A Simple Lattice Infiller

User Manual

(June, 2024)

ASLI website
ASLI github repository

ASLI Version 0.1

KU LEUVEN

Contents

1 Introduction

ASLI (A Simple Lattice Infiller) is a cross-platform command line open-source tool written in C++ that gives users the ability to provide functionally graded lattice infills to any 3D geometry. The lattice infill is constructed out of unit cells, described by implicit functions, whose type, size and feature can be varied locally to obtain the desired local properties. ASLI also has an optional Graphical User Interface (GUI) available, called QASLI.

Details on the technical aspects of ASLI can be found in "A flexible and easy-to-use open-source tool for designing functionally graded 3D porous structures".

1.1 Authors

ASLI and QASLI are developed by the Biomechanics Research Unit (University of Liège and KU Leuven).

Principal developers

- F. Perez-Boerema [Developer of ASLI] (KU Leuven, Belgium)
- M. Barzegari [Developer of QASLI] (KU Leuven, Belgium)

Principal investigator

- L. Geris (University of Liège and KU Leuven, Belgium)

1.2 Licensing

ASLI is licensed under the terms of the GNU Affero General Public License.

1.3 Citing ASLI

If you use ASLI for your research we kindly ask you to cite:

- F. Perez-Boerema, M. Barzegari and L. Geris. (2022). A flexible and easy-to-use open-source tool for designing functionally graded 3D porous structures, *Virtual and Physical Prototyping*, 17:3, 682-699, DOI: 10.1080/17452759.2022.2048956.

1.4 Acknowledgments

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2 Getting started

The easiest way to get started with ASLI is to use its pre-build binaries. To this end, all you need to do is download the tarball or zip file for your preferred platform (Linux or Windows) from the release page of ASLI repository, unpack them and if using Linux install oneTBB if not already available on your system (only required by the parallel version of ASLI). For more advanced advanced users, it may be more interesting to build ASLI from scratch. Not only is this likely to increase performance since the program will get optimized for the platform in which it is going to be run, but it will also enable users to customize ASLI in any way they need. The prerequisites to be able to build ASLI are detailed in Section 2.1, while the procedure to build ASLI is detailed in Section 2.2 and 2.3, for Linux and Windows respectively.

2.1 Prerequisites

ASLI makes use of CMake and GNU Make to automate the building process. It also has a series of dependencies, which are listed below.

- AdaptTools
- ALGLIB
- CGAL
  - GMP
  - MPFR
  - Boost
  - oneTBB (optional, required for parallelization)
- Eigen
- MMG
  - Scotch (optional)
- Yaml-cpp
- QASLI (optional, the GUI of ASLI)
  - QT (optional, required if compiling the GUI)

Most dependencies are included with ASLI so that the user does not need to worry about them. Not included with ASLI are GMP, MPFR, Boost, TBB (optional) and Scotch (optional). QT, required to compile the GUI of ASLI is not included either. To be able to compile ASLI, depending on the compilation settings, users will need some or all of these libraries available on their system.

2.2 Building ASLI in Linux

If you are missing some required or optional dependencies they can be installed on Debian and Ubuntu with a couple of commands.

- Install build tools:

```
$ sudo apt-get install git cmake
```

- Install compilers:

```
$ sudo apt-get install build-essential
```

- Install libraries (GMP, MPFR, Boost):

```
$ sudo apt-get install libgmp-dev libmpfr-dev libboost-all-dev
```

- Install libraries (oneTBB):

```
$ sudo apt-get install libtbb-dev
```

- Install libraries (Scotch):

```
$ sudo apt-get install libscotch-dev
```

- Install libraries (QT):

```
$ sudo apt-get install qt3d5-dev
```

Once the build tools, compilers and required dependencies are available on the system the main steps to build ASLI in Linux are the following.

1. Retrieve ASLI from the repository:

```
$ git clone https://github.com/tpms-lattice/ASLI.git
```

2. Compile:

```
$ cd ASLI
$ mkdir build
$ cd build
$ cmake -DCMAKE_BUILD_TYPE=Release -DMARCH_NATIVE=ON ..
$ make
```

To clean up, simply delete the `build` and `bin` directories found in the source directory.

2.3 Building ASLI in Windows

Windows compilation is supported with MSYS2. Once you have installed MSYS2 in windows the required and optional dependencies can be installed through the MSYS2 MinGW 64-bit terminal with a couple of commands.

- Install build tools:

```
$ pacman -S git mingw-w64-x86_64-cmake
```

- Install compilers, and libraries (GMP, MPFR, Boost):

```
$ pacman -S --needed base-devel mingw-w64-x86_64-toolchain
$ pacman -S msys2-runtime-devel
$ pacman -S mingw-w64-x86_64-boost
```

- Install libraries (oneTBB):

  ```
  $ pacman -S mingw-w64-x86_64-intel-tbb
  ```

  and add the location of `tbb.dll` and `tbbmalloc.tbb` to the windows environment variables.

