FoamGeo

User Guide

GeoDict release 2024

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GeoDict

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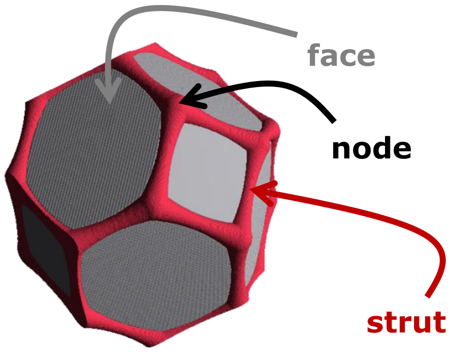
Modeling regular Kelvin structures and random foams with FoamGeo

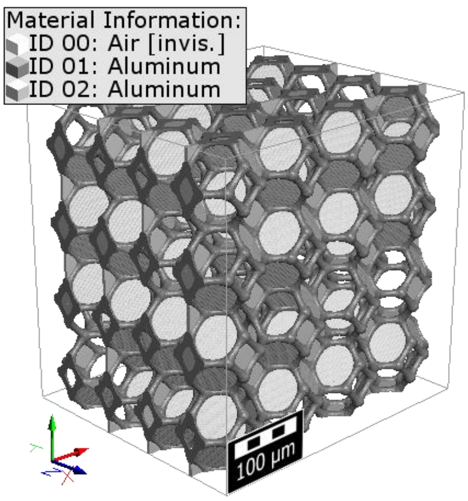
FoamGeo is the module to model foams in GeoDict. A foam consists of individual cells, which have the following components:

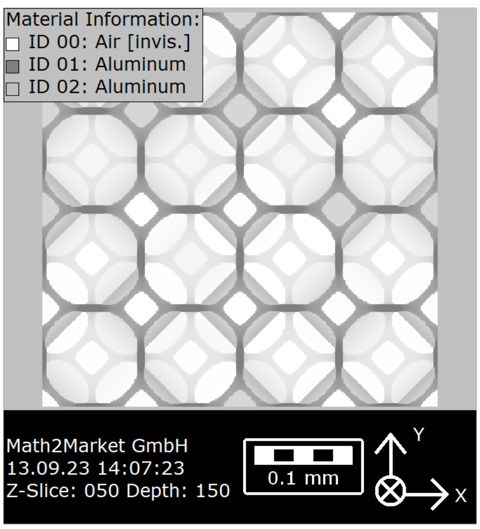
- A **strut** is the edge of a foam cell.
- A **node** is where the struts meet.
- A **face** is the surface surrounded by struts and nodes. When the structure is an open-cell foam (not a closed-cell foam), no faces are generated.



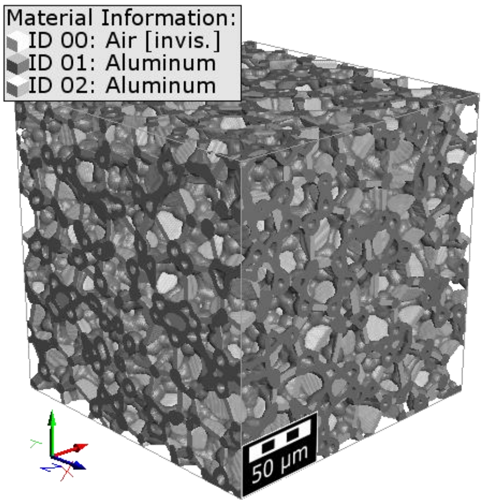
Two types of foams can be generated:

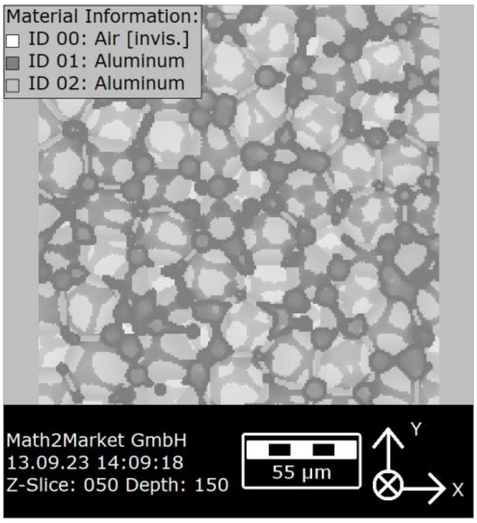
- **Kelvin structures**: a regular foam based on the bitruncated cubic honeycomb (or tessellation) by which space is partitioned into cells of equal volume. Kelvin structures are made up of 4 truncated octahedra around each vertex. Being composed entirely of truncated octahedra, it is cell-transitive.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





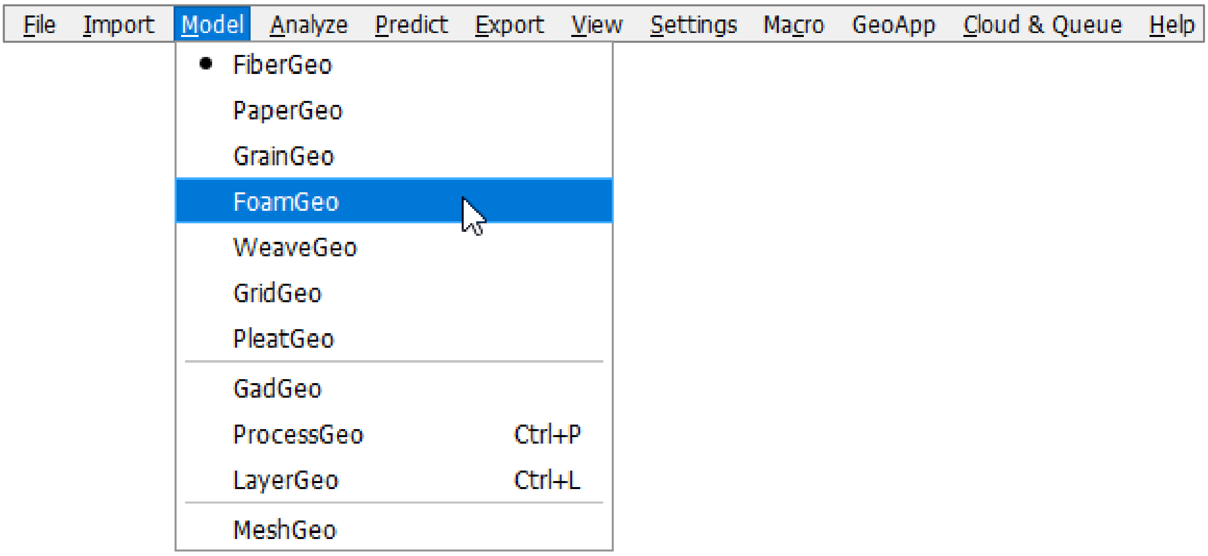
- **Random Foams** are based on the Voronoi tessellation (also called Voronoi decomposition, Voronoi partition or Dirichlet tessellation). It is a way of dividing space into a number of regions. A set of points (called seeds, sites, or generators) is specified beforehand and for each seed there will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

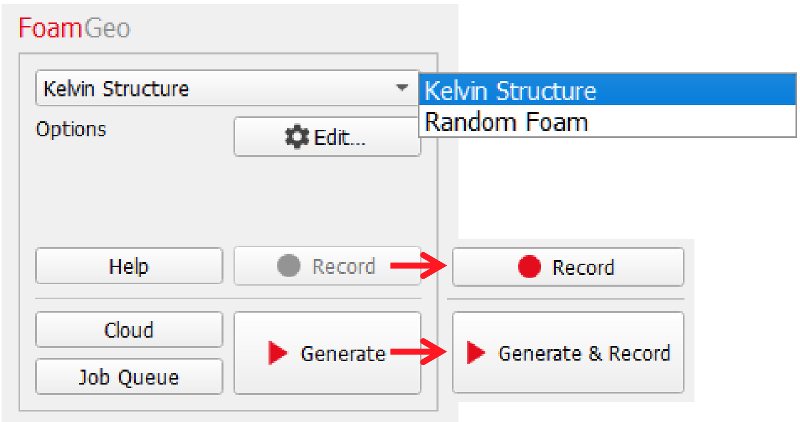

Material Information:
ID 00: Air [invis.]
ID 01: Aluminum
ID 02: Aluminum
50 µm


Material Information:
ID 00: Air [invis.]
ID 01: Aluminum
ID 02: Aluminum
Math2Market GmbH
13.09.23 14:09:18
Z-Slice: 050 Depth: 150
55 µm
Y
X

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 **Basis Geometry**, **Foam Options** and **Output**. The parameters under the **Foam Options** tab are nearly the same for both types of foams.

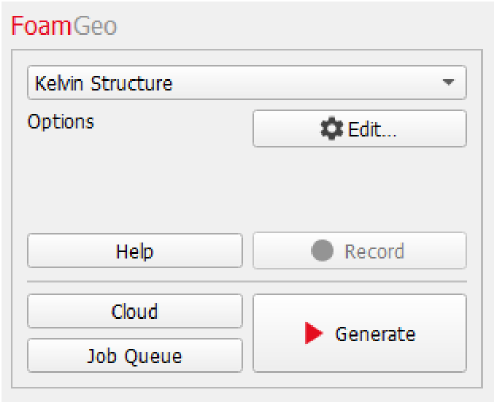
Clicking **Generate** at the bottom of the **FoamGeo** section starts the program's generation run.

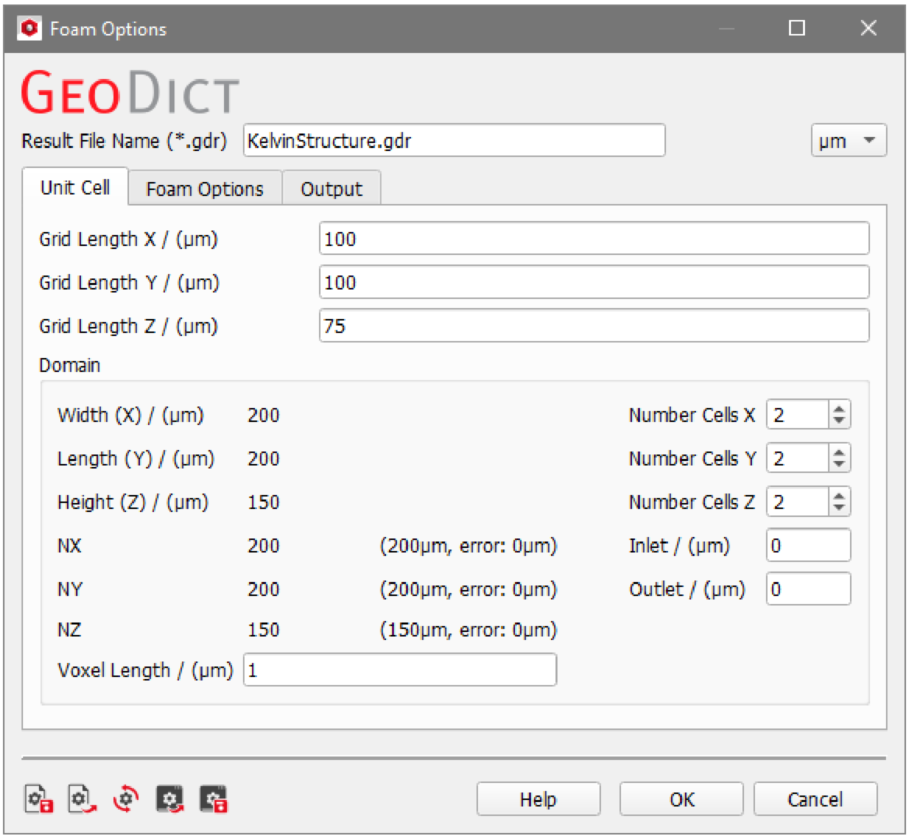
When recording a macro, the **Record** button becomes active and the **Generate** button changes to **Generate & Record**.

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 top right.

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



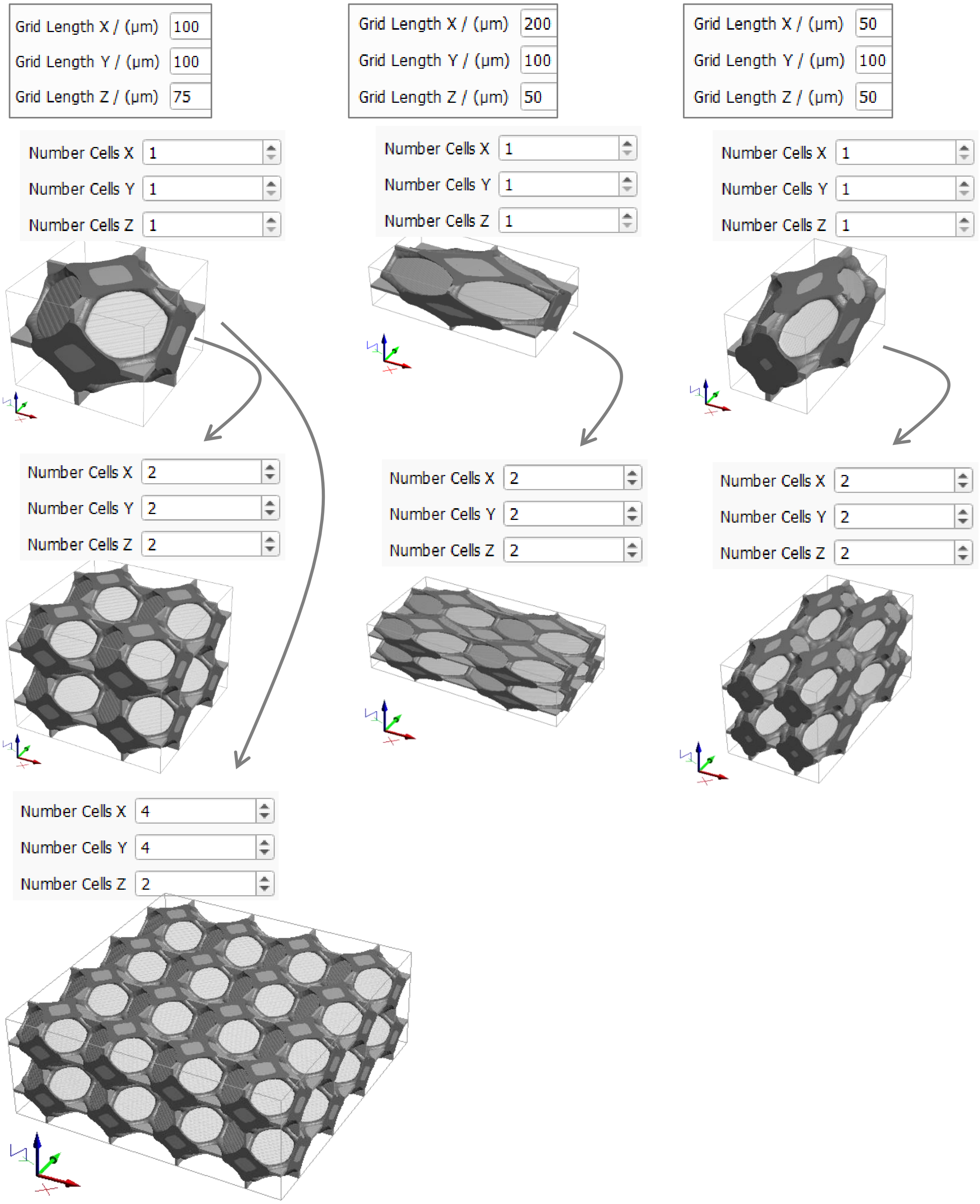


A customized **Result File Name (*.gdr)** should be entered to differentiate the results of different FoamGeo runs. The *.gdr result file created during the generation is automatically placed inside the chosen project folder.

