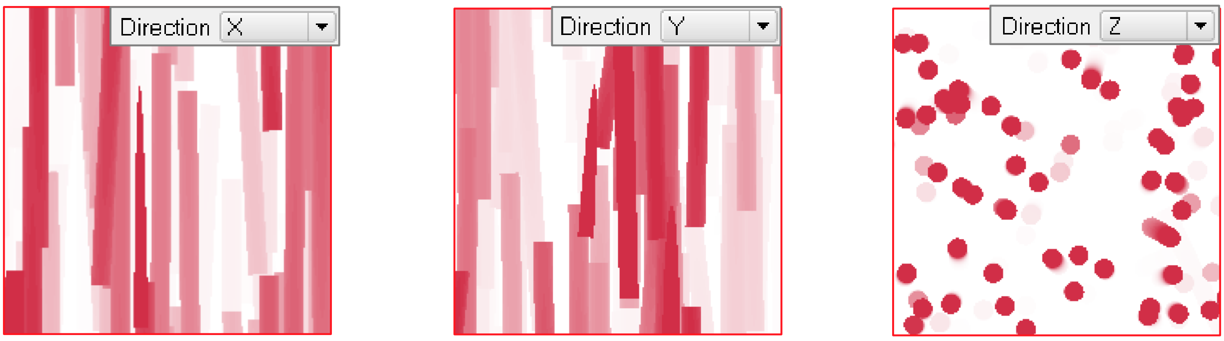
Anisotropy 1 < 1

The material is stretched in the Z-direction and the fibers tend to be oriented in the Z-axis, so that the fibers run parallel to the YZ-plane and the XZ-plane when viewed from the X- or Y-direction. The smaller the value of Anisotropy 1, the more anisotropic the fibers behave.



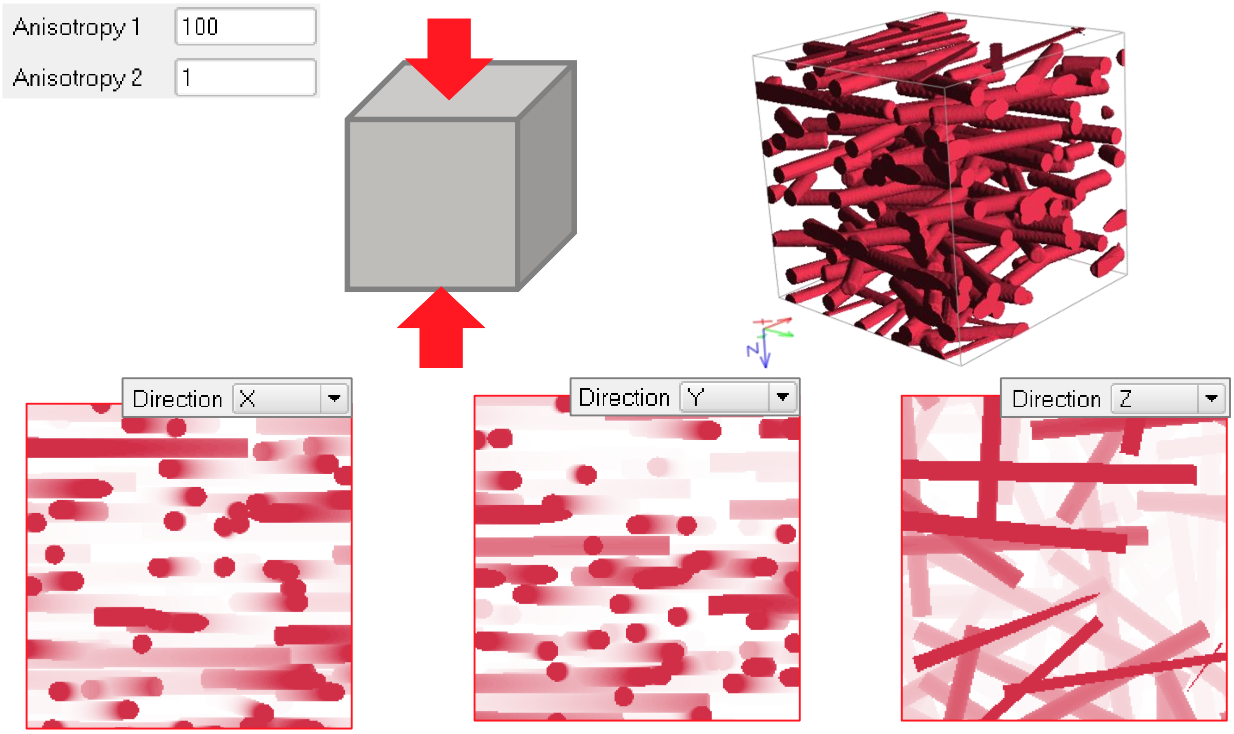






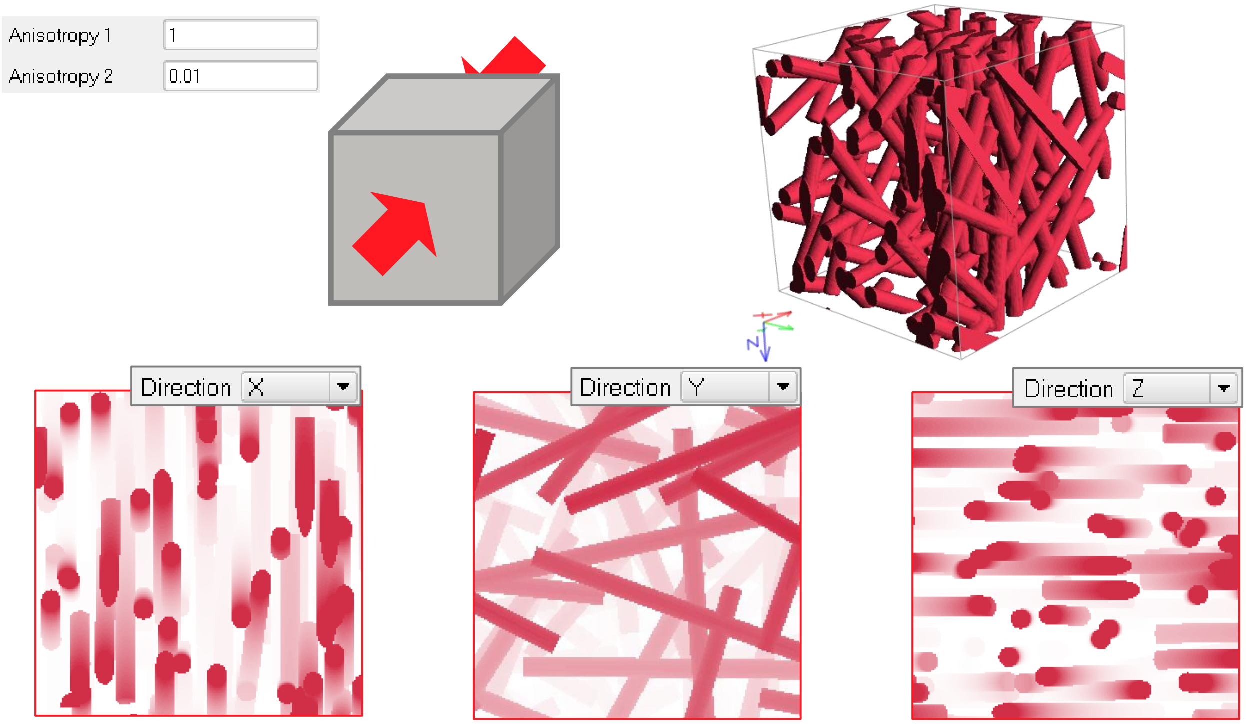
Anisotropy 1 > 1

The material is compressed in the Z-direction and the fibers are isotropic in the XY-plane (Z-slice), while they run parallel in the XZ-plane and the YZ-plane, when viewed from the Y- or the X-direction. The higher the value of Anisotropy 1, the stronger is the anisotropy.



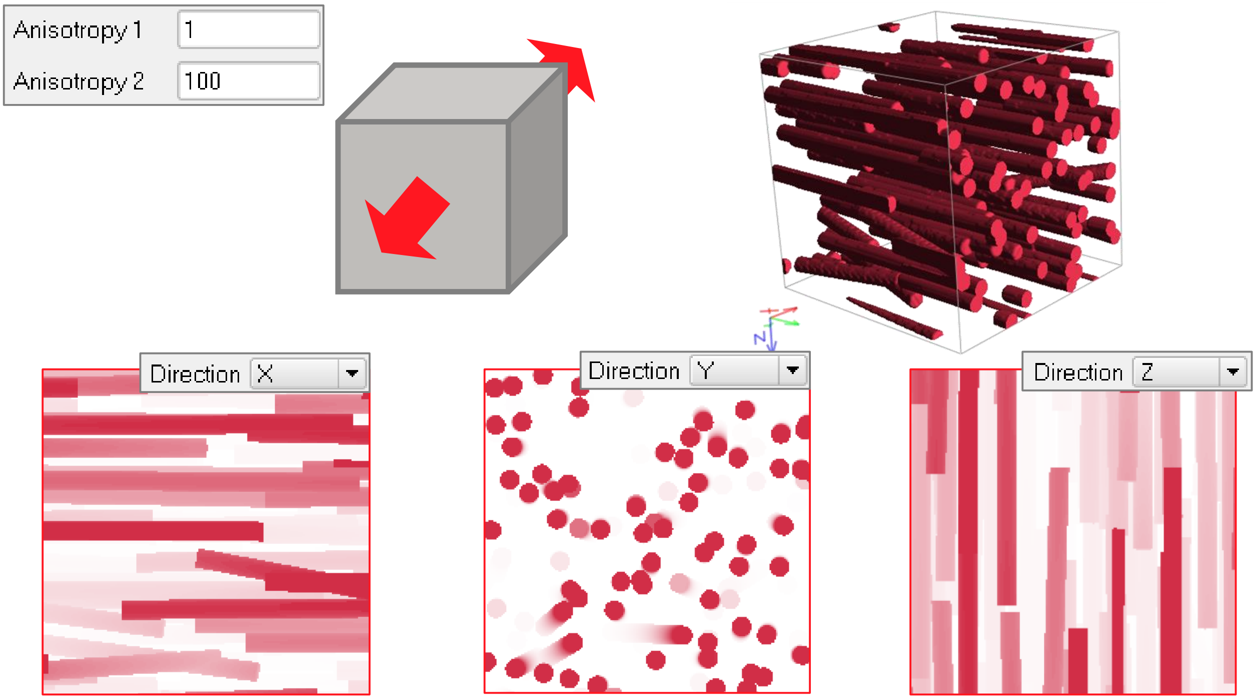
Anisotropy 2 < 1

The material is compressed in the Y-direction. Anisotropy 2 has a similar effect to that of Anisotropy 1, with the deformation occurring in the Y-direction. Observe that the fibers are isotropic in the XZ-plane (Y-slice), while they run parallel in the YZ-plane and the XY-plane, when viewed from the X- or the Z-direction.

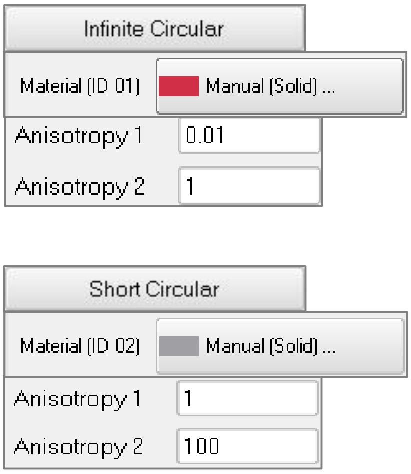


Anisotropy 2 > 1

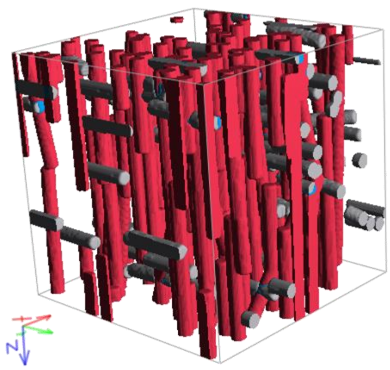
The material is stretched in the Y-direction and the fibers tend to be oriented along the Y-axis. Observe that the fibers cut the XZ-plane (Y-slice), while they run parallel in the YZ-plane and the XY-plane when viewing them from the X- or the Z-direction.



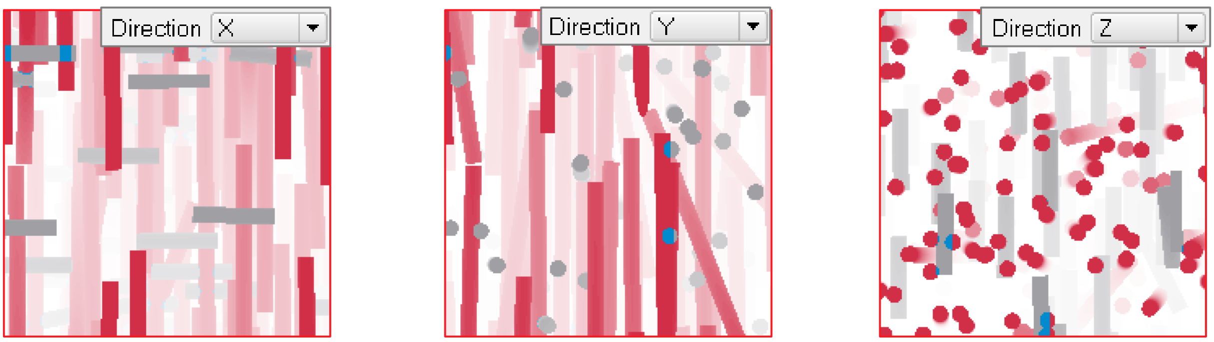
As mentioned before, the orientation can be separately set for each fiber type so that differently oriented fibers may coexist within the same structure. In the following structure, observe that the Anisotropy 1 and Anisotropy 2 are set to 0.01 and 1 for the infinite circular (red) fibers, whereas the short circular (grey) fibers have Anisotropy 1 and Anisotropy 2 of 1 and 100, respectively.



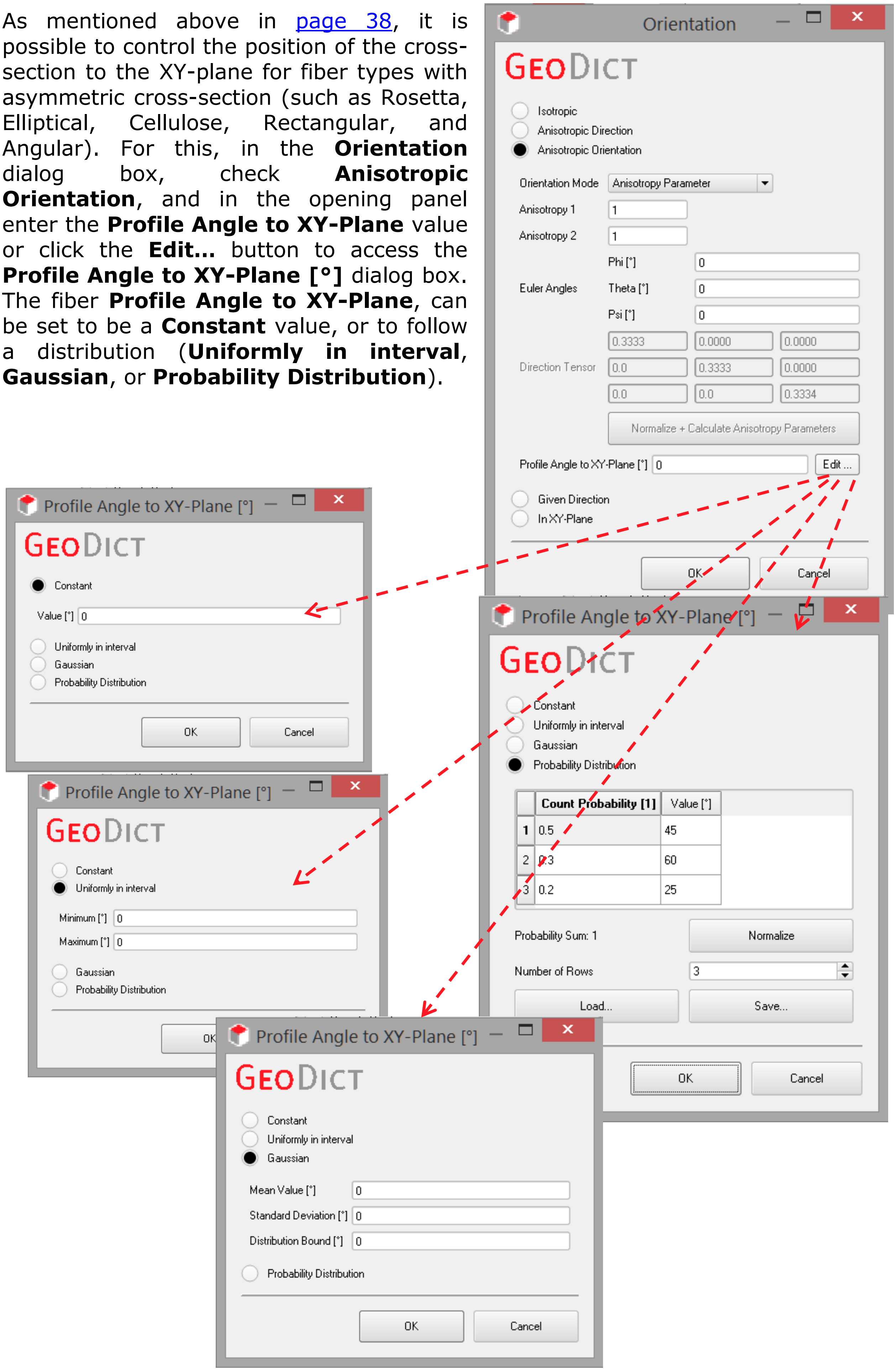
The red fibers tend to be oriented along the Z-axis, so that the fibers run parallel when viewed from the X- or Y-direction.



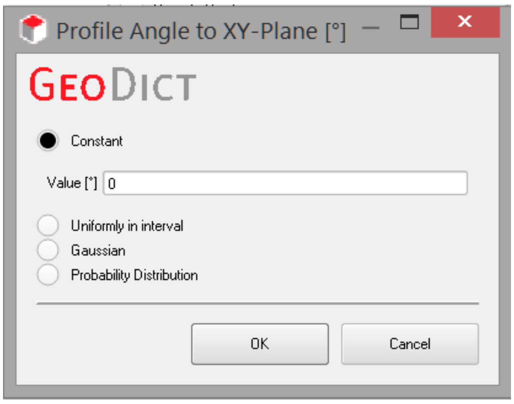
The grey fibers tend to be oriented in the Y-axis and cut the XZ-plane, while they run parallel to the YZ-plane and the XY-plane, as observed from the X- or the Z-direction.

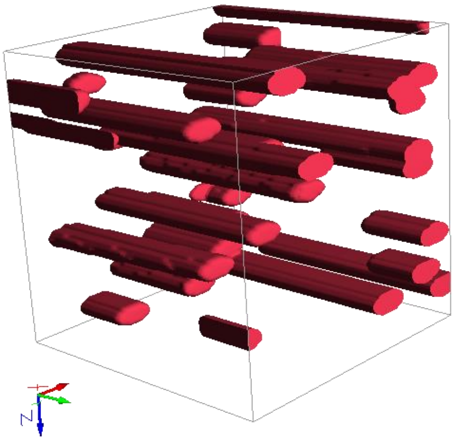


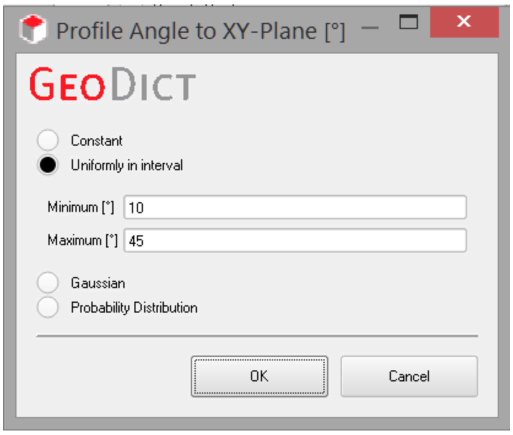
As mentioned above in page 38, it is possible to control the position of the cross-section to the XY-plane for fiber types with asymmetric cross-section (such as Rosetta, Elliptical, Cellulose, Rectangular, and Angular). For this, in the **Orientation** dialog box, check **Anisotropic Orientation**, and in the opening panel enter the **Profile Angle to XY-Plane** value or click the **Edit...** button to access the **Profile Angle to XY-Plane [°]** dialog box. The fiber **Profile Angle to XY-Plane**, can be set to be a **Constant** value, or to follow a distribution (**Uniformly in interval**, **Gaussian**, or **Probability Distribution**).

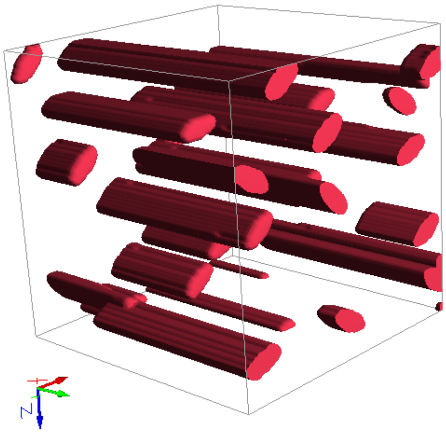


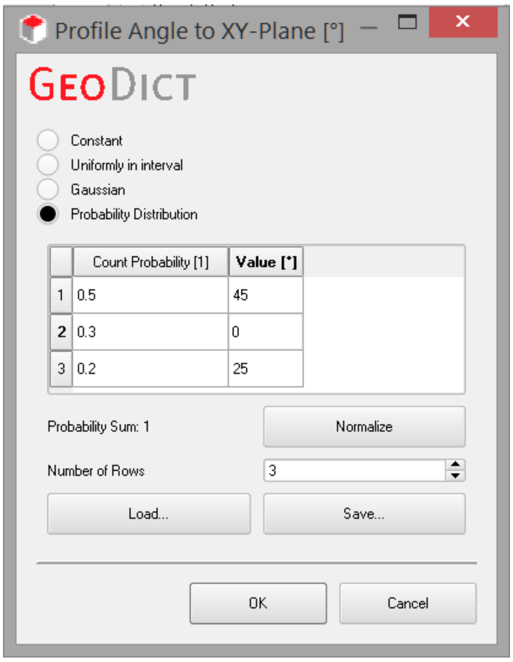
Observe the effect of varying the **Profile Angle To XY-Plane** in a structure made of Short Elliptical fibers strongly oriented in the Y-axis (Anisotropy 1 =1, Anisotropy 2 = 1000). Other parameters are unchanged.



