FoamGeo

User Guide

GeoDict release 2022

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GeoDict

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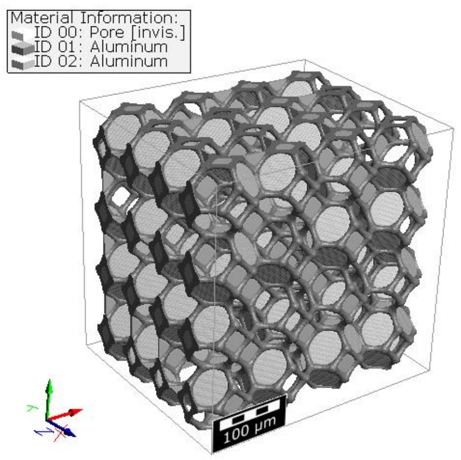
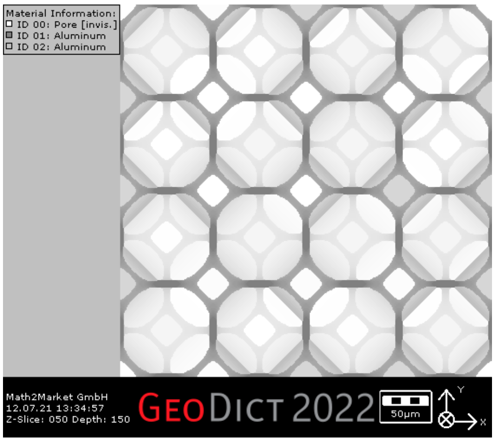
MODELING REGULAR KELVIN STRUCTURES AND RANDOM FOAMS WITH FOAMGEO

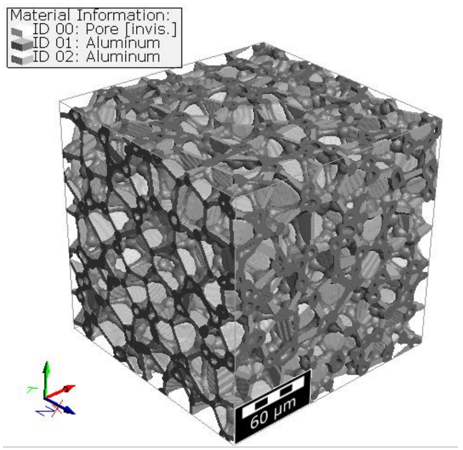
FoamGeo is GeoDict's module to model foams. Two types of foams can be generated:

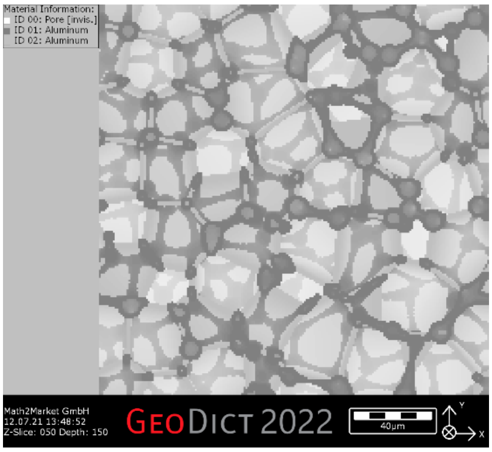
- **Kelvin structures**: a regular foam based on the bitruncated cubic honeycomb (or tessellation) by which space is partitioned into cells of equal volume. Kelvin structures are made up of 4 truncated octahedra around each vertex. Being composed entirely of truncated octahedra, it is cell-transitive. It is also edge-transitive, with 2 hexagons and one square on each edge, and vertex-transitive. It is one of 28 uniform honeycombs.





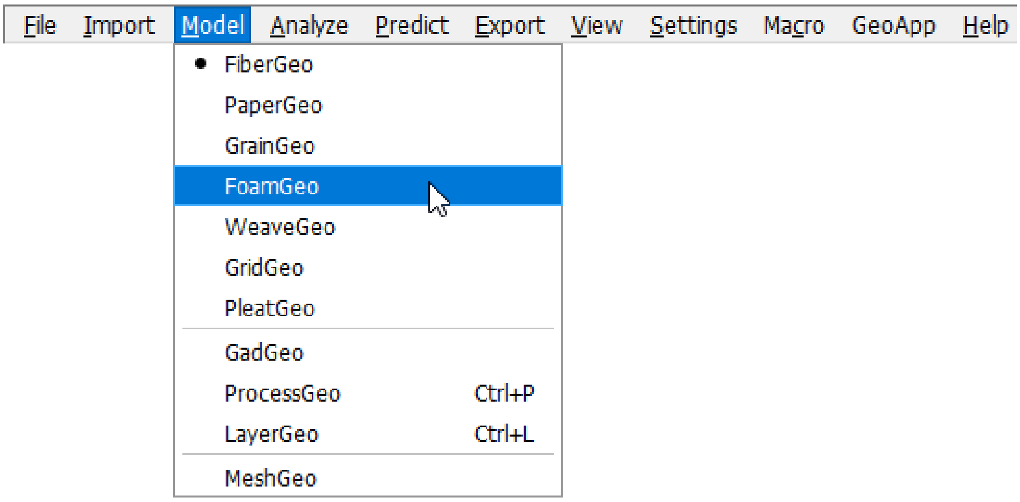
- **Random Foams** are based on the Voronoi tessellation (also called Voronoi decomposition, Voronoi partition or Dirichlet tessellation). It is a way of dividing space into a number of regions. A set of points (called seeds, sites, or generators) is specified beforehand and for each seed there will be a corresponding region consisting of all points closer to that seed than to any other. The regions are called Voronoi cells.

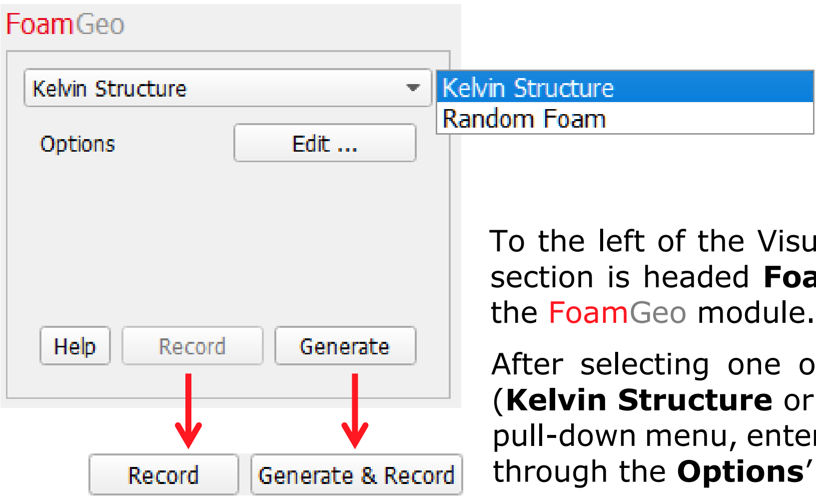




FoamGeo Module Section

FoamGeo starts after selecting **Model → FoamGeo** in the Menu bar. It can be used to generate Kelvin structures and random open-cell and closed-cell foams.





To the left of the Visualization area, the module section is headed **FoamGeo** when working with the FoamGeo module.

After selecting one of the two types of foams (**Kelvin Structure** or **Random Foam**) from the pull-down menu, enter the necessary parameters through the **Options**' **Edit ...** button.

Depending on the chosen type of foam, a different **Foam Options** dialog opens when clicking the **Options**' **Edit...** button.

For the Kelvin Structure, the dialog contains the **Unit Cell** tab, the **Foam Options** tab and the **Output** tab.

For the Random Foam, the dialog box contains the tabs **Basic Geometry**, **Foam Options** and **Output**. The parameters under the **Foam Options** tab are the same for both types of foams.

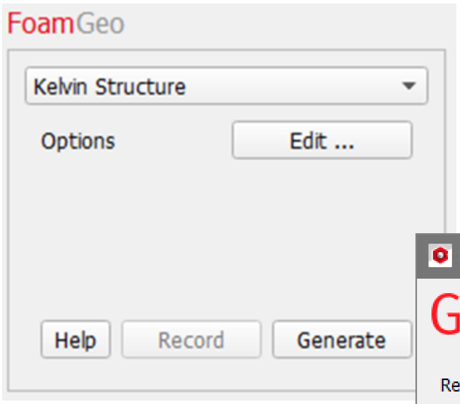
Clicking **Generate** at the bottom of the **FoamGeo** section starts the program's generation run.

When recording a macro, the **Record** button becomes active and the **Generate** button changes to **Generate & Record**.

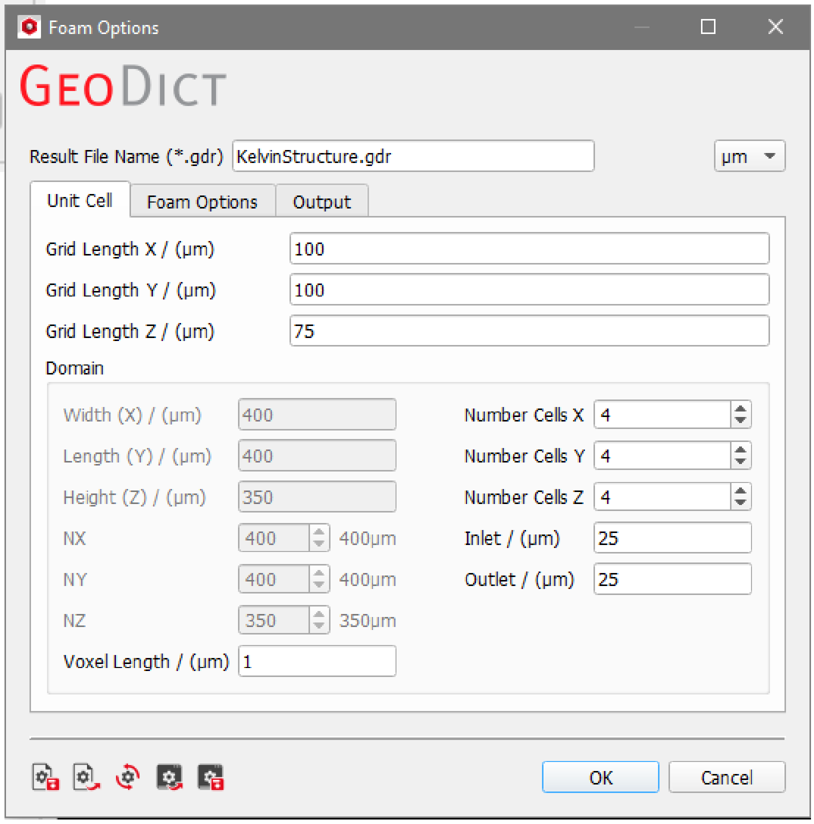
Kelvin Structure

The **Foam Options** dialog box for the generation of Kelvin structures opens by clicking the **Edit…** button. The available units (m, mm, µm and nm) are selectable from the pull-down menu on the right.

The **Foam Options** dialog box contains the **Unit Cell** tab, the **Foam Options** tab, and the **Output** tab.



A customized **Result File Name (*.gdr)** should be entered to differentiate the results of different FoamGeo runs. The *.gdr result file ensuing from the generation is automatically placed inside the chosen project folder.