UNIT CELL

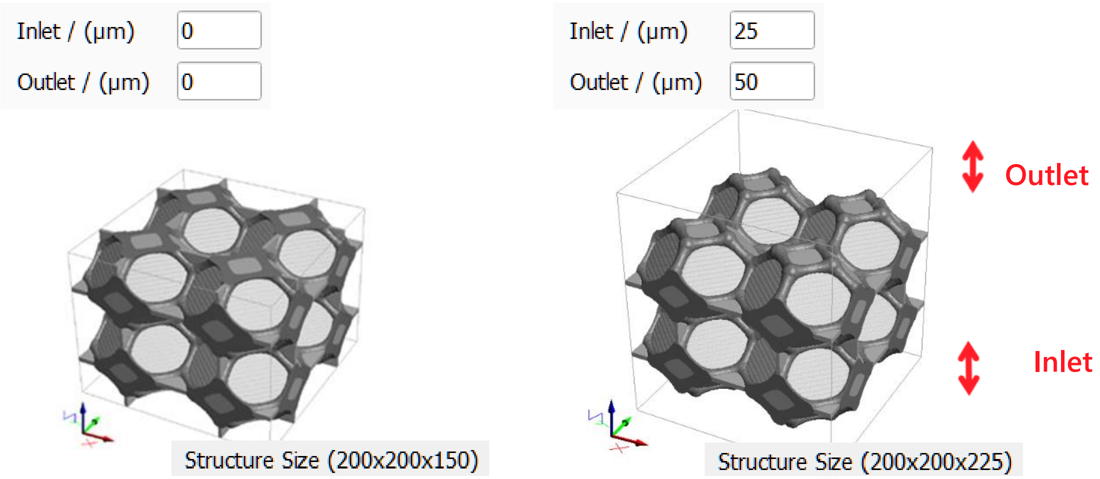
Grid Length X, **Grid Length Y**, and **Grid Length Z** define the size of one unit cell of the generated Kelvin structure inside the domain. The default values define a Kelvin structure of 100 x 100 x 75 µm, but these values can be changed as shown below.

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



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 are generated without and with **Inlet** and **Outlet**.



The final size of the domain is shown in the chosen metrical unit as **Width (X)**, **Length (Y)**, and **Height (Z)** in the Domain panel of the Unit Cell tab. Also shown is the number of voxels in each direction (**NX**, **NY**, and **NZ**), which depends on the entered **Voxel Length**.

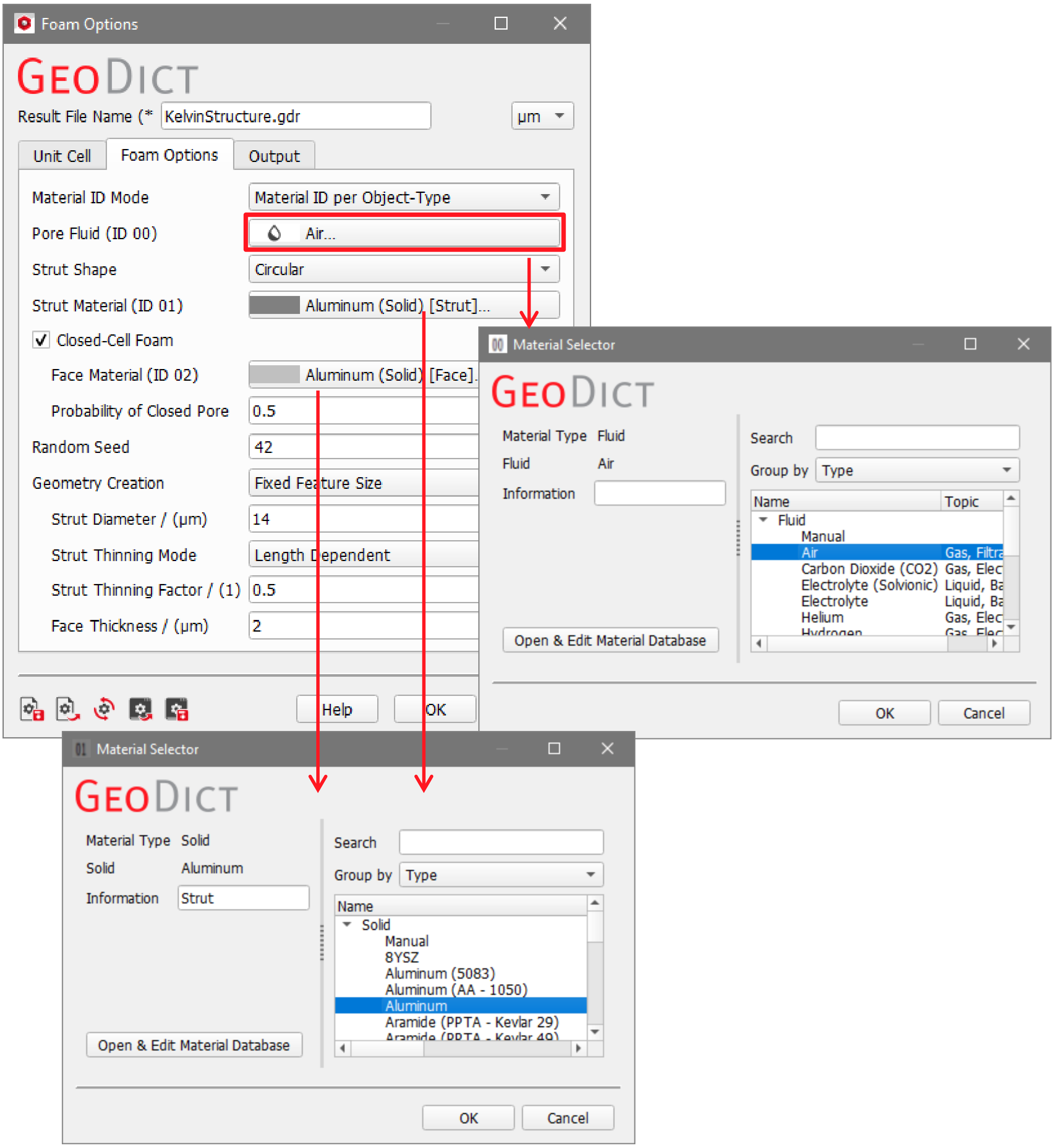
Foam Options

In the **Foam Options** tab the materials of the foam components and the options for the struts can be entered. Here, one can also select to model an open-cell foam or a closed-cell foam. If a closed-cell foam is modelled, options for the faces become available.

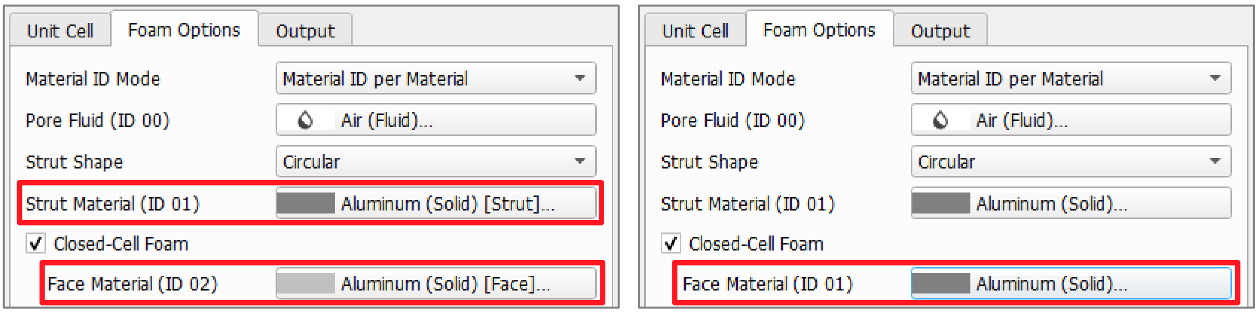
Material Options

The pull-down menu of **Material ID Mode** has two options: **Material ID per Object-Type** and **Material ID per Material**.

For **Material ID per Object-Type**, different IDs are assigned to the fluid material in the pore space and the solid materials of the struts and faces. The materials for **Pore Fluid (ID 00)**, 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.

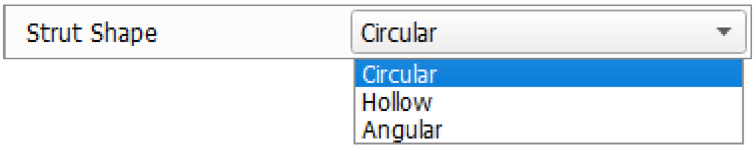


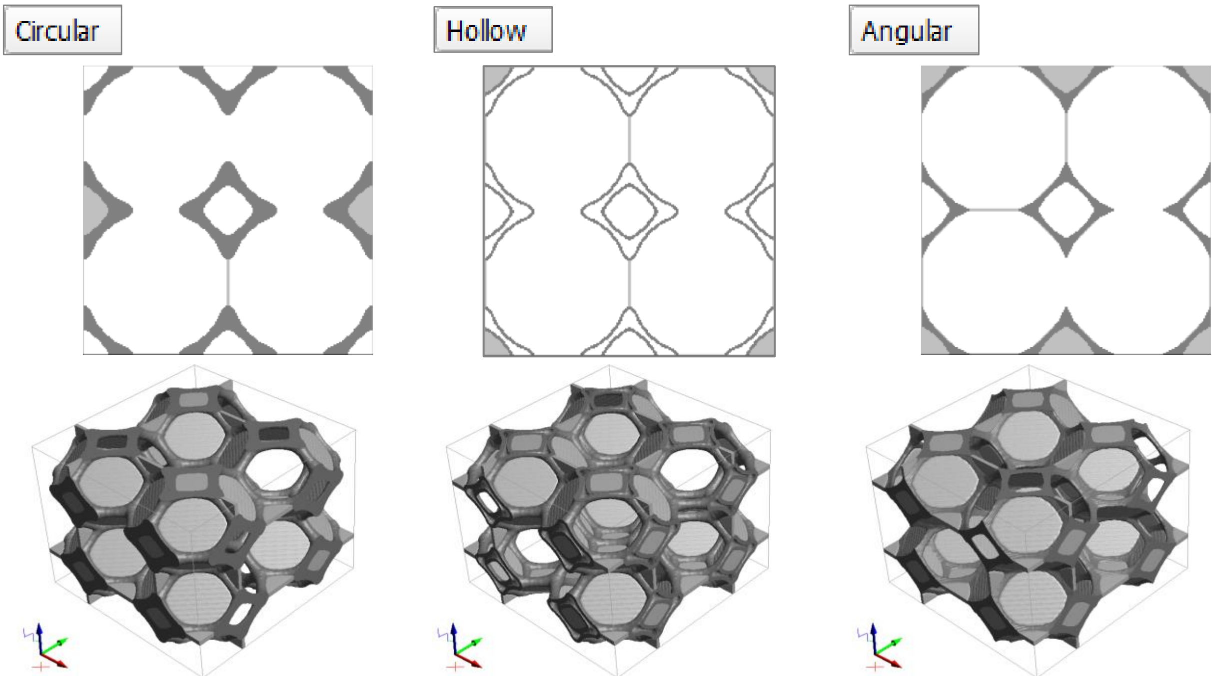
For **Material ID per Material**, Strut Material and Face Material are assigned to the same Material ID (ID 01), if the same material is chosen. By default, the materials have the additional information Strut or Face. This has to be deleted in order to have the same material for both components. To do so, click on the material name and clear the **Information** field in the **Material Selector**.



Strut Shape

The shape of the foam cell strut can be selected in the **Strut Shape** pull-down menu. The strut shape can be **Circular**, **Hollow** or **Angular**.

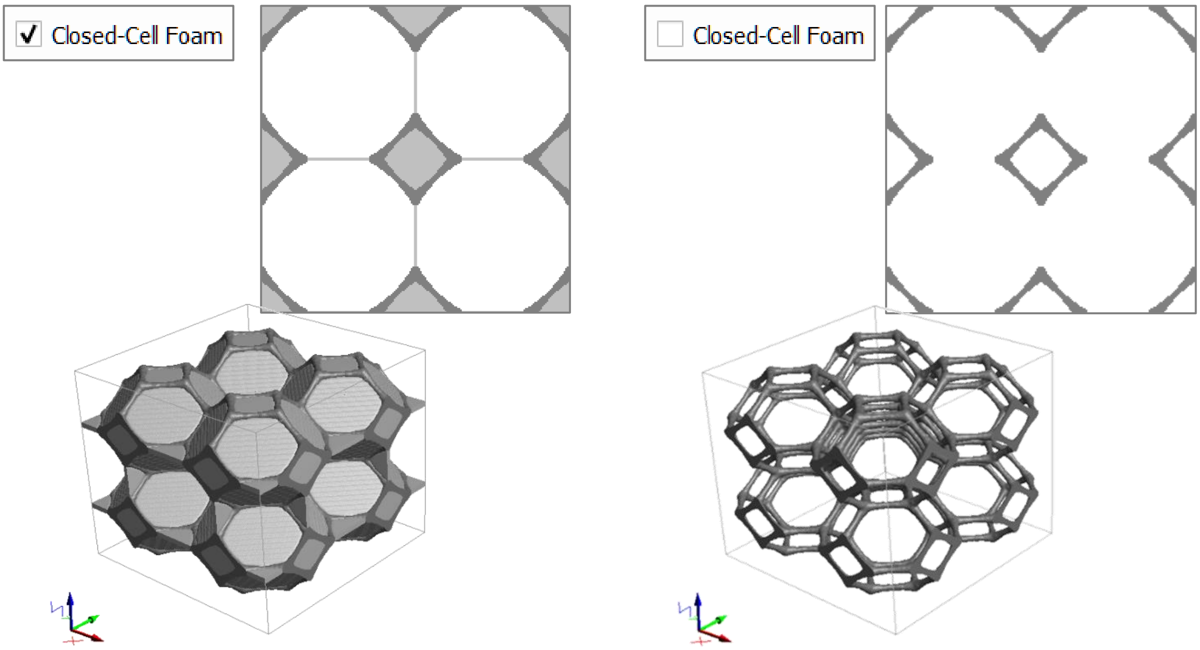




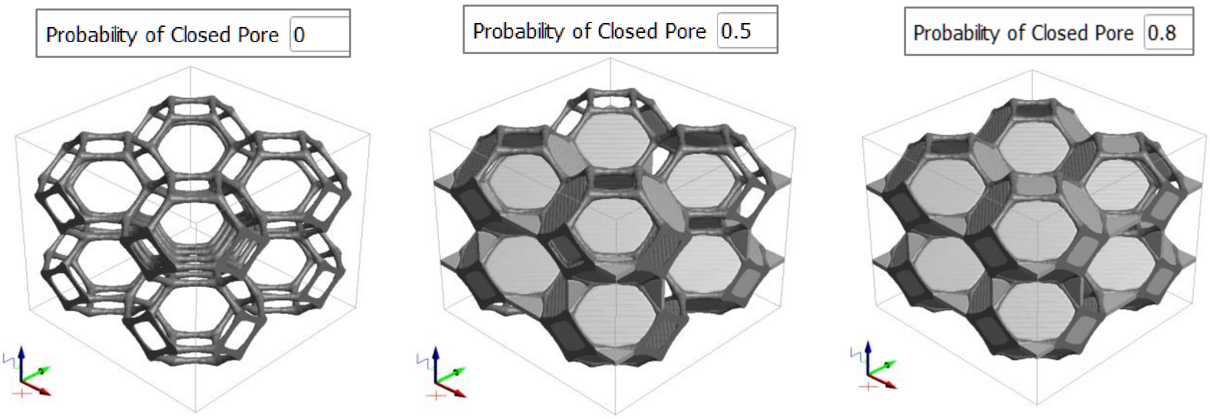
Closed-Cell Foam

If **Closed-Cell Foam** is checked, cells with faces are generated. The **Probability of Closed Pore** determines how many cells are closed.