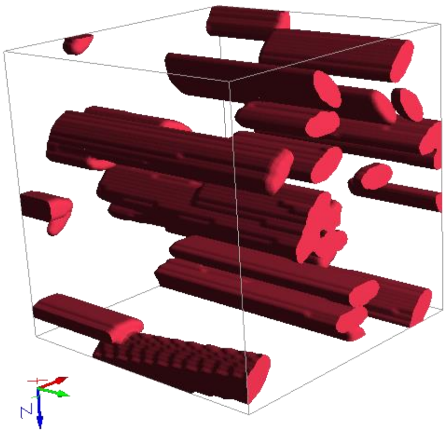




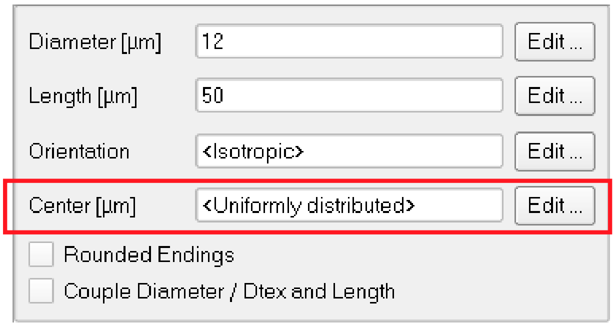




50% of the elliptical fibers are at an angle of 45º with the XY-plane, 30% lie on the plane (0º angle), and 20% are at a 25º angle.



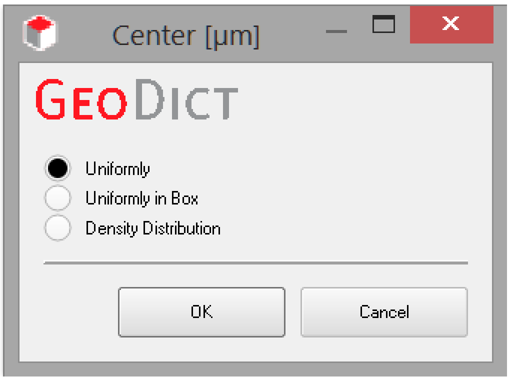
Center

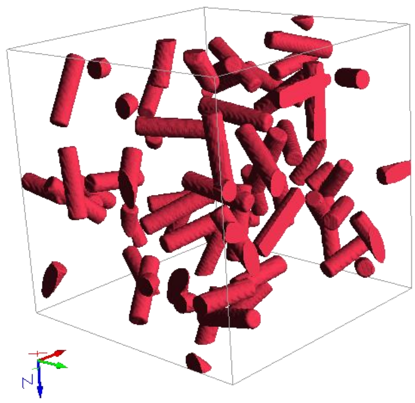


The position of short and curved fibers in a generated structure can be controlled by adjusting the position of their **Center** through the **Edit...** button.

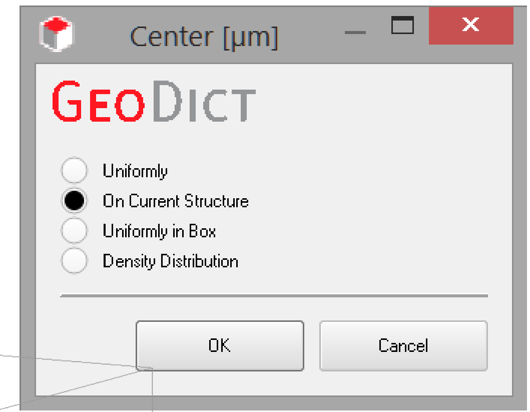
The **Center** of the fibers may be distributed **Uniformly**, **On current structure**, **Uniformly in box**, or follow a **Density Distribution**.

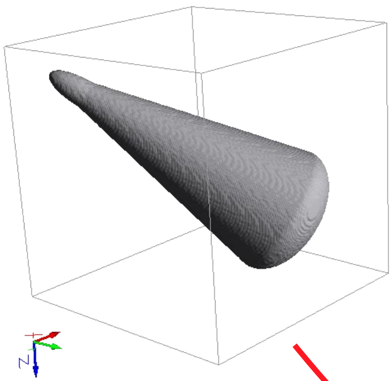
When **Uniformly** is checked, the random fiber center values will be randomly distributed across the whole structure. The uniform distribution of the centers is clearly observed when the fibers in the structure are fairly short circular fibers.

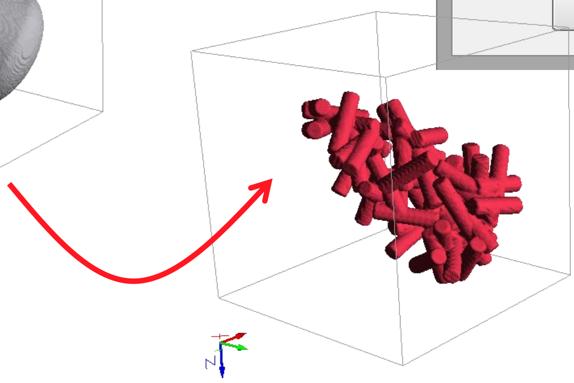




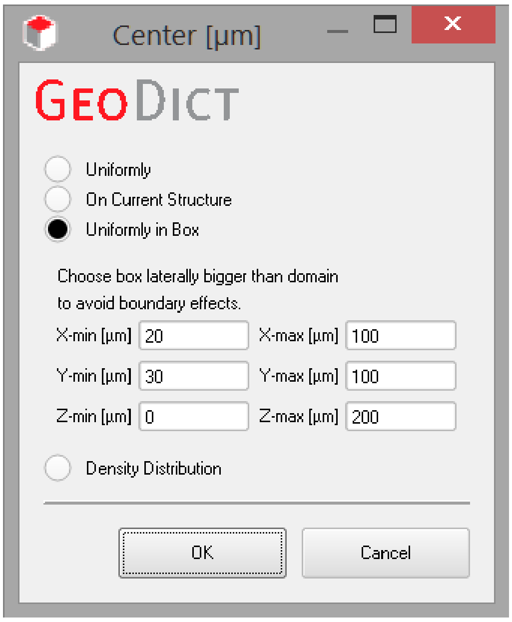
Observe the placement of short circular fibers' centers on the loaded **Cone.gad** structure (generated with GadGeo), when **On current structure** is chosen in the **Center** dialog box.

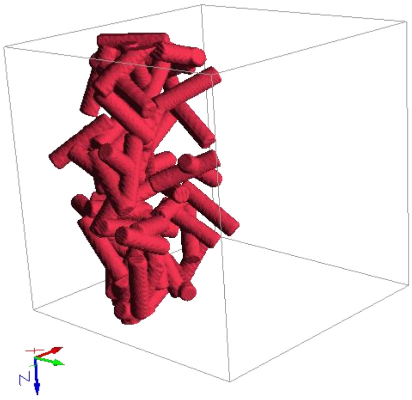


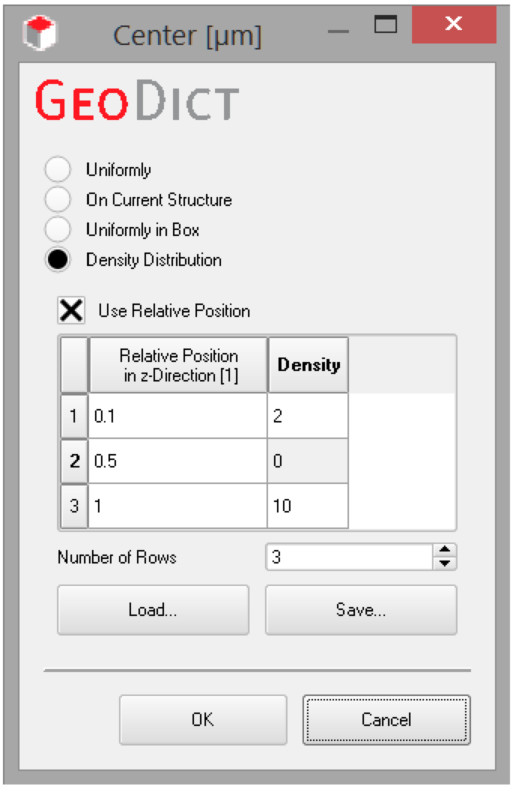




With **Uniformly in box** checked, the values entered for **Xmin**, **Xmax**, **Ymin**, **Ymax**, **Zmin** and **Zmax**, limit the distribution of the center's positions to certain areas. These directionally limiting values define an area in which the structure occurs. For a 200 x 200 x 200 µm structure, the values on the left dialog box limit an area in which the fibers' centers occur extending from 20 µm to 100 µm in the X-direction, from 30 µm to 100 µm in the Y-direction, and from the origin (0 µm) to the end of the domain in the Z-direction.

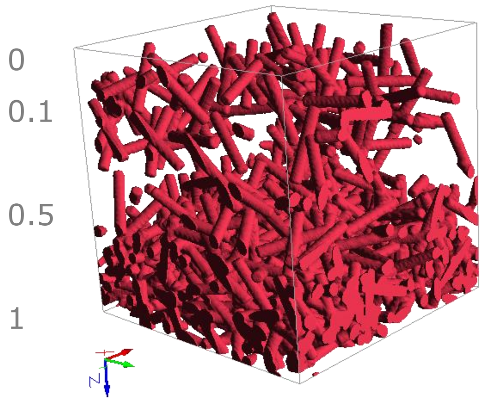






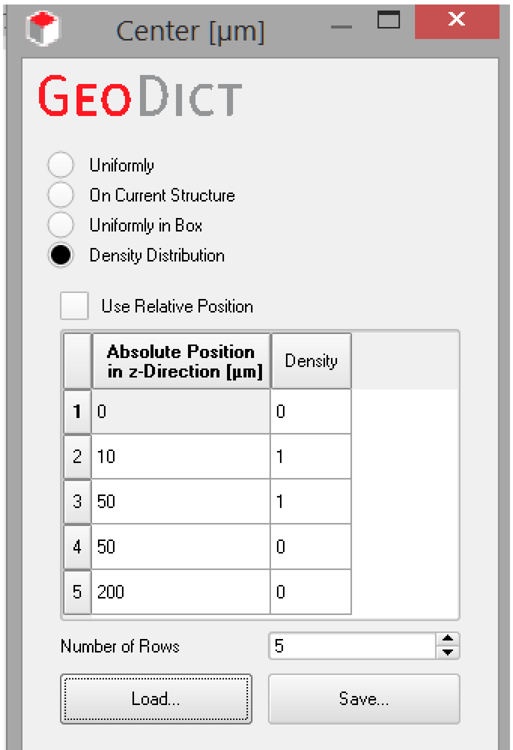
The **Density Distribution** table describes the probability of a random center taking certain position values. For the structure, the effect of the centers following a density distribution is that the centers of the fibers (and thus, the fibers) appear clustered around locations in relation to the Z-direction.

When checking **Use Relative Position**, 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 at the origin and the value 1 is at end of the domain. The right column assigns relative density values at these locations. The value **10** means that there are five times more fiber centers at Z = 1 than at Z = 0.1, with a density value of **2**. The fiber density increases and decreases linearly between the given locations in the Z-direction.



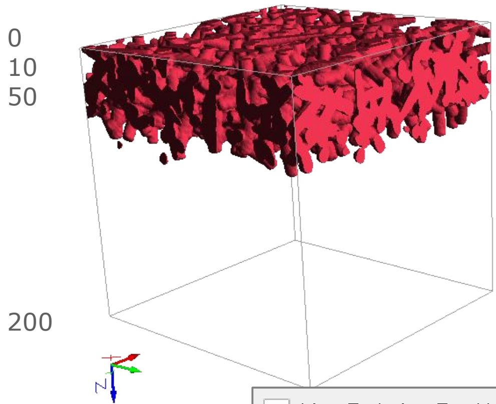
Observe how, with the values in this table, some fibers occupy the area near the Z origin (Z=0.1), then there is an area almost empty of fibers in the middle (Z=0.5), and most fibers are at the bottom in Z-direction (Z =1).

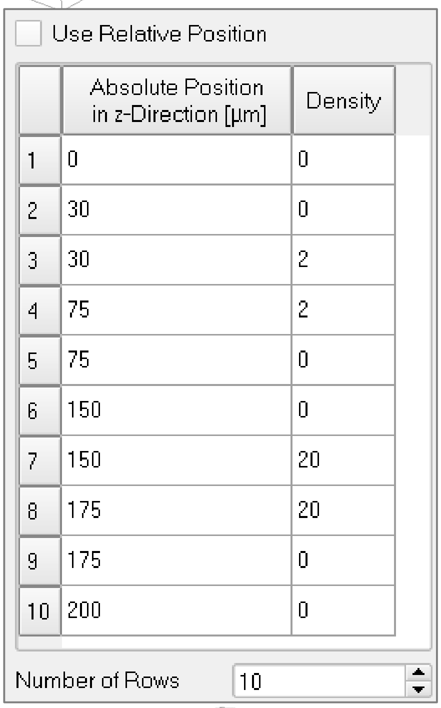
With **Use Relative Position** un-checked, the left column values of the density distribution table correspond to absolute locations in the structure. In the Z-direction, in a structure of size 200 x 200 µm, the value 0 is at the origin and the value 200 is at end of the domain. The right column assigns density values at these locations, where **0** means that fiber centers are absent at that location, and **1** means that fiber centers are present at the location.



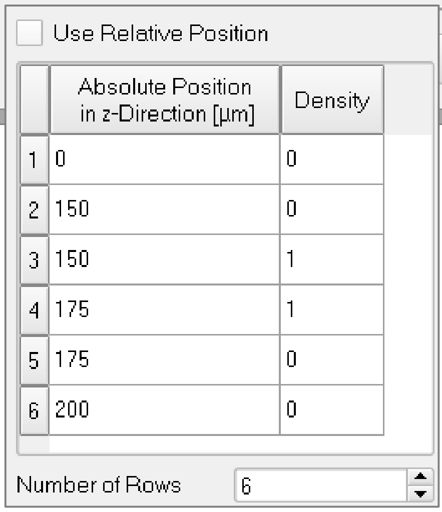
	Absolute Position in z-Direction [µm]	Density
1	0	0
2	10	1
3	50	1
4	50	0
5	200	0

Observe how, with the values in these tables, fibers are absent or appear at the given locations. The fiber density increases and decreases linearly between the given locations in the Z-direction.

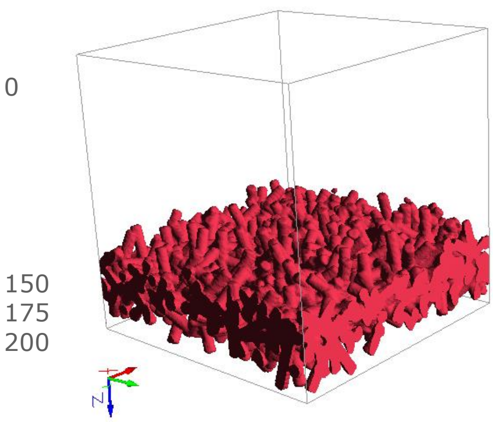


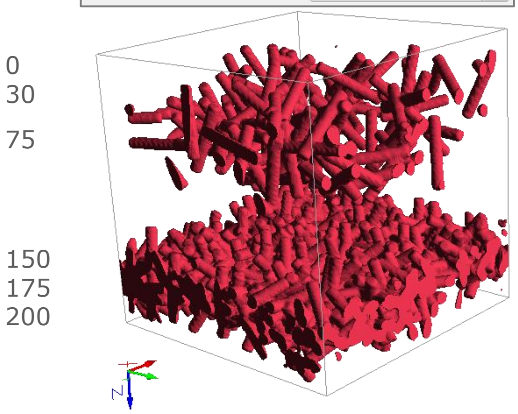


	Absolute Position in z-Direction [µm]	Density
1	0	0
2	30	0
3	30	2
4	75	2
5	75	0
6	150	0
7	150	20
8	175	20
9	175	0
10	200	0

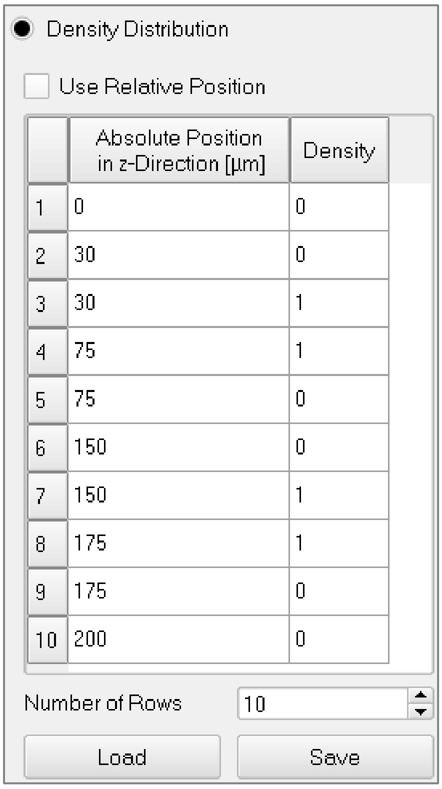


	Absolute Position in z-Direction [µm]	Density
1	0	0
2	150	0
3	150	1
4	175	1
5	175	0
6	200	0

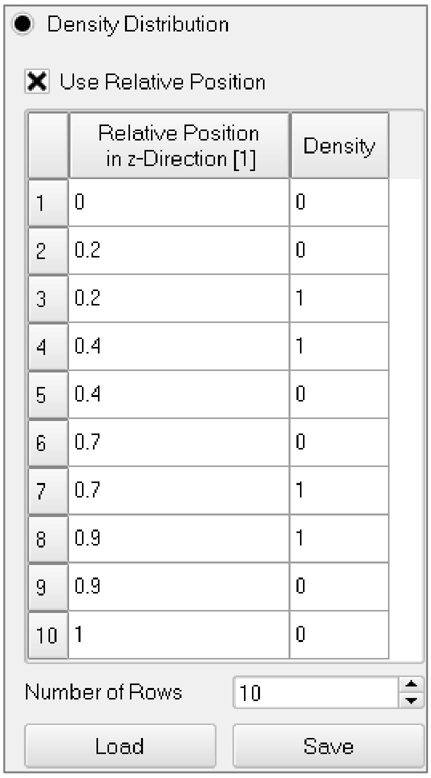




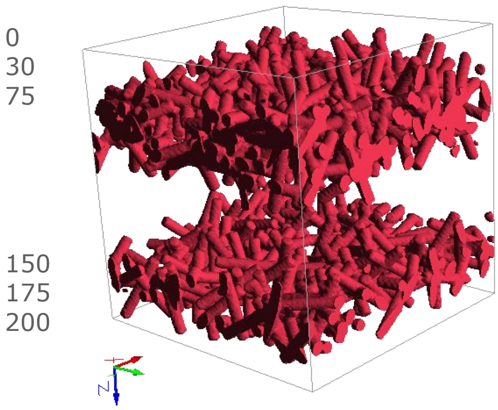
Similar structures can be obtained when using or not using relative positions, as seen in the following example:

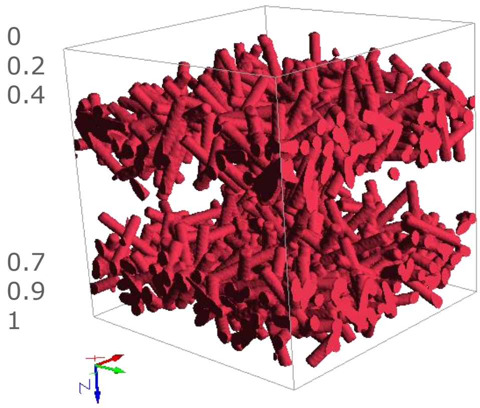


	Absolute Position in z-Direction [µm]	Density
1	0	0
2	30	0
3	30	1
4	75	1
5	75	0
6	150	0
7	150	1
8	175	1
9	175	0
10	200	0

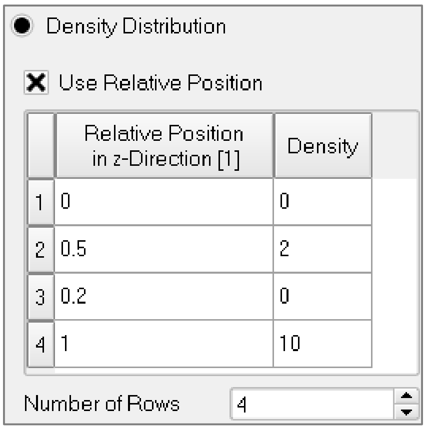


	Relative Position in z-Direction [1]	Density
1	0	0
2	0.2	0
3	0.2	1
4	0.4	1
5	0.4	0
6	0.7	0
7	0.7	1
8	0.9	1
9	0.9	0
10	1	0



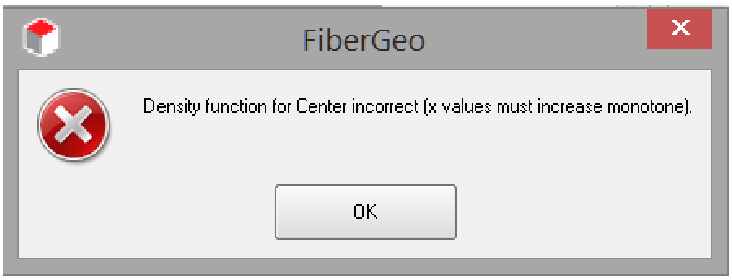


The center density distribution is **monotonic** (or **monotone**), i.e. the relative or absolute position values in the left column must follow a given order, either increasing or decreasing.



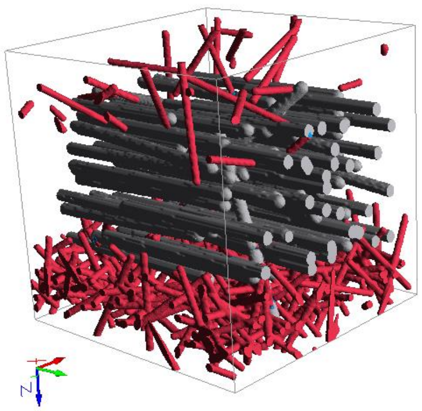
	Relative Position in z-Direction [1]	Density
1	0	0
2	0.5	2
3	0.2	0
4	1	10

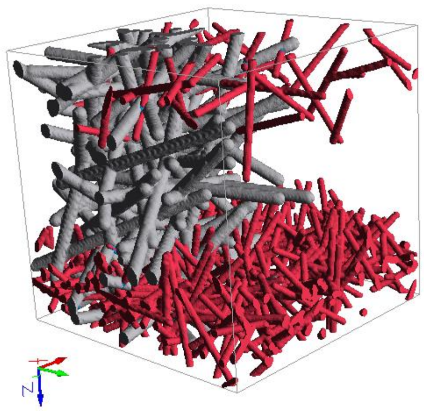
Non-monotone density distributions (as the one shown here) are not allowed, and an error message appears when trying to generate the structure.