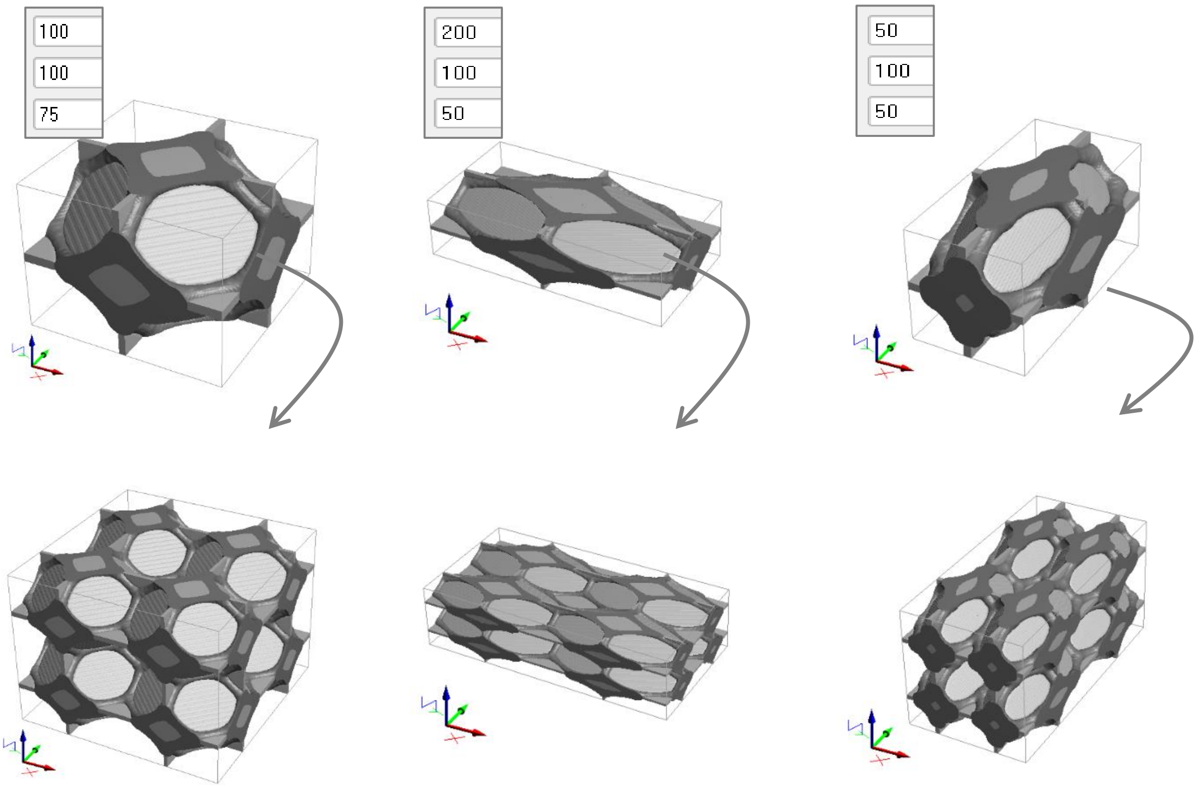


Unit Cell

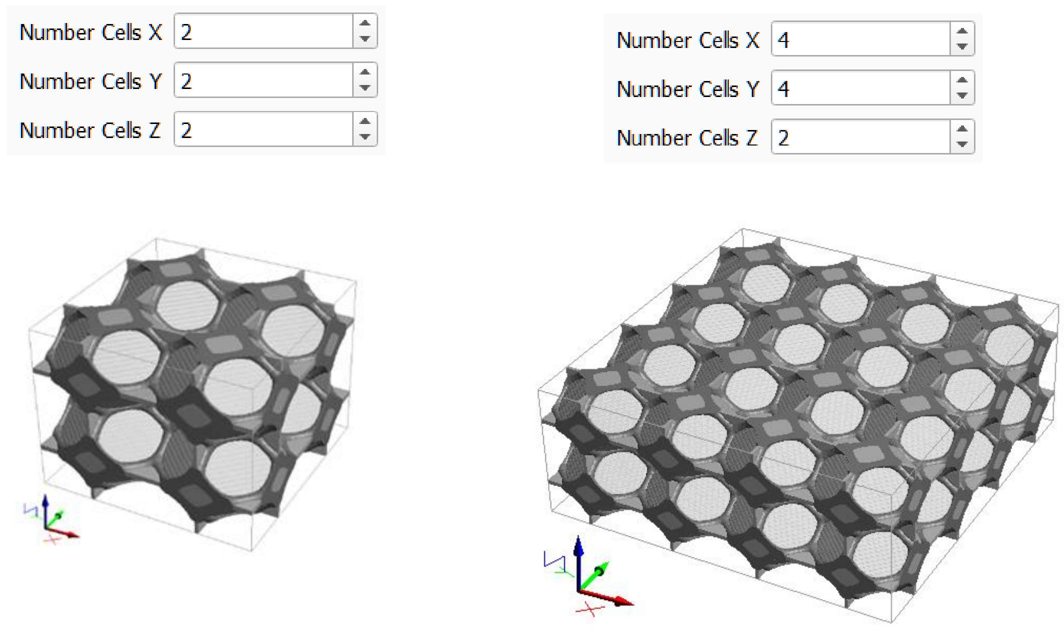
Grid Length X, **Grid Length Y**, and **Grid Length Z** define the size of one unit cell of the generated Kelvin structure inside the domain. The default values define a Kelvin structure of 100 x 100 x 75 µm, but these values can be changed.

For the final Kelvin structure, the grid lengths are combined with the number of cells that should be generated in the three directions in the **Domain** panel (**Number Cells X**, **Number Cells Y**, and **Number Cells Z**).

By setting the value of **Number Cells X**, **Number Cells Y**, and **Number Cells Z**, the generated period cell is repeated as many times. Here, the first row is generated with a Number Cells X, Y, and Z values of 1. The second row is generated with the values set all to 2.

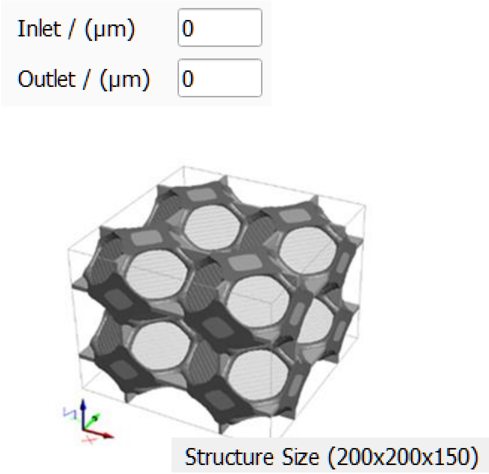


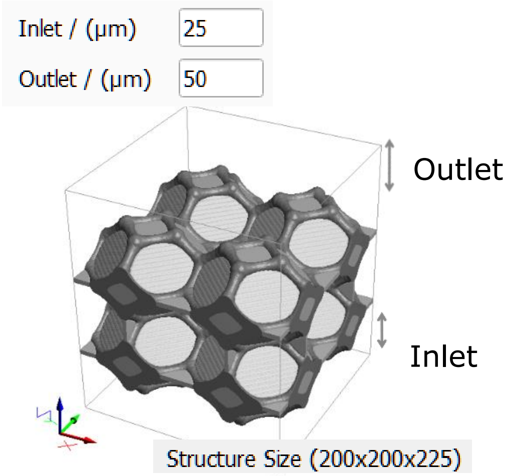
The Kelvin structure on the left of the next figure was generated using a value of 2 for **Number Cells X**, **Number Cells Y** and **Number Cells Z**, while for the structure on the right the **Number Cells X** and **Number Cells Y** were set to 4. **Number Cells Z** remained unchanged (2).



Additionally, an **Inlet** and **Outlet** for the structure can be specified, when needed. The full size of the foam in Z-direction is the result of combining the **Grid Length Z** for all cells and the size of the **Inlet** (below) and **Outlet** (above) void regions.

The following foams were generated without **Inlet** and **Outlet** or with the indicated values.





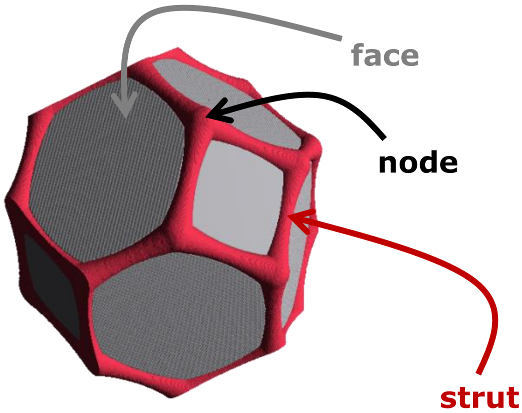
Foam Options

The shape of the foam cell strut can be selected in the **Strut Shape** pull-down menu.

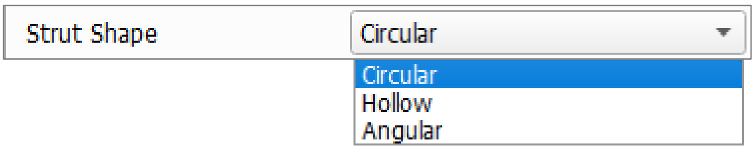
A **strut** is the edge of a foam cell.

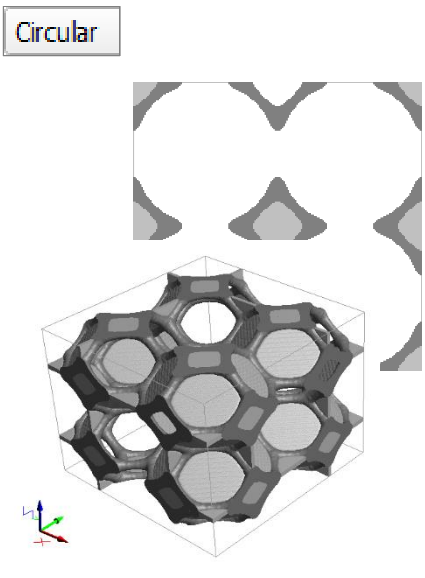
A **node** is where the struts meet.

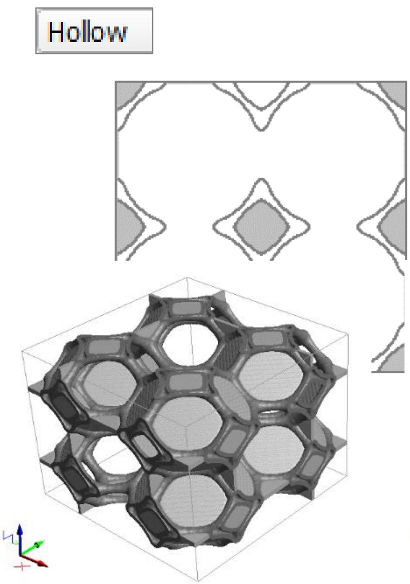
A **face** is the surface surrounded by struts and nodes. When the structure is an open-cell foam (not a closed-cell foam), no faces are generated.

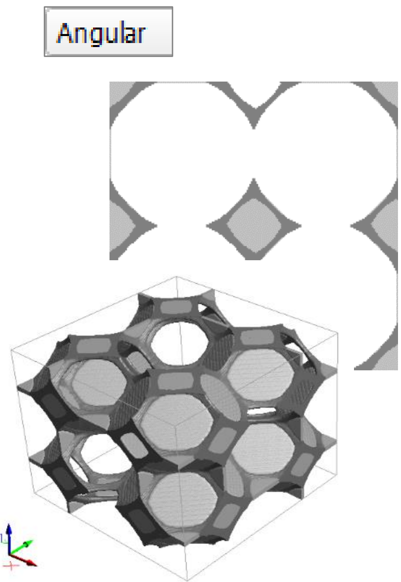


The strut shape can be **Circular**, **Hollow** or **Angular**.

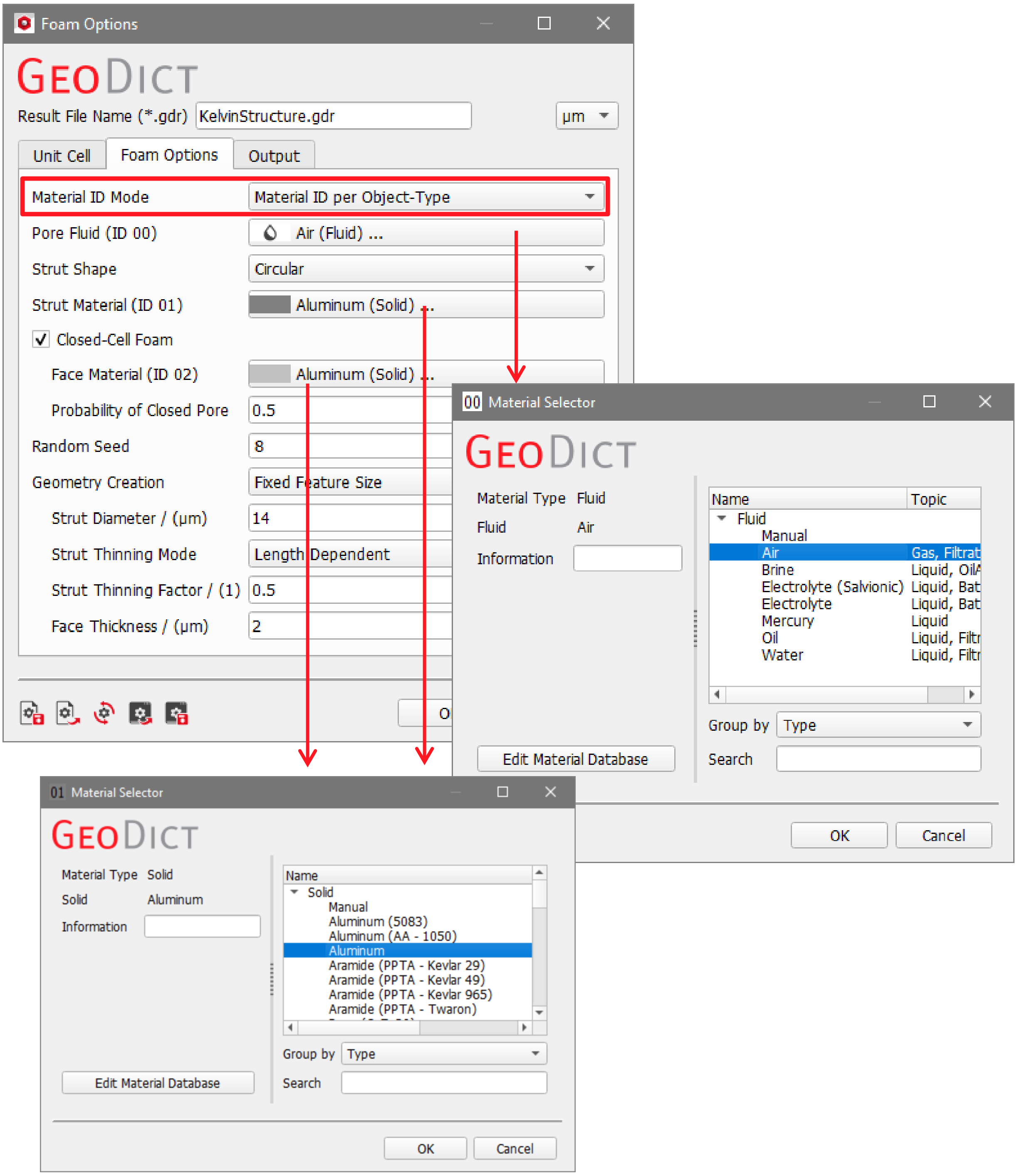




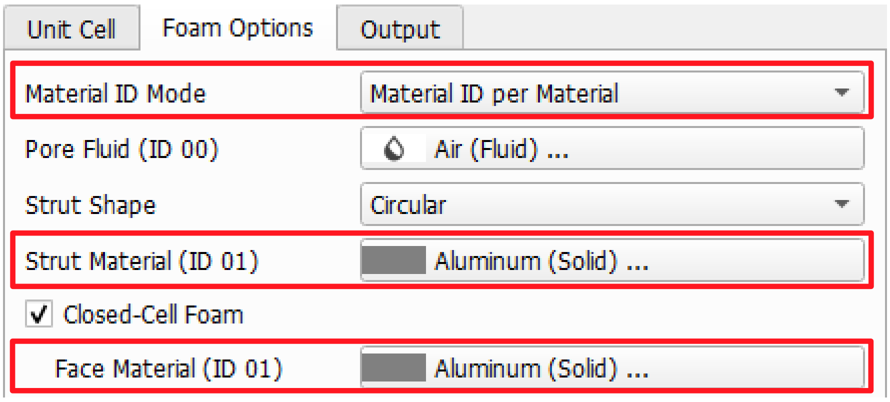




For the **Material ID Mode** Material ID per Object-Type, the fluid in the pore space (Pore Fluid (ID 00)), and the solid material for the **Strut Material (ID 01)** and, below, the **Face Material (ID 02)** can be selected from the Material Selector by clicking the buttons consecutively.