Unchecking **Closed-Cell Foam** generates a sponge or open-cell foam, with the struts forming a polygon without faces in between.



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.



When **Closed-Cell Foam** is unchecked, the structure has no faces and thus, the **Face Material**, the **Probability of Closed Pore** and the **Face Thickness** (see page 10) cannot be chosen.

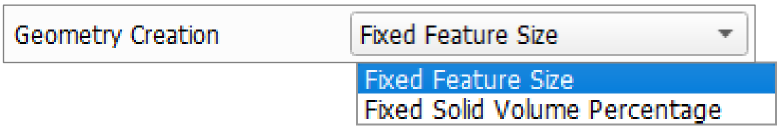
Random Seed

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. **Random Seed** is a non-negative integer number.

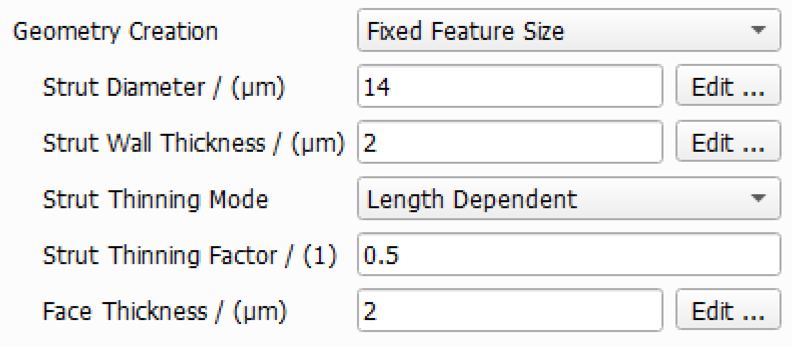
Varying the **Random Seed** allows generating different samples of the same foam structure.

Geometry Creation

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



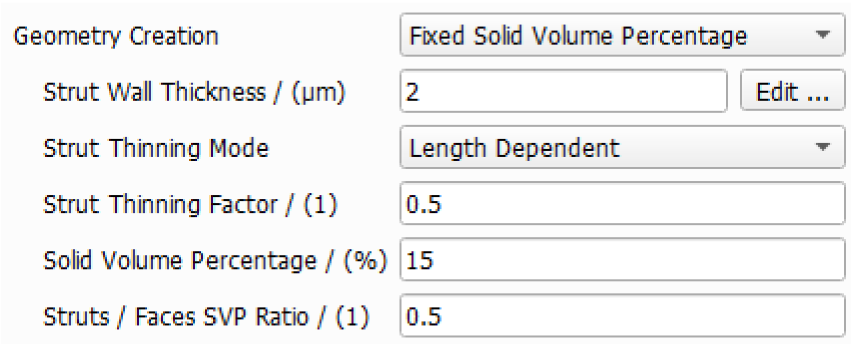
Select **Fixed Feature Size** to create a foam with a fixed size distribution for the strut diameters, the face thickness and, if **Hollow** as Strut Shape is selected, the thickness of the strut walls.



Strut Diameter distribution, **Strut Wall Thickness** distribution and **Face Thickness** distribution can be entered by clicking the **Edit...** buttons in this mode. Details are explained in the next section.

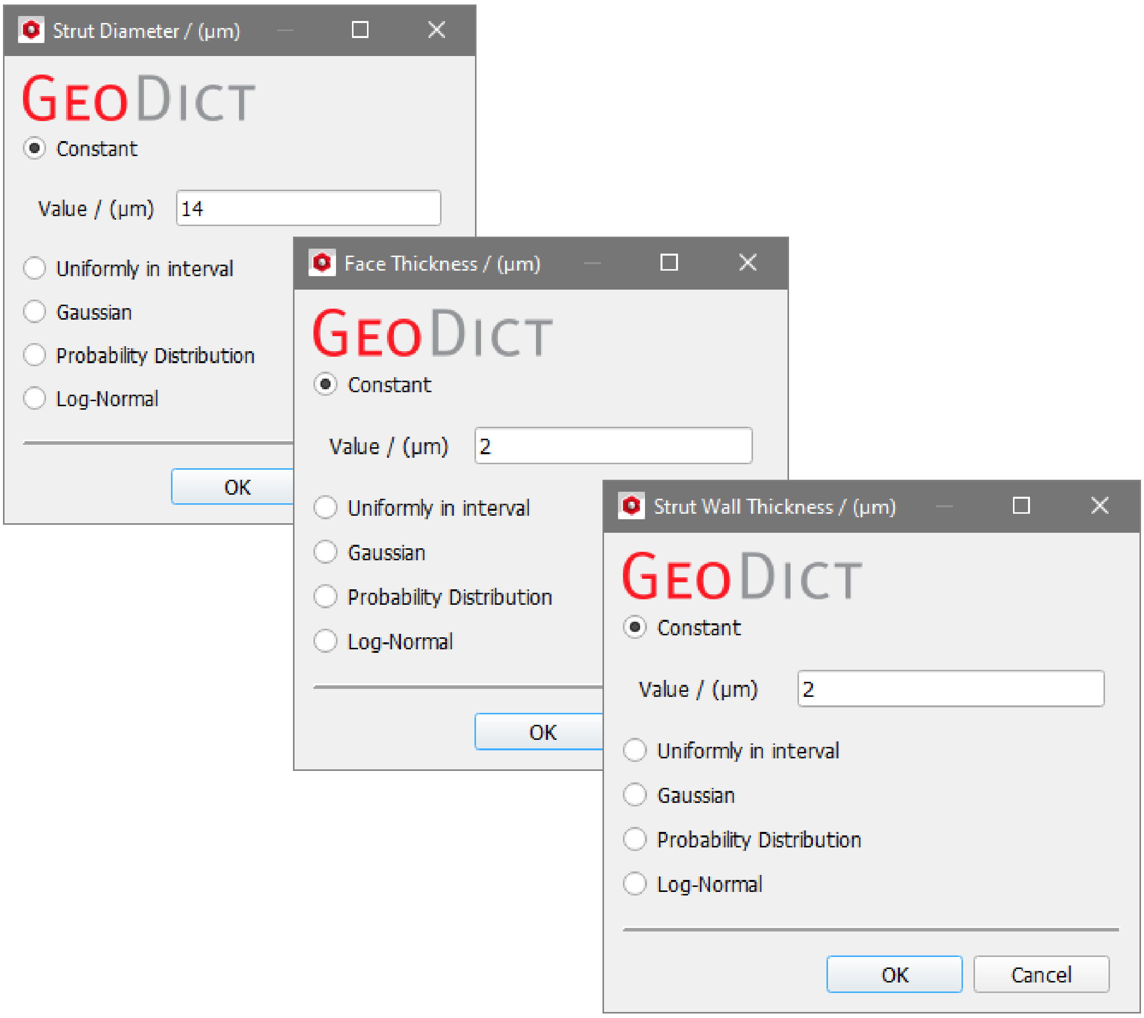
For both modes, the thinning of struts is defined by the **Strut Thinning Factor** and the **Strut Thinning Mode**. The **Strut Thinning Factor** determines the rate by which the diameter of the strut diminishes towards the center of each strut. The **Strut Thinning Mode** defines if this thinning depends on the length of the strut or is independent of the length and thus fixed. More details can be found in the section Strut Thinning.

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. The **Strut Wall Thickness** is only available for the Strut Shape **Hollow** and can be defined in the same way as before.

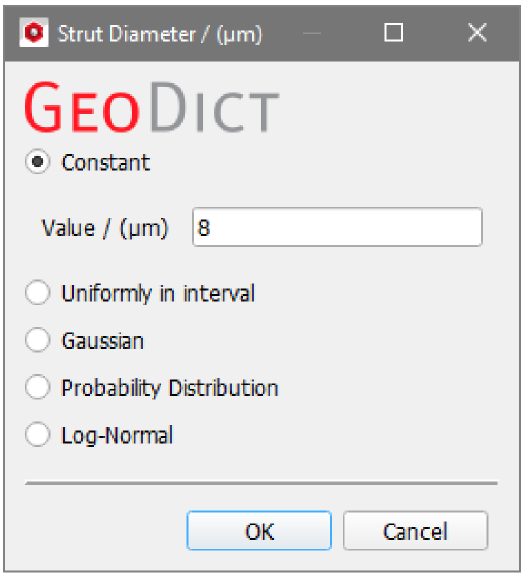


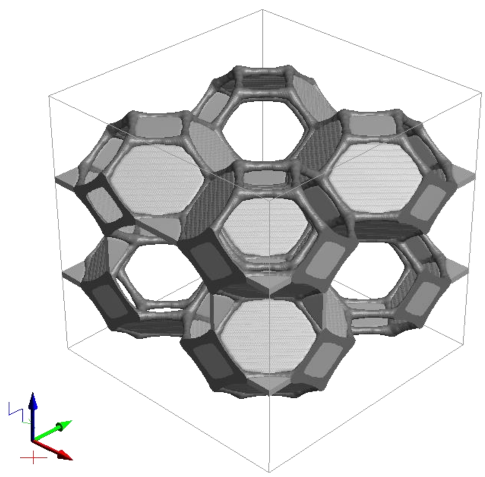
Strut Diameter, Face Thickness and Strut Wall Thickness Distribution

Clicking on the **Edit...** button for the **Strut Diameter**, the **Face Thickness** and the **Strut Wall Thickness** offers several options. Every parameter can be set to a **Constant** value, or to follow a distribution (**Uniformly in interval**, **Gaussian**, **Probability Distribution**, or **Log-Normal**).

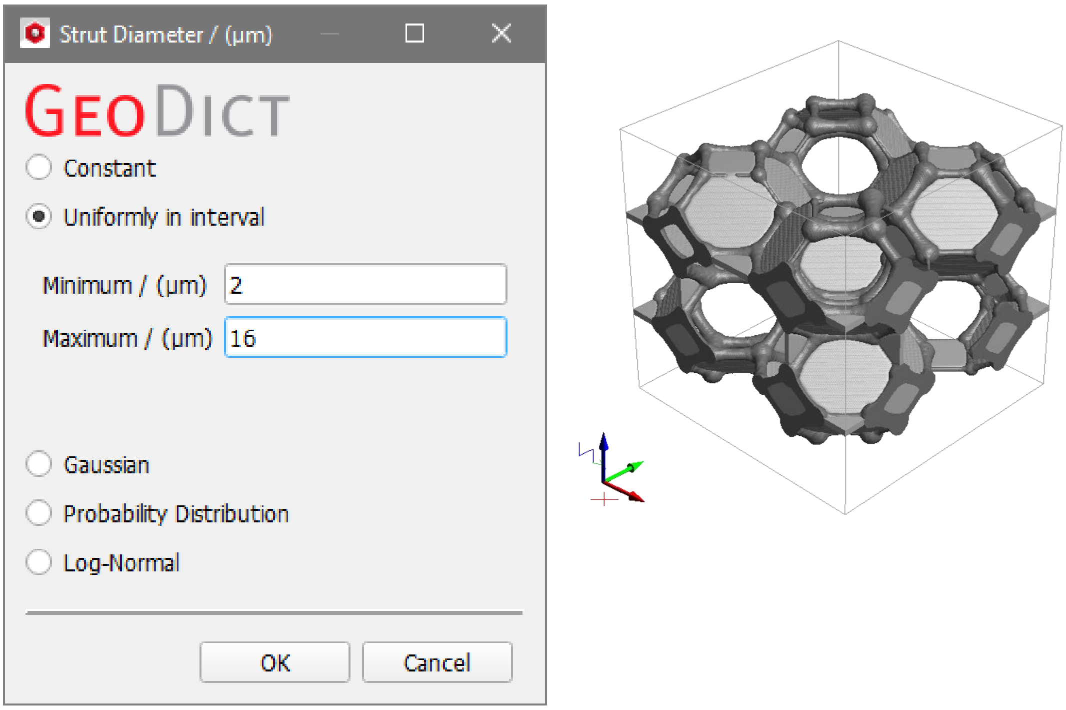


Observe the effect of entering values of **Strut Diameter**, as shown in the dialog boxes, on the generated random foam shown on the right.