As before with orientation, the distribution of centers can be separately set for each fiber type so that differently distributed fiber types may coexist within the same structure. In the following structures, observe that the same grey short circular fibers are distributed **Uniformly in box**, whereas the red short circular fibers follow a **Density Distribution**.

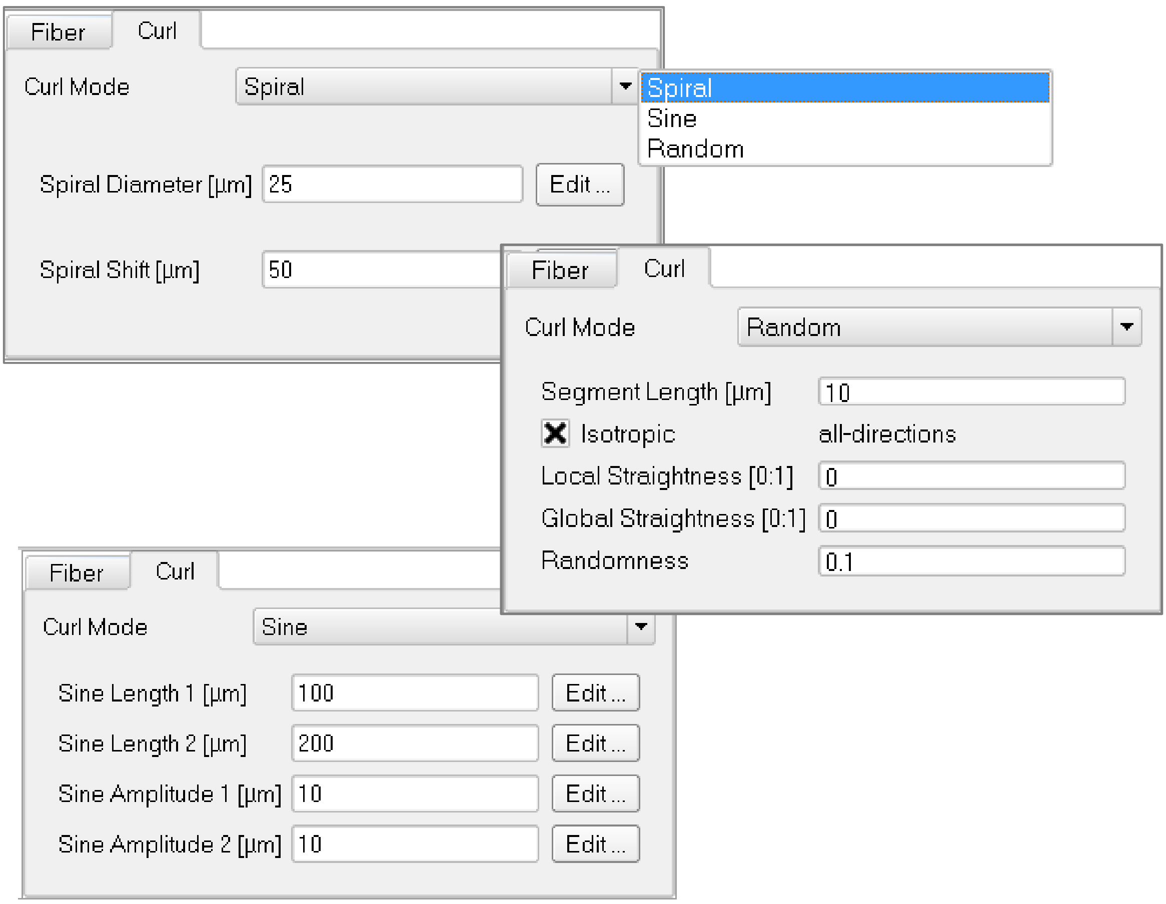
The .gps settings files that result in the generation of these two structures are provided with the documentation for this FiberGeo2014 Reference manual (DensityDist_UniBox1.gps and DensityDist_UniBox2.gps).





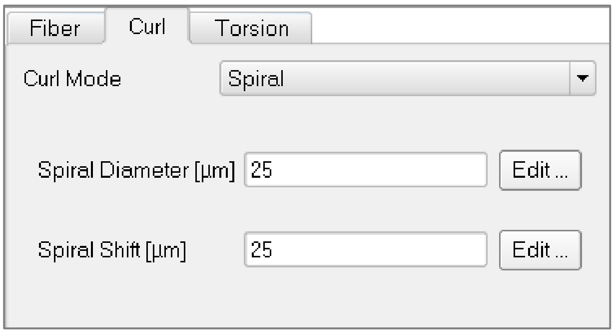
Curl Parameters

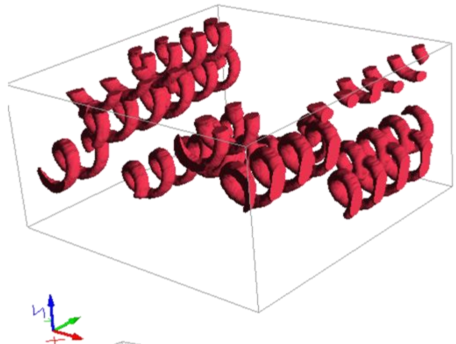
If the fibers added to the structure are curved fibers, a **Curl** tab appears in the right panel. Curved fibers can bend in three modes, selectable in from **Curl Mode** pull-down menu: **Spiral**, **Sine**, and **Random**. The curl parameters are different for these modes.

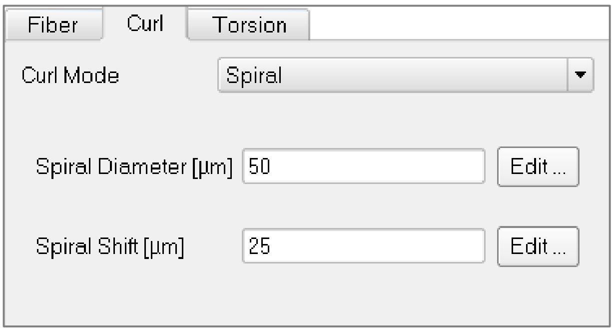


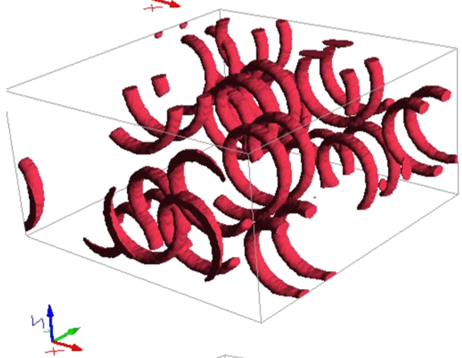
Spiral curved fibers form a three-dimensional curve that winds around an axis. The spirals are defined by the **Spiral Diameter** and the **Spiral Shift**. The spiral shift is the distance between the same relative positions in two consecutive loops of the spiral.

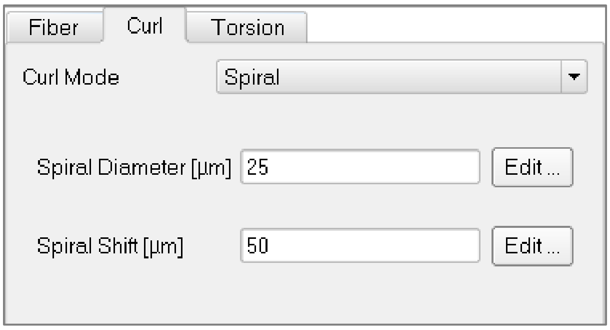
Observe the effect changing these two parameters has on the form of the generated spiral curved fibers.

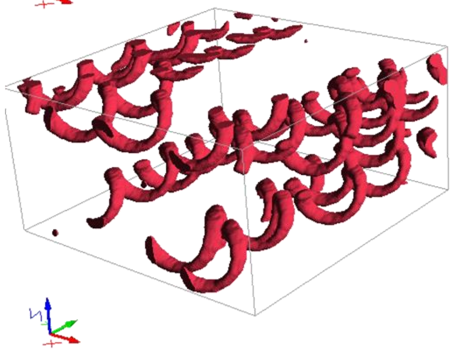






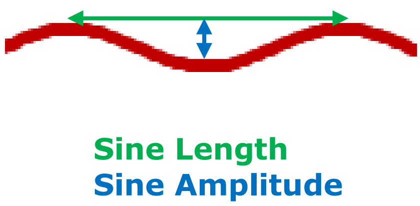


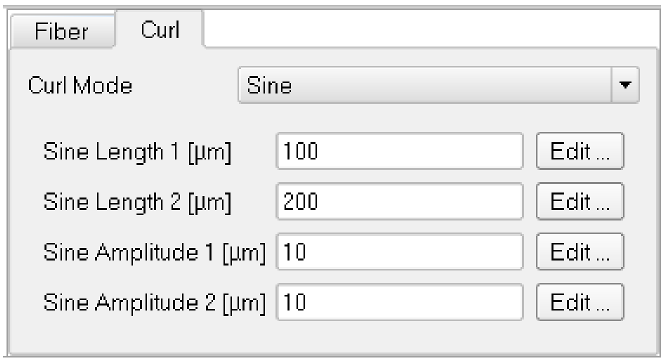




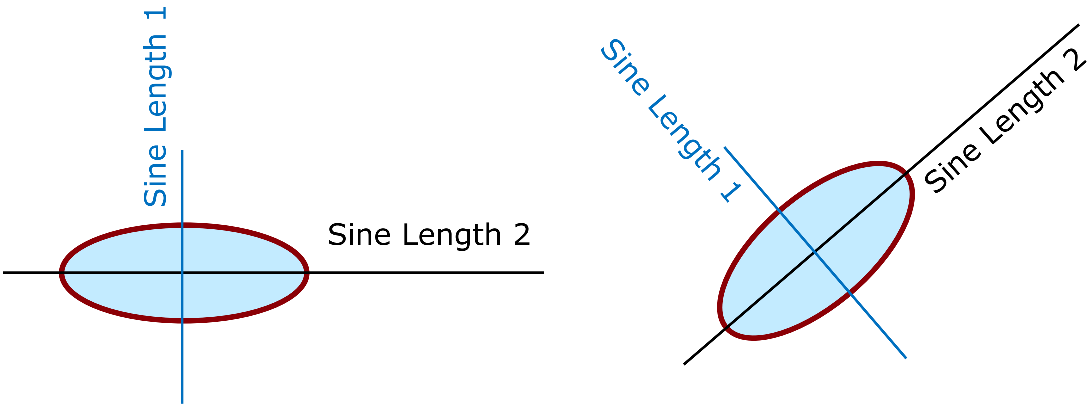
Sine (sinusoidal) curved fibers follow a sinusoid curve defined by the equation

$y = \sin x$.

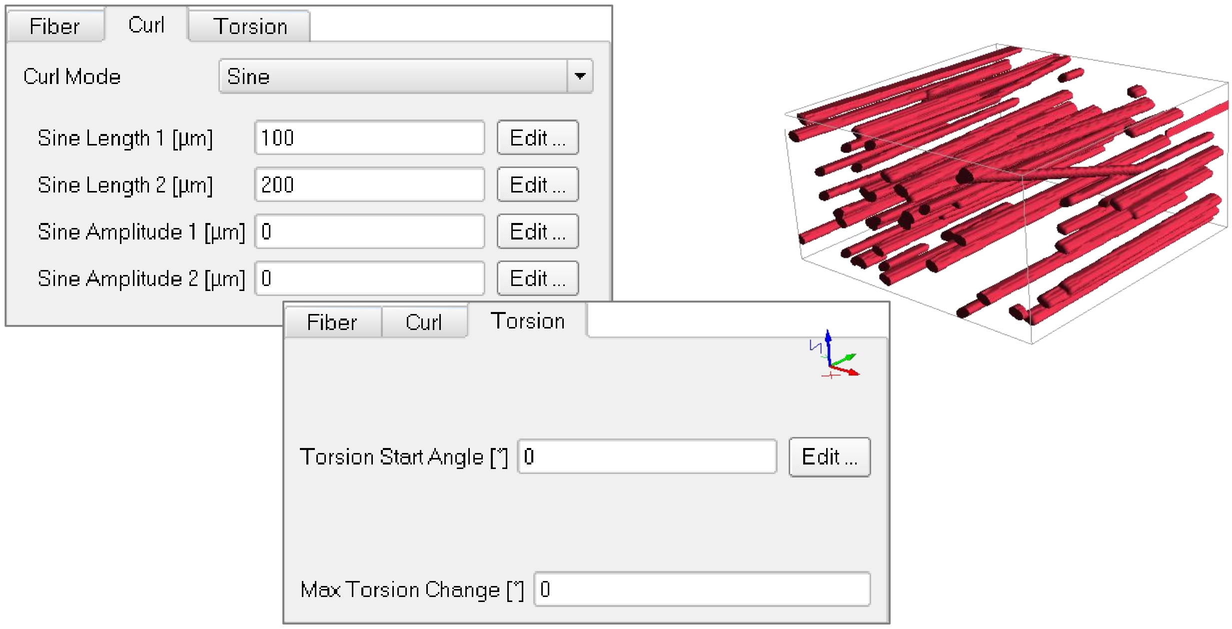




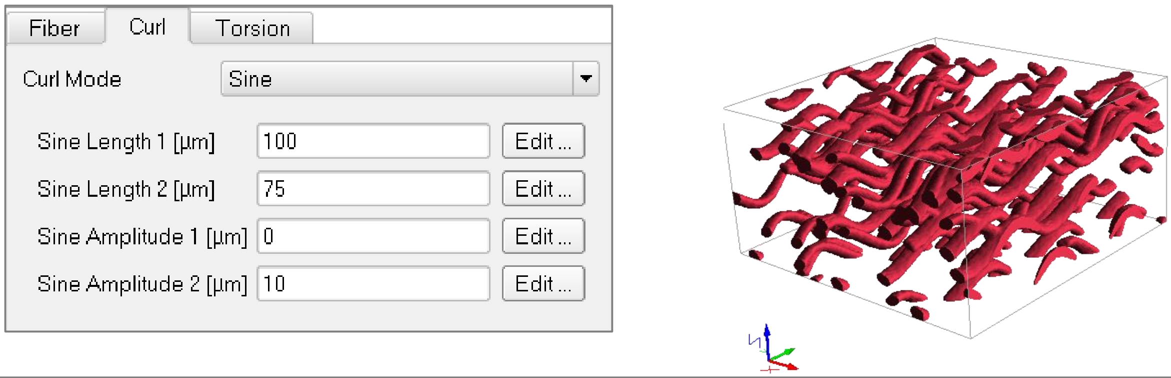
For sine curved fibers, the parameters **Sine Length 1**, **Sine Length 2**, **Sine Amplitude 1**, and **Sine Amplitude 2** are determined by the fiber orientation. **Sine Length 1** and **Sine Length 2** describe the oscillation amplitude in the direction of the main axis. This is shown below for an elliptical fiber.



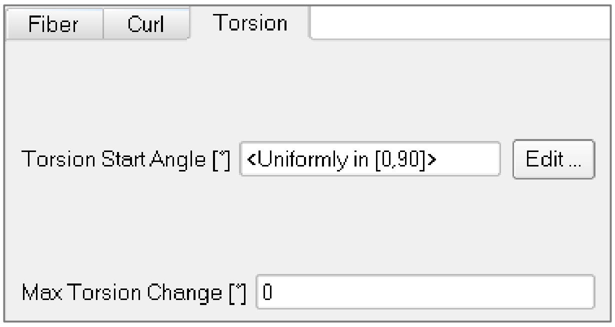
Initially, keep the default values of **Sine Length 1**, and **Sine Length 2,** whereas the **Sine Amplitude 1** and **Sine Amplitude 2** are set to 0, as is the **Torsion Start Angle**. These parameters produce curved elliptical fibers that are actually straight.

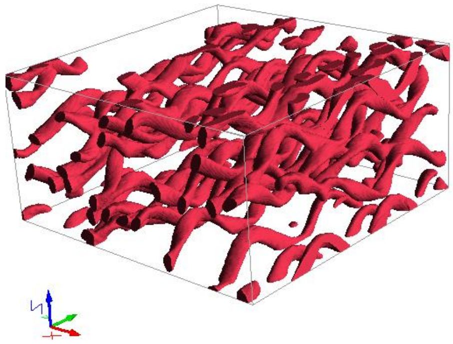


When the same fibers are created with a smaller **Sine Length 2** (75 µm) and a **Sine Amplitude 2** of 10 µm, the sine fibers appear curved.

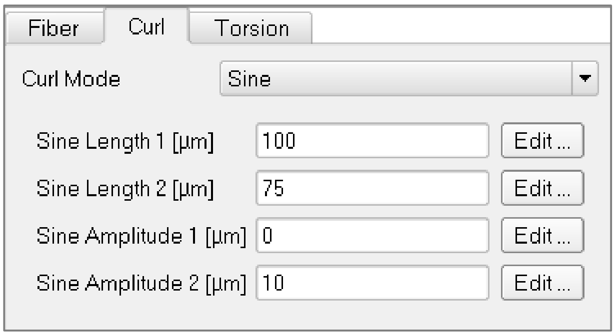


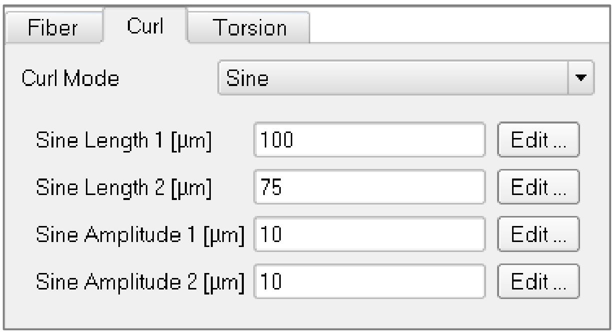
When these same curved sine fibers are created with a **Torsion Start Angle** that follows a uniform distribution in the interval 0 to 90º, the sine fibers appear curved and twisted.

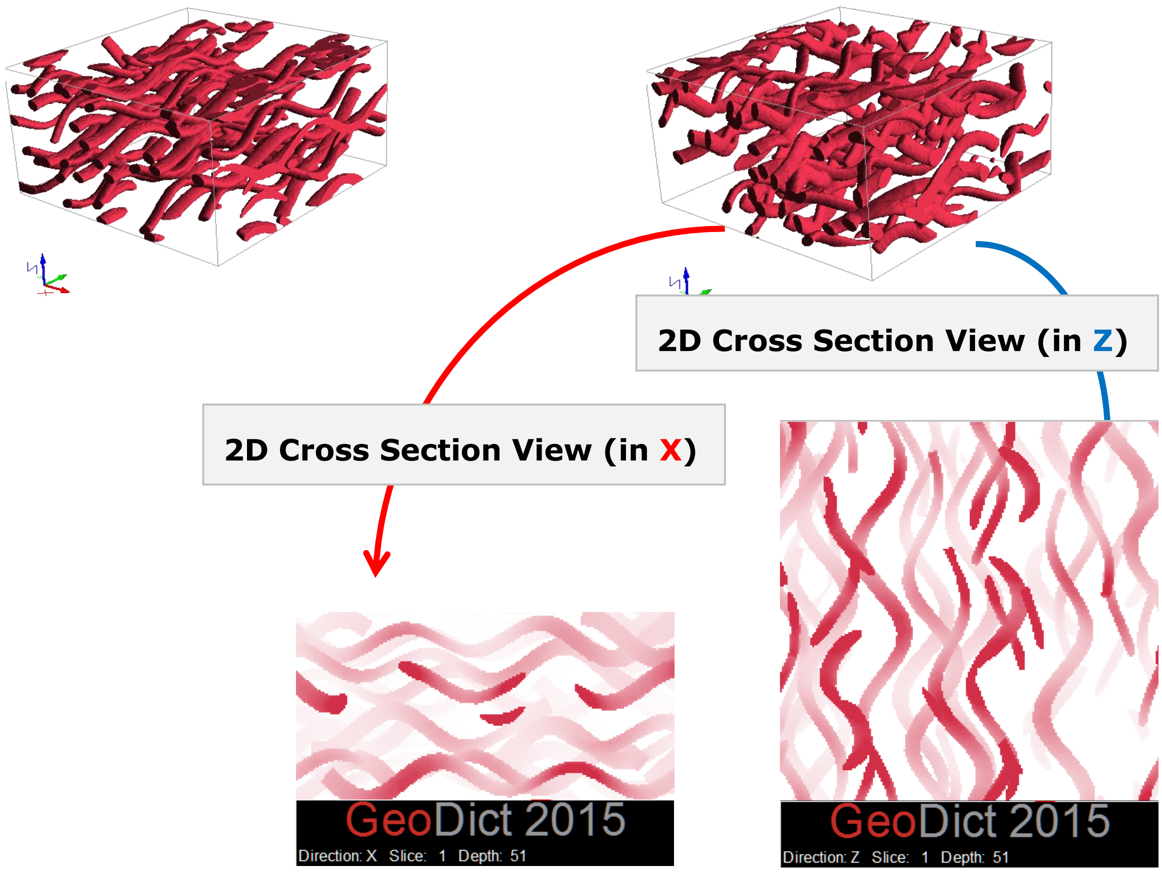


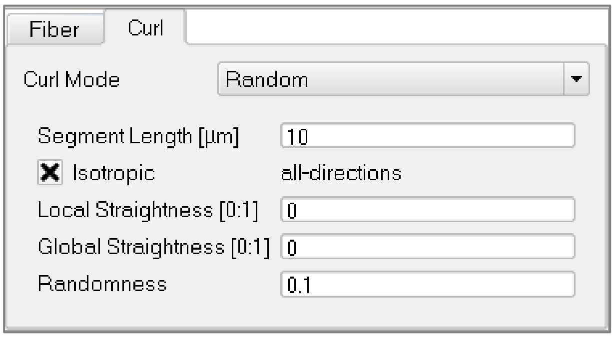


Sine fibers have only one sinusoidal component when the **Sine Amplitude 1** (OR **Sine Amplitude 2**) is 0, while the other sine amplitude is set to a positive value. Sine fibers with a combination of components are obtained when both sine amplitudes are set to positive values. For example, with the following values:



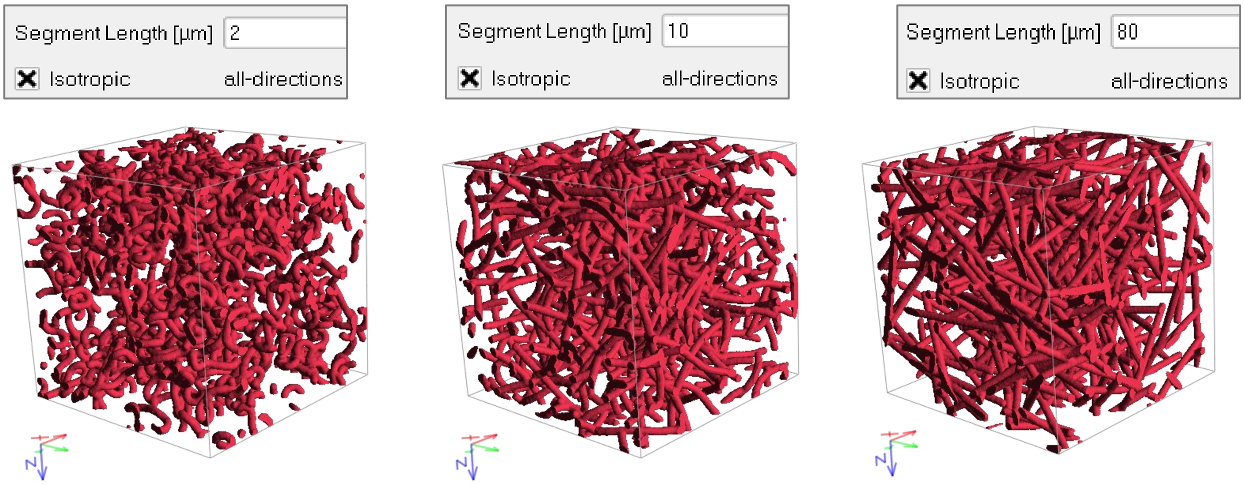




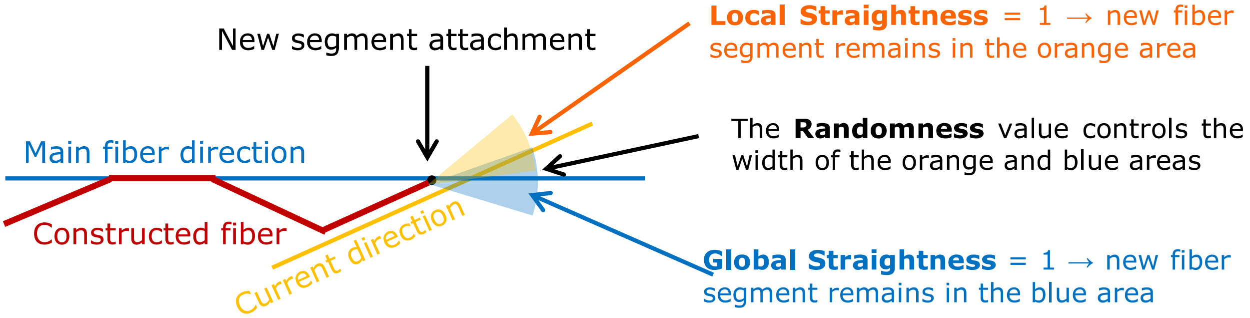


Curved random fibers consist of straight fiber segments of a given **Segment Length**, a discretization parameter of the fibers. Its value determines the length of the linear parts that build the fiber, so that small values lead to well resolved fibers with smooth curving. A large segment length may lead to fibers that appear almost straight.