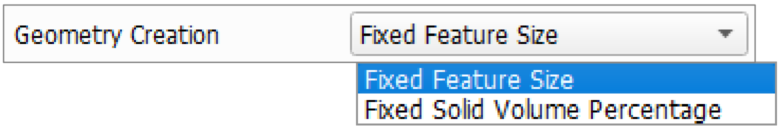
For **Material ID Mode** Material ID per Material, Strut Material and Face Material are assigned to the same Material ID (ID 01), if the same material is chosen.



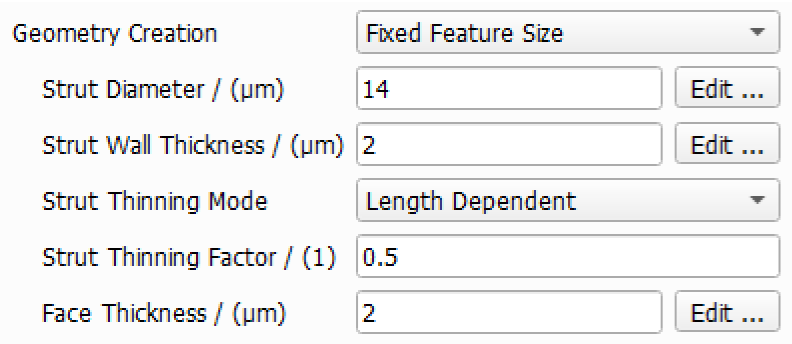
Random Seed initializes the random number generator behind the structure generator. Changing its value produces different sequences of random numbers and hence, different realizations of the specified structure. If all settings are equal, generating with the same **Random Seed** value produces exactly the same structure. **Random Seed** is a non-negative integer number.

Varying the **Random Seed** allows generating different samples of the same foam structure.

The chosen **Geometry Creation** mode defines the parameters of the structure, that can be selected. From GeoDict 2022 on, Fixed Feature Size, or Fixed Solid Volume Percentage are available as Geometry Creation modes.

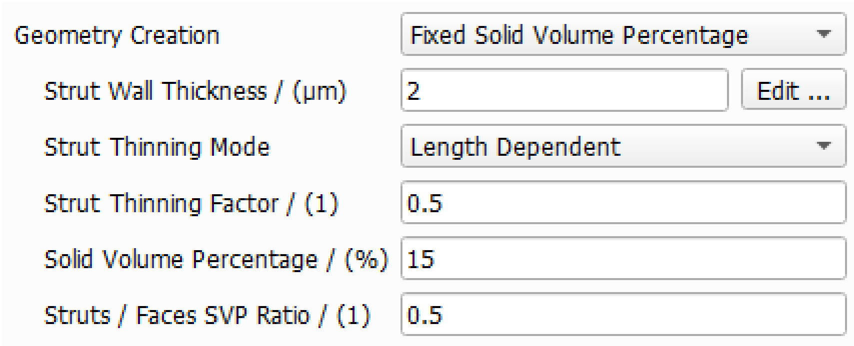


Select **Fixed Feature Size** to create a foam with a fixed size distribution for the strut diameters and the cell walls.



Strut Diameter distribution and **Face Thickness** distribution can be entered by checking the **Edit...** buttons in this mode.

With the Geometry Creation mode **Fixed Solid Volume Percentage**, the **Solid Volume Percentage** of the structure created, as well as the **Struts/Faces SVP Ratio** are defined instead.

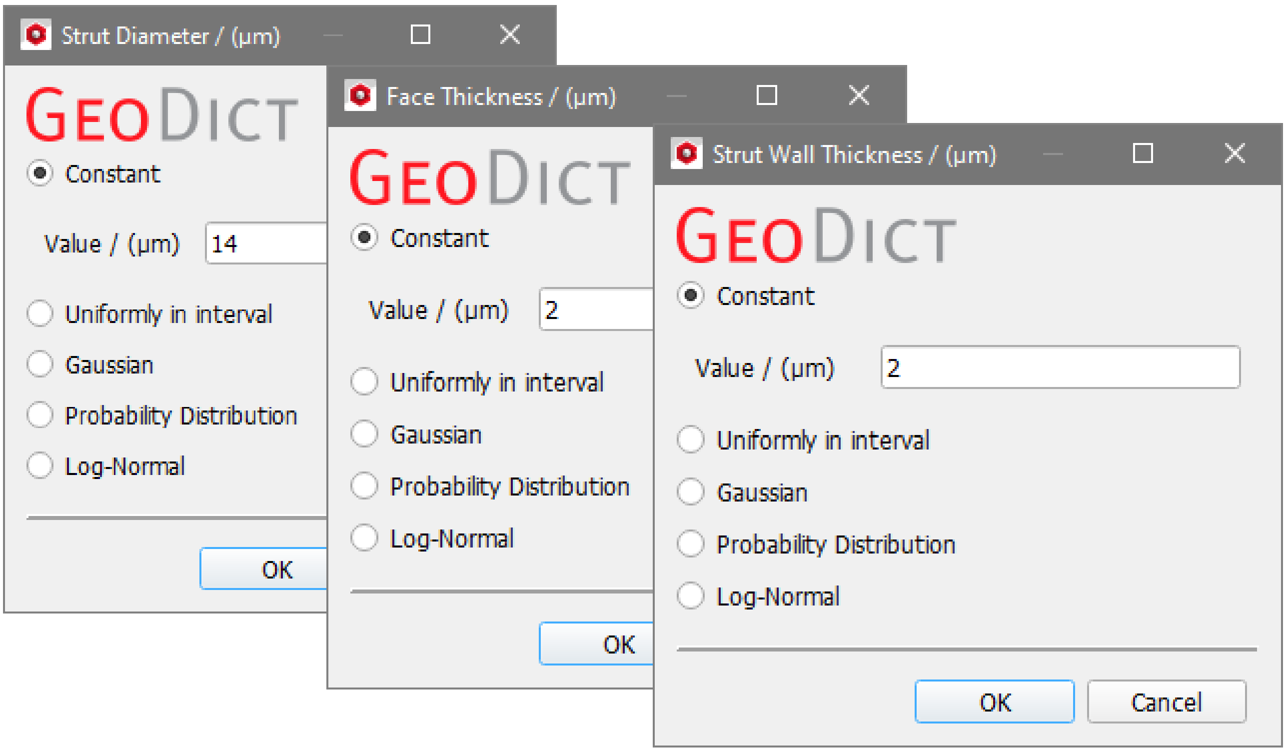


For both modes, the thinning of struts is defined by the **Strut Thinning Factor** and the **Strut Thinning Mode**. The **Strut Thinning Factor** determines the rate by which the diameter of the strut diminishes toward the center of each strut. The **Strut Thinning Mode** defines if this thinning depends on the length of the strut or is independent on the length.

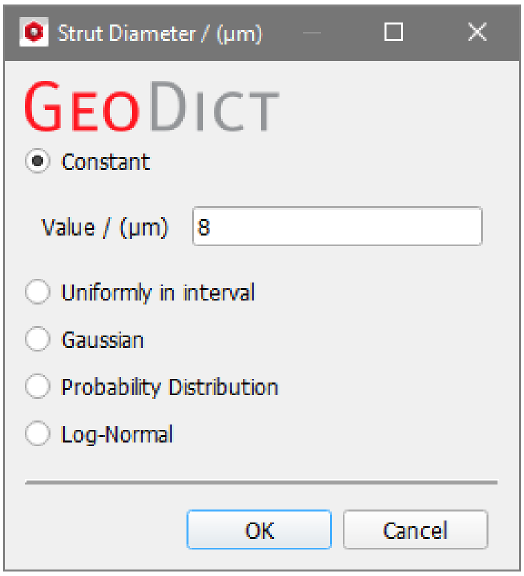
Additionally, for both modes, when **Hollow** is selected as Strut Shape, the thickness of the strut wall is entered under **Strut Wall Thickness**.

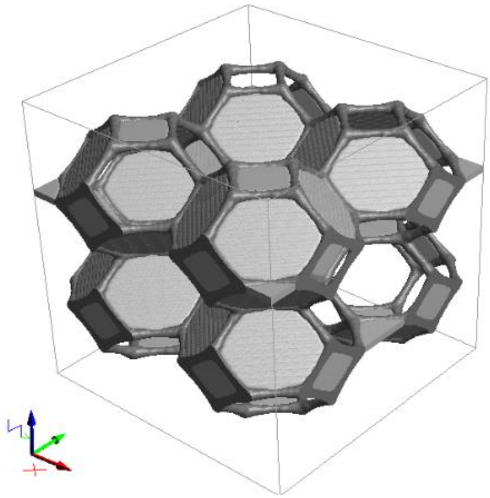
STRUT DIAMETER, FACE THICKNESS AND STRUT WALL THICKNESS DISTRIBUTION

The **Strut Diameter**, the **Face Thickness** and the **Strut Wall Thickness** can be set to be a **Constant** value, or to follow a distribution (**Uniformly in interval**, **Gaussian**, **Probability Distribution**, or **Log-Normal**).

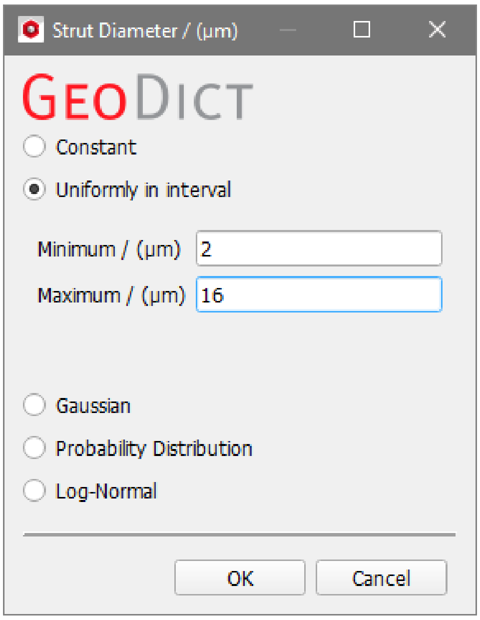


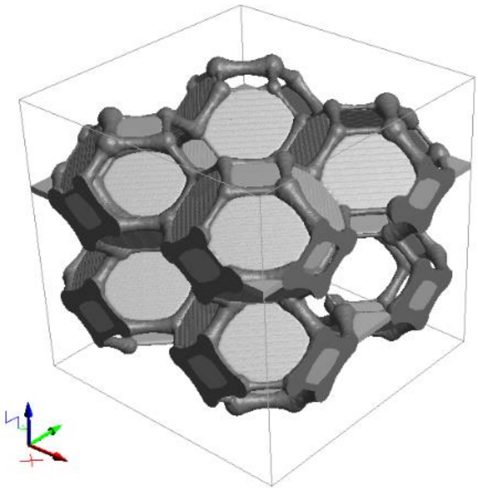
Observe the effect of entering values of **Strut Diameter**, as shown in the dialog boxes, on the generated random foam shown on the right.





When selecting **Uniformly in interval**, and entering a **Minimum** value and a **Maximum** value, the strut diameter can take any value within this interval.

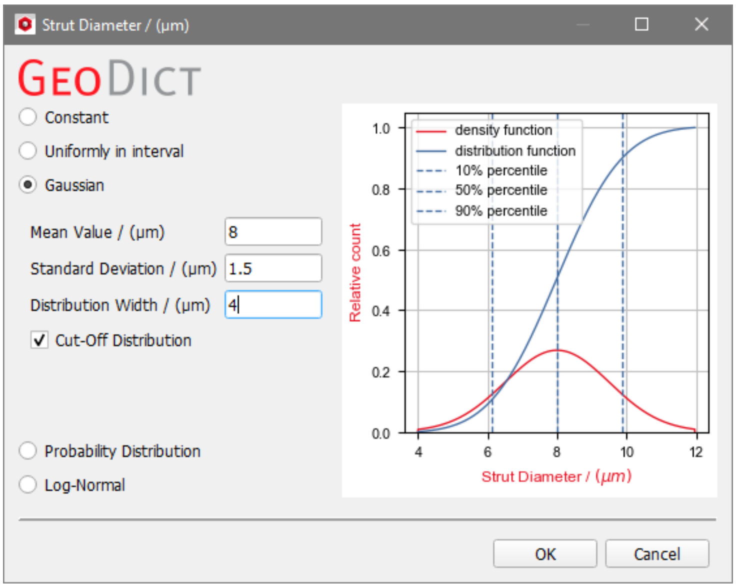


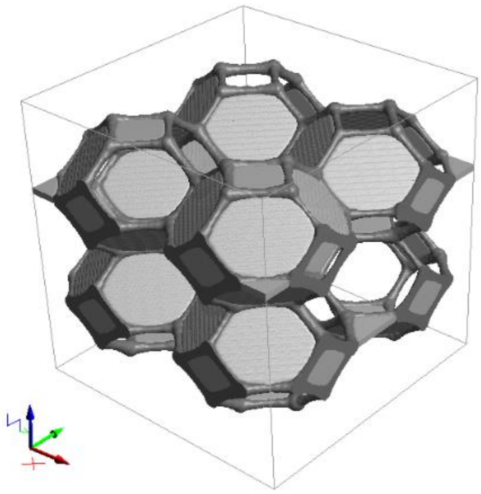


Taking the **Gaussian** (or **normal**) distribution, the value follows a bell-shaped distribution. The strut diameter value clusters around the entered **Mean Value** but may vary according to the entered **Standard Deviation**.