- Install libraries (Scotch):

  ```
  $ pacman -S mingw-w64-x86_64-scotch
  ```

- Install libraries (QT):

  ```
  $ pacman -S mingw-w64-x86_64-qt5
  ```

Once the build tools, compilers and required dependencies have been installed the main steps to build ASLI for Windows with MSYS2 are the following.

1. Retrieve ASLI from the repository:

   ```
   $ git clone https://github.com/tpms-lattice/ASLI.git
   ```

2. Compile:

   ```
   $ cd ASLI
   $ mkdir build
   $ cd build
   $ cmake -G "MSYS Makefiles" -DCMAKE_BUILD_TYPE=Release
   ↪  -DMARCH_NATIVE=ON ..
   $ make
   ```

To clean up, simply delete the `build` and `bin` directories found in the source directory.

2.4 Parallel mode

To compile ASLI in parallel mode include the tag `-DACTIVATE_CONCURRENT_MESHING=ON` when calling cmake. Note that parallel mode is currently limited to the CGAL workflow.

2.5 Graphical user interface

To compile ASLI together with its GUI include the tag `-DASLI_GUI=ON` when calling cmake.

3 Using ASLI

After compiling ASLI you will find an executable file named `ASLI` in the bin folder. If you specified you would like the GUI to be compiled along with ASLI you will find a second executable in the bin folder named `QASLI`.

In order to call ASLI from the command line you only need to type the following command in the Linux terminal:

```
./ASLI config.yml
```

or if using windows:

```
ASLI.exe config.yml
```

where `config.yml` points to the configuration file.

If using the GUI of ASLI users will only need to open QASLI, through which all user input parameters can be specified prior to executing ASLI.

3.1 Configuration file

ASLI makes use of a YAML configuration file that can be edited in any text editor. Through this file users can specify the user input parameters. The structure of the configuration file is shown in Fig. 1 while a detailed description of each input parameter can be found in Appendix 4.

3.2 Graphical user interface

QASLI, the GUI of ASLI, is an alternative to using the configuration file. The GUI is shown in Fig. 2. For the sake of simplicity the GUI hides by default most non-essential parameters. Access to these more advanced parameters can be obtained by pressing ctrl + ⇧ shift + e. For more details regarding the "Standard" and "Advanced" parameters see Appendix 4.

3.3 Demo

ASLI includes one demo problem. The files required for the demo are the `cube.stl` file, containing the $1 \times 1 \times 1$ cube shown in Fig. 3a, and the `cube.tap`, `cube.sap` and `cube.fap` files, which contain the local type, size and feature (volume fraction) specifications shown in Fig. 3b-d. All four files can be found in the `inputs` folder of ASLI.

The demo files allow users to create a cube with constant infill (Fig. 4a) or a cube with a functionally graded infill that can be hybrid, pseudo-periodic and/or heterogeneous (Fig. 4b-e).

3.3.1 Running the demo making use of the configuration file

To run the demo problem using the configuration file start by opening the unedited `config.yml` file provided with a text editor and modify the parameters specified below depending on the infill you would like to obtain.

a) Constant infill (Fig. 4a)

```yaml
# ----  CONFIGURATION FILE  ---- #

# Input & output files
files:
  stl: inputs/cube.stl
  tap: inputs/cube.tap
  sap: inputs/cube.sap
  fap: inputs/cube.fap
  output: outputs/cube.*

# Lattice settings
lt_type: gyroid
lt_type_side: scaffold
lt_type_filterRadius: 1.0
lt_type_correctionFactor: 0.25

lt_size: 0.5

lt_feature: volumeFraction
lt_feature_val: 0.5
lt_feature_mode: relative

# Mesh settings
me_mesher: CGAL
me_nThreads: 1
me_elementSize: 0.5
me_volumeMesh: FALSE

# Mesh settings (CGAL)
CGAL_facetDistance: 0.01
CGAL_relativeErrorBound: 1e-3
CGAL_facetAngle: 30
CGAL_cellRadiusEdgeRatio: 3.0

# Mesh settings (MMG)
MMG_hausd: 0.3
MMG_hgrad: 1.3
MMG_hinitial: 0.36
```

Figure 1: Example of YAML configuration file.

- Set `lt_size` to `0.25`

b) Hybrid infill (Fig. 4b)

- Set `tap` to `inputs/cube.tap`
- Set `lt_type to hybrid`
- Set `lt_size to 0.25`

c) Pseudo-periodic infill (Fig. 4c)

- Set `sap` to `inputs/cube.sap`
- Set `lt_size` to `0`

d) Heterogeneous infill (Fig. 4d)

- Set `fap` to `inputs/cube.fap`
- Set `lt_size` to `0.25`
- Set `lt_feature_val` to `0`

e) Hybrid pseudo-periodic heterogeneous infill (Fig. 4e)

- Set `tap` to `inputs/cube.tap`