In the following examples, all parameters are left unchanged while curved circular fibers with a length of 100 µm are given varying **Segment Length**, as indicated.



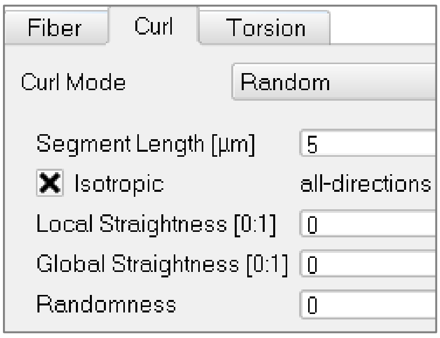
The first segment is placed in space according to the **Center** and **Orientation** values previously entered under the **Fiber** tab. The curved fiber follows a main fiber direction given by this Orientation value (Anisotropy 1 and Anisotropy 2).



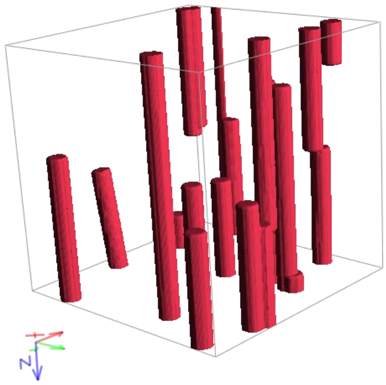
The checking or un-checking **Isotropic** controls the direction in which the parameters **Local Straightness**, **Global Straightness**, and **Randomness** are applied to the new segment. These parameter values (between 0 and 1) define the direction of each new attached segment and determine how rapidly a fiber may change direction from one segment to the next.

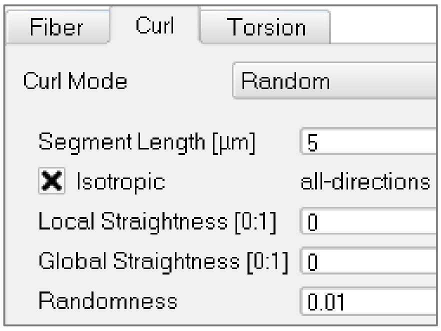
Observe the effect of varying these three parameters on a structure made of highly anisotropic (oriented in the Z-axis, **Anisotropy 1** = 0.001, **Anisotropy 2** = 1) curved circular fibers. All other parameters remain unchanged.

Randomness corresponds to the standard deviation of the Gaussian distribution.

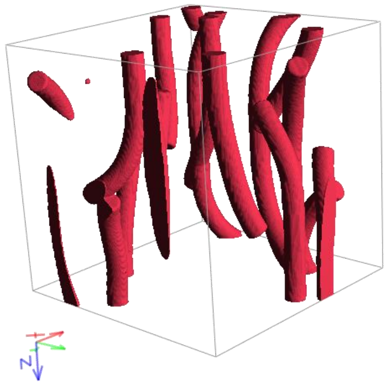


With **Randomness** set to zero, all segments have the same direction, resulting in straight fibers. The high anisotropy makes fibers to lie almost parallel to Z-axis.

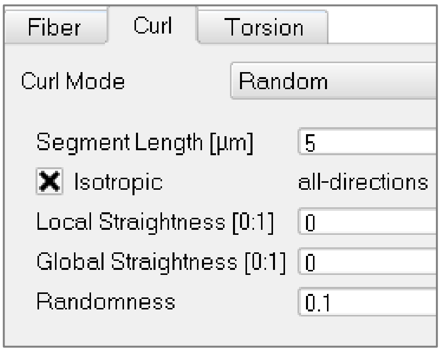


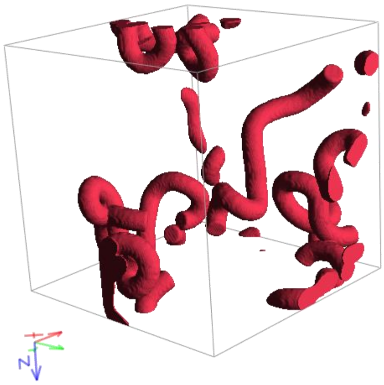


With a slightly higher **Randomness** value, the fibers are allowed to change their direction from one segment to the next.

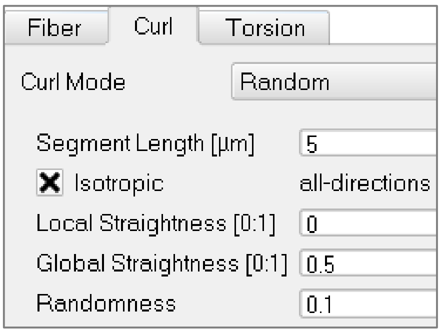


The fiber curvature increases with the **Randomness** value. With **Global Straightness** set to 0, only the initial segment shows the predefined anisotropic orientation, and the fiber direction is random. Zero **Local Straightness** leads to an almost constant curvature throughout the fiber.

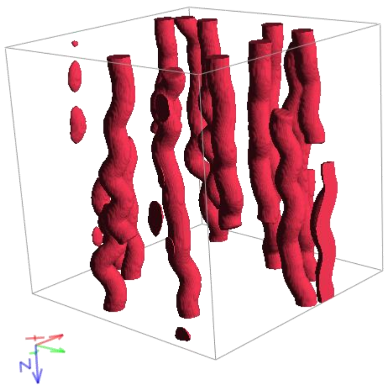


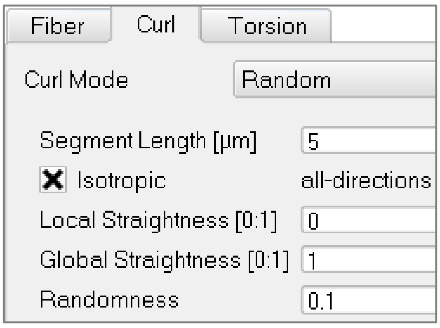


The **Global Straightness** value can be set between 0 and 1. With a **Global Straightness** value of 0, the fiber can be bent in any direction while with a **Global Straightness** value of 1 the fiber tends towards the main direction (for anisotropic fibers). Observe that the Randomness value is kept at 0.1.

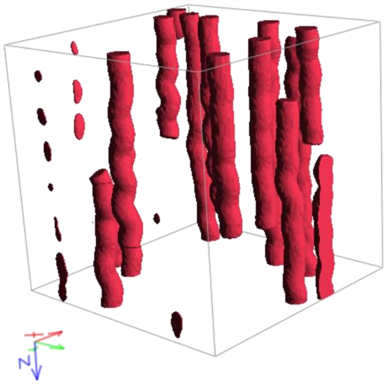


With a non-zero **Global Straightness** value, the fibers tend to return to the initial prescribed strong anisotropic **Orientation**

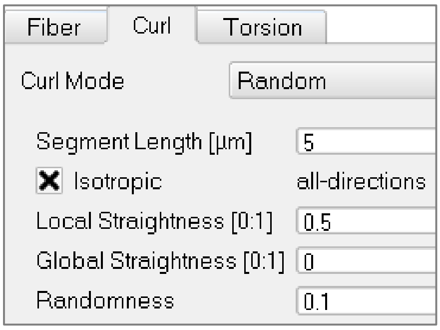




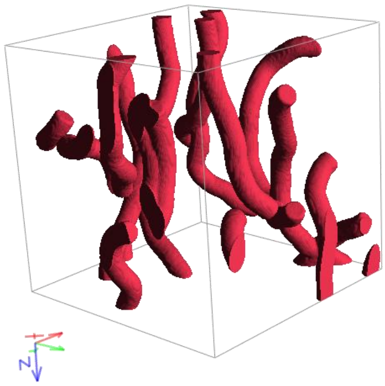
With a **Global Straightness** value of 1, the fibers have an acute tendency to keep to the anisotropic **Orientation** (Anisotropy 1 = 0.001)



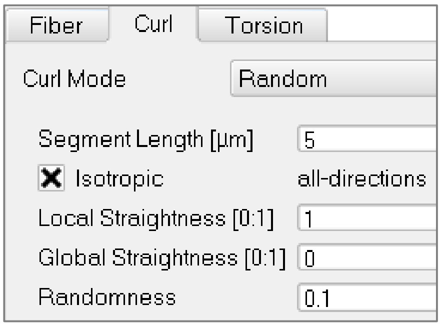
A **Local Straightness** value of 0 allows the fibers to curve. A value of 1 impels each new segment to maintain a direction similar to that of the previous segment, resulting in low curvature of the fiber. Observe that **Randomness** is kept at 0.1.



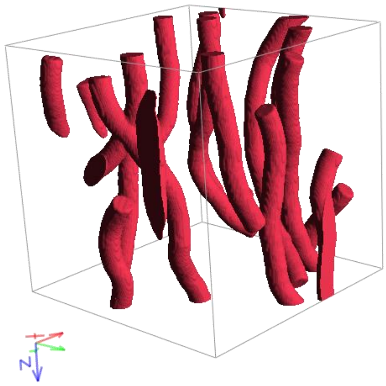
A non-zero value of **Local Straightness**, results in a reduction of the fibers' curvature (compared to the structure with Local Straightness of 0 and Randomness of 0.1 above).

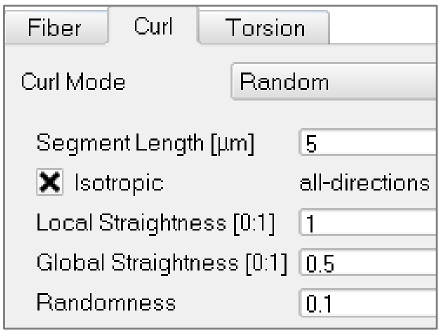


The fibers are not restrained to the stay in the Z-axis, since the **Global Straightness** value is 0.

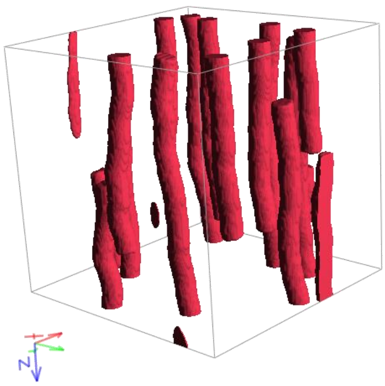


A **Local Straightness** value of 1 leads to low curvature and almost straight fibers.



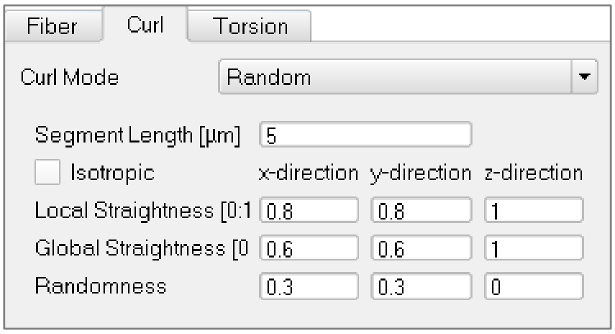


A higher **Global Straightness** value, with a **Local Straightness** value of 1, forces the straighter fibers to comply with the high anisotropy and be aligned to the Z-direction.



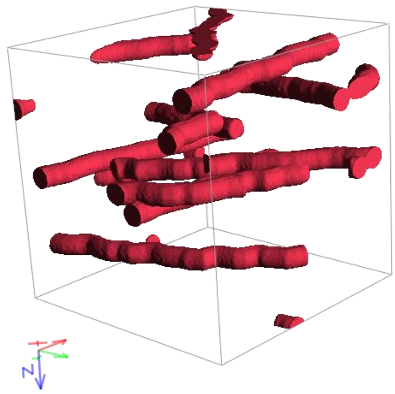
Global Straightness and **Local Straightness** are pure simulation parameters lacking direct physical meaning.

The curl parameters can be **Isotropic**, when the deformation parameters are applied in **all-directions** or anisotropic, when **Isotropic** is unchecked, and the deformation parameter values are modified for one or more directions. Setting anisotropic curl parameters makes sense only in combination with an anisotropic fiber orientation.



Here, the same curl parameter values are entered for the X- and Y-directions, whereas no deformation is allowed in Z-direction, where **Local Straightness** and **Global Straightness** have been set to 1 and **Randomness** to 0.

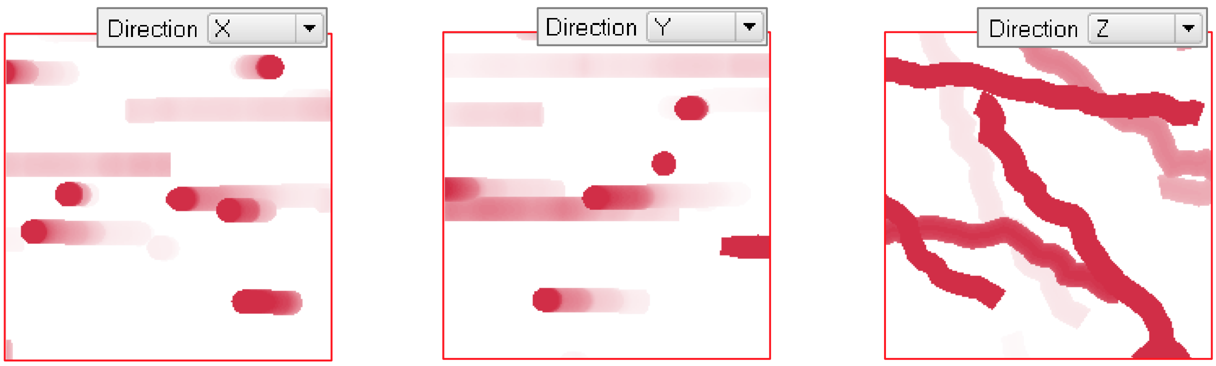
In the following example, observe how the deformation of curved circular fibers occurs only in the XY-plane of an anisotropic-oriented structure (**Anisotropy 1** =100 and **Anisotropy 2** =1) when entering the anisotropic curl parameters shown above.



With values of Anisotropy 1 and Anisotropy 2 being 100 and 1, the generated structure is compressed in the Z-direction.

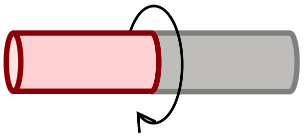
Views from the X- and the Y-direction show that there is no deformation of fibers in Z-direction. This is a consequence of setting the **Randomness** in Z-direction to zero.

The view from the Z-direction shows that the fibers are curved in the X and Y directions.



Torsion Parameters: Torsion Start Angle and Maximum Torsion Change

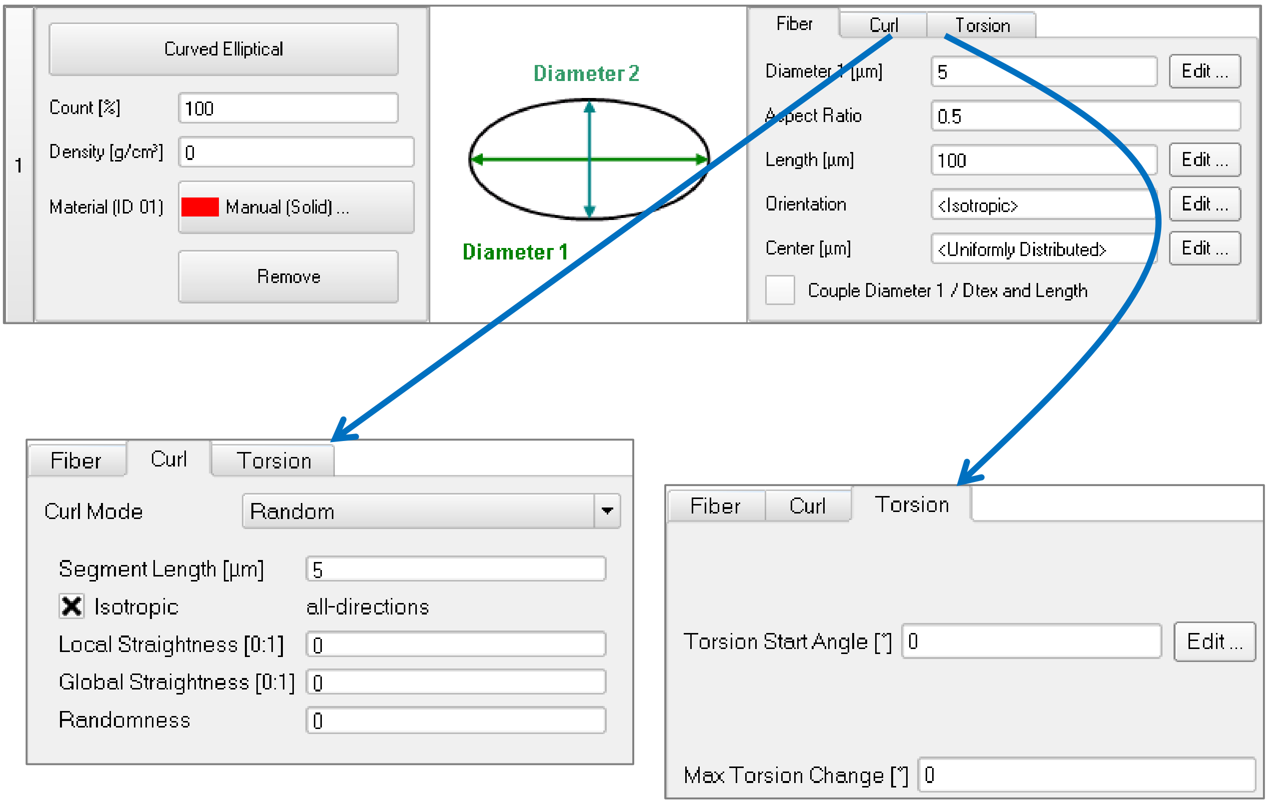
Curved fibers, except **Circular** and **Hollow** fibers, can be internally spun to achieve torsion, when entering adequate values for **Torsion Start Angle** and **Max Torsion Change.**



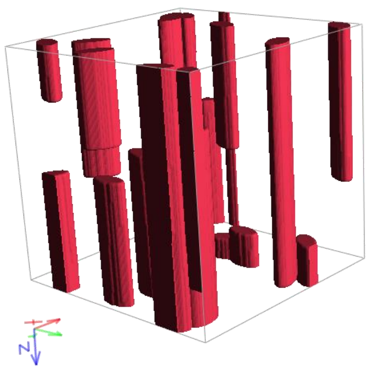
The **Torsion Start Angle** defines how strongly the fibers are spun or twisted within one segment length.

The **Maximum Torsion Change** determines the maximum allowed degree of change of the **Torsion Start Angle** from one segment to the next.

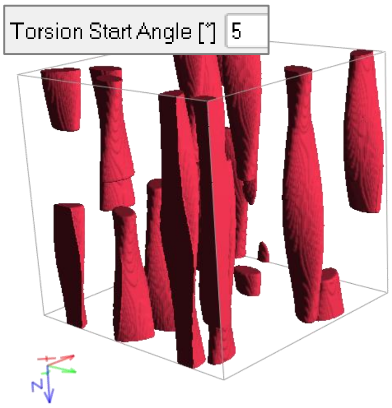
Observe the effect of varying the torsion parameters on a highly anisotropic structure (**Anisotropy 1** = 0.001, **Anisotropy 2** = 1) made of curved ellipsoidal fibers. The curl parameters are isotropic and randomness is 0, producing straight fibers parallel to the Z-axis.