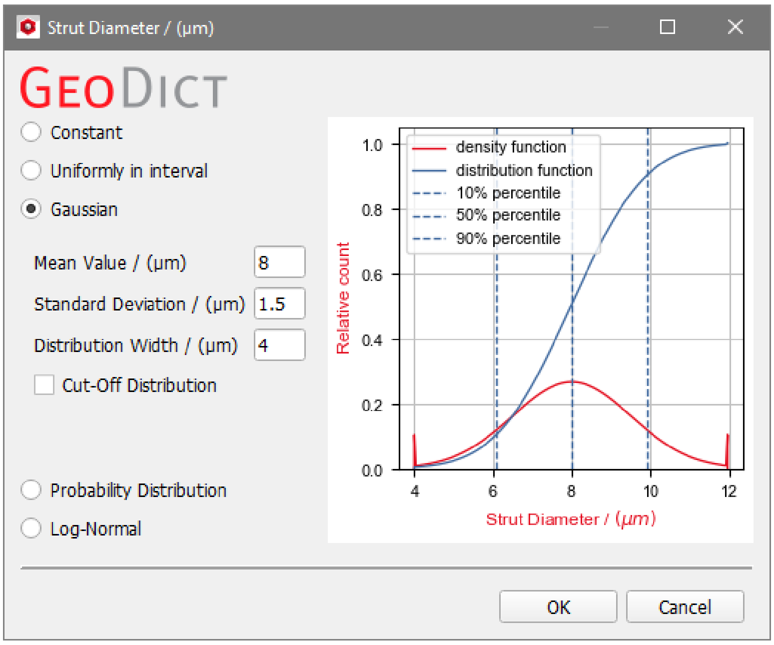
The value in **Distribution Width** corresponds to the interval on both sides of the mean value limiting the random value that is acceptable. For the strut diameter, a **Distribution Width** value of 4 µm means that diameter values may vary only between -4 µm to +4 µm from the given **Mean Value**, here 8 µm. The parameters must be set so that no negative values are possible.

The diagram on the right of the dialog shows the distribution of strut diameters.





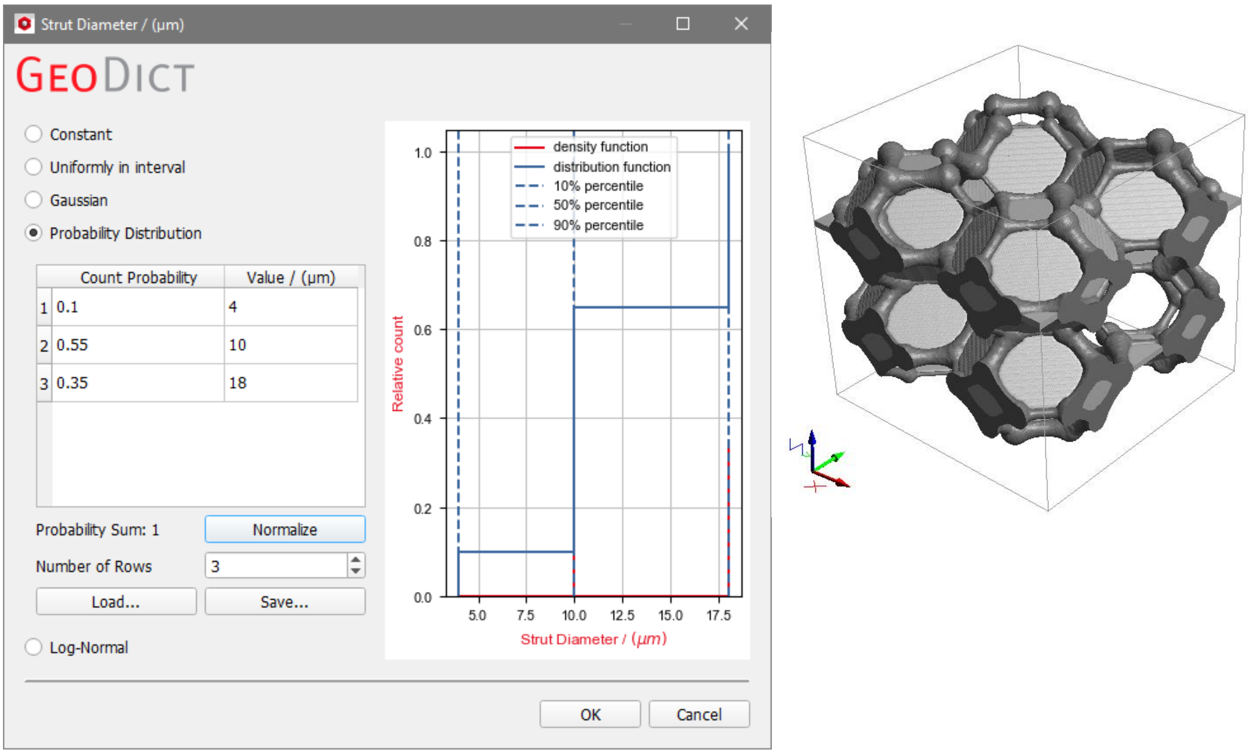
If **Cut-Off Distribution** is checked, the distribution is truncated at the bounds. This means, that all values outside the bounds are dropped and not considered for generation. If this option is not checked, then all values that are outside of the bounds are set to be on the distribution bound.



The **Probability Distribution** table describes the probability that the strut diameter takes certain values. The **Number of Rows** can be increased or decreased to enter as many **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 sum of the count probabilities. When the **Probability Sum** is not equal to 1, click the **Normalize** button to automatically normalize the **Count Probability** values.

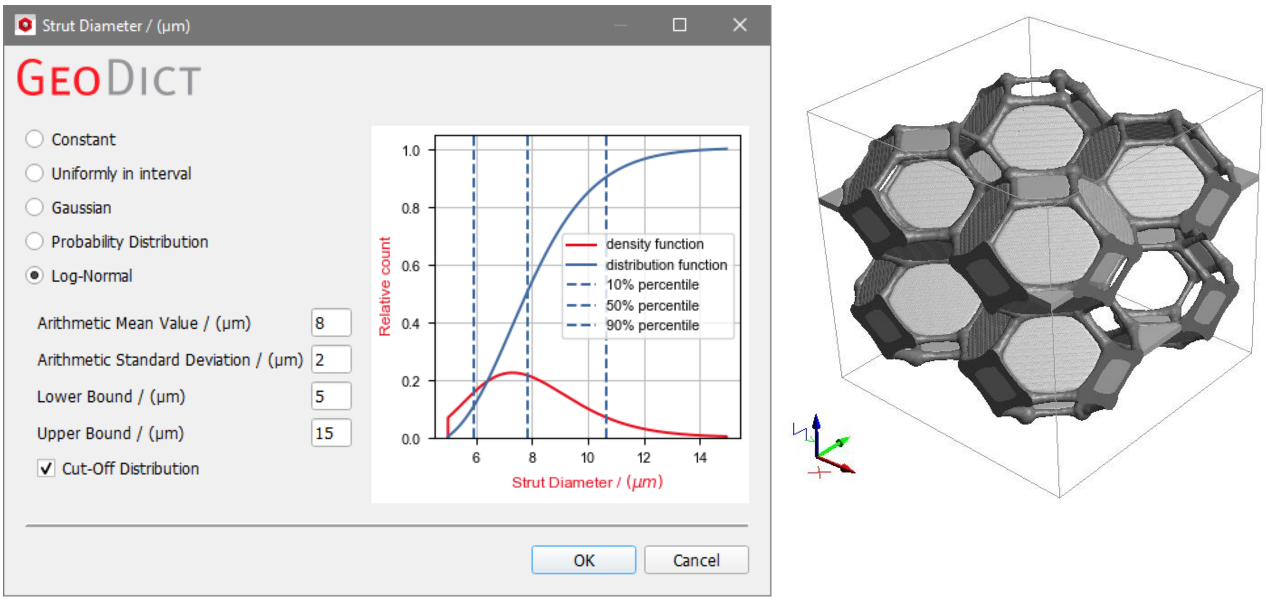
Use **Load** and **Save** to load a previous probability distribution or to save the current one for later use.



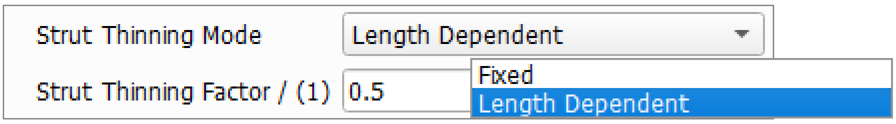
The **Log-Normal** distribution describes the situation in which the logarithm of the strut diameter follows a Gaussian distribution.

The strut diameter values group around the entered **Arithmetic Mean Value** but may diverge according to the entered **Arithmetic Standard Deviation**.

The values in **Lower Bound** and **Upper Bound** limit the possible values under and over the arithmetic mean value, thus restricting the values that the random diameters can take.



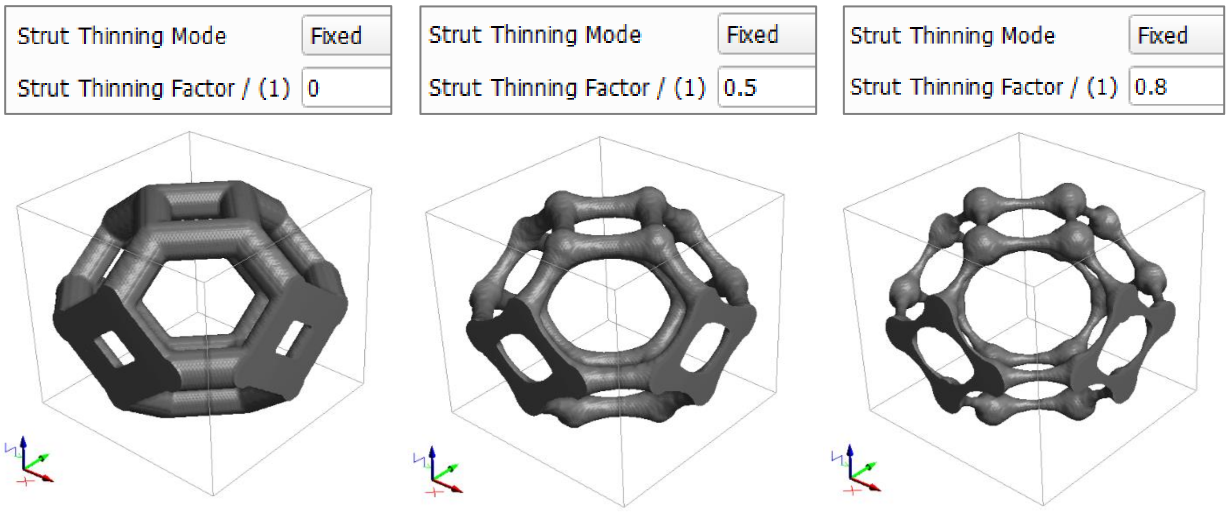
Strut Thinning



The **Strut Thinning Factor** determines the rate by which the diameter of the strut diminishes toward the middle of one strut.

The **Strut Thinning Mode** determines if this thinning is length dependent or not. Select **Fixed** to thin all struts equally, independent on their length. Choose **Length Dependent** for a thinning dependent on the length of each strut. Short struts have less thinning than long struts.

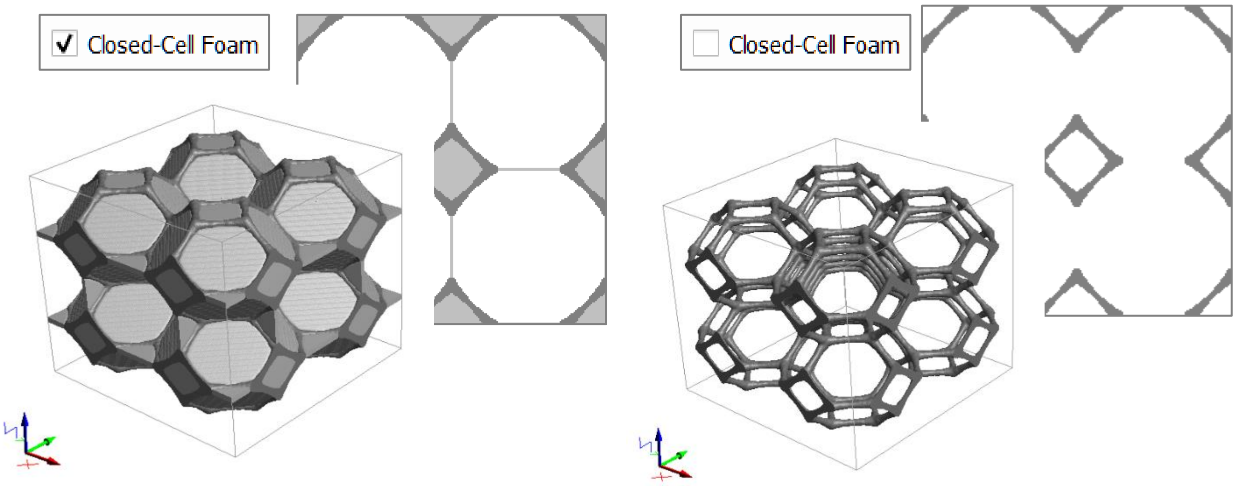
Thinning factor values vary from 0 to 1. When the value is 0, the strut diameter does not change. For fixed strut thinning, with a value of 0.5, the strut diameter decreases 50% from near the nodes to the middle of the strut. For length dependent strut thinning, the strut diameter decreases 50% from the nodes to the middle for the longest strut. The other struts have less thinning, dependent on their relative length, compared to the longest strut.