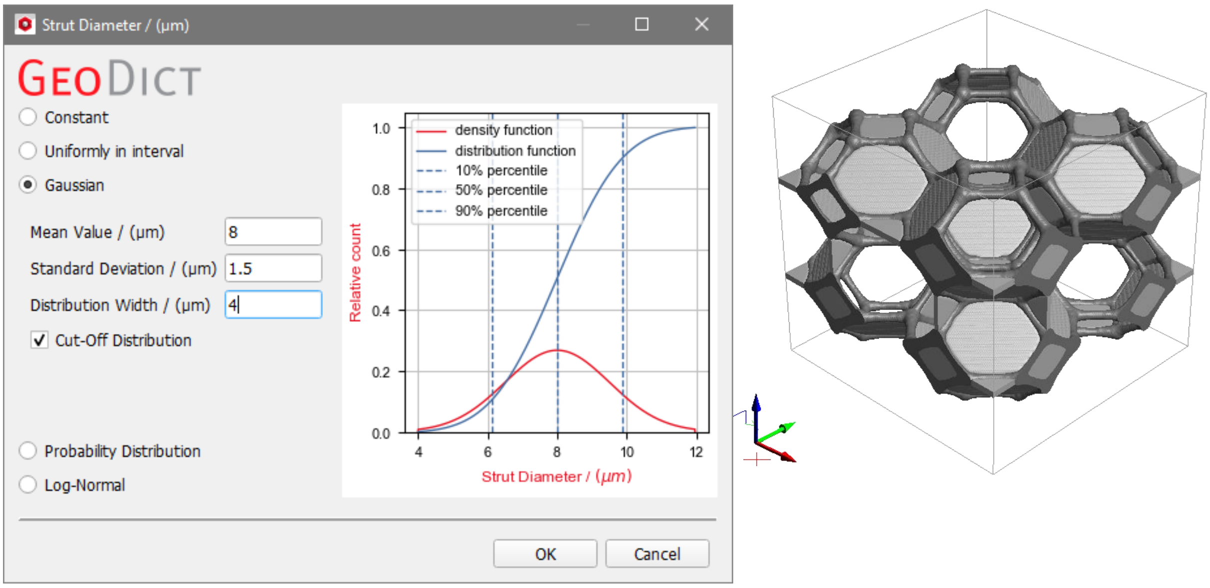
When selecting **Uniformly in interval**, and entering a **Minimum** value and a **Maximum** value, the strut diameter can take any value within this interval.



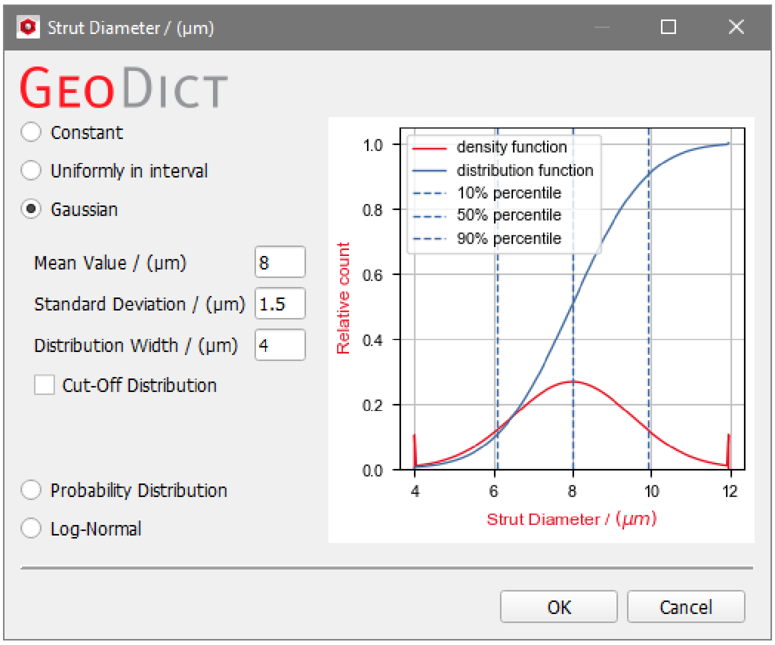
Taking the **Gaussian** (or **normal**) distribution, the value follows a bell-shaped distribution. The strut diameter value clusters around the entered **Mean Value** but may vary according to the entered **Standard Deviation**.

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, resulting in strut diameters between 4 µm and 12 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.



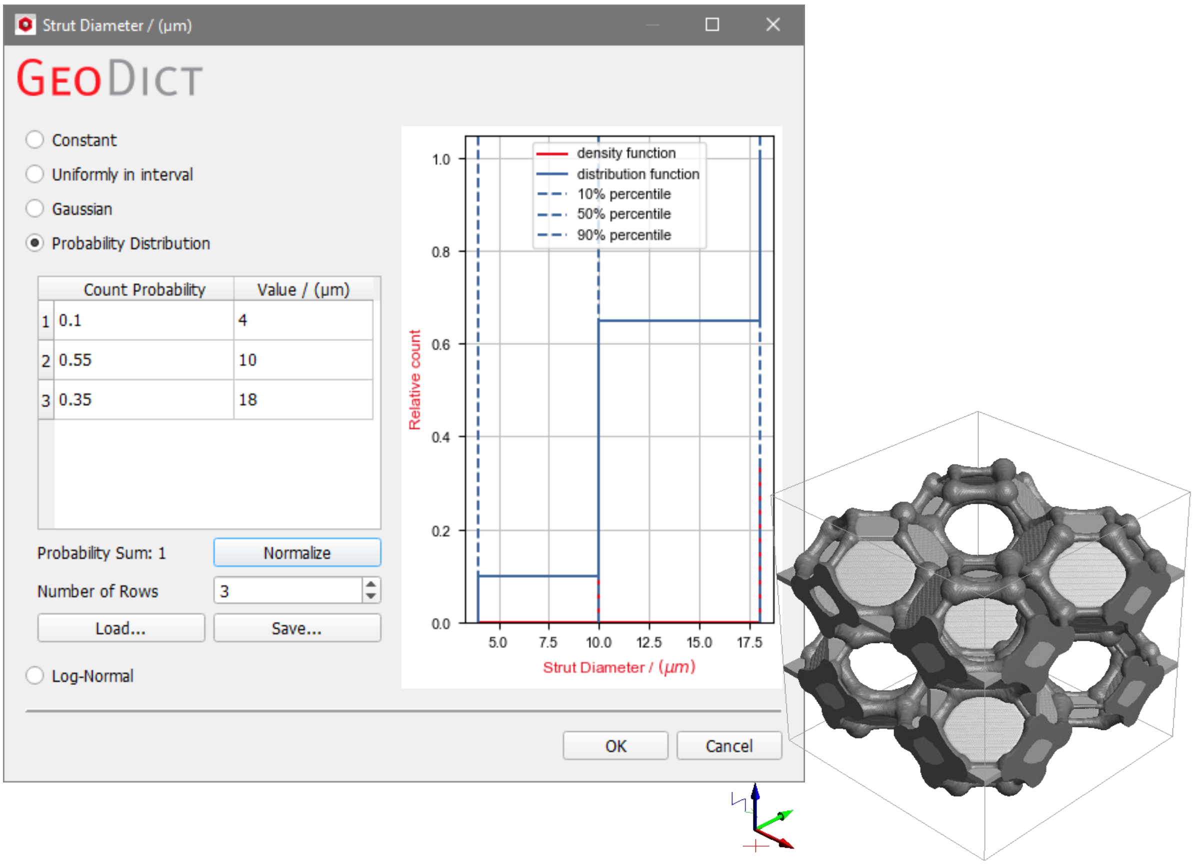
If **Cut-Off Distribution** is checked, the distribution is truncated at the bounds. This means, that all values outside the bounds are dropped and not considered for generation. If this option is not checked, then all values that are outside of the bounds are set to be on the distribution bound.



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 as desired.

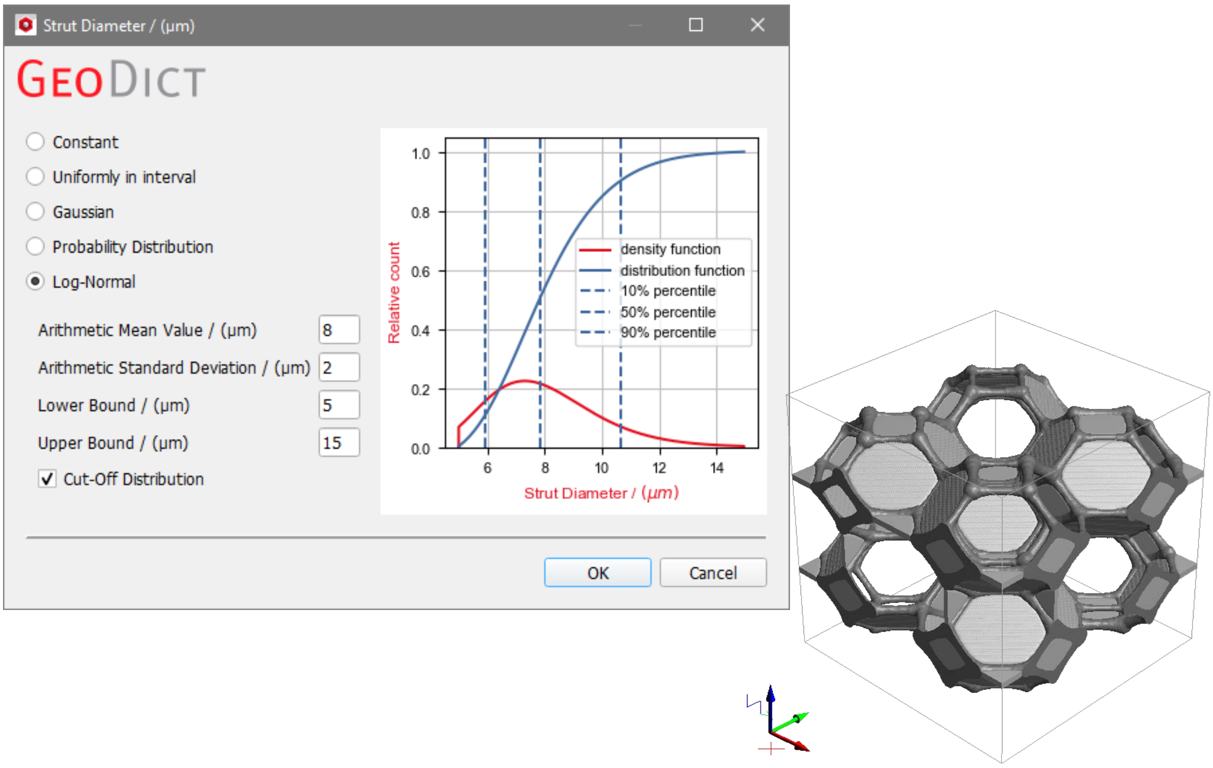
For large tables, it is useful to observe the value of **Probability Sum**. It corresponds to the sum of the count probabilities. When the **Probability Sum** is not equal to 1, click the **Normalize** button to automatically normalize the **Count Probability** values, such that the probability sum is 1.

Use **Load** and **Save** to load a probability distribution previously saved as *.txt file 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.

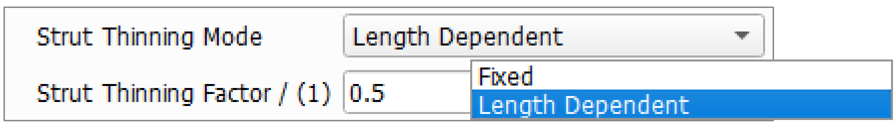
The strut diameter values group around the entered **Arithmetic Mean Value** but may diverge according to the entered **Arithmetic Standard Deviation**. The values in **Lower Bound** and **Upper Bound** limit the possible values under and over the arithmetic mean value, thus restricting the values that the random diameters can take. The effect of **Cut-Off Distribution** is the same as described before when choosing Gaussian distribution.



Strut Thinning

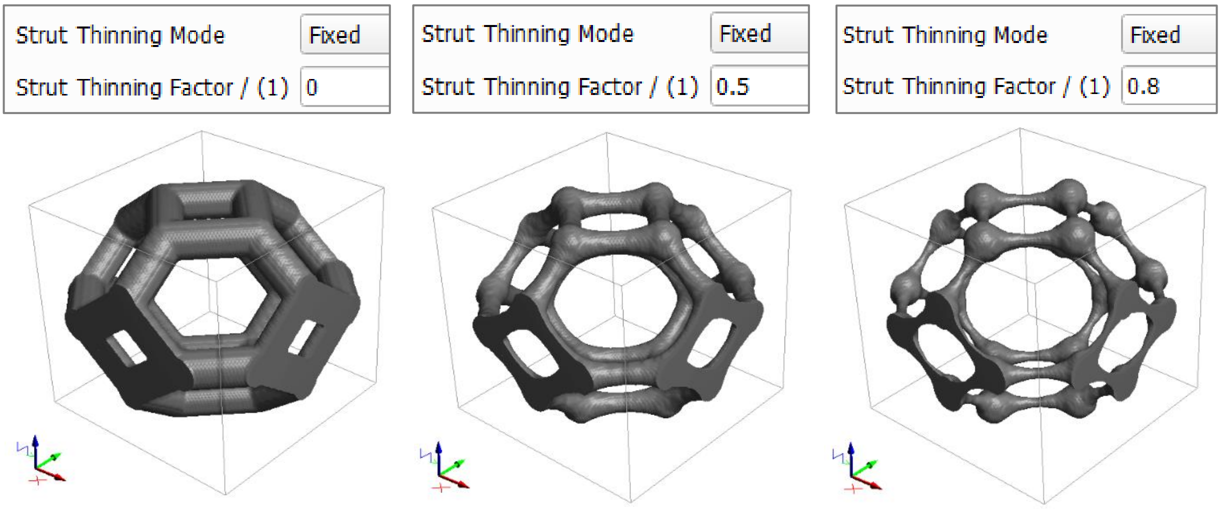
The **Strut Thinning Factor** determines the rate by which the diameter of the strut diminishes towards the middle of one strut.

The **Strut Thinning Mode** determines if this thinning is length dependent or not. Select **Fixed** to thin all struts equally, independent of 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 by 50% from near the nodes to the middle of the strut. For length dependent strut thinning, the strut diameter decreases by 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.

The effect of different thinning factors for the thinning mode **Fixed** is shown here.

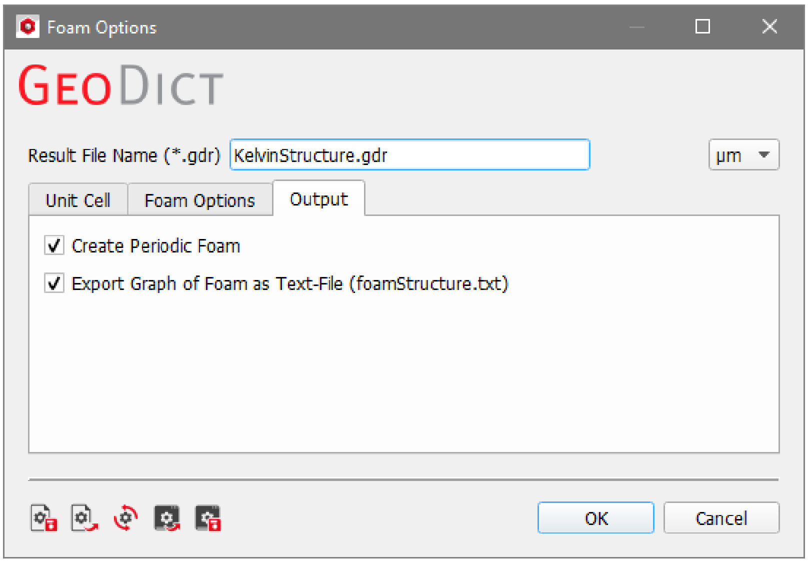


Since the effect of length dependent strut thinning is better visible for random foams, an example is shown on page 24.