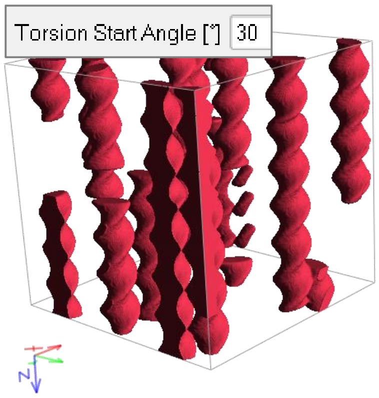


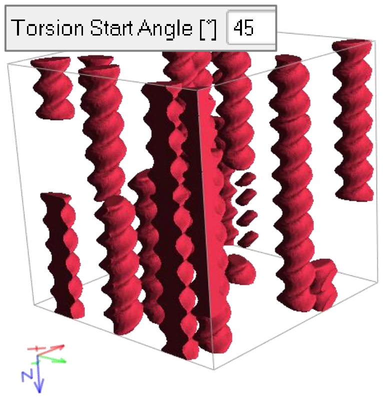
Both **Torsion Start Angle** and **Max Torsion Change** values are initially set to 0 in the **Torsion** panel to generate fibers without torsion.



With **Torsion Start Angle** values of 5, 30, and 45, and a **Max Torsion Change** value of 0, fibers with a constant spun of 5º, 30º and 45º within each segment are generated.

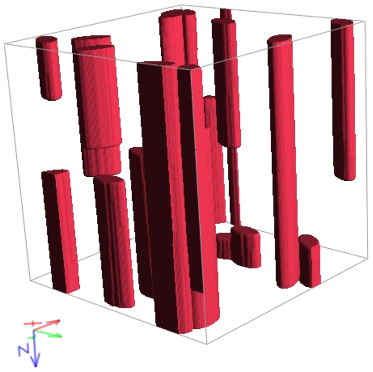


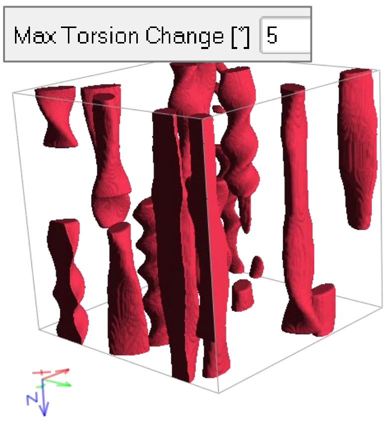


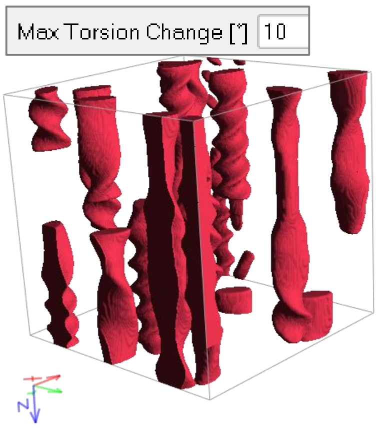


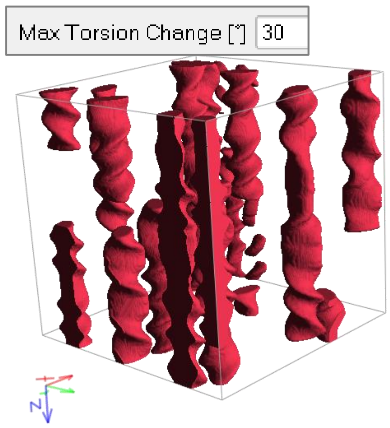
The use of **Max Torsion Change** brings some natural degree of randomness to generated cellulose fibers, simulating a slight rotation now and then. The spun of each segment is not kept constant but varies in the range defined by the **Max Torsion Change** value. The magnitude of the maximal torsion change is on the order of the standard deviation of a Gaussian distribution with typical values being in the range of 1º to 2º.

Observe the effect of keeping a **Torsion Start Angle** of 0 and entering increasing values of **Maximal Torsion Change** (5, 10 and 30) on a highly anisotropic structure made of curved cellulose fibers.



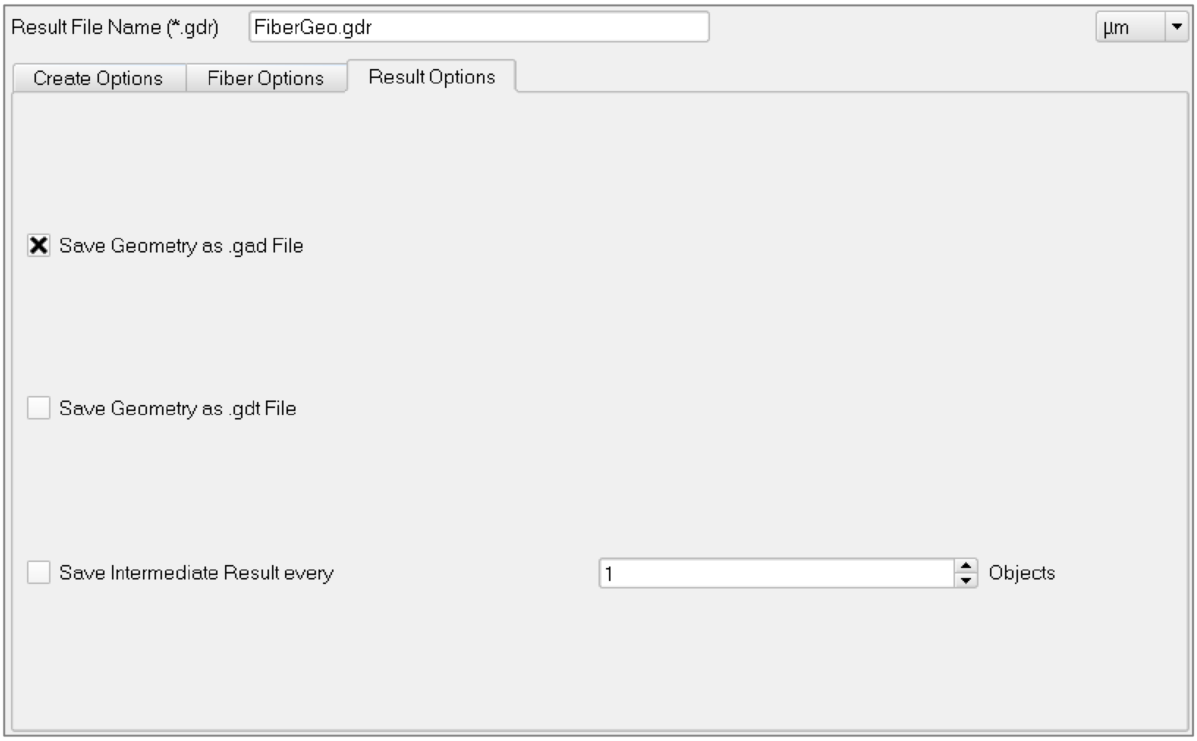


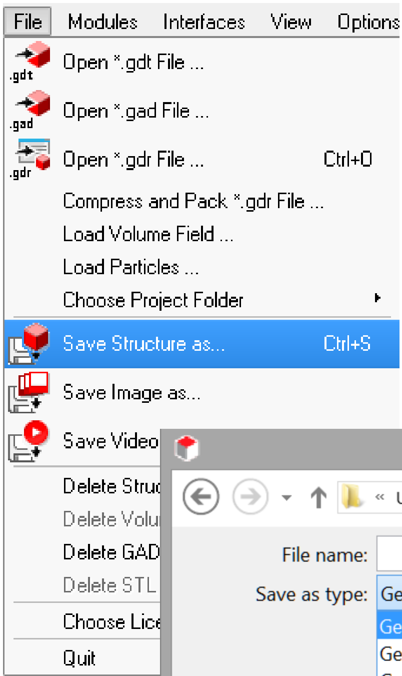




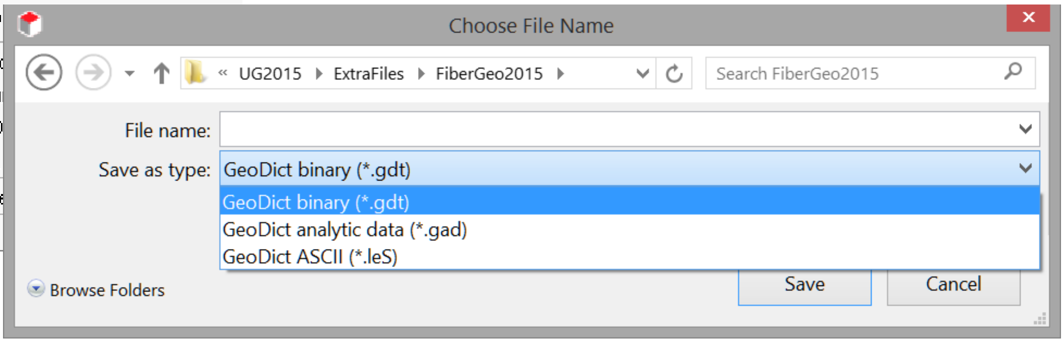
Result Options

The default is to have **Save Geometry as *.gad File** (GeoDict analytic data) checked, so that the analytic data describing the position of the fibers in the structure is saved. This *.gad file is placed in an automatically created result folder inside the chosen project folder (**File → Choose Project Folder…** in the Menu bar). Additionally, the generated structure can be saved in .gdt format when checking **Save Geometry as .gdt File**. Both the *.gad file and the *.gdt file, as well as the result folder, take the name entered as **Result File Name (*.gdr)** at the bottom of the dialog box.





The *.gad or *.gdt file can also be saved by selecting **File → Save Structure As…** in the Menu bar, and then choosing **GeoDict analytic data (*.gad)** or **GeoDict binary (*.gdt)** as the file type in the pull-down menu of the **Choose File Name** dialog box.



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 fibers are added to the fibrous structure during the generation, an intermediate result file is saved every time the number of placed objects reaches the entered value.

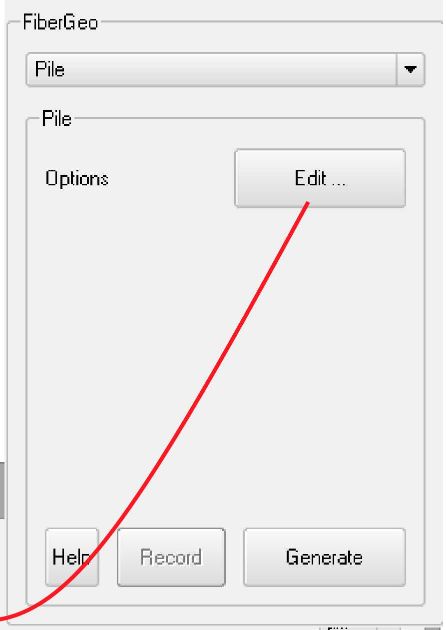
This option may be interesting when studying the properties of a series of increasingly dense fibrous structures

The parameters entered in the **FiberGeo Create Options** dialog box can be saved into *.gps (GeoDict Project Settings) files and/or loaded from them. Remember to restore and reset your (or GeoDict's) default values through the icons at the bottom of the dialog box when needed and/or before every FiberGeo run.

Resting the mouse pointer over an icon prompts a ScreenTip showing the icon's function to appear.

PILE

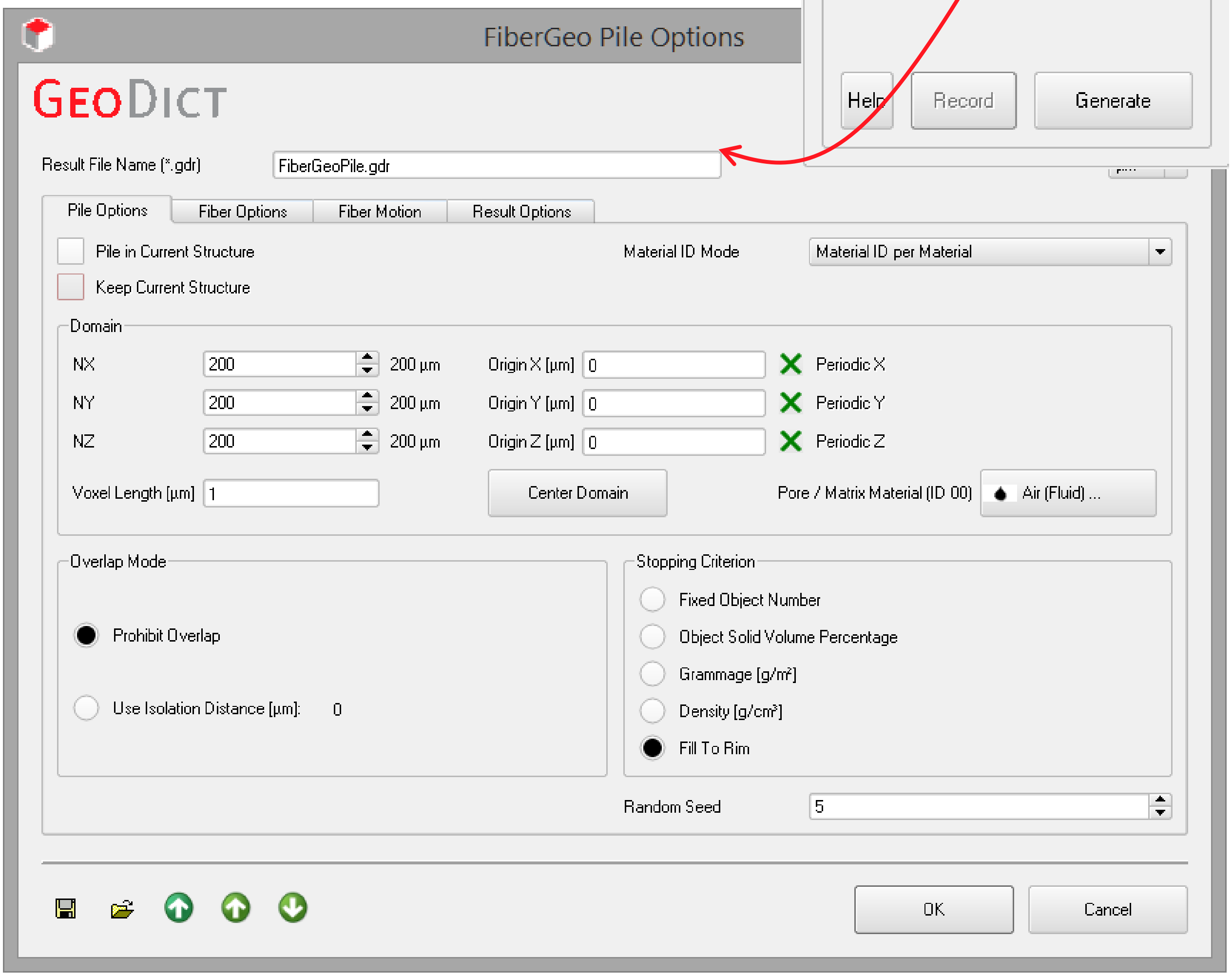
With the selection of **Pile** from the **FiberGeo** section pull-down menu, fibers fall from their initial positions during the structure's generation and form a piled fibrous structure. Clicking the pile **Options**' **Edit...** button opens the **FiberGeo Pile Options** dialog box.



At the top left, the name for the files 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 available units (**m**, **mm**, **µm**, **nm**, and **Voxel**) are selectable at the top right of the dialog box. When the units are changed, the entered values are adjusted automatically.

The options are organized through tabs.

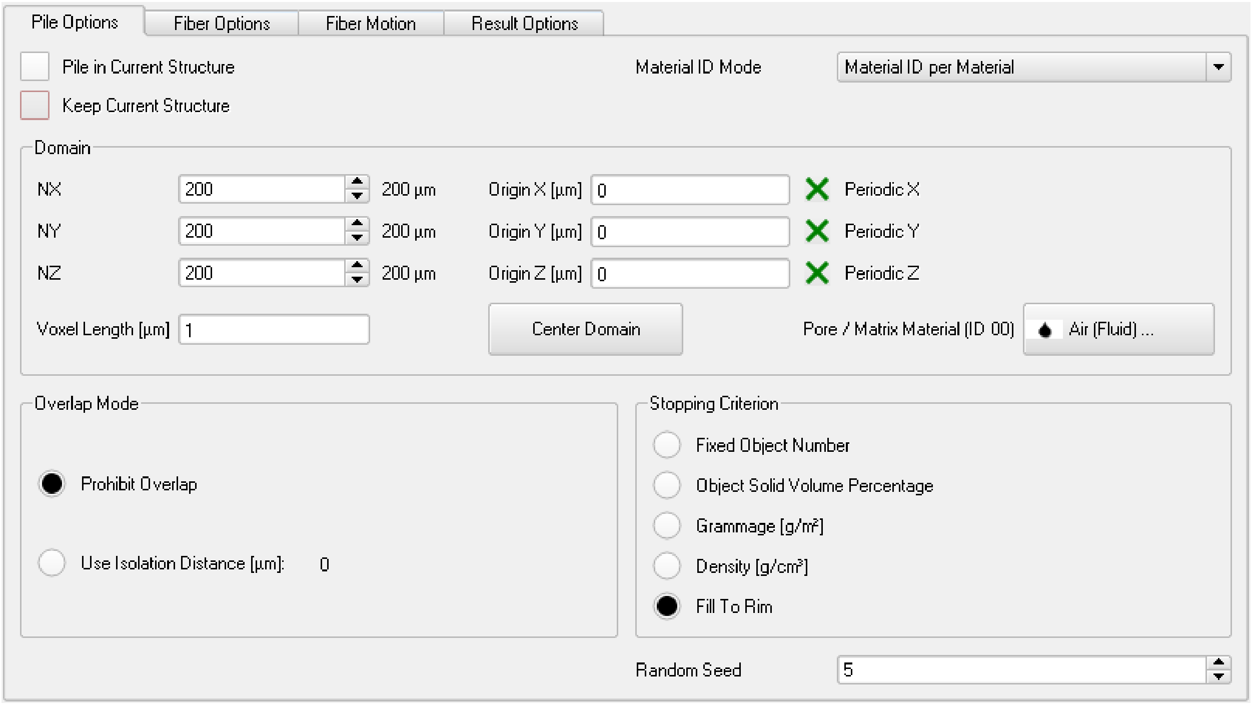


- The **Pile Options** determine physical properties of the resulting structure model such as size, resolution, and solid volume fraction.
- The **Fiber Options** define the geometrical properties of individual fiber types such as cross-section, length, and orientation. Up to four different object types can be used in one structure.
- The **Fiber Motion** controls the manner in which the objects should be piled through piling direction and the initial object positions.

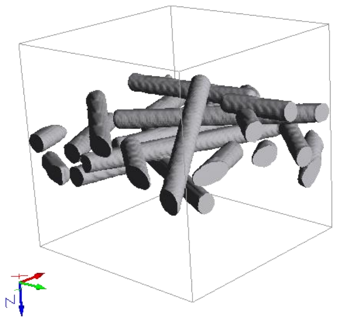
- The **Result Options** determine how the result files are saved.

Pile Options

The physical properties parameters of the piled structure are entered through the selected **Pile Options** tab, and grouped into **Domain**, **Overlap Mode**, and **Stopping Criterion** panels.

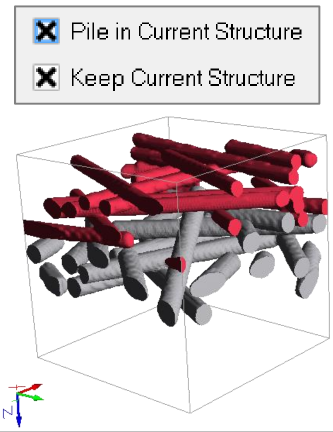


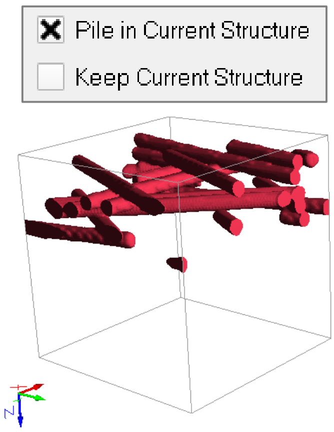
When checking **Pile in Current Structure**, the structure currently in memory, showing in the Visualization area, is kept to be combined with the newly piled fibrous structure.

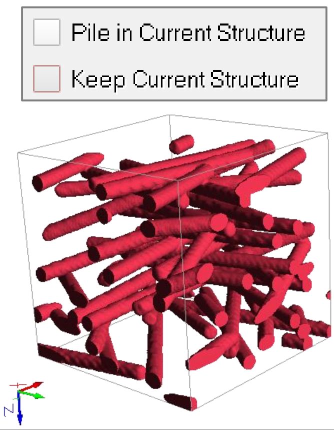


Observe the effect that checking, or leaving un-checked, the **Pile in Current Structure** and the **Keep Current Structure** boxes have on the generation of a fibrous structure.

A (grey) structure is already in memory and the red fibers fall from the Z+ direction. When the grey current structure is kept, the red fibers fall on this structure and cannot reach the bottom of the bounding box. When the grey current structure is not kept, the red fibers fall all the way.



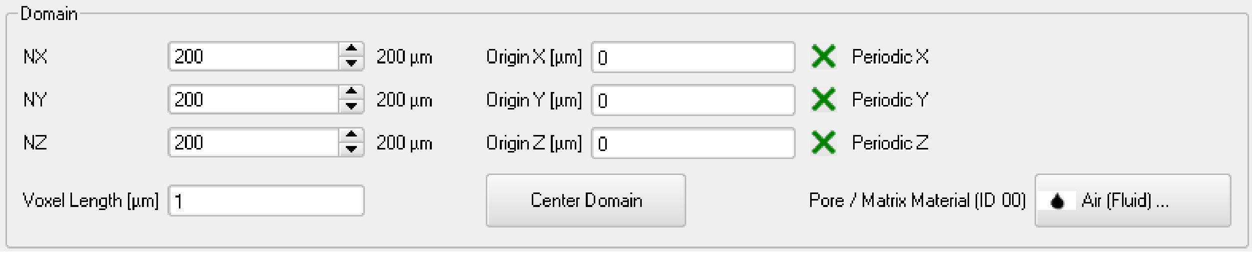




Notice that the size parameters, grouped under the **Domain** panel, cannot be modified when the **Pile in Current Structure** box is checked, because they are kept from the structure already in memory.