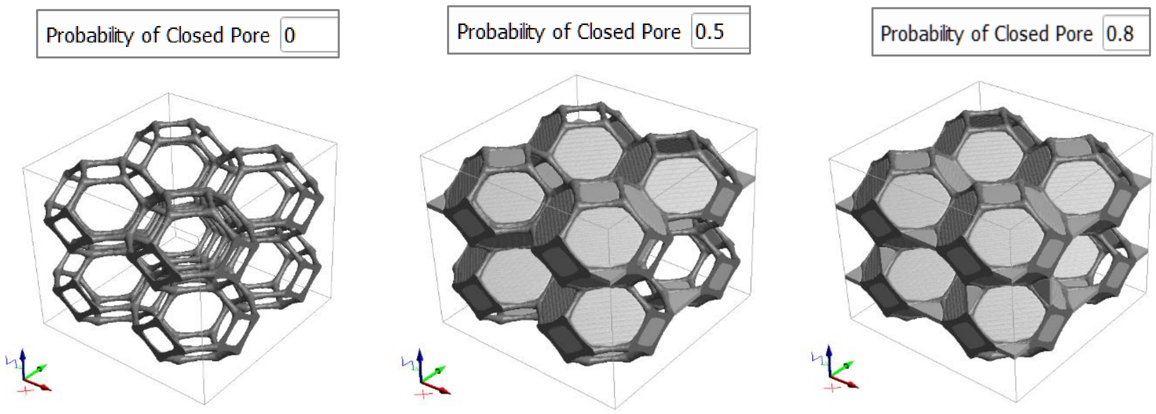
Since the effect of length dependent strut thinning is better visible for random foams, an example is shown on page 22.

Closed-Cell Foam

Unchecking **Closed-Cell Foam** generates a sponge or open-cell foam, with the struts forming a polygon without faces in between. When **Closed-Cell Foam** is unchecked, the structure has no faces and thus, the **Face Material** color, the **Probability of Closed Pore** and the **Face Thickness** cannot be chosen.



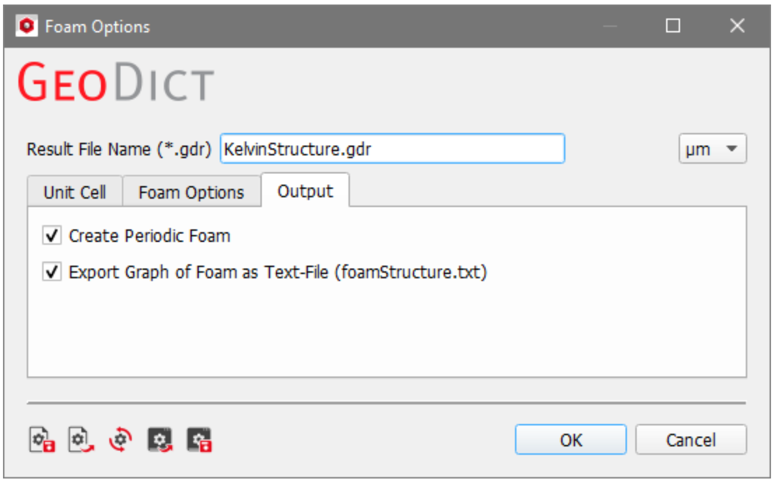
When the structure is a closed-cell foam, values between 0 and 1 can be entered for the **Probability of Closed Pore**. When the value is 1, all pore walls are closed. When the value is 0, the result is an open foam.



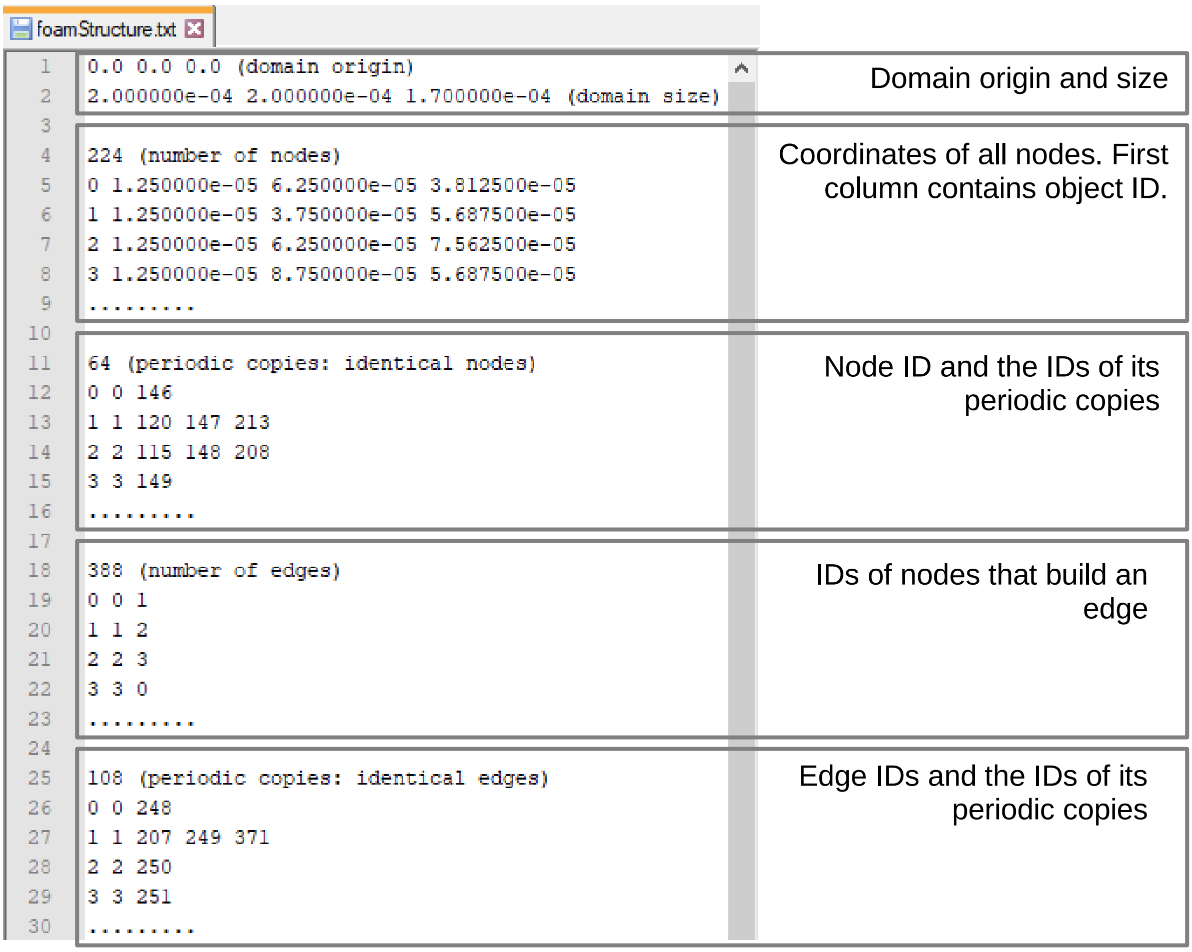
OUTPUT

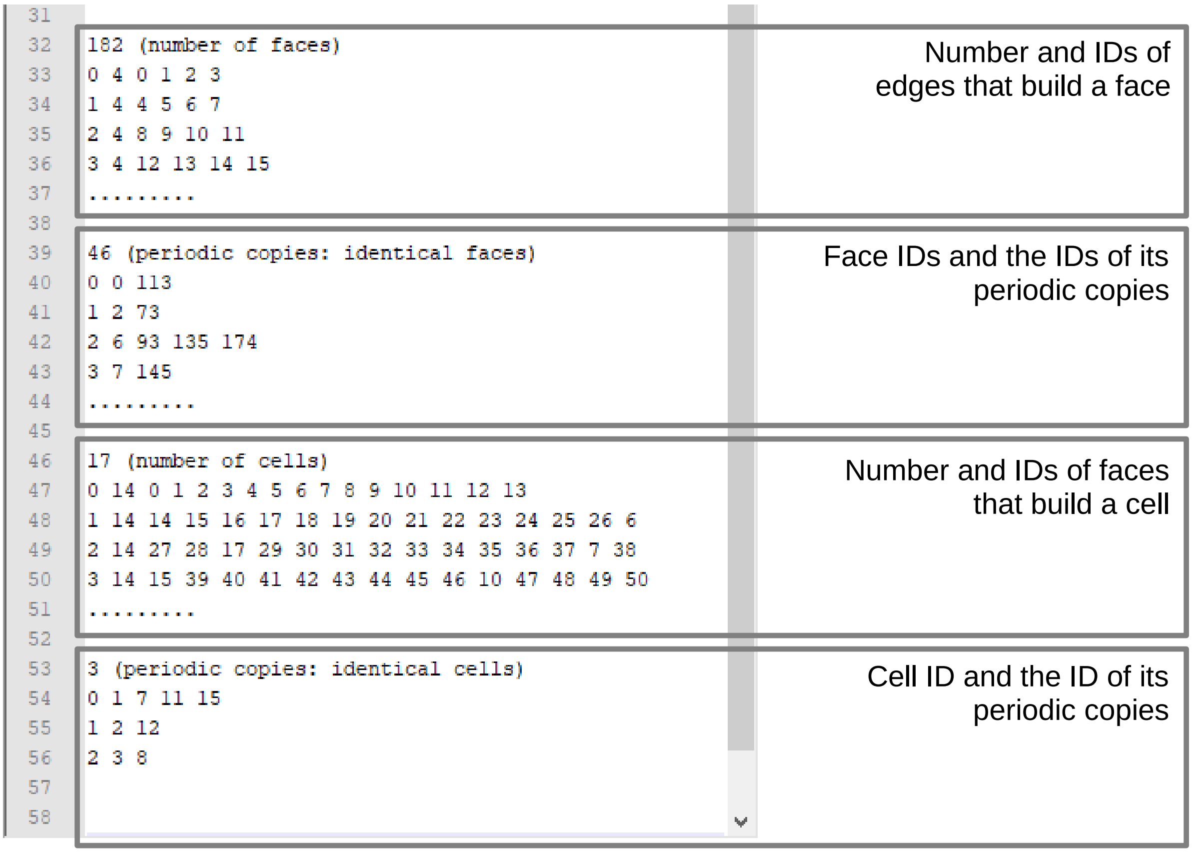
Under the **Output** tab, it is possible to choose whether the generated foam structure is periodic or not.

It is also possible to export a text file containing all geometric information of the foam as a graph.



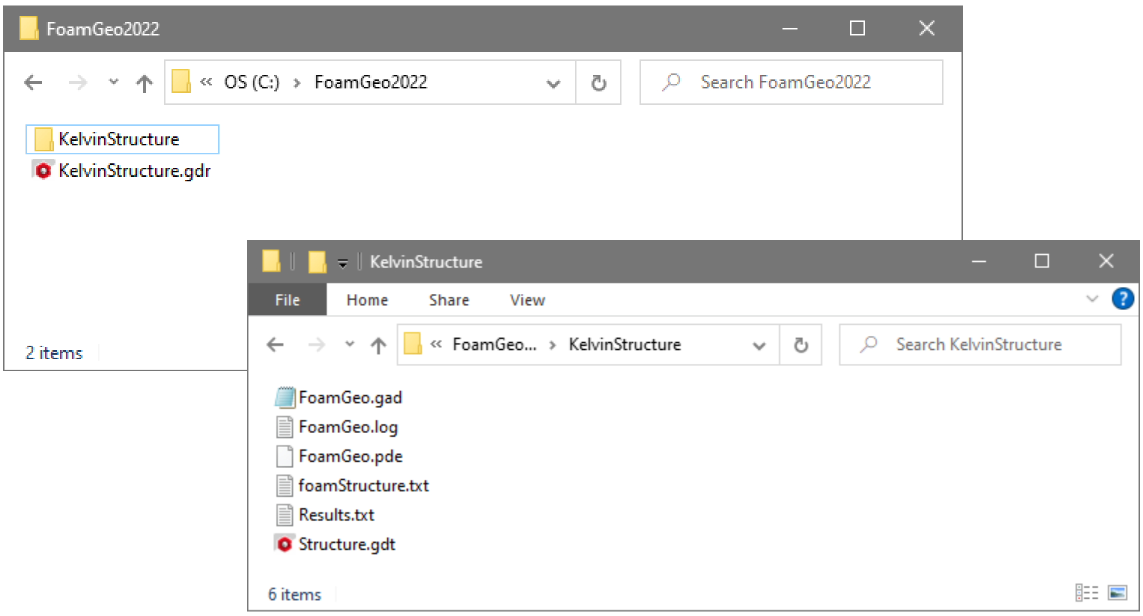
The text file is explained in the next figure.





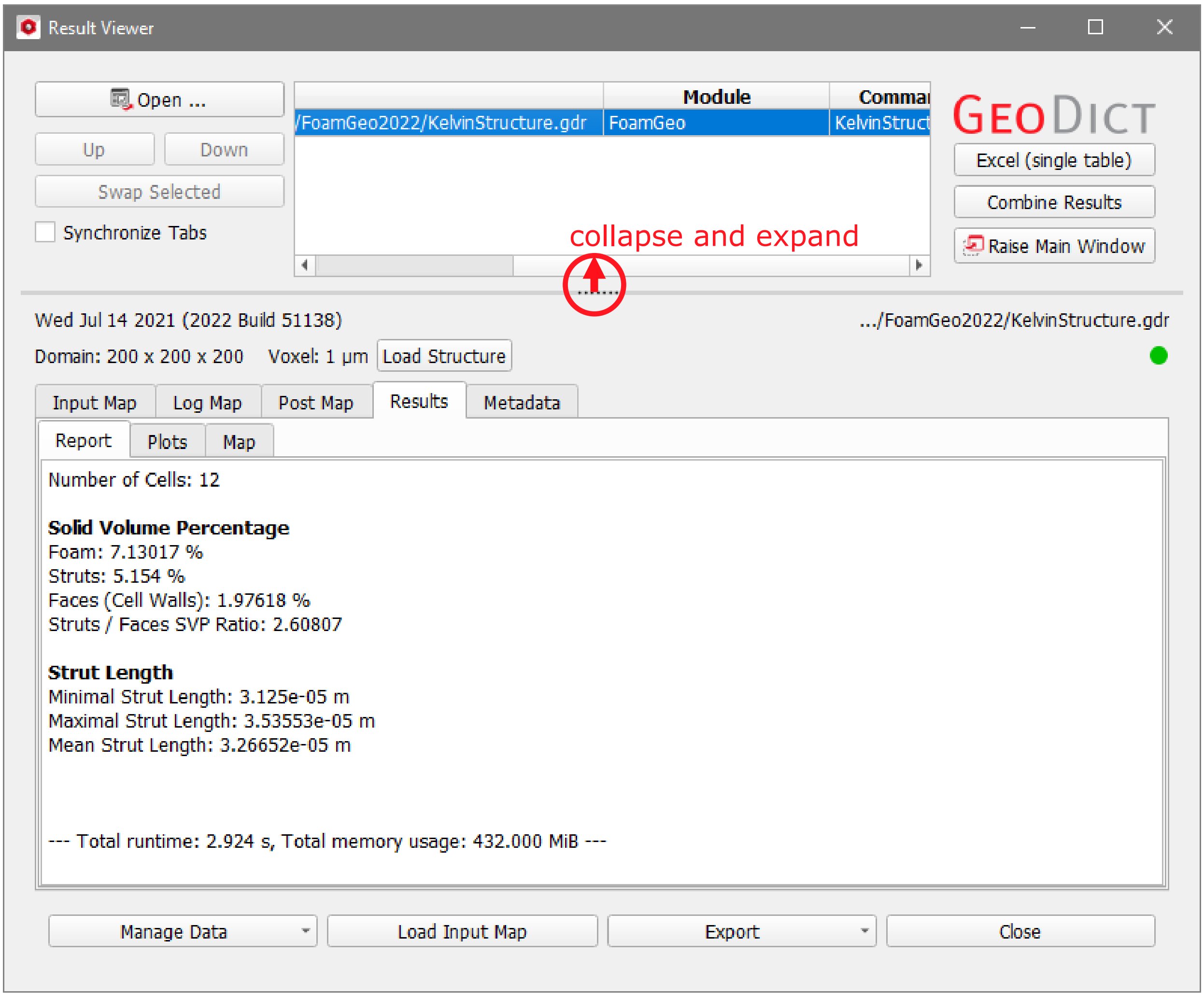
Result File

After the generation of a Kelvin structure, the project folder contains the result file (.gdr format) and a folder of the same name as the result file, with the structure in .gad and .gdt format, a .log file of the generation, a condensed result file in .txt format and a .pde file with all the generation input parameters. If the Graph of Foam was exported as .txt file, this file is also located in this folder (foamStructure.txt).