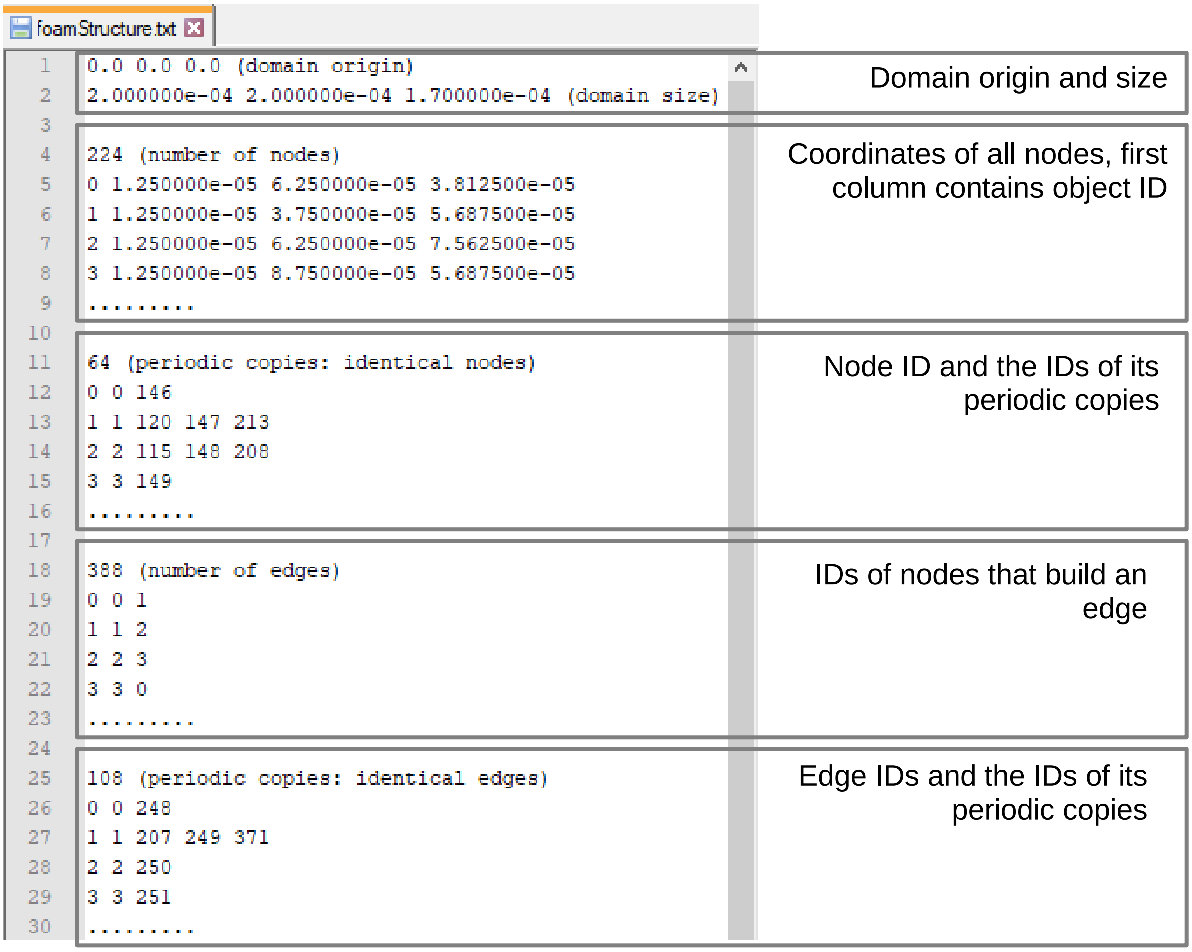
OUTPUT

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.



```
182 (number of faces)
0 4 0 1 2 3
1 4 4 5 6 7
2 4 8 9 10 11
3 4 12 13 14 15
.........
```

Number and IDs of edges that build a face

```
46 (periodic copies: identical faces)
0 0 113
1 2 73
2 6 93 135 174
3 7 145
.........
```

Face IDs and the IDs of its periodic copies

```
17 (number of cells)
0 14 0 1 2 3 4 5 6 7 8 9 10 11 12 13
1 14 14 15 16 17 18 19 20 21 22 23 24 25 26 6
2 14 27 28 17 29 30 31 32 33 34 35 36 37 7 38
3 14 15 39 40 41 42 43 44 45 46 10 47 48 49 50
.........
```

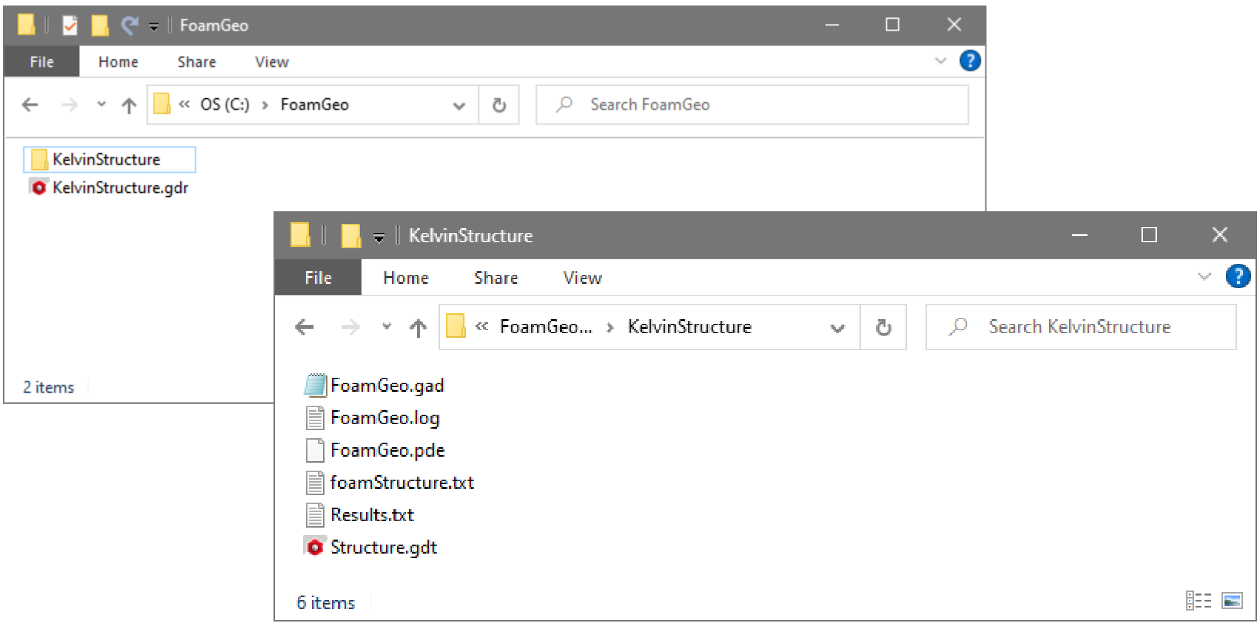
Number and IDs of faces that build a cell

```
3 (periodic copies: identical cells)
0 1 7 11 15
1 2 12
2 3 8
```

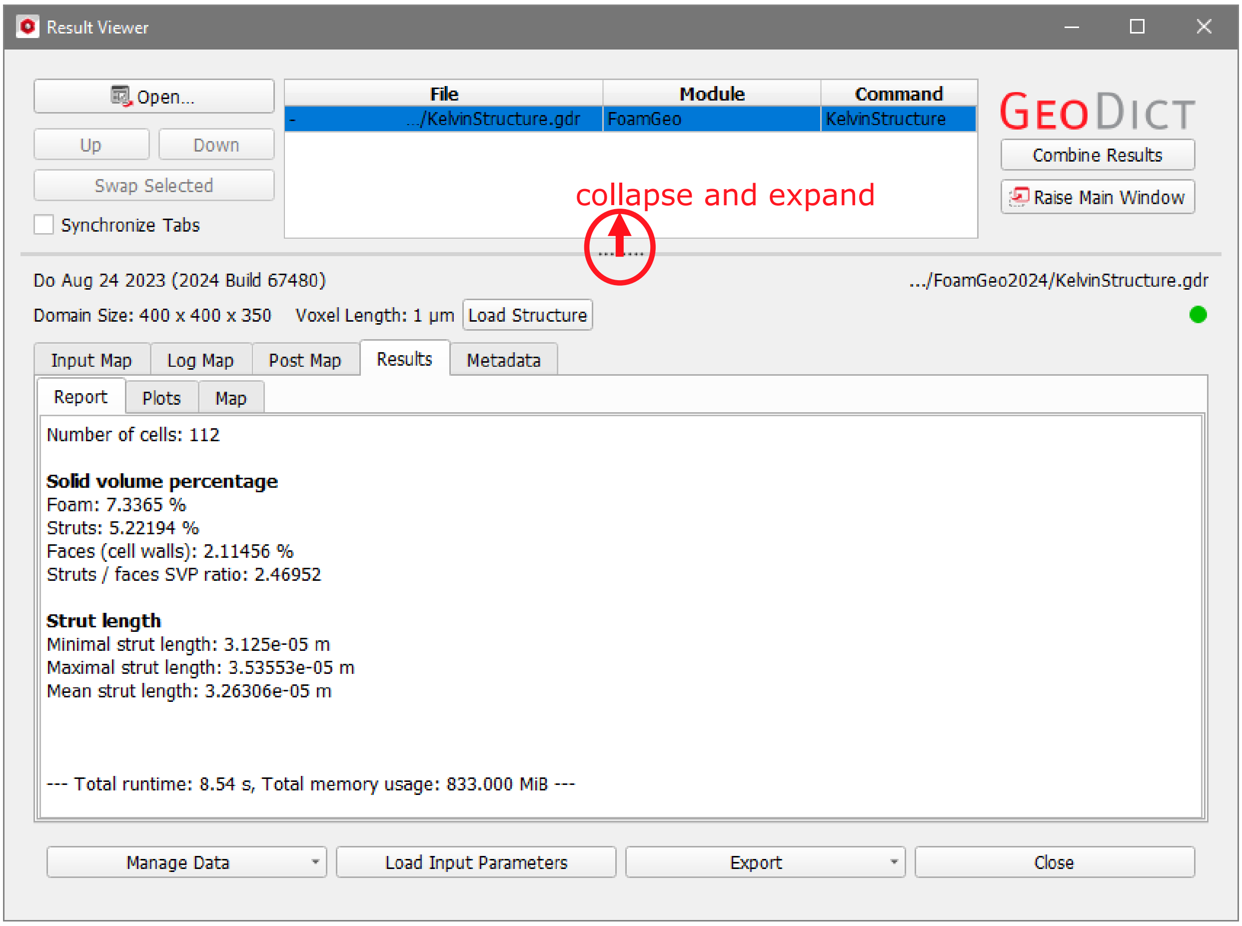
Cell ID and the ID of its periodic copies

Result Files

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).

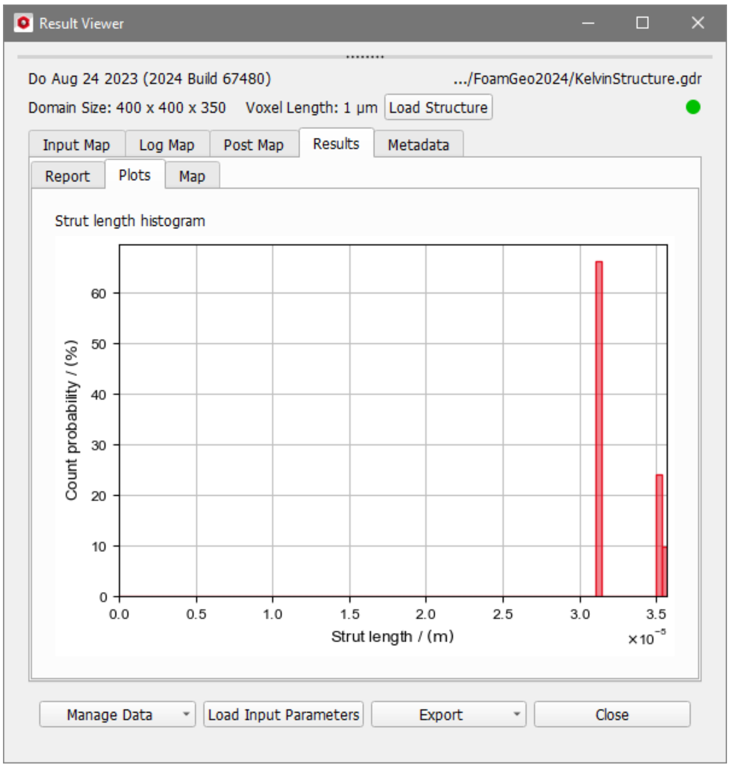


The GeoDict Result Viewer for the *.gdr file created opens automatically after the generation is finished. More information on working with the Result Viewer can be found in the GeoDict Result Viewer handbook.



The **Results - Report** subtab lists the solid volume percentages (SVP) for the whole foam, and for struts and faces separately. The Struts / faces SVP ratio is the SVP of the struts divided by the SVP of faces; here 5.22 % / 2.11 % = 2.47. The minimal, maximal and mean strut length are reported additionally.