Domain Parameters

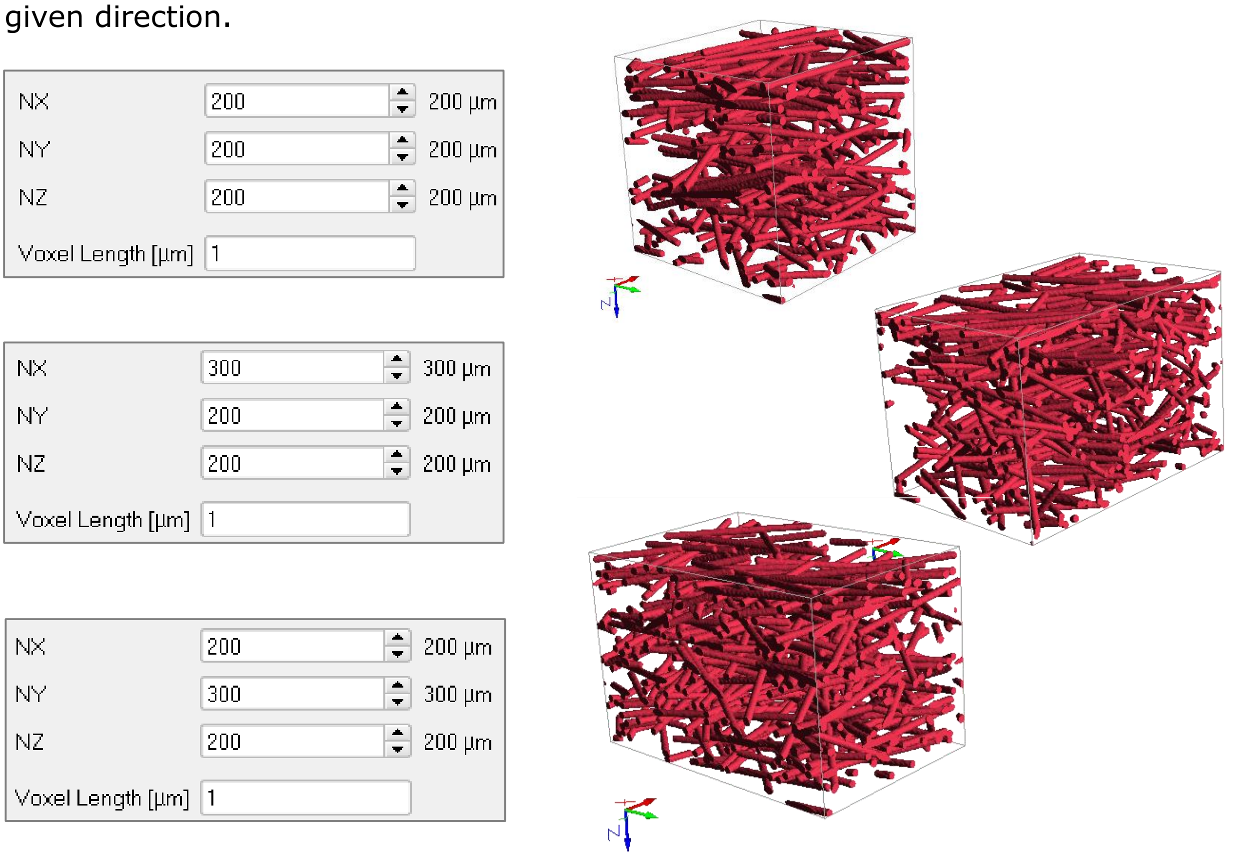
The **Domain** panel contains the parameters defining the structure size (**NX**, **NY,** and **NZ**) in combination with the resolution (**Voxel Length**), as well as the **Origin** parameters, the **Periodicity** check-boxes, the **Center Domain** button, and the **Matrix Material** pull-down menu. The periodicity boxes are disabled (and checked) for **Pile**, because the objects are always piled periodically.



NX, NY, NZ, and Voxel Length

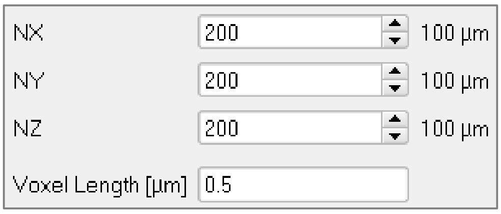
The internal representation of a structure in GeoDict consists of rectangular 3D arrays of equal sized boxes, hereafter called volume elements or **voxels**. **NX**, **NY,** and **NZ** are the number (N) of voxels in X, Y and Z directions.

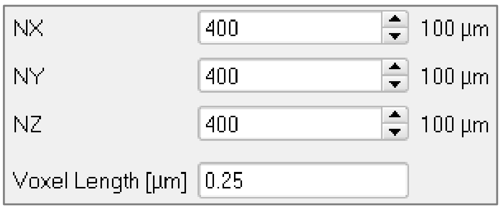
The **Voxel Length** is the size of one voxel in the chosen units. Varying the values for NX, NY, and NZ has the effect of changing the size of the piled structure in the given direction.

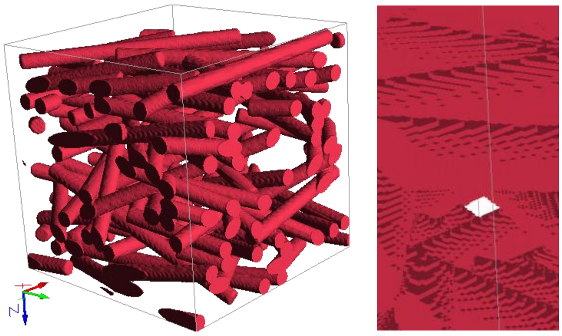


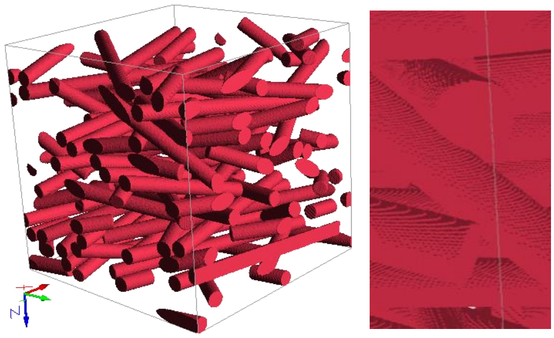
Low values for voxel length result in higher resolution, but also higher computational time. After setting the values of NX, NY, and NZ, and Voxel Length, the physical structure size is automatically displayed in the chosen units.

Observe how keeping the structure size a constant 100 x 100 x 100 μm^3 while decreasing the Voxel Length from 0.5 µm to 0.25 µm has the effect of refining the fibers in the pile by increasing the resolution. Since the voxel length has decreased to half, the size of the structure is kept by doubling the **NX**, **NY**, and **NZ** values from 200 to 400.









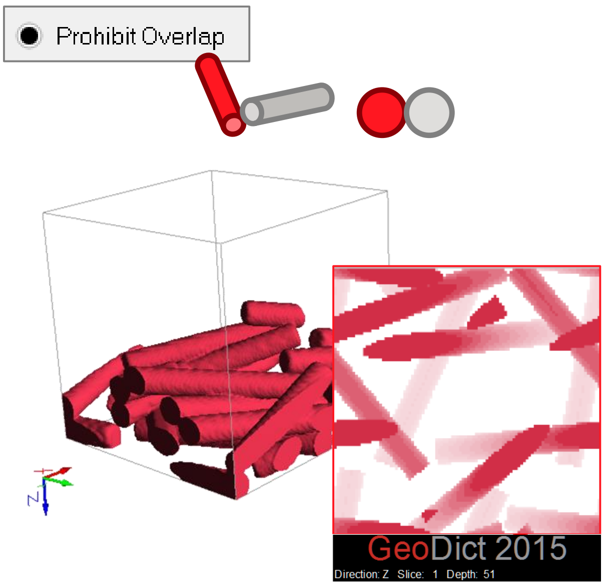
Origin x, Origin y, and Origin z, and Center Domain

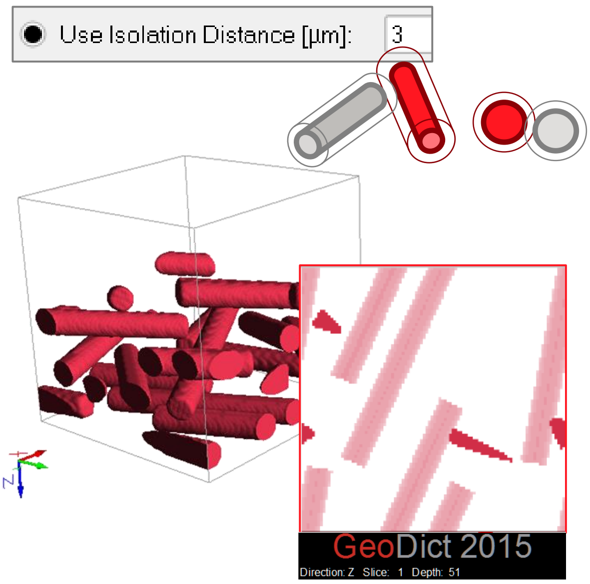
The **Origin X**, **Origin Y**, and **Origin Z** parameters, together with the **Center Domain** button, determine the placement of the piled structure in the physical space in the same way as seen above for FiberGeo – **Create** (pages 11-13).

Overlap Mode

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

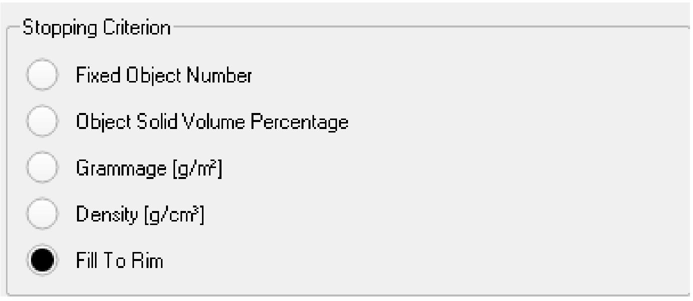
Fibers may touch (but not overlap) when **Prohibit Overlap** is selected. Fibers may not touch when **Use Isolation Distance** is selected, and a positive value is entered. Then, the gaps between fibers have at least this preset voxel distance. The choice of **Use Isolation Distance** may lead to delays in achieving a high resolution in big structures.





Stopping Criterion

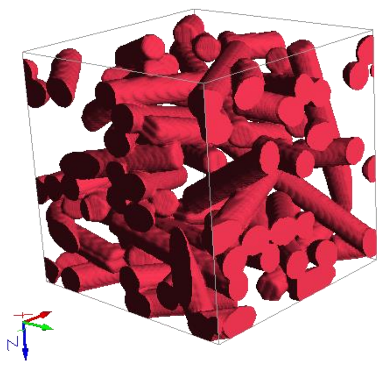
The parameters in the **Stopping Criterion** panel control whether the pile process should be continued or the material is "ready". The analysis of the results file (*.gdr file) shows any disparity between achieved result values and desired ones.



Besides the same options available for FiberGeo – **Create** (pages 17-20), it is also possible to choose **Fill to Rim**.

Fill to rim

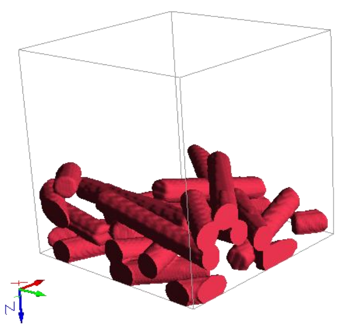
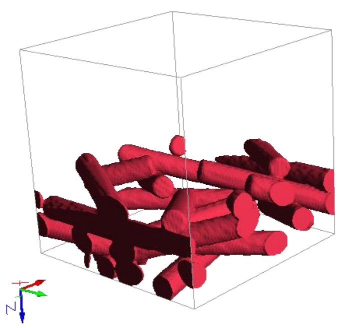
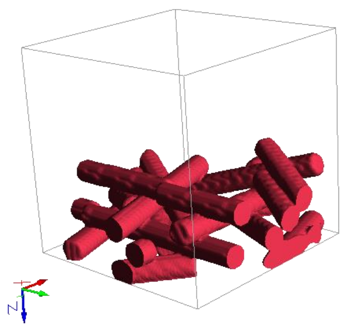
Fill to Rim forces the fibers to keep piling until they reach the top of the bounding box in the Z-direction.



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, which is shown in the Visualization area. **Random Seed** is a non-negative integer number.

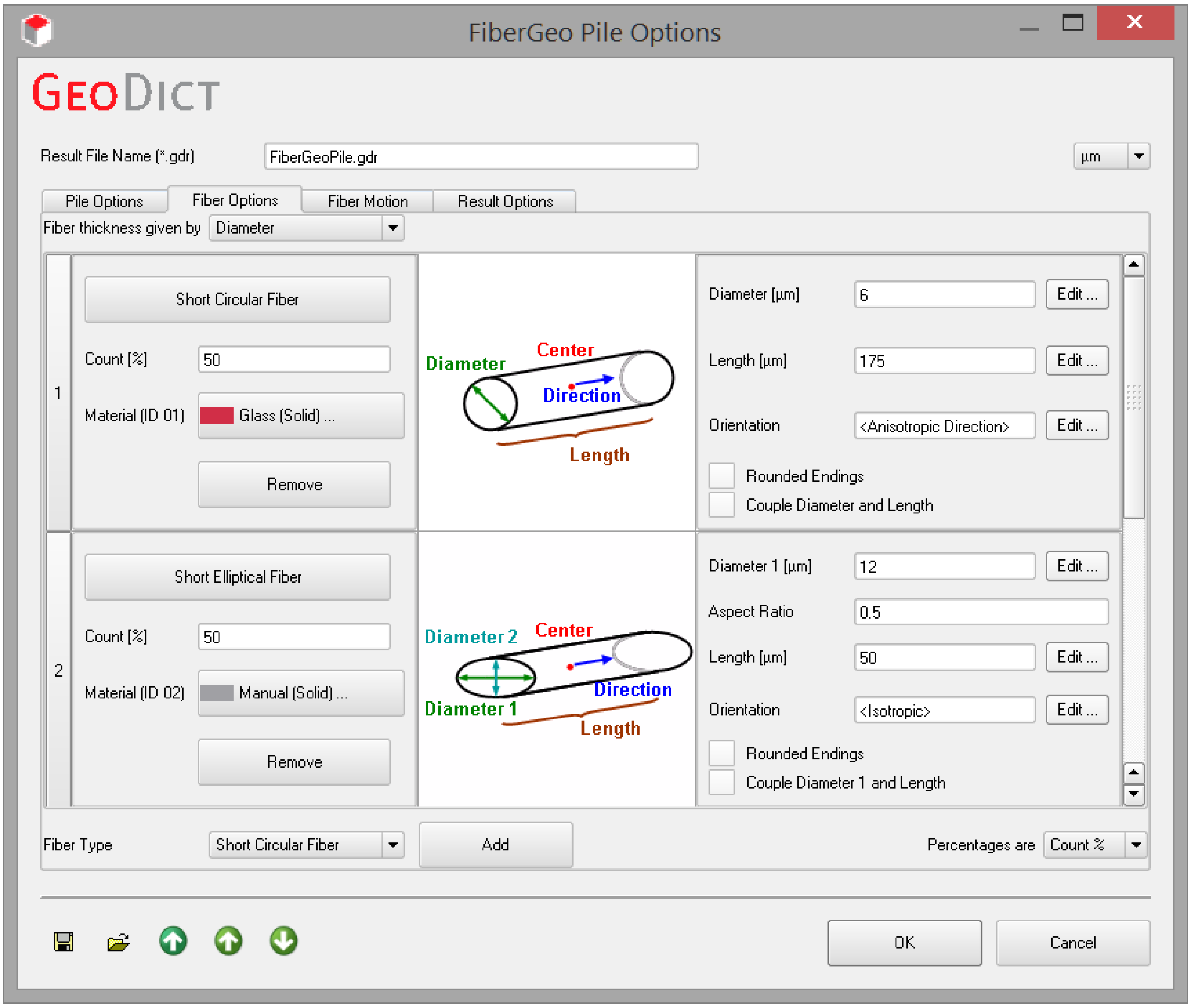
Varying the **Random Seed** allows generating different samples of the same piled fibrous structure. In the following examples, all parameters are unchanged while the Random Seed changes with every generation run (e.g. 6, 15, 22).

FIBER OPTIONS

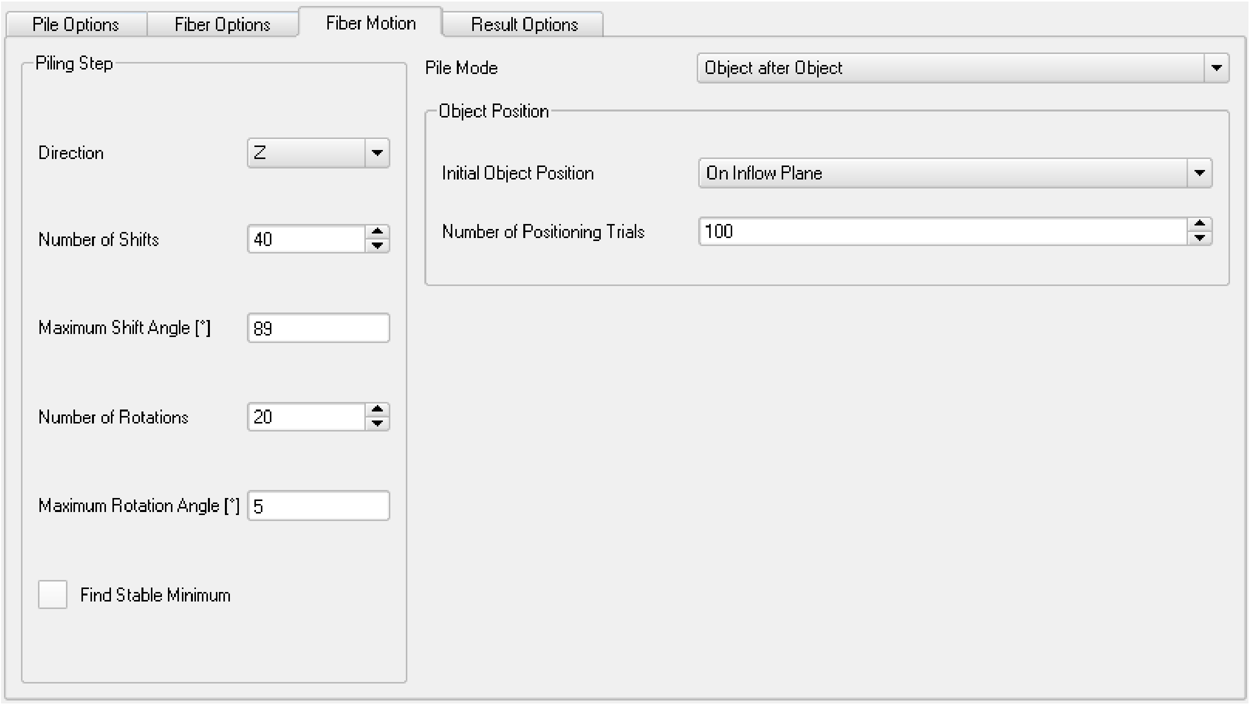
The objects available to pile fibrous structures (**Pile**) are organized and listed in panels in a way almost identical to the one for creating fibrous structures (**Create**). The object list is limited to Short fibers. See the detailed explanations above, starting on page 24.

The center position of the objects is a result of the piling process and cannot be specified.



Fiber Motion

The **Fiber Motion** parameters control the object's movement and initial position during the piling process, and are grouped into the **Piling Step**, and the **Object Position** panels. The **Pile Mode** can be selected from the pull-down menu.

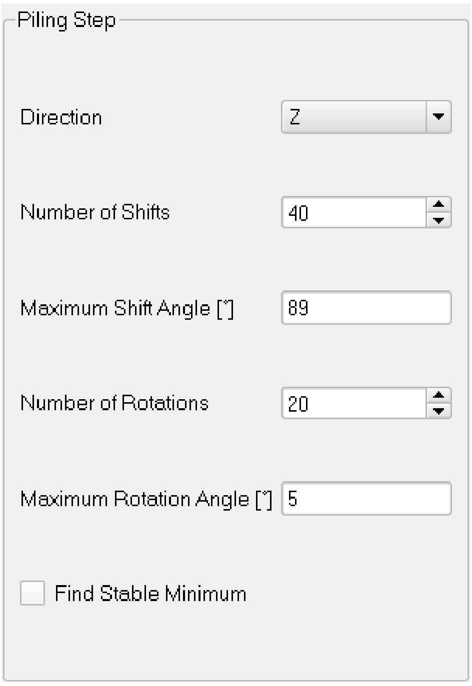


Piling Step

The object movements during the piling steps are mainly defined by the falling **Direction** and by the automatic finding of the stable minimum (**Find Stable Minimum**).

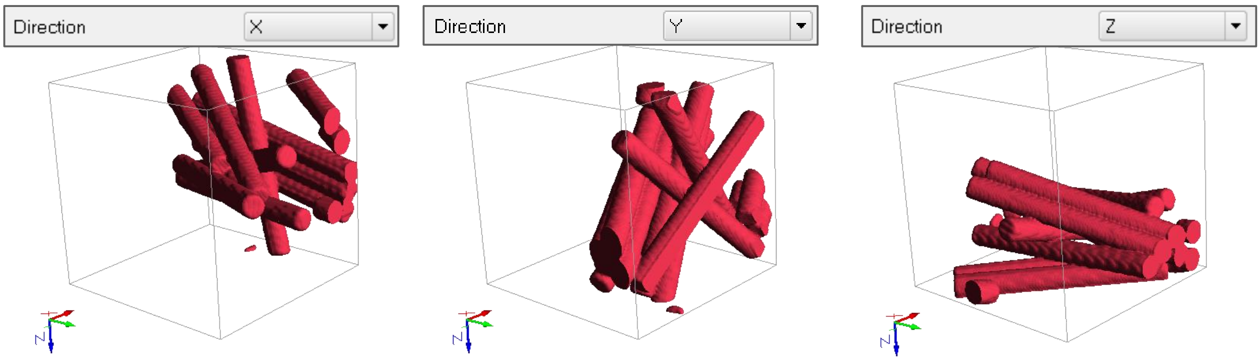
When the result is unsatisfactory, additional parameters can be used to refine it (**Number of Shifts**, **Maximum Shift Angle**, **Number of Rotations** per shift and **Maximum Rotation Angle**.

The option to find the stable minimum is not available when all objects fall at the same time (Pile Mode → All Objects at Once).



Direction

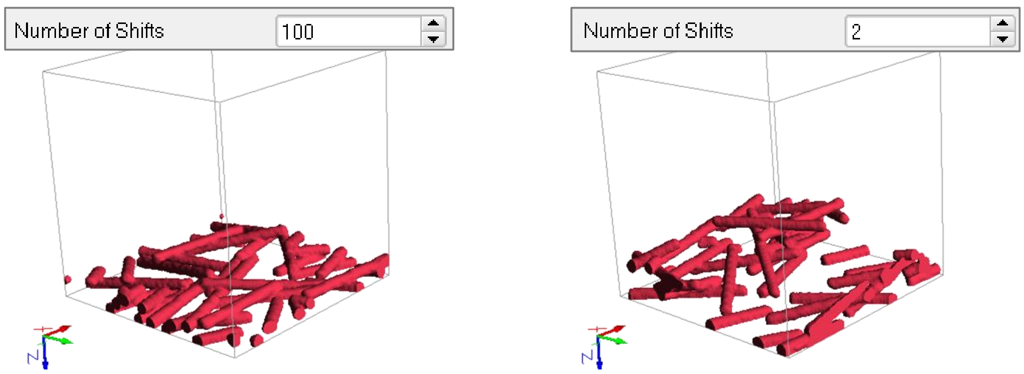
The direction in which the piling process happens can be chosen from the pull-down menu. For all three axes, the objects fall towards the positive direction (X+, Y+, or Z+). Observe the piling of fibers with **On Inflow Plane Center** as initial object position, falling from all three directions.