The GeoDict Result Viewer opens for the .gdr file created. The result file name and directory, as well as the module and command used to create the result are shown on top. The GDR file can be opened at any time by selecting **File → Open *.gdr File...**in the menu bar.

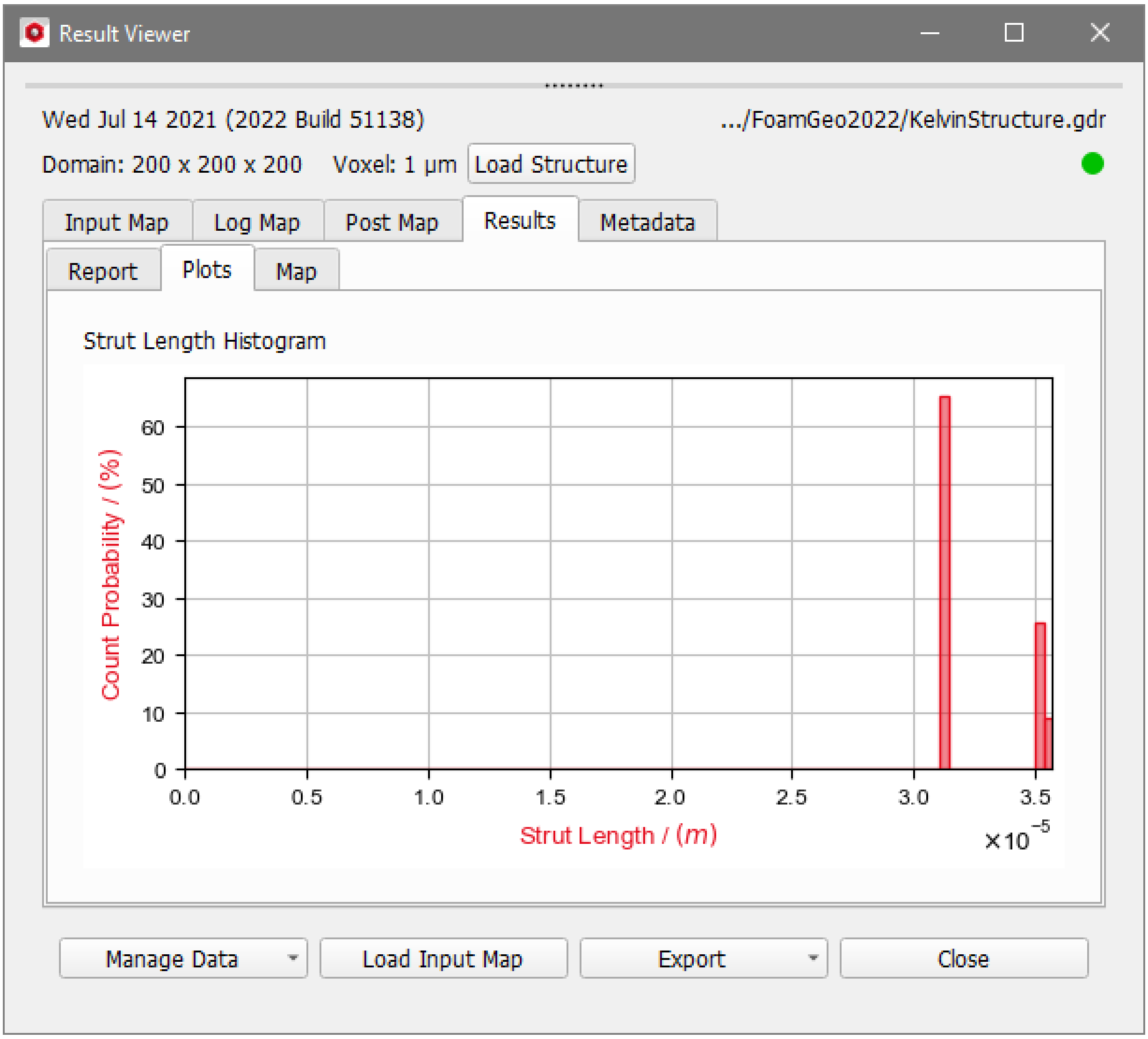
The green dot in the right corner of the Result Viewer indicates that it contains the results computed for the structure currently in memory and showing in the **Visualization** area. More information on working with the Result Viewer can be found in the GeoDict Result Viewer documentation.



On the **Results** tab, the subtab **Report** lists the solid volume percentages (SVP) for the whole foam, as well as for struts and faces separately. The Struts / Faces SVP Ratio is the SVP of the struts divided by the SVP of faces, here 5.154 % / 1.976 % = 2.608.

The minimal, maximal and mean strut length are reported additionally.

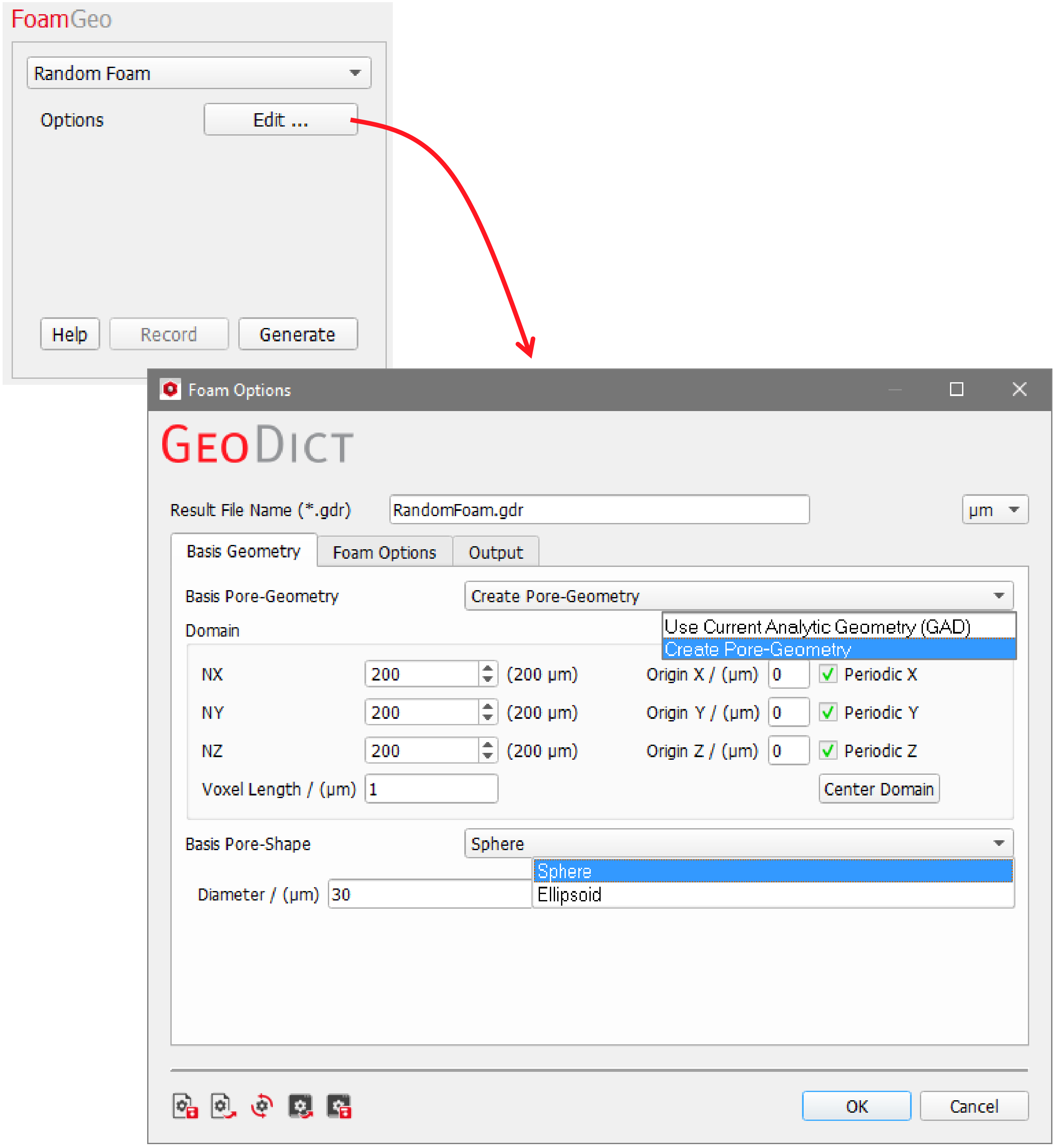
A more detailed information about the strut length distribution, is available on the **Plots** subtab, where a strut length histogram is shown.


Result Viewer
Wed Jul 14 2021 (2022 Build 51138)
.../FoamGeo2022/KelvinStructure.gdr
Domain: 200 x 200 x 200
Voxel: 1 µm
Load Structure
Input Map
Log Map
Post Map
Results
Metadata
Report
Plots
Map
Strut Length Histogram
Count Probability / (%)
Strut Length / (m)
×10^-5
Manage Data
Load Input Map
Export
Close

Random Foam

For the Random Foam, the dialog box contains the tabs **Basis Geometry**, **Foam Options** and **Output**.

The available units (**m**, **mm**, **µm**, and **nm**) are selectable from the pull-down menu.



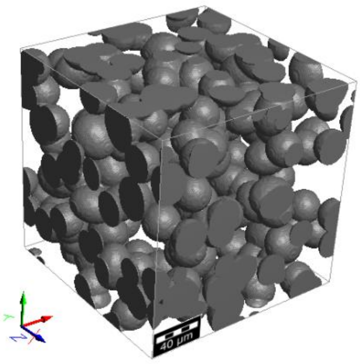
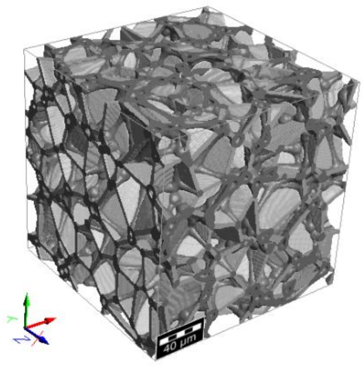
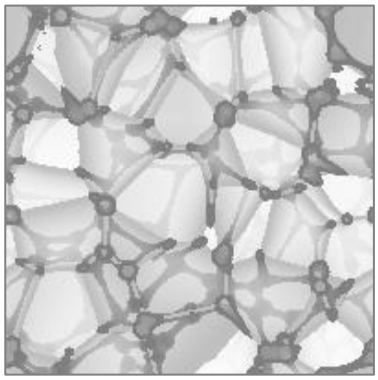
A customized **Result File Name (*.gdr)** should be entered to differentiate the results of different FoamGeo runs. The *.gdr result file ensuing from the generation is automatically placed inside the chosen project folder

Basis Geometry

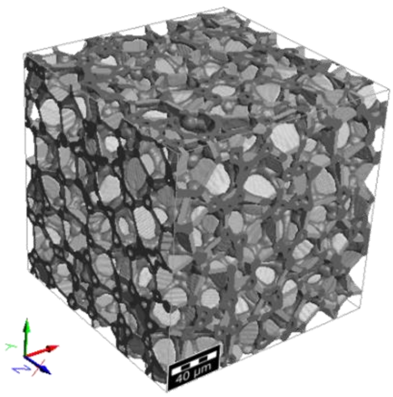
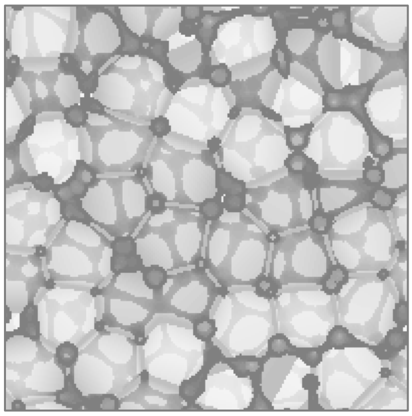
A random foam is generated based on a random homogeneous pack of spheres or ellipsoids called **Basis Pore-Geometry**. Each cell in the generated foam corresponds to an object (sphere or ellipsoid) in the **Basis Pore-Geometry**. For example, if the **Basis Pore-Geometry** contains 100 spheres with a diameter of 50 µm, the foam will contain 100 cells with a diameter of ca. 50 µm.