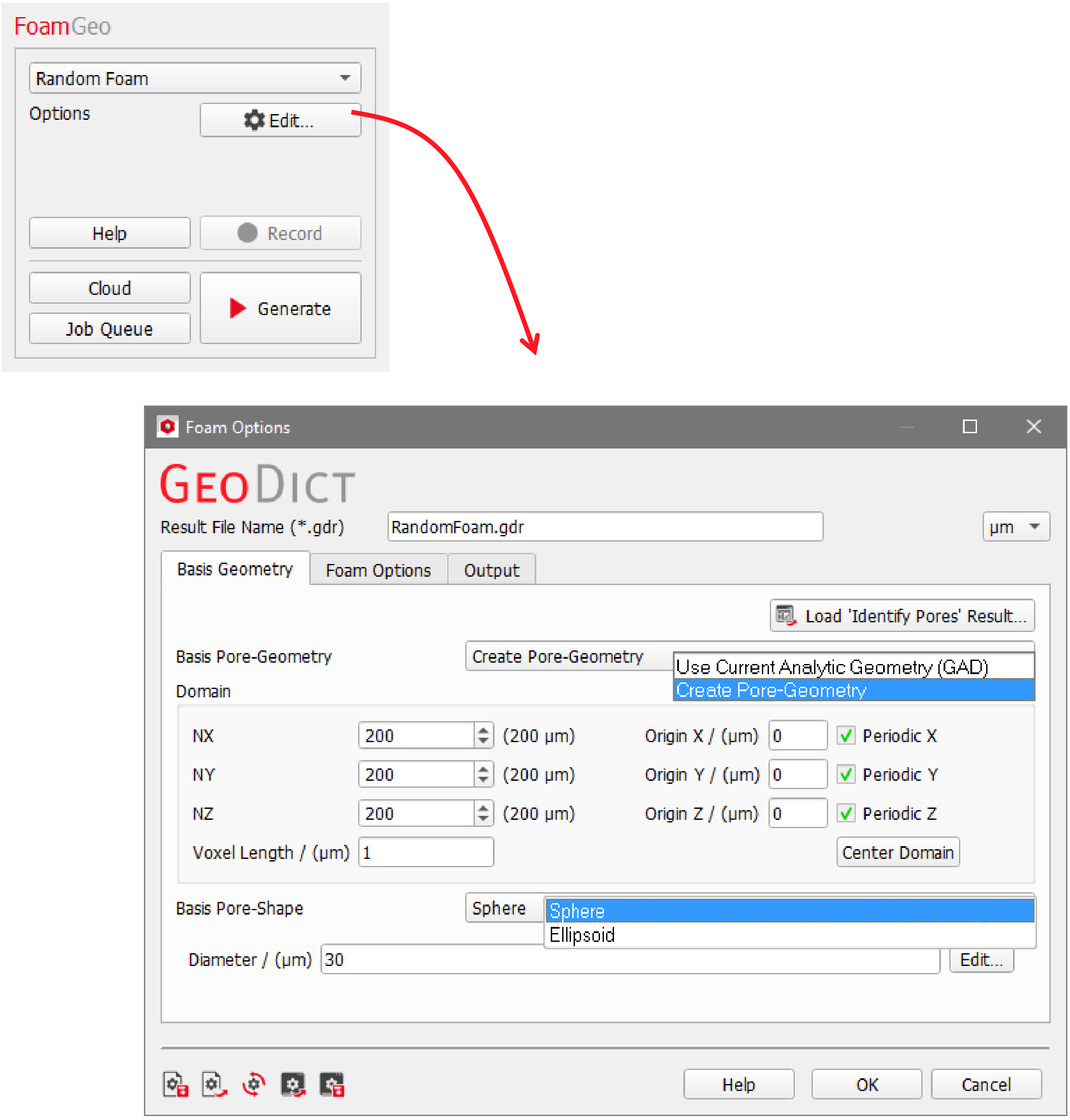
More detailed information about the strut length distribution, is available on the **Plots** subtab, where a strut length histogram is shown.



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 in the upper right corner.



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

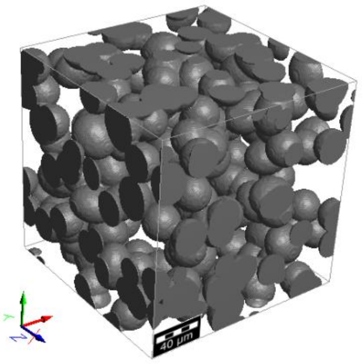
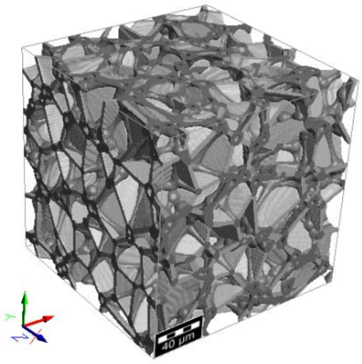
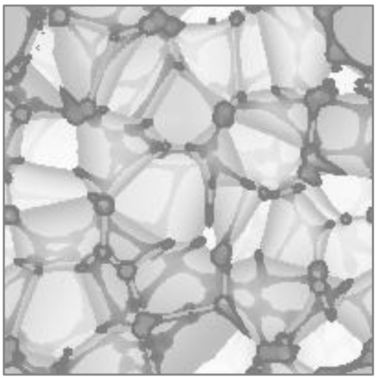
In the upper right corner of the **Foam Options** dialog, click **Load 'Identify Pores' Result ...** and select a GeoDict result file (*.gdr) from a PoroDict Identify Pores run. The data from the *.gdr file is now directly loaded into FoamGeo.

Basis Geometry

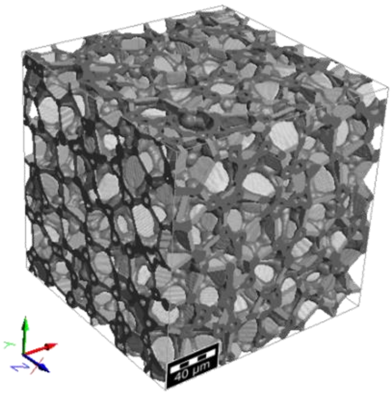
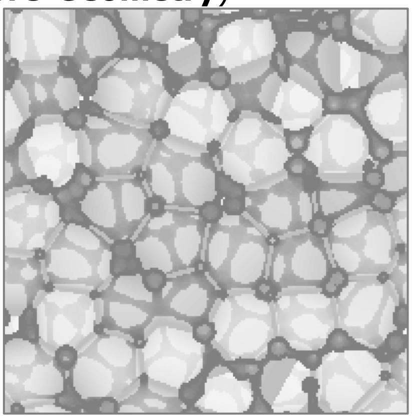
A random foam is generated based on a random homogeneous pack of spheres or ellipsoids called **Basis Pore-Geometry**. Each cell in the generated foam corresponds to an object (sphere or ellipsoid) in the **Basis Pore-Geometry**. For example, if the **Basis Pore-Geometry** contains 100 spheres with a diameter of 50 µm, the foam will contain 100 cells with a diameter of approx. 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. To create a random foam, at least 9 GAD-objects with a minimal object diameter of 20 voxel must be present in the structure. The analytic data is then taken as basis geometry to form the foam.

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

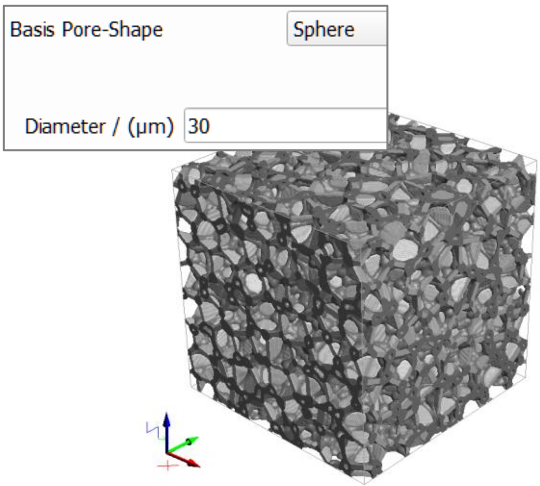
The parameters described in the following are only available if **Create Pore-Geometry** is chosen. If instead the current analytic geometry is used, no more settings need to be made in the **Basis Geometry** tab.

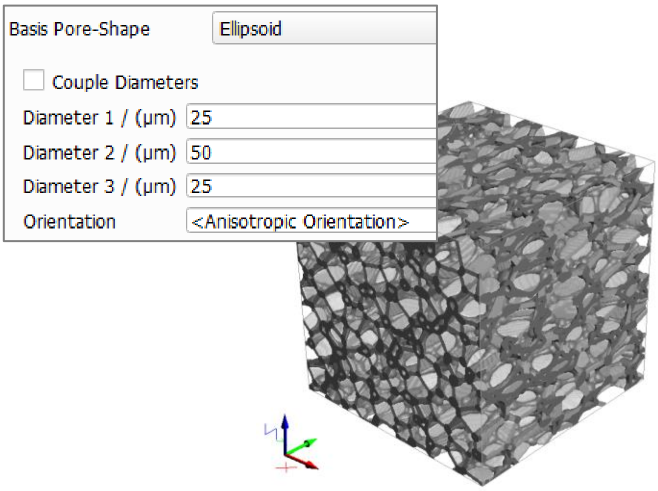
The parameters in the **Domain** panel determine the random foam size. **NX**, **NY**, and **NZ** determine the number of voxels of the grid in the X, Y, and Z direction, respectively. The size of the structure created depends on **NX**, **NY**, and **NZ** and on the entered **Voxel Length** (size of a voxel in the selected units).

The coordinates of the domain origin can be set to those given in **Origin X, Origin Y** and **Origin Z**. Alternatively, click **Center Domain** to set the origin (0,0,0) to NX/2, NY/2, and NZ/2.

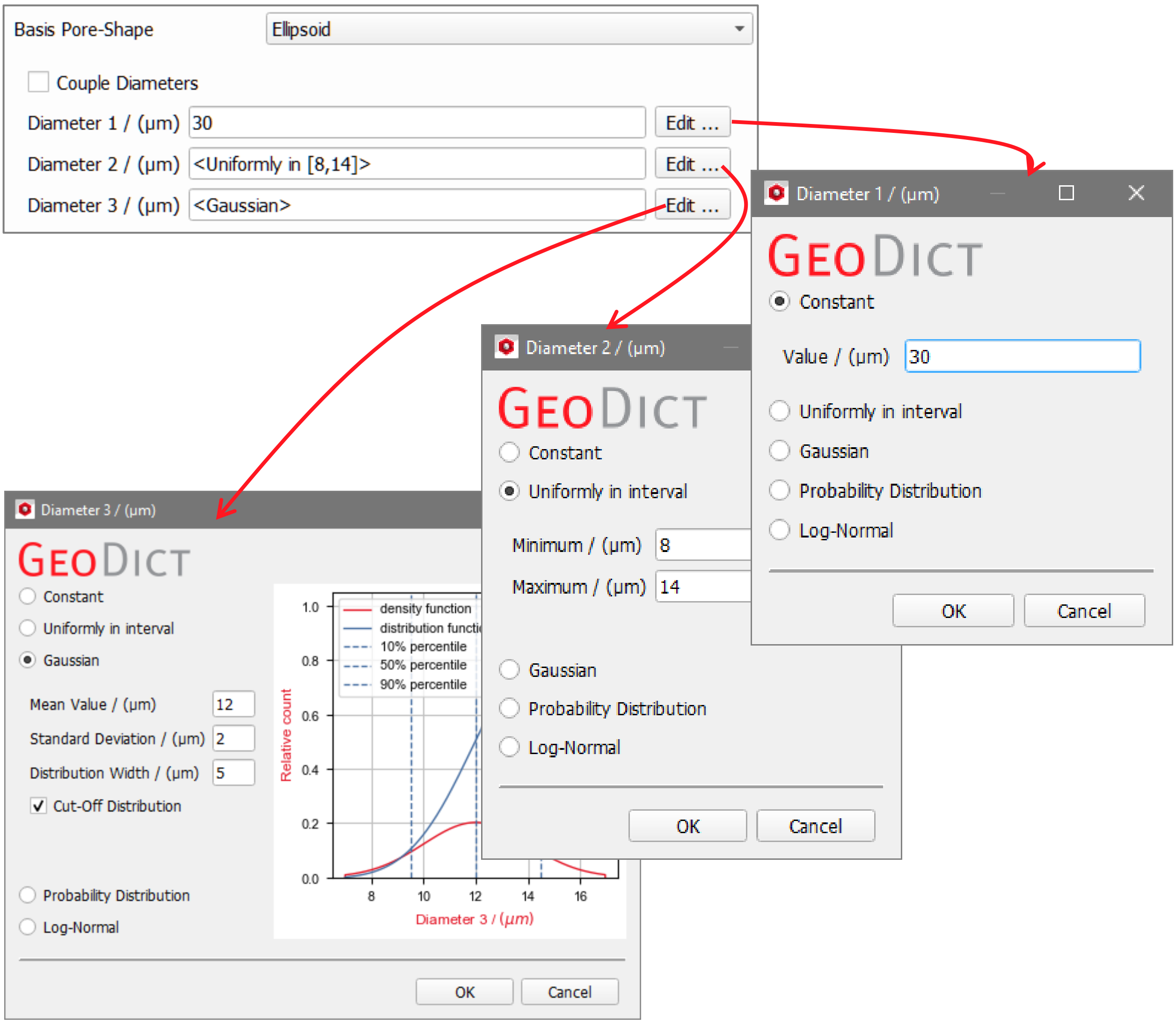
From the **Basis Pore-Shape** pull-down menu, select the shape for the desired basis pore to be a **Sphere** or an **Ellipsoid**. The volume of the random foam cells resulting from the selected basis pore shape is always a bit larger than the basis pore shape volume.

When selecting **Sphere**, the user enters the **Diameter** of the spheres on which the generated foam is based. By selecting **Ellipsoid**, complex random foams can be generated.





As explained in pages 10ff 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…**.