Number of Shifts, Maximum Shift Angle, Number of Rotations, Maximum Rotation Angle

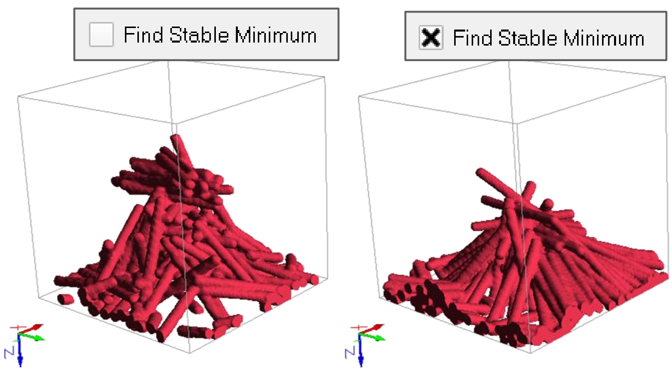
Throughout the piling process, the objects fall and roll to their final location in the fibrous structure. During the fall, the objects shift and rotate as many times as defined by the values for **Number of Shifts** and **Number of Rotations** before they come to rest at the bottom of the structure. Low values for shifts and rotations produce structures with fibers which settle earlier compared to larger values of these parameters, resulting in lower packing density. The **Maximum Shift Angle** and **Maximum Rotation Angle** restrict the angle that the objects can adopt during the fall respect to the lay-down plane.

Observe the effect of setting a low or a high **Number of Shifts** value on the final position of fibers in the same piled structure.



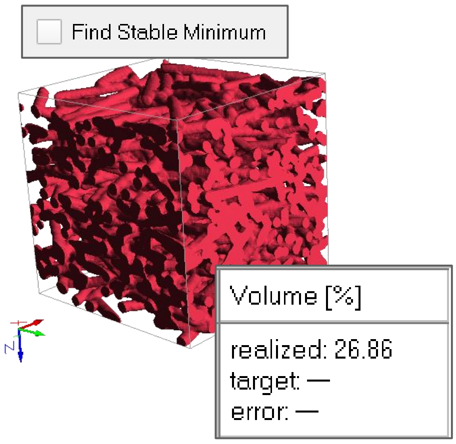
Find Stable Minimum

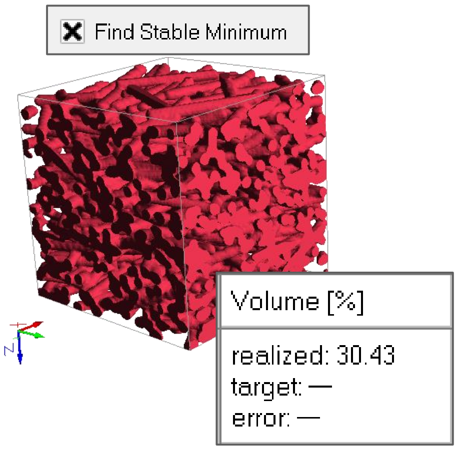
When checking **Find Stable Minimum**, each fiber is checked to have a stable state with respect to gravity at the end of the piling process. Observe the effect of checking or un-checking **Find Stable Minimum** in the piling of 100 fibers with initial object position **On Inflow Plane Center**.



While it is faster to pile structures with an un-checked **Find Stable Minimum** box, the resulting packing densities are lower.

Observe the realized **Volume [%]** value (shown in the result file under the Results Info tab) when **Find Stable Minimum** is checked or un-checked. The piled structures of fibers with initial object position **On Inflow Plane**, and **Fill To Rim** as stopping criterion, look fairly similar but the realized volume percentages are rather different.



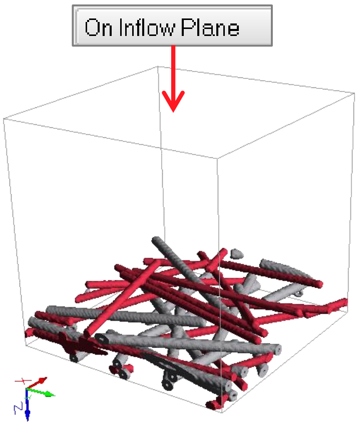


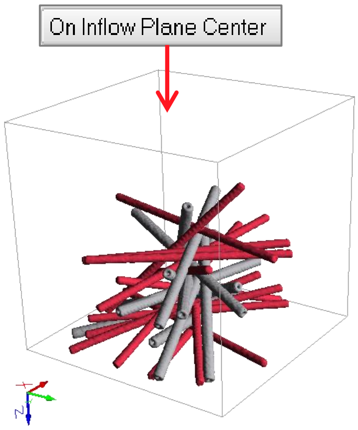
PILE MODE AND OBJECT POSITIONS

Select from the pull-down menu whether the objects should fall one after another (**Object after Object**) or all should fall at once (**All Objects at Once**).

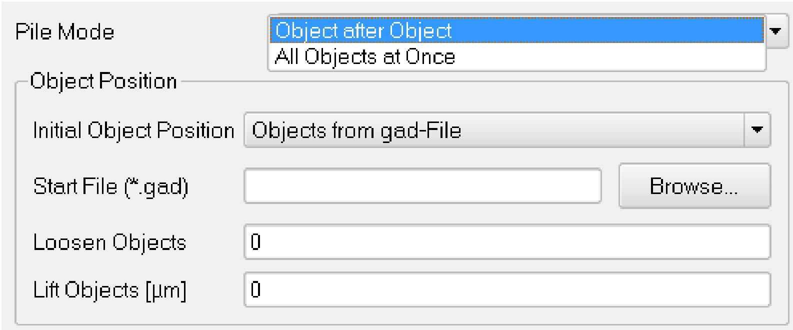
When choosing **Object after Object,** the pull-down menu allows setting the initial position from which the piling objects are set to fall: the whole initial position plane (**On Inflow Plane**), from its center (**On Inflow Plane Center**), or to originate from an existing structure (**Objects from gad File**).

When piling objects **On Inflow Plane** or **On Inflow Plane Center**, and to increase the quality of the piled structure, the **Number of Positioning Trials** can be adjusted at the cost of additional runtime.





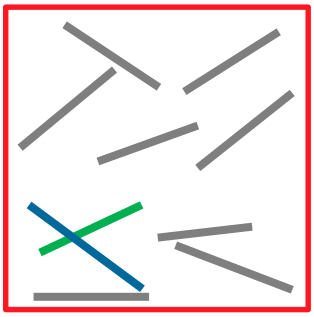
When piling from an existing .gad structure, the objects are those already in the structure and no objects (and their geometry parameters) need to be selected through the **Object Options** tab. Clicking **Browse**, a structure saved in .gad format can be selected as the origin of the objects.



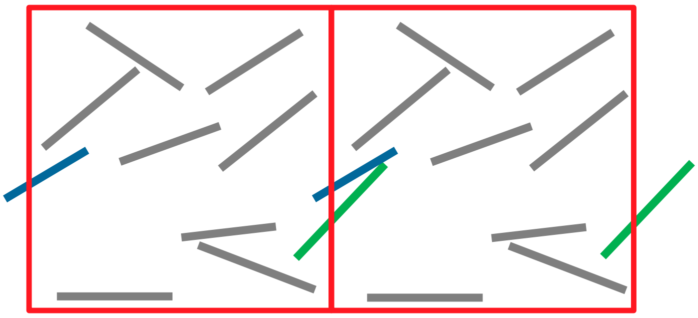
When choosing **All Objects at Once**, the objects can only originate from the analytic data of an existing structure.

Structures in .gad format to be used for piling must conform to certain requirements (no overlapping, periodicity, no objects crossing bottom plate) and should be generated for later piling with these requirements in mind. Overlap can be removed after generation using GadGeo → Remove Object Overlap.

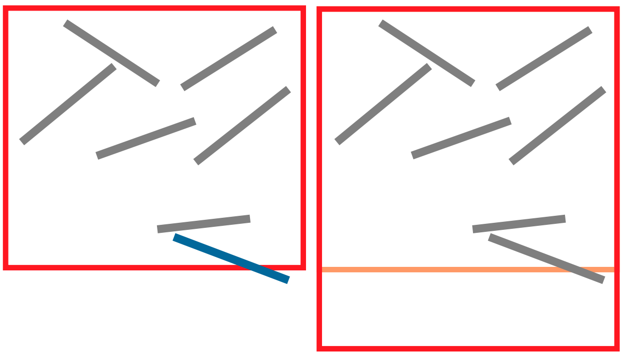
Assuming the Z-direction to be the piling direction, and downwards to be the positive direction (Z+), the following situations must be excluded:



Touching, but not overlapping, is allowed for piling. The initial structure must be generated without overlapping. For example, by selecting **Remove Overlap** when generating with FiberGeo → **Create** (or other GeoDict generators).

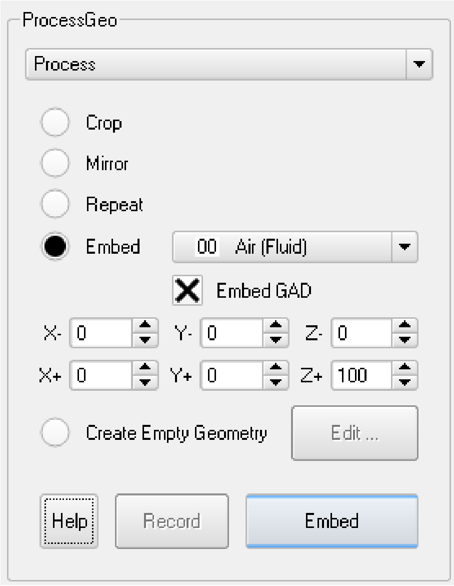


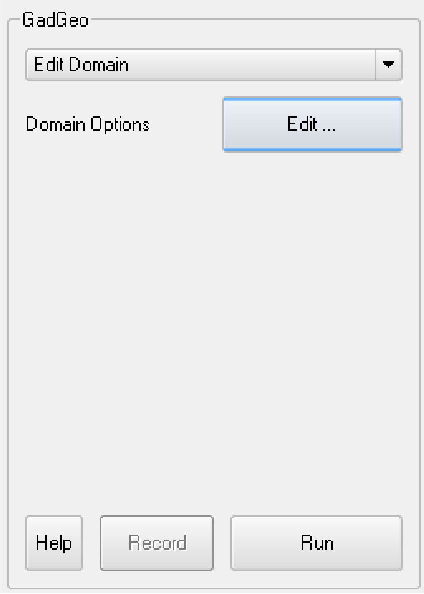
Periodicity is needed in the X and Y directions for piling, to avoid undesired intersections at the edge of the structure. The initial *.gad file must be generated to be periodic (in all directions).



No objects are allowed to drop off the bottom of the structure. When this happens, the dimensions of the initial *gad file must be processed to include the extruding object.

This can be done by adding enough empty voxels in Z+ direction by **ProcessGeo** → **Embed** (check to keep the GAD format) or by increasing the size of the domain in Z-direction **GadGeo** → **Edit Domain**.

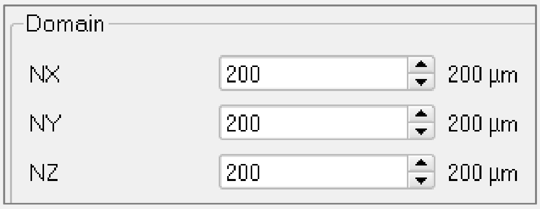


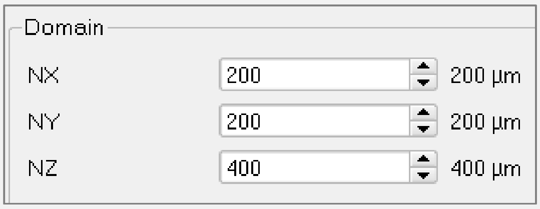


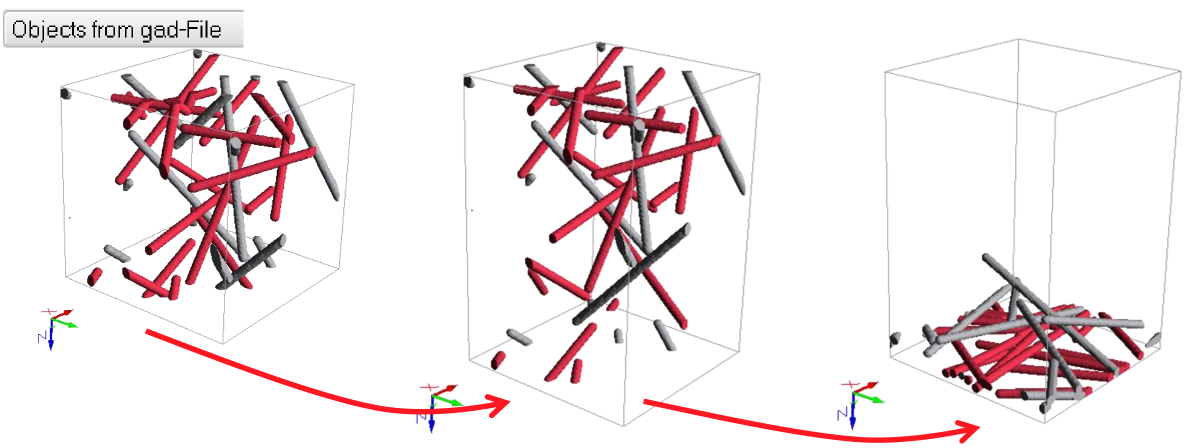
The number of voxels to add or the increase in domain size must take into account that the structure model has been created periodic and fibers extend in Z-direction beyond the initial domain.

Before piling, the domain size in the Z-direction under the **Pile Options** tab – **Domain** panel must be increased to adjust to the larger one of the modified *.gad file.

For example:





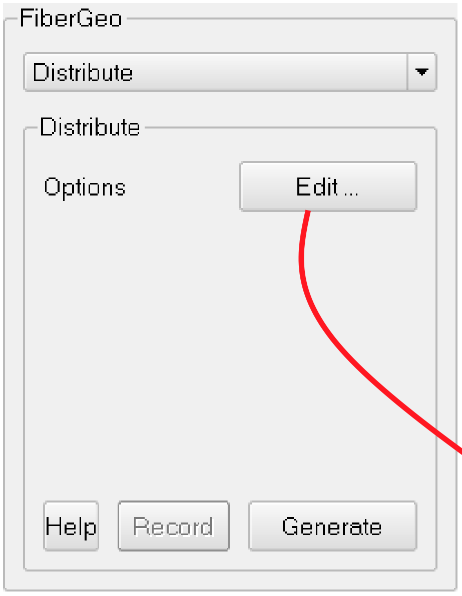


Before the piling process starts from a structure in .gad-format, the fibers in it can be shifted in their position or length in the piling direction by the factor entered in **Loosen Objects**. Additionally, they can be lifted by the value entered in **Lift Objects**. These parameters can be used to simulate sieving processes with additional shaking.

Result Options

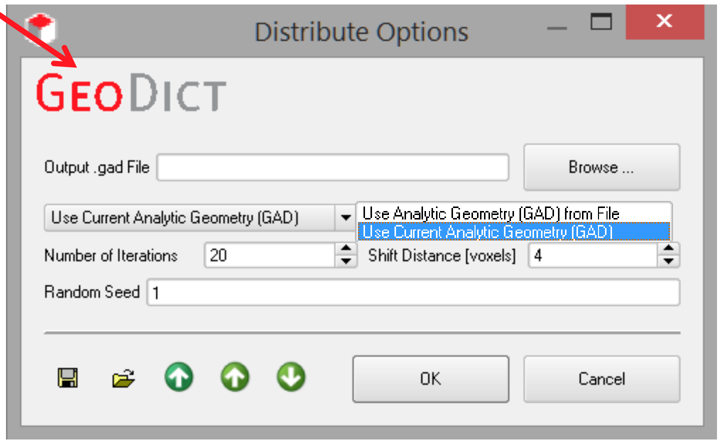
The pile **Result Options** on managing the saving of result and geometry files are completely analogous to the create Result Options explained above (pages 61-62).

DISTRIBUTE



When **Distribute** is selected from the pull-down menu in the **FiberGeo** section, the fibers are uniformly spread throughout the structure. Only structures that contain analytic information (.gad format) can be used for the distribution of fibers. To use this feature the domain must be periodic and the objects are not allowed to overlap. **Distribute** allows to create a homogeneous structure even for structures created with **Pile** where one has boundary effects in the lay-down direction.

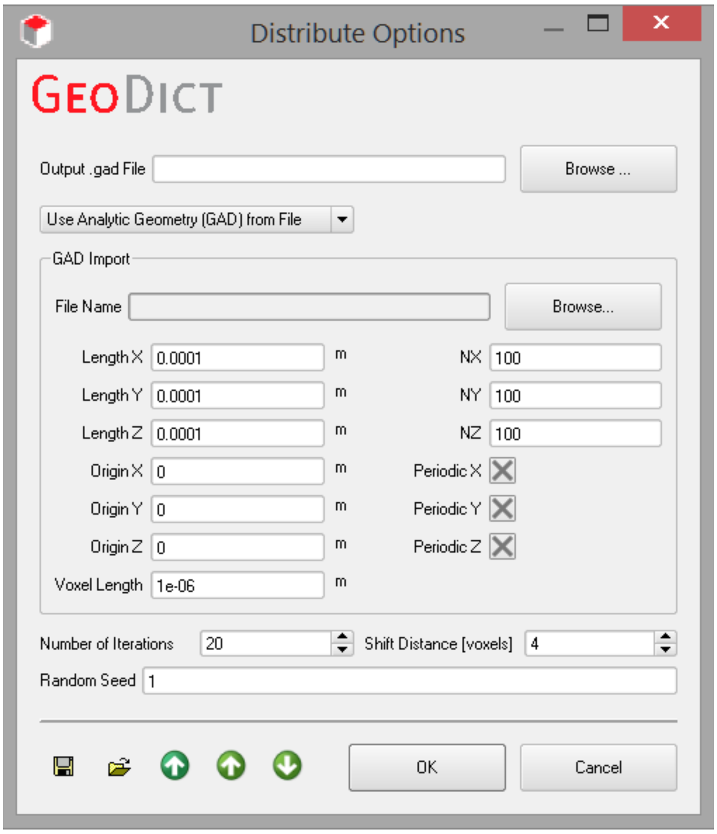
Clicking the **Options' Edit...** button opens the **Distribute Options** dialog box.



When the desired parameters have been entered in the **Distribute Options** dialog box, clicking **OK** closes the dialog box and returns to the **FiberGeo** section.

Clicking **Generate** starts the distribution process.

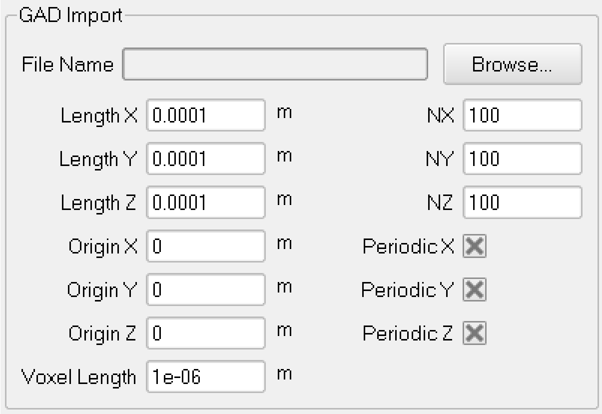
The result of the distribution process is saved in a *.gad file in the project folder (**File** → **Choose Project Folder** in the Menu bar) when a name is entered in the **Output .gad File** field. The distribution result is not saved, when the field is left empty.



When a fibrous structure in *.gad format is already in memory (and displayed in the Visualization area), the pull-down menu in the **Distribute Options** dialog box offers the choice to **Use Current Analytic Geometry (GAD)** or to load a new structure and **Use Analytic Geometry (GAD) from File**.

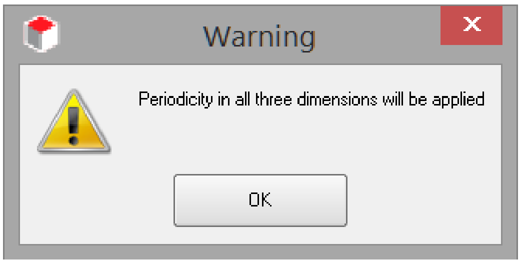
Without a .gad format structure in memory and showing in the Visualization area, the pull-down menu in the **Distribute Options** dialog box is not selectable.

Clicking **Browse** allows searching for a file in *.gad format to import. When a *.gad file is imported, its size parameter values fill the boxes and can then be edited.



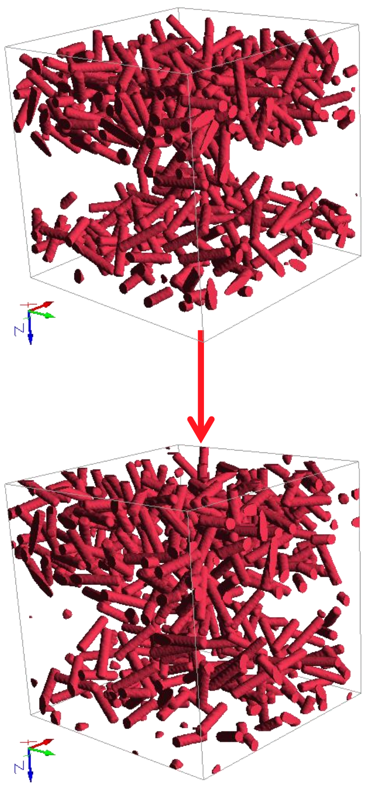
When editing the **Length X**, **Length Y**, and **Length Z** of the structure, the **NX**, **NY**, and **NZ** values are adjusted automatically and vice versa.