The **Basis Pore-Geometry** can be created:

- From a pre-existing periodic packing, generated e.g. with GrainGeo as GeoDict analytic data (.gad). The periodic packing must be loaded in memory (**Use Current Analytic Geometry**), that is, shown in the visualization area. The analytic data is then taken as basis geometry to form the foam.

- As a new geometry in FoamGeo (**Create Pore-Geometry**)

The parameters in the **Domain** panel determine the random foam size. **NX**, **NY**, and **NZ** determine the number of voxels of the grid in the X, Y, and Z axes. The size of the structure created depends on **NX**, **NY**, and **NZ** and on the **Voxel Length**.

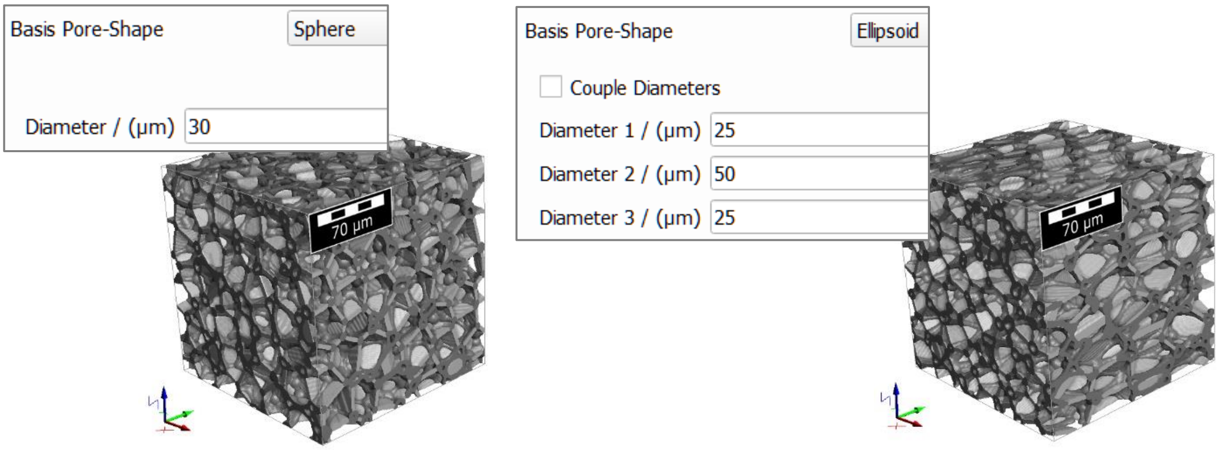
Voxel Length is the size of a voxel in the selected units.

The coordinates of the domain origin can be set in **Origin X, Origin Y,** or **Origin Z**. Alternatively, click **Center Domain** to set the origin to NX/2, NY/2, and NZ/2.

From the **Basis Pore-Shape** pull-down menu, select the shape for the desired basis pore to be a **Sphere** or an **Ellipsoid**. The volume of the random foam cells resulting from the selected basis pore shape is always a bit larger than the basis pore shape volume.

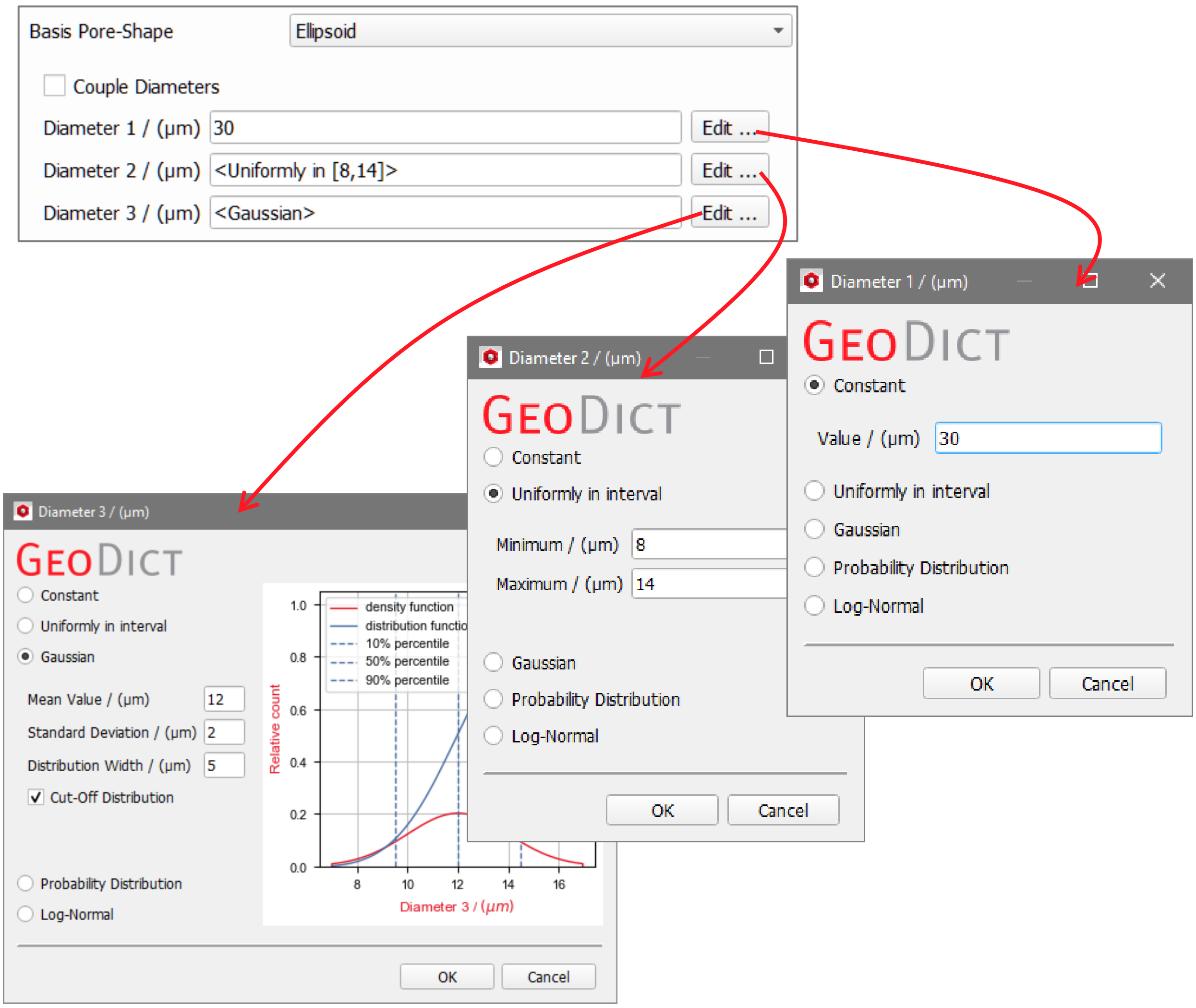
When selecting **Sphere**, the user enters the **Diameter** of the spheres on which the generated foam is based.

By selecting **Ellipsoid**, complex anisotropic random foams can be generated.



As explained in pages 8ff. for strut diameters, the diameter of the spheres (**Diameter**) or ellipsoids (**Diameter 1** in X-direction, **Diameter 2** in Y-direction, **Diameter 3** in Z-direction) can be changed by clicking **Edit...**.

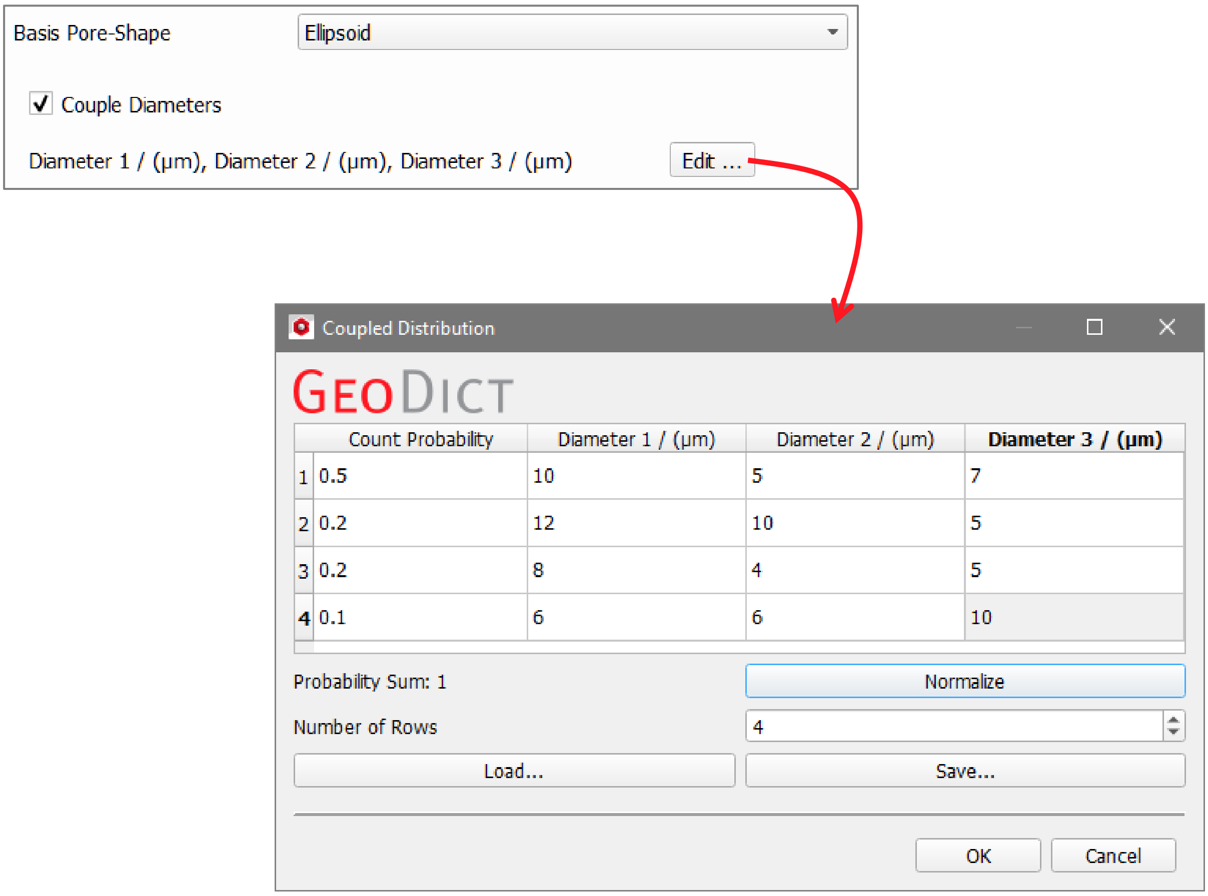
The diameters can be set independently to take a **Constant** value, or to follow a distribution (**Uniformly in interval**, **Gaussian**, **Probability Distribution**, or **Log-Normal**; see 8ff).



When **Ellipsoid** is the Basis Pore-Shape, a probability can be assigned to the combination of the three diameters by checking **Couple Diameters**. Instead of independent probability distributions for diameter 1, for diameter 2 and for diameter 3, the three coupled diameters share the same probability in the distribution.

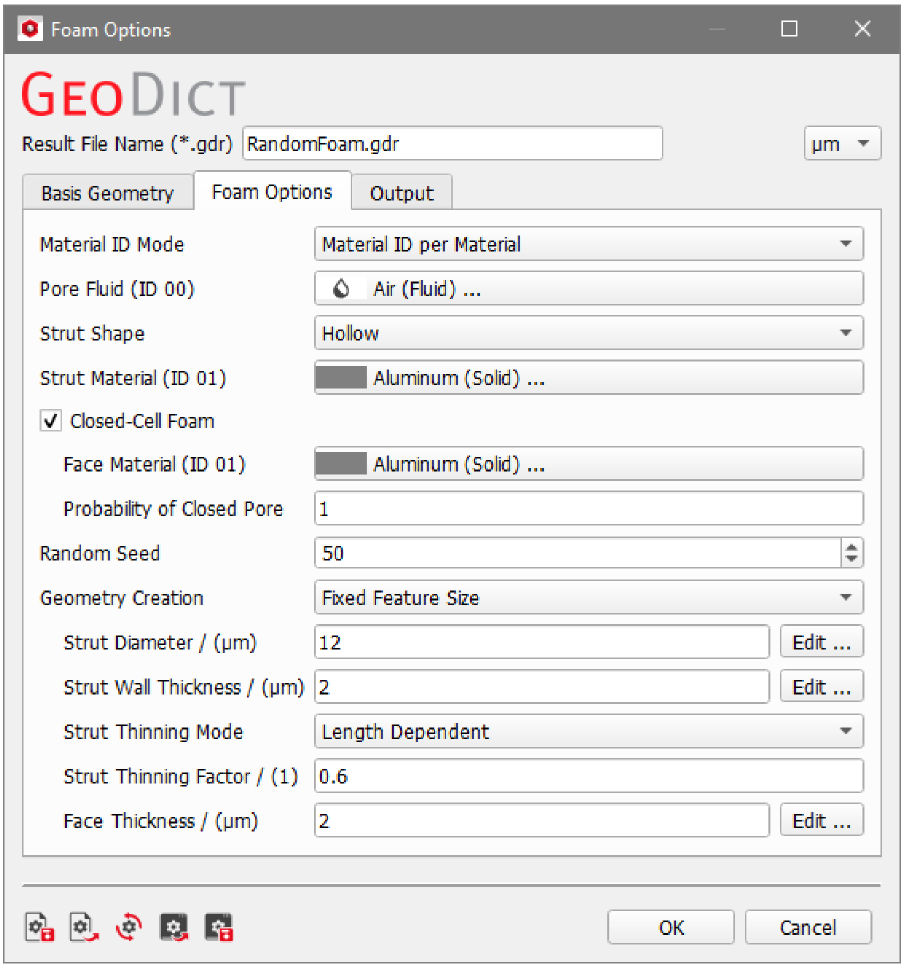
For example, leaving **Couple Diameters** un-checked, the user can click the Edit… buttons and assign a **Constant** value for **Diameter 1**, a **Uniformly in interval** distribution for **Diameter 2** and a **Gaussian** distribution for **Diameter 3**.