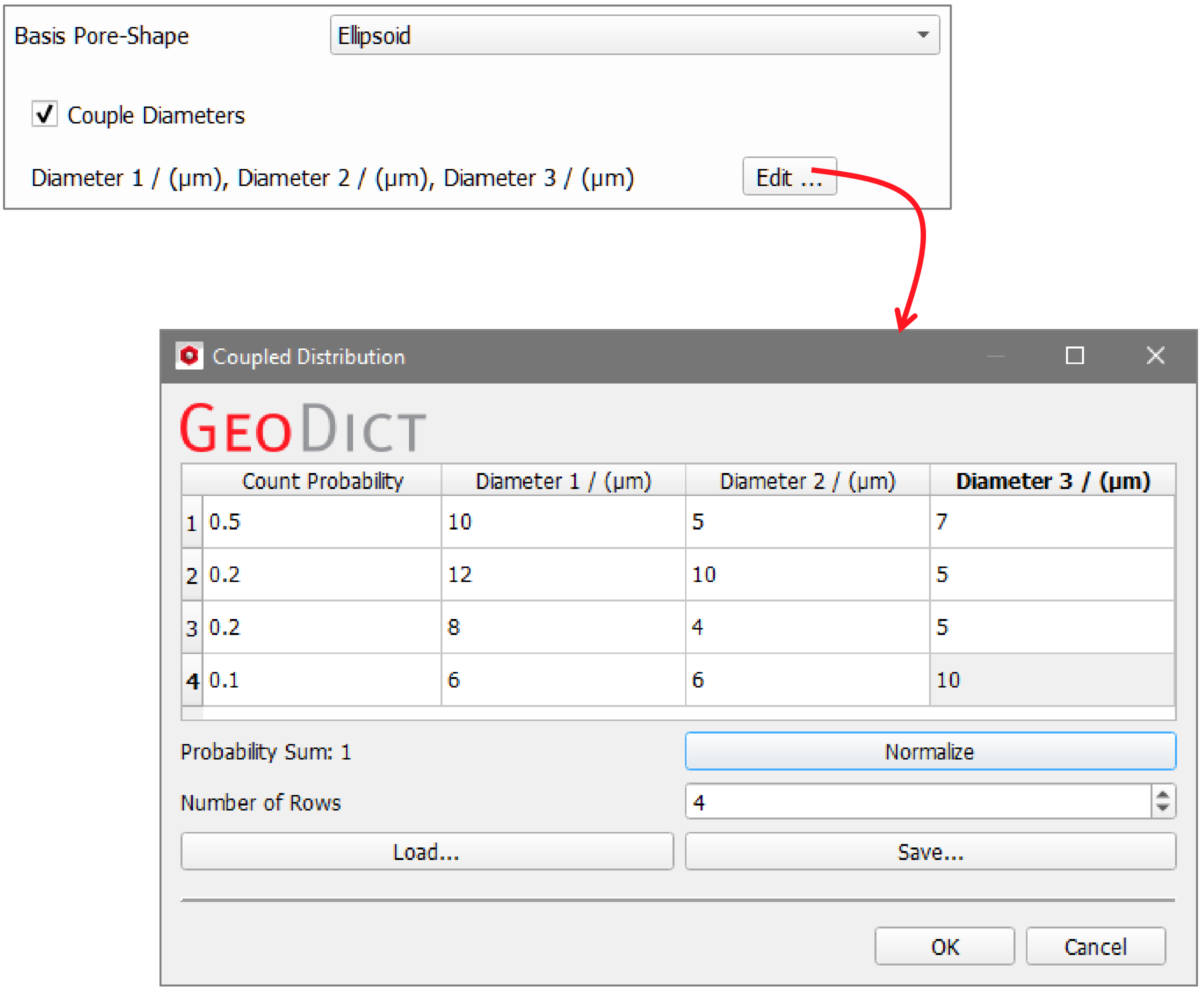


Then the diameters can be set independently to take a **Constant** value, or to follow a distribution (**Uniformly in interval**, **Gaussian**, **Probability Distribution**, or **Log-Normal**).

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.

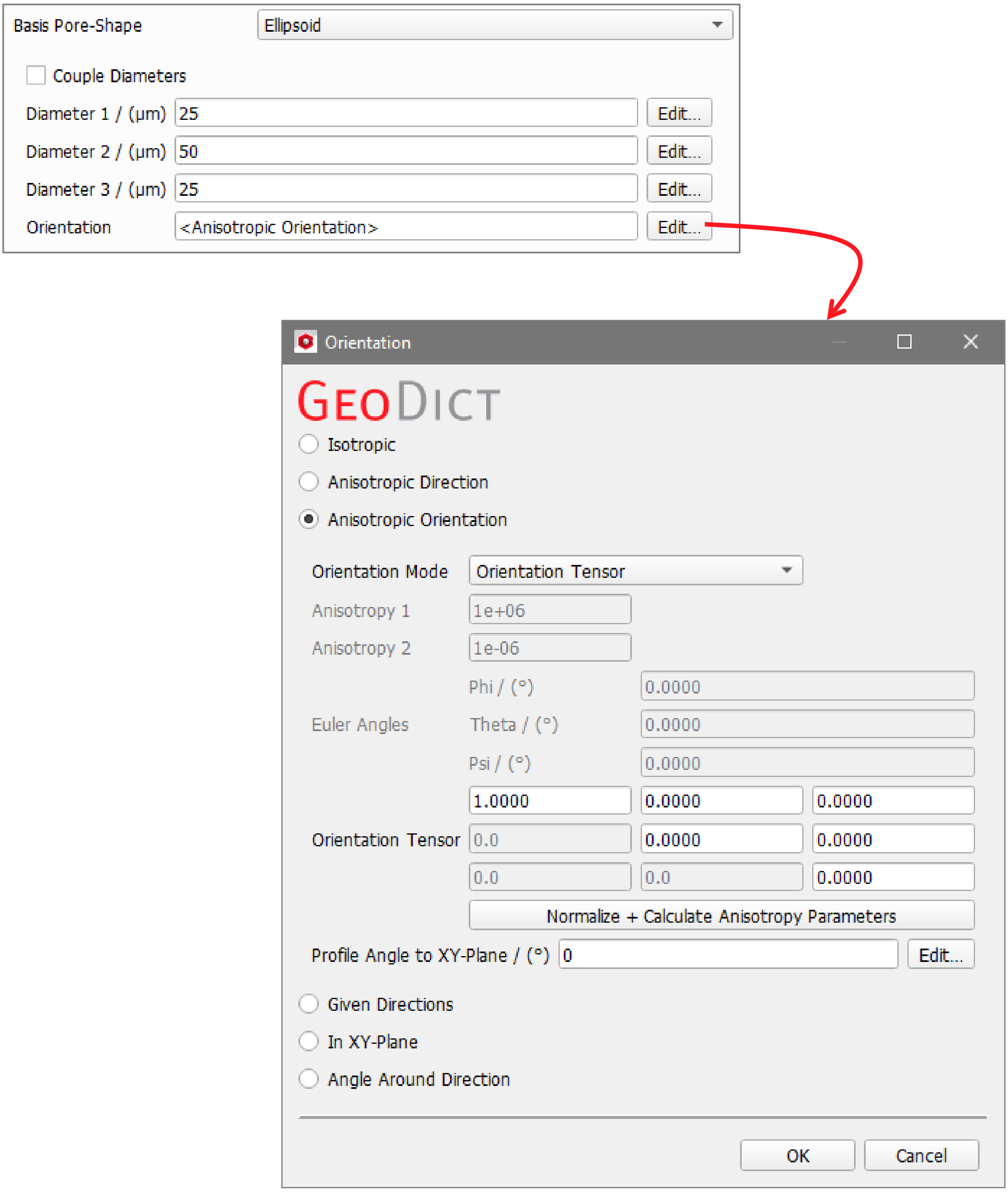
For example, leaving **Couple Diameters** un-checked, the user can click the Edit… buttons and assign a **Constant** value for **Diameter 1**, a **Uniformly in interval** distribution for **Diameter 2** and a **Gaussian** distribution for **Diameter 3**.

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.



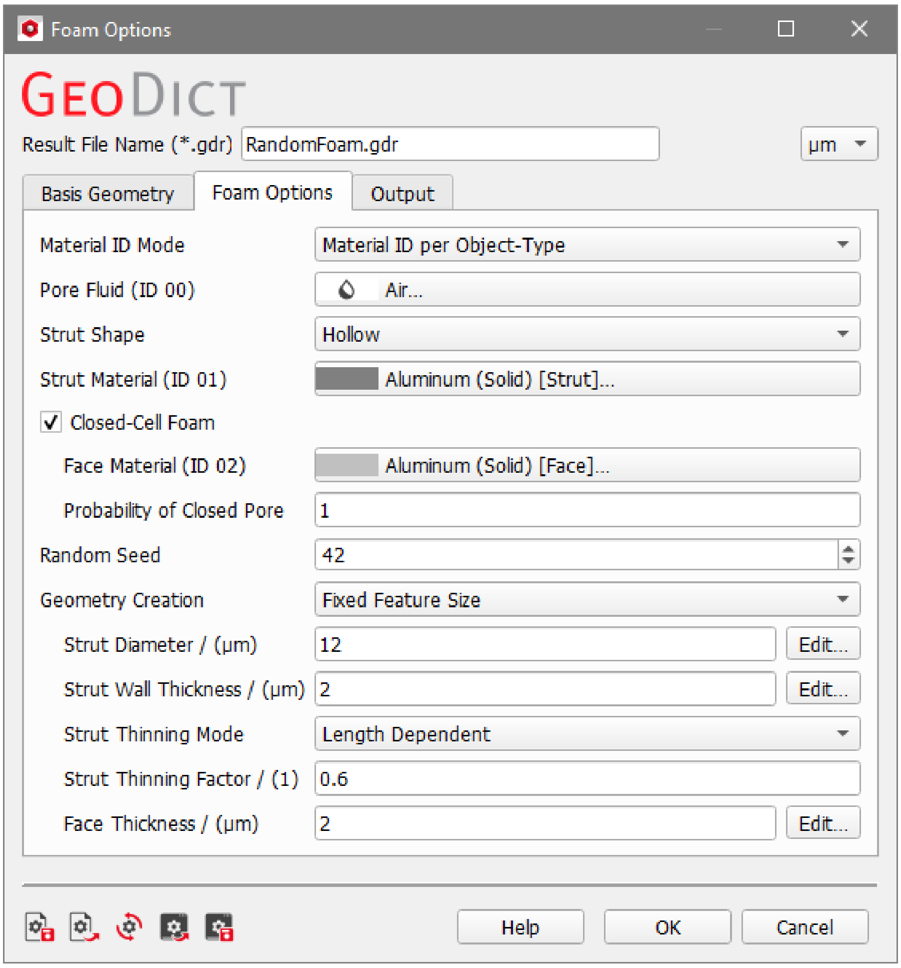
Orientation

For the Basis Pore-Shape **Ellipsoid**, an **Orientation** can be set by clicking the **Edit…** button. In the **Orientation** dialog, objects can be defined to be **Isotropic**, have a certain **Anisotropic Direction**, **Anisotropic Orientation**, **Given Directions**, are oriented **In XY-Plane** or have a maximum **Angle Around Direction**. More details on the different orientation modes can be found in the GrainGeo handbook.

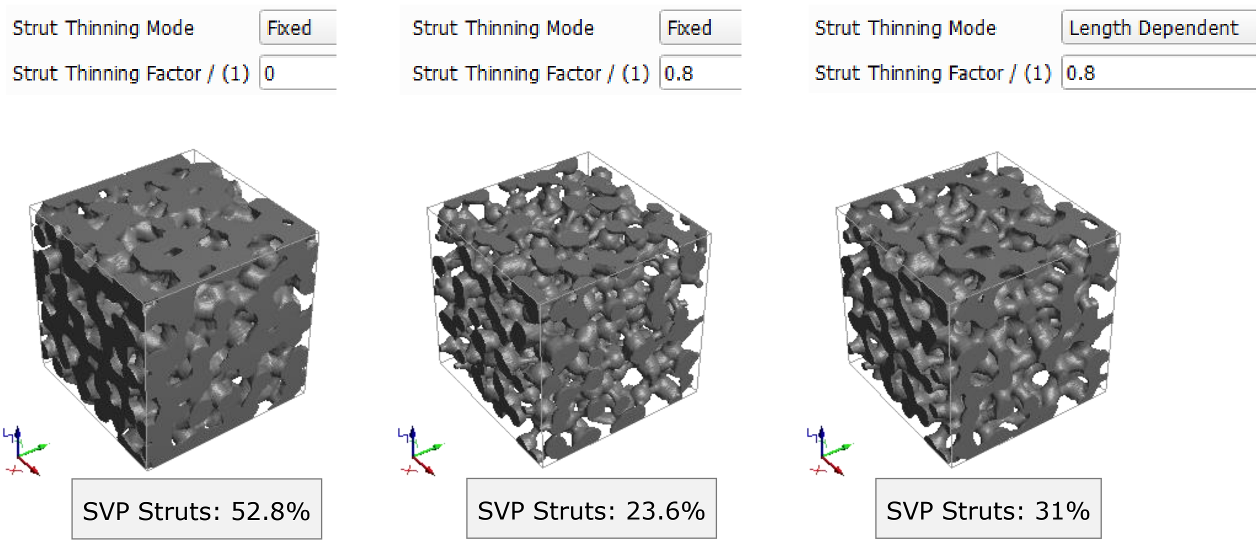

Basis Pore-Shape
Ellipsoid
Couple Diameters
Diameter 1 / (µm)
25
Diameter 2 / (µm)
50
Diameter 3 / (µm)
25
Orientation
<Anisotropic Orientation>
Edit...
Orientation
GeoDict
Isotropic
Anisotropic Direction
Anisotropic Orientation
Orientation Mode
Orientation Tensor
Anisotropy 1
1e+06
Anisotropy 2
1e-06
Euler Angles
Phi / (°)
Theta / (°)
Psi / (°)
0.0000
Orientation Tensor
1.0000
0.0
Normalize + Calculate Anisotropy Parameters
Profile Angle to XY-Plane / (°)
0
Given Directions
In XY-Plane
Angle Around Direction
OK
Cancel

Foam Options

Under the **Foam Options** tab, the parameters are the same as explained starting on page 4 for the generation of Kelvin structures.



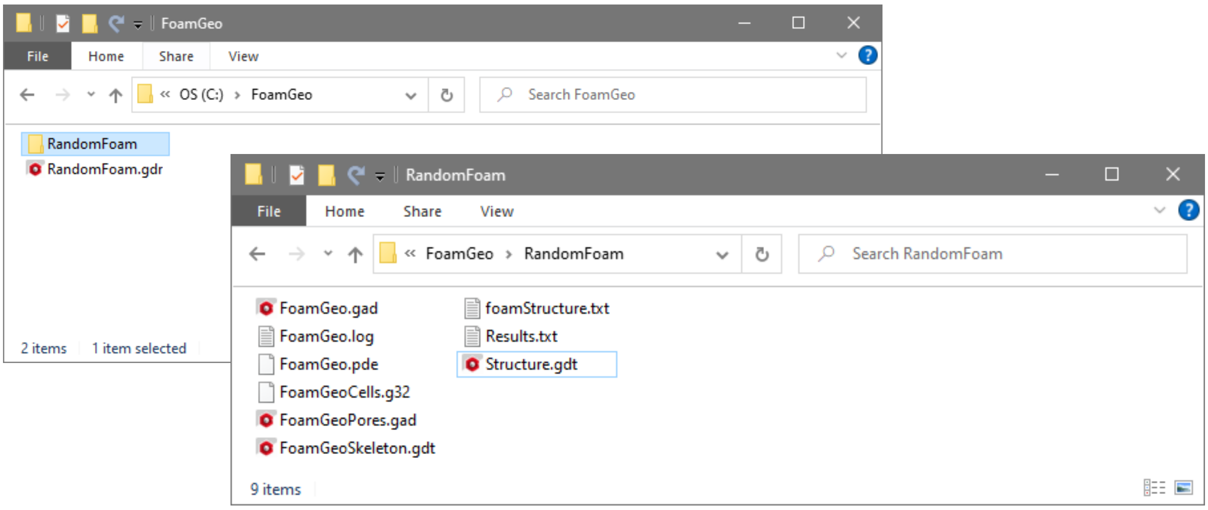
Here, an example for the strut thinning with and without length dependent thinning is shown for an open-cell foam. Observe the difference in SVP of the struts created.