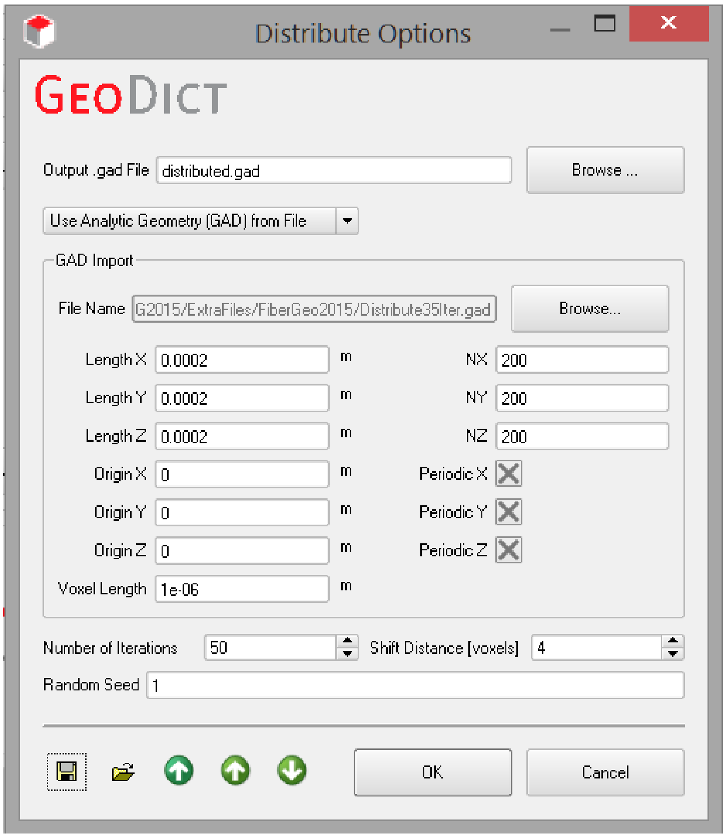
When the imported structure is not periodic, a warning message appears when clicking **Generate** indicating that, unless a periodic structure's *.gad file is provided, the loaded structure will be treated as periodic.



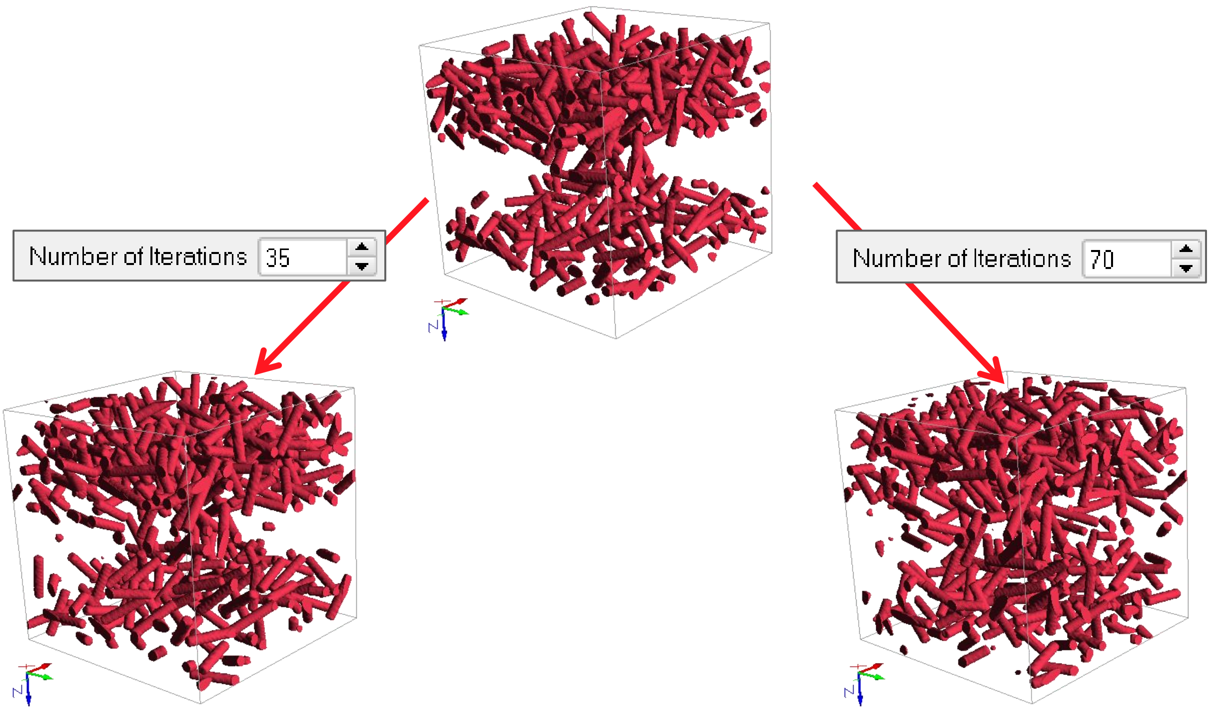
At the bottom of the **Distribute Options** dialog box, **Number of Iterations**, **Shift Distance**, and **Random Seed** specify the distribution process.

Observe the process of distributing the short circular fibers in a 200 x 200 x 200 structure, periodic in all directions, generated with FiberGeo **Create** with a Voxel Length of 1 µm, and imported as *.gad file. The fiber centers follow a density distribution, which results in a layered structure. The following values are used for the distribution process: **Number of Iterations** are 50, **Shift Distance** is 4 voxels, **Random Seed** is 1.

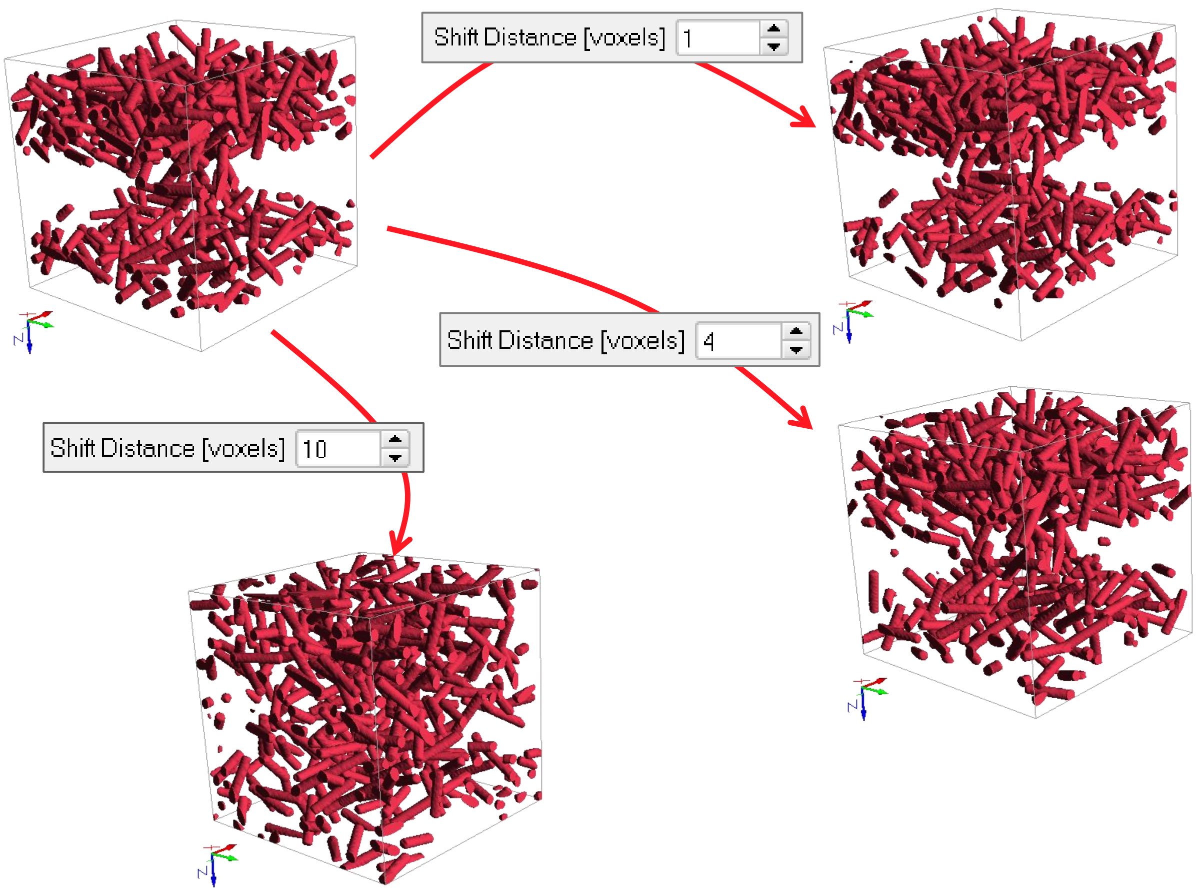




The **Number of Iterations** determines how many distribution steps are done, so that the more iterations the more uniform the final distribution is.

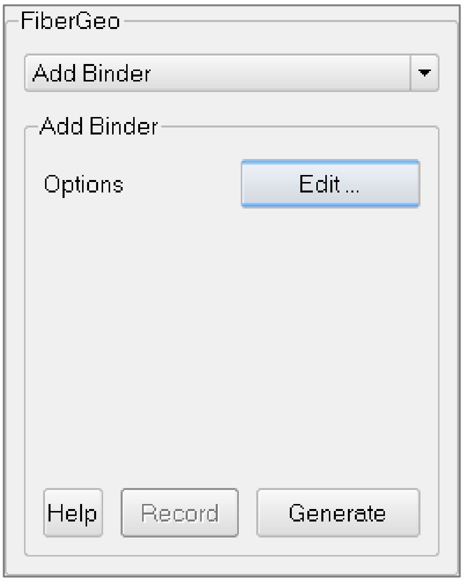


The **Shift Distance** determines the maximal object movement during a single iteration. Large shift distances lead to more computational time per iteration. Observe the effect of increasing the shift distance from 1, to 4 and then to 10, while the number of iterations is kept at 35.



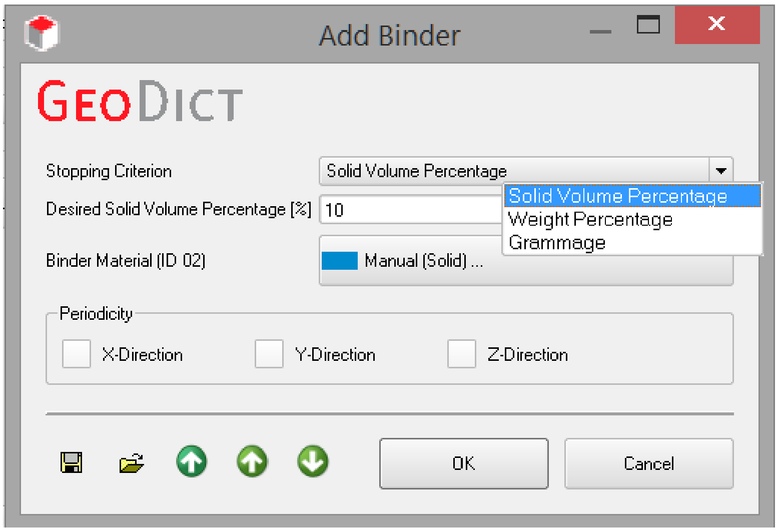
ADD BINDER

To generate realistic models of nonwoven fibrous structures (for example for the technical textile industry), the correct addition of binder is essential. It reproduces the bonding of fibers with binder often done to provide structural integrity to the fibrous structure.



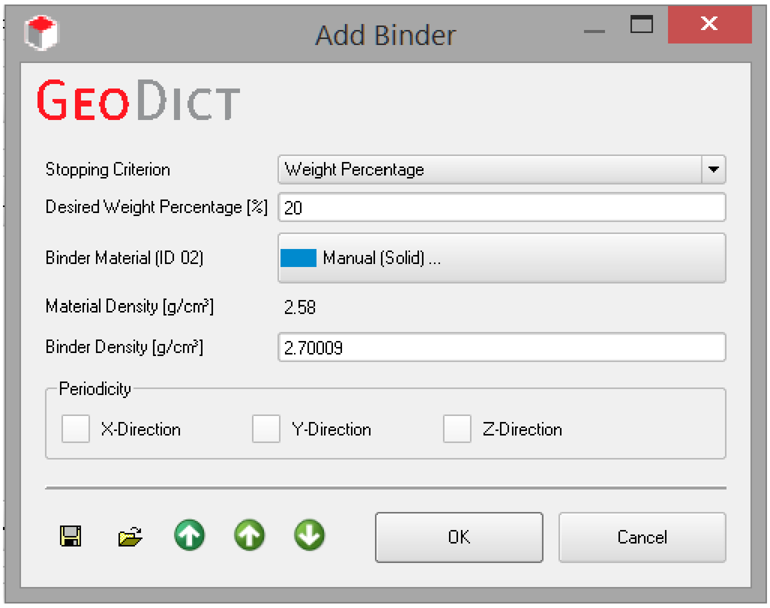
Add Binder to a structure consists of adding material in the shape of a concave meniscus in locations where surfaces in that structure's material get close together.

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



A **Stopping Criterion** to interrupt the addition of binder when it is reached can be entered here. The possible stopping criterions are:

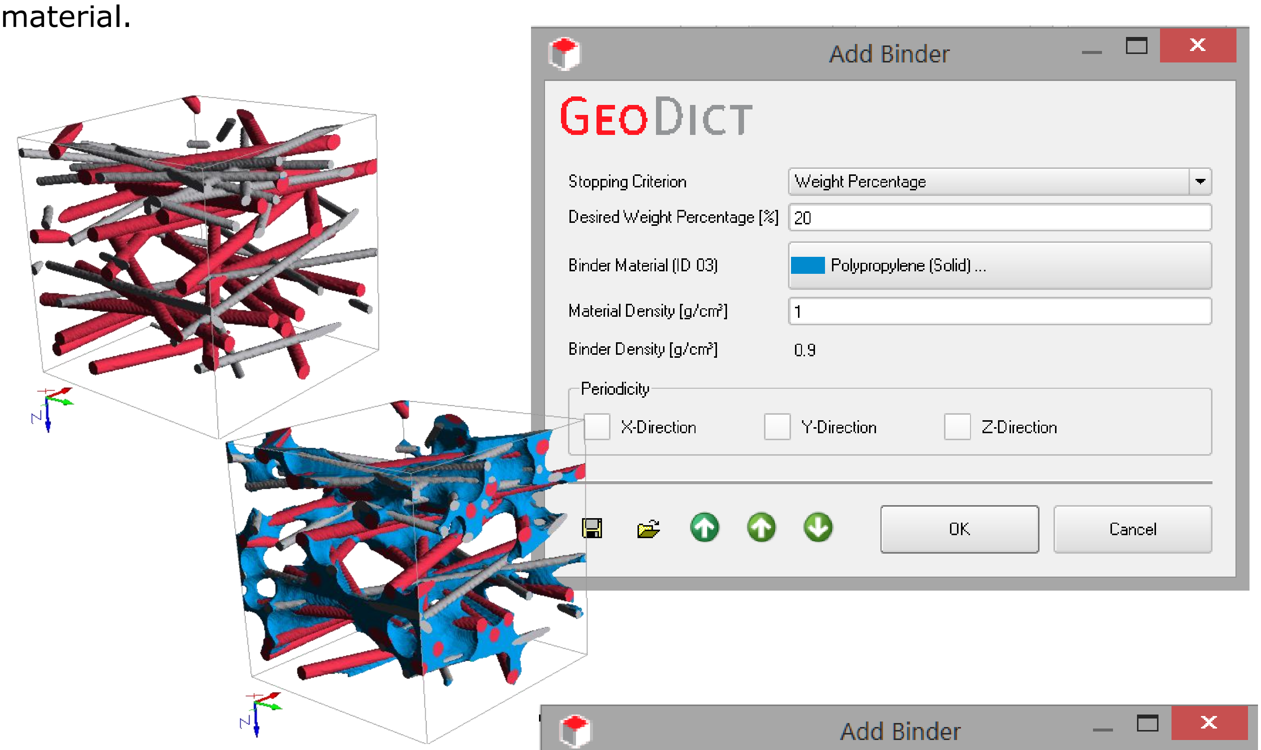
- **Weight Percentage**: The weight of binder reaches a certain percentage of the weight of material. This is the usual setting because the practical parameter when adding binder is normally weight and not volume.



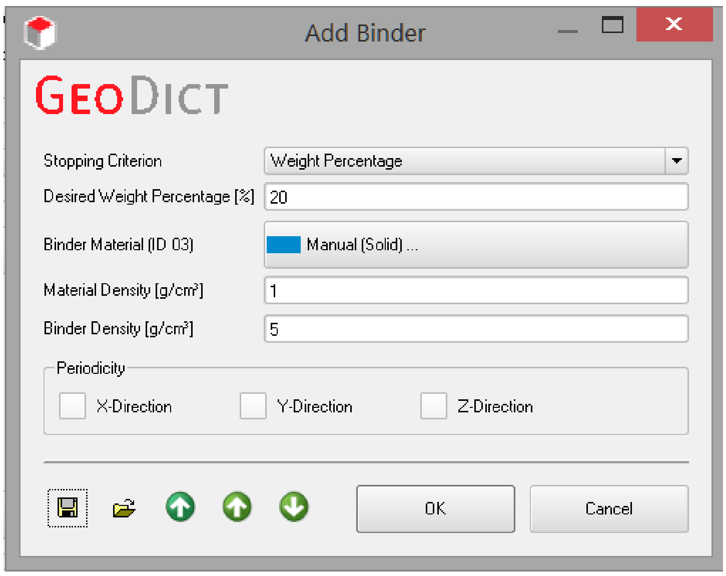
It is necessary to set the weight-to-volume relationship for the structure's material (**Material Density**) and for the binder material (**Binder Density**) both in g/cm^3, as well as the desired (weight) percentage of binder material to structure material (**Desired weight percentage**, in %).

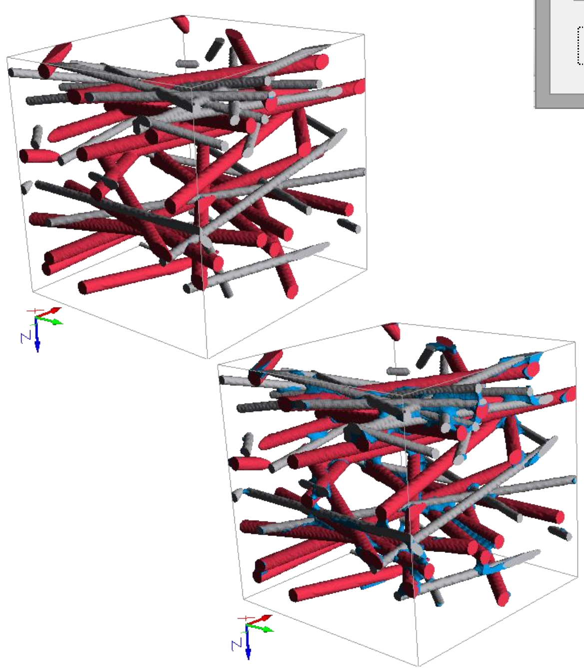
That is, a **Desired weight percentage** of 20 means that there are 20 g of binder added per 100 g of fibers.

When the material is dense (i.e. 5 g/cm^3) and the binder to add is light (i.e. Polypropylene, 0.9 g/cm^3), setting a **Desired weight percentage** of 20% (20 g binder/100 g fibers/objects), has the effect of depositing a great amount of binder material.



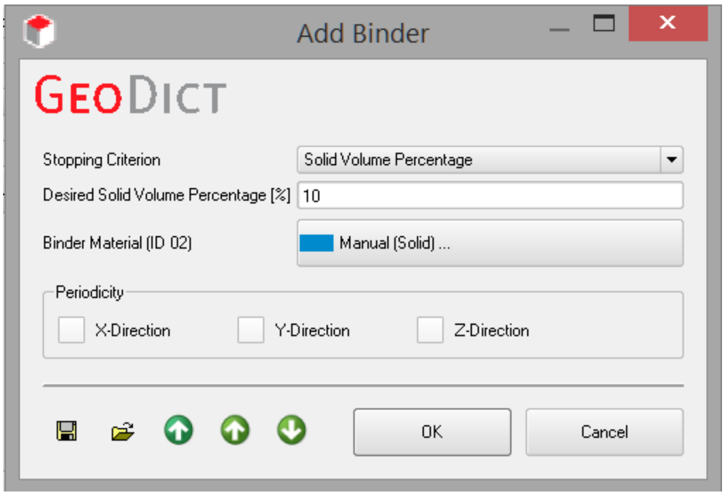
When the fibers are of a dense material (i.e. 5 g/cm^3), but the binder is denser than before (i.e. 5 g/cm^3), keeping the **Desired weight percentage** at 20% has the effect of depositing less amount of binder material on the fiber meniscuses.



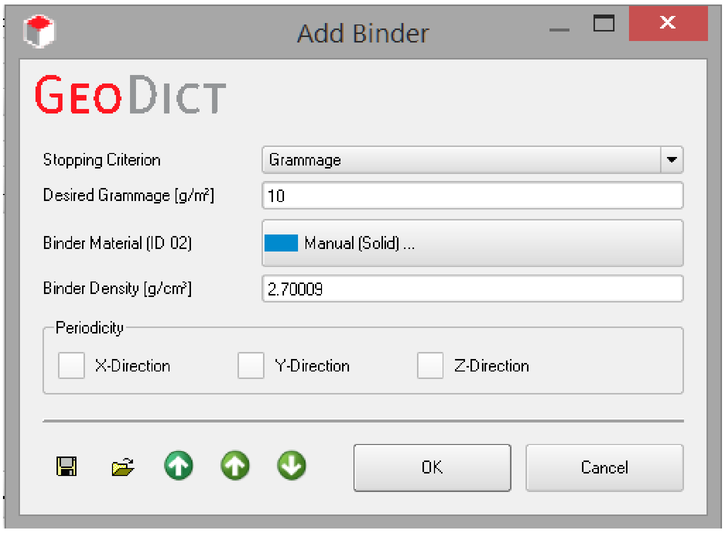


The **Binder Density** is automatically taken from the GeoDict Material Database when a pre-defined material is selected as **Binder Material**. If **Undefined** or **Manual** is selected, the **Binder Density** can be entered.

- **Solid Volume Percentage**: The process is stopped if the binder volume reaches the Desired Solid Volume Percentage.



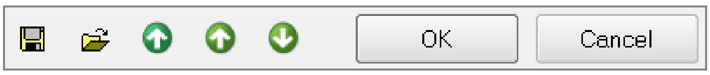
- **Grammage**: the addition of binder stops when the **Desired Grammage** (material and binder, g/m^2) is reached. In this case, define also the **Binder Density** (in g/cm^3).



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. The binder is added symmetrically when none of the **Periodicity** boxes is checked.

Adding binder periodically in certain direction(s) only makes sense if the 3D-structure model is periodic in that/those direction(s).

The parameters entered in the **Add Binder** dialog box can be saved into *.gps (GeoDict Project Settings) files and/or loaded from them. Remember to restore and reset your (or GeoDict's) default values through the icons at the bottom of the dialog box when needed and/or before every FiberGeo–**Add Binder** run. Resting the mouse pointer over an icon prompts a ScreenTip showing the icon's function to appear.



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