Checking **Couple Diameters**, the user can (for example) assign the following probability distribution table to **Diameter 1, Diameter 2** and **Diameter 3**. According to the table, ellipsoids of diameters 10 µm/5 µm/7 µm have a 50% (0.5) probability to be the basis pore-shapes for the generated random foam.

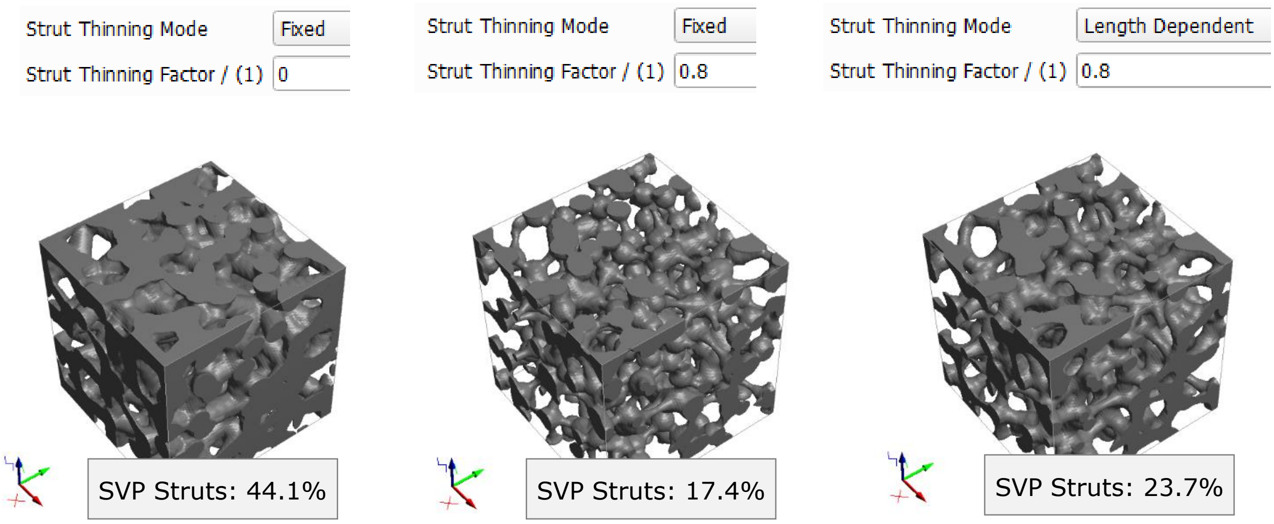


Foam Options

Under the **Foam Options** tab, the parameters are the same as explained starting in page 5 for the generation of Kelvin structures.



Here, an example for the strut thinning with and without length dependent thinning is shown for an open-cell foam. Observe the difference in SVP of the struts created.

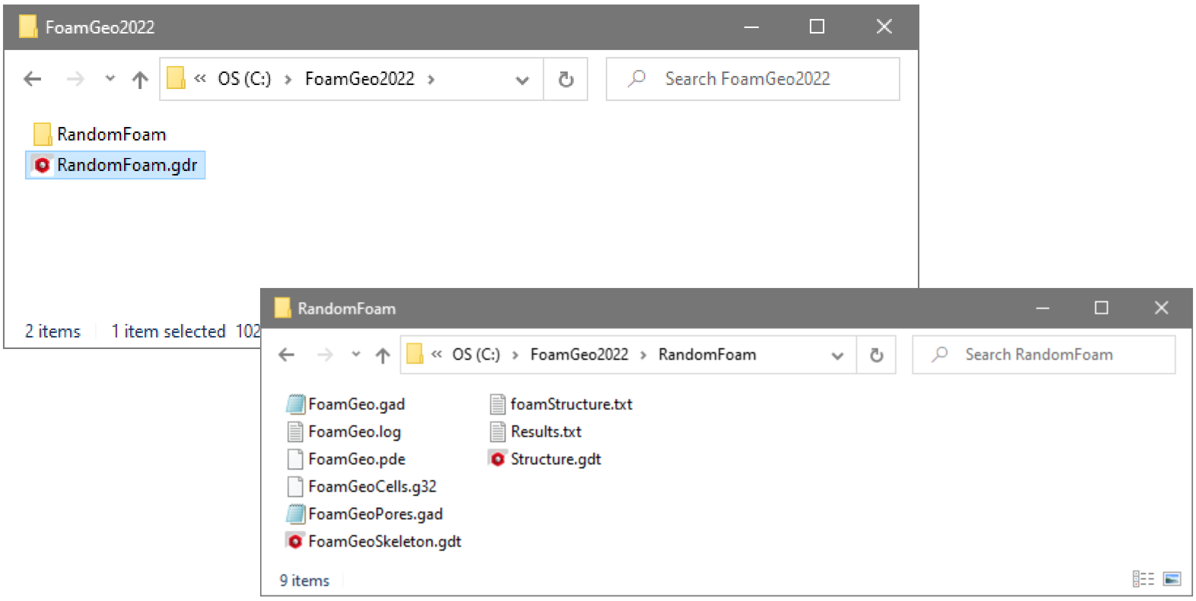


Output

The **Output** tab is described in page 14.

After the generation, the project folder contains the result file (in .gdr format) and a folder of the same name as the result file.

The result folder contains several files: the generated foam structure in .gad format, the generated foam structure in .gdt format (Structure.gdt), the .gad file of the basis geometry used to generate the foam, a .log file of the generation, a .pde file with all the generation input parameters, a condensed result file in .txt format, the index image map in .g32 format, the skeleton of the foam in .gdt format, and the foamStructure.txt file which contains a list of the coordinates of each node, the nodes of struts, and the struts of each face.

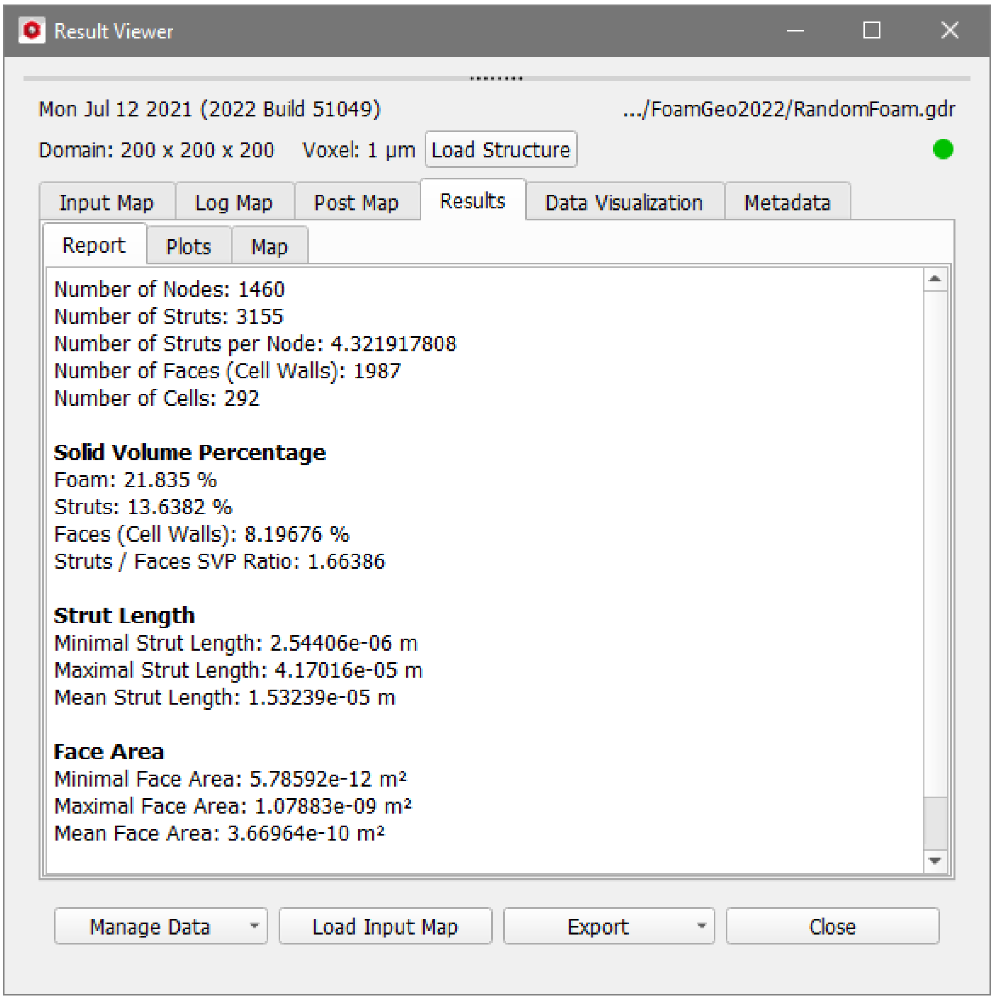


Result File

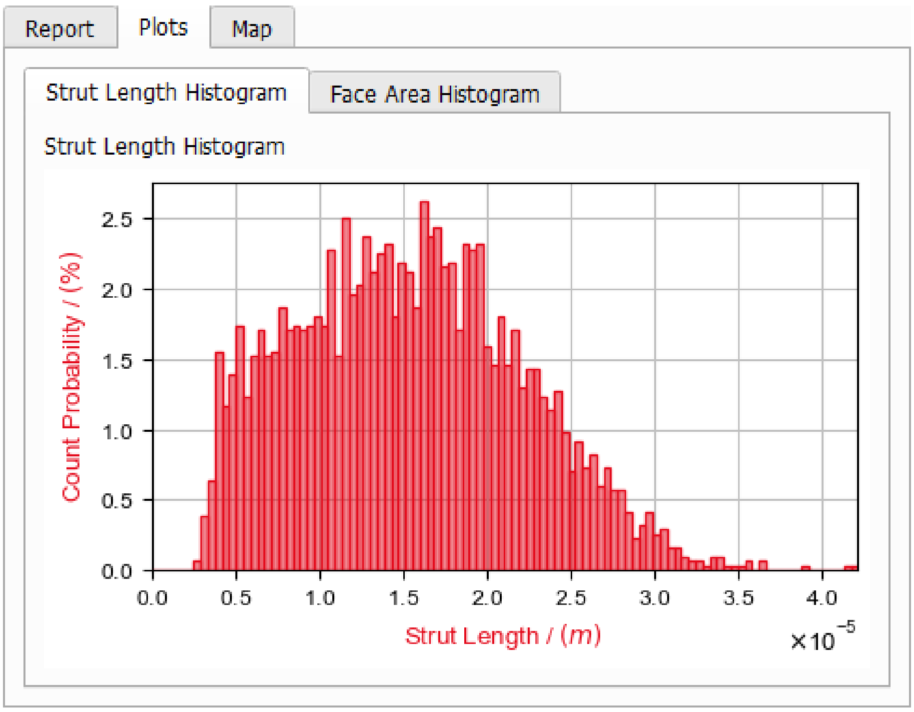
The .gdr file created, opens in the GeoDict Result Viewer. On the **Results** tab, the subtab **Report** shows on top the number of nodes, struts, faces and cells and the average number of struts per node for the random foam structure.

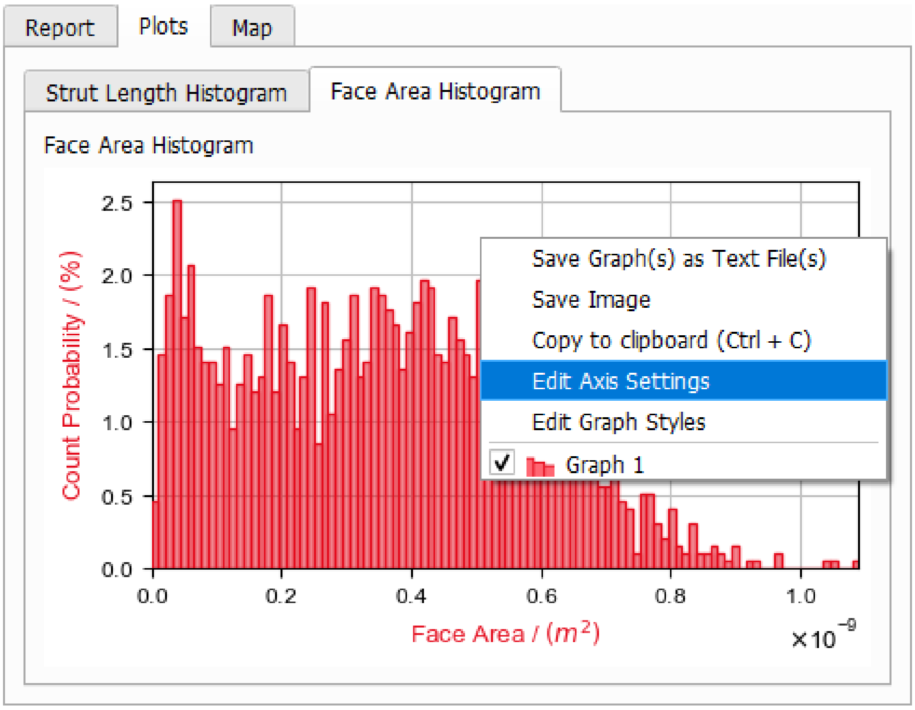
The solid volume percentages (SVP) of the whole foam, for only the struts or faces as well as the ratio between the SVP for the struts and the SVP for the faces is listed under **Solid Volume Percentage**.

Next, for the struts, the minimal, maximal and mean length is shown and for the faces the minimal, maximal and mean area.



A more detailed information about the strut lengths and face areas is shown on the subtab **Plots**. The strut length distribution as well as the face area distribution are visualized as histograms.





By a right mouse click, the settings of the histogram can be changed, or the histogram data can be saved as text file or image as well as copied to the clipboard.

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