Output

The **Output** tab is described on page 16.

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



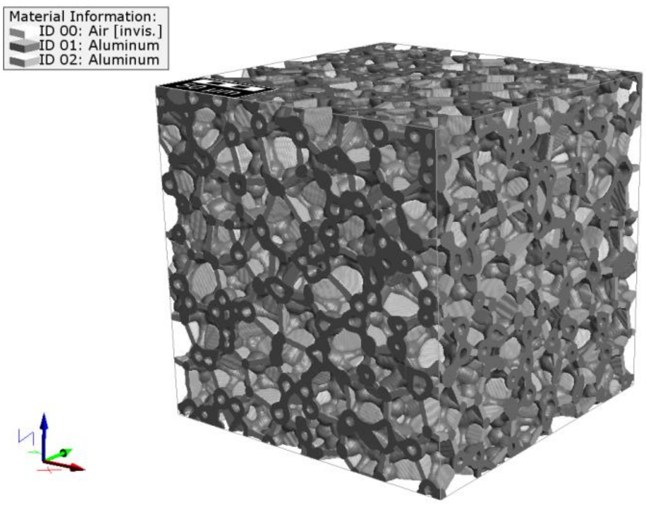
The result folder contains several files: the generated foam structure in .gad format, the generated foam structure in .gdt format (Structure.gdt), the *.gad file of the basis geometry used to generate the foam, a *.log file of the generation, a *.pde file with all the generation input parameters, a condensed result file in .txt format, the index image map in .g32 format, the skeleton of the foam in .gdt format, and, if selected in the output tab, 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

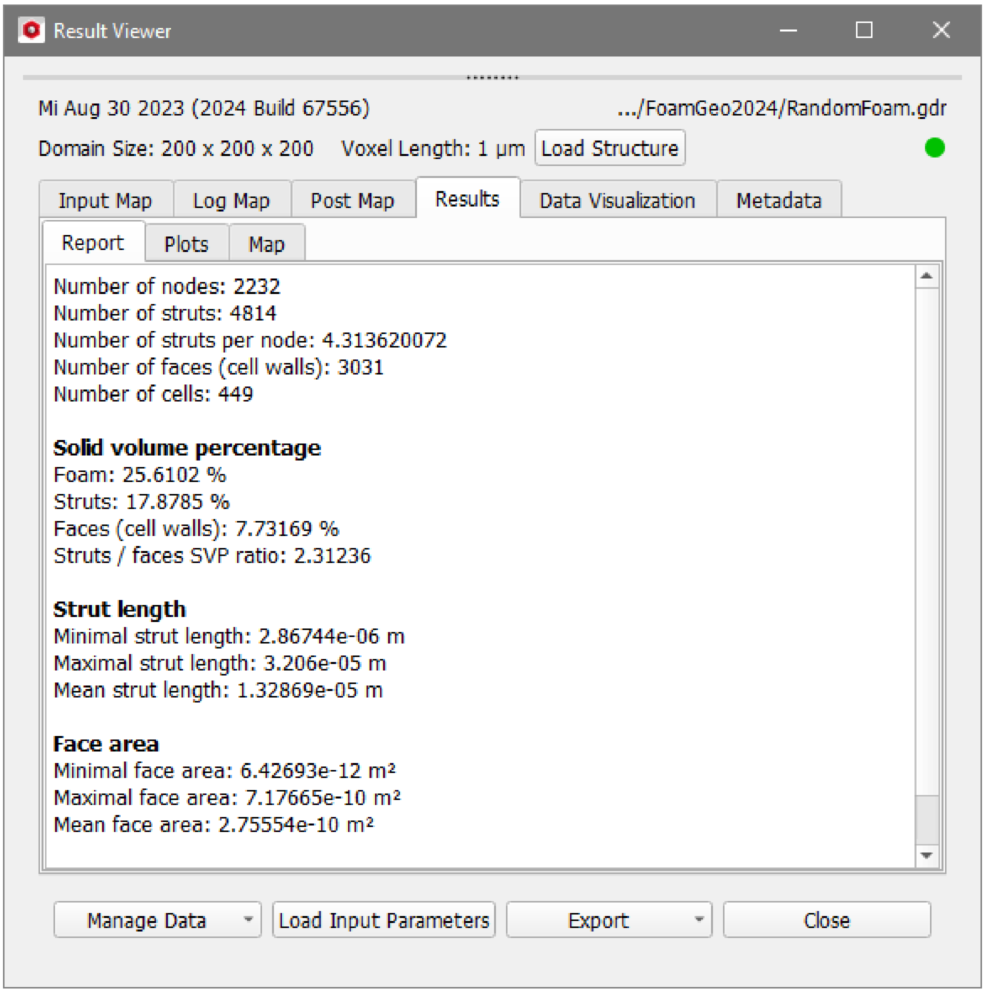
In the Visualization Area, the generated foam is displayed.

The *.gdr file created during the generation opens in the Result Viewer. In 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.

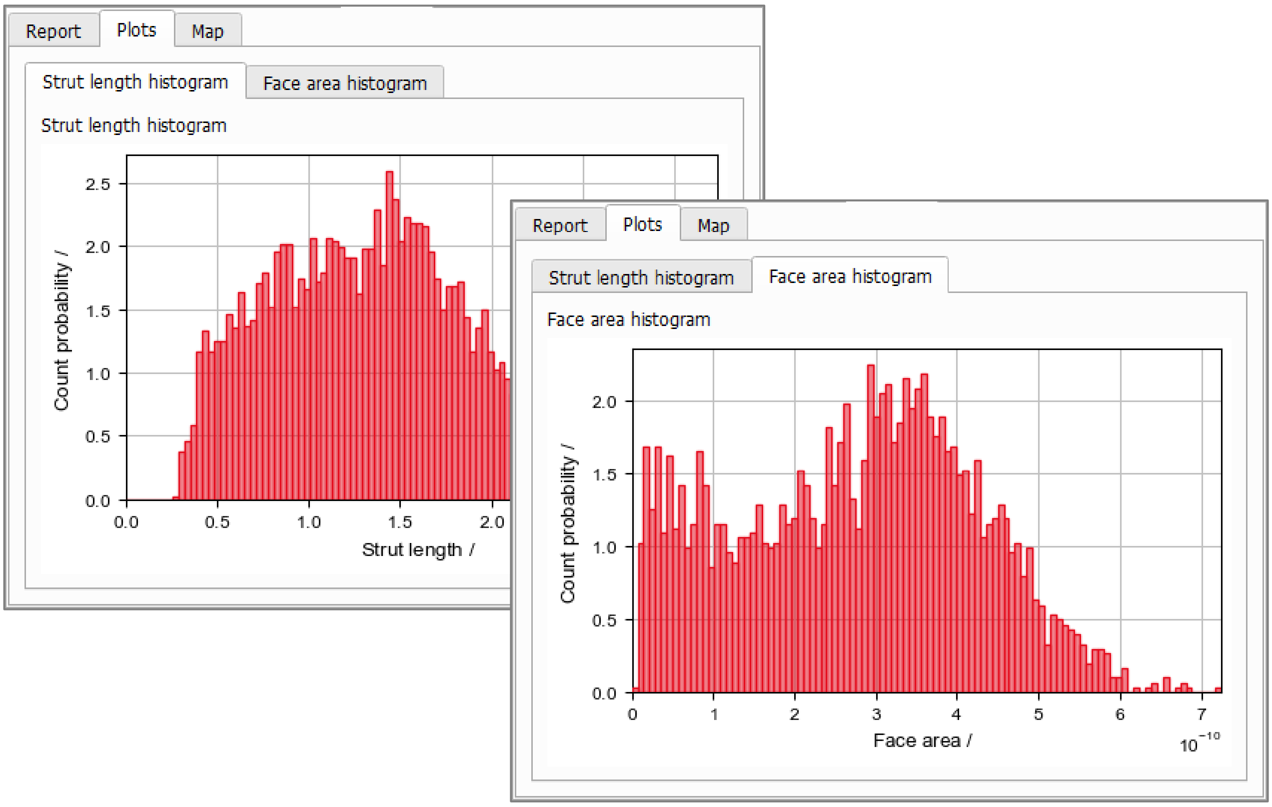
The solid volume percentages of the whole foam, for only the struts or faces as well as the ratio between the SVP for the struts and the SVP for the faces are listed under **Solid Volume Percentage**.



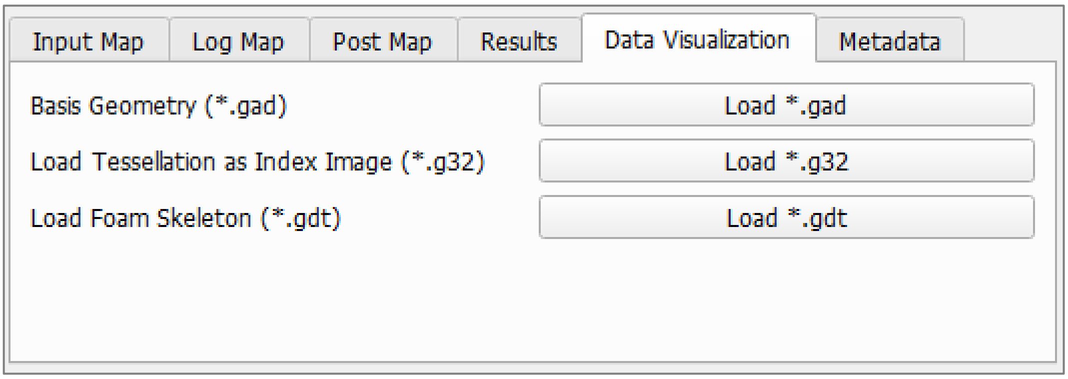
Next, for the struts, the minimal, maximal and mean length is shown and for the faces the minimal, maximal and mean area.



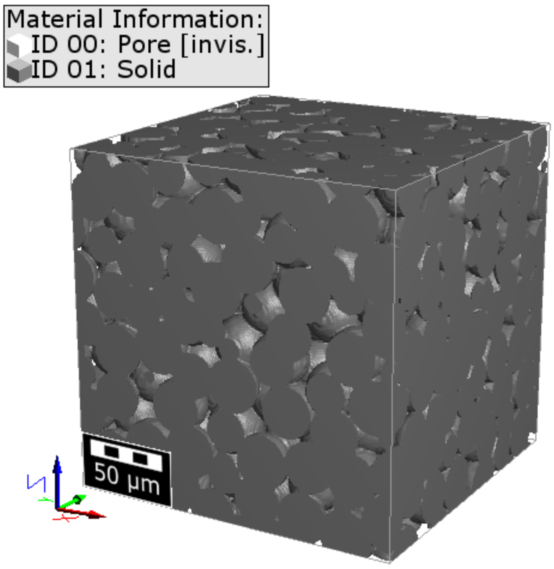
More detailed information about the strut lengths and face areas is shown on the subtab **Plots**. The strut length distribution as well as the face area distribution are visualized as histograms.



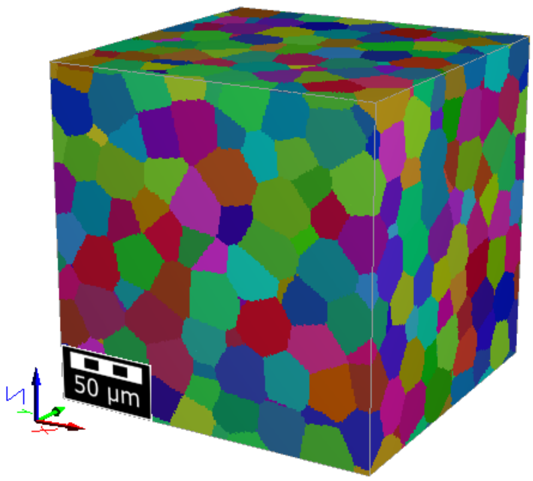
Through the **Data Visualization** tab, three files can be loaded into the Visualization area of the GeoDict GUI.



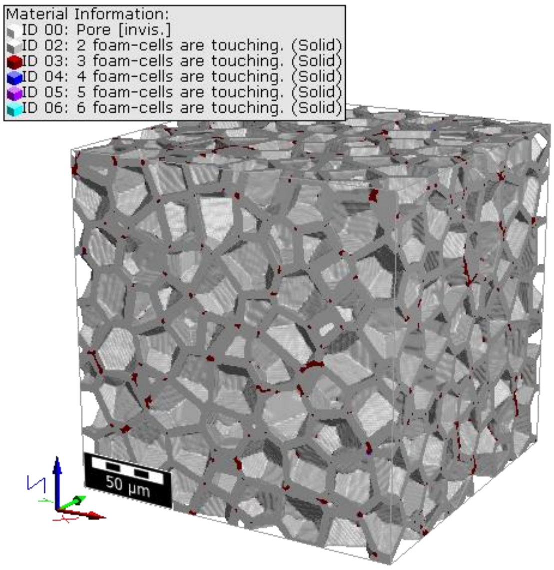
With **Load *.gad**, the **Basis Geometry (*.gad)**, which was defined in the options menu, can be displayed.

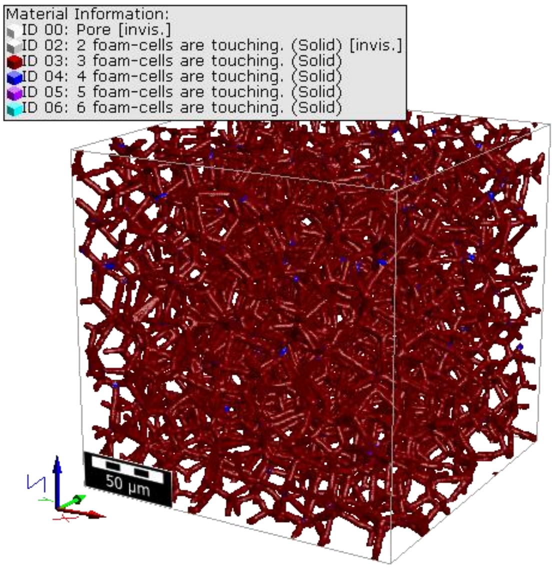


It is possible also to **Load Tessellation as Index Image (*.g32)** by clicking **Load *.g32**. Each foam cell is given an individual ID.



A third option is **Load Foam Skeleton (*.gdt)**, where each number of the Material ID stands for the number of cells that meet at this point. This means Material ID 2 represents the faces between two cells and Material ID 3 represents the struts of the foam. In the right picture, Material ID 2 was set to invisible, so Material ID 3 representing the struts can be better seen.





https://doi.org/10.30423/userguide.geodict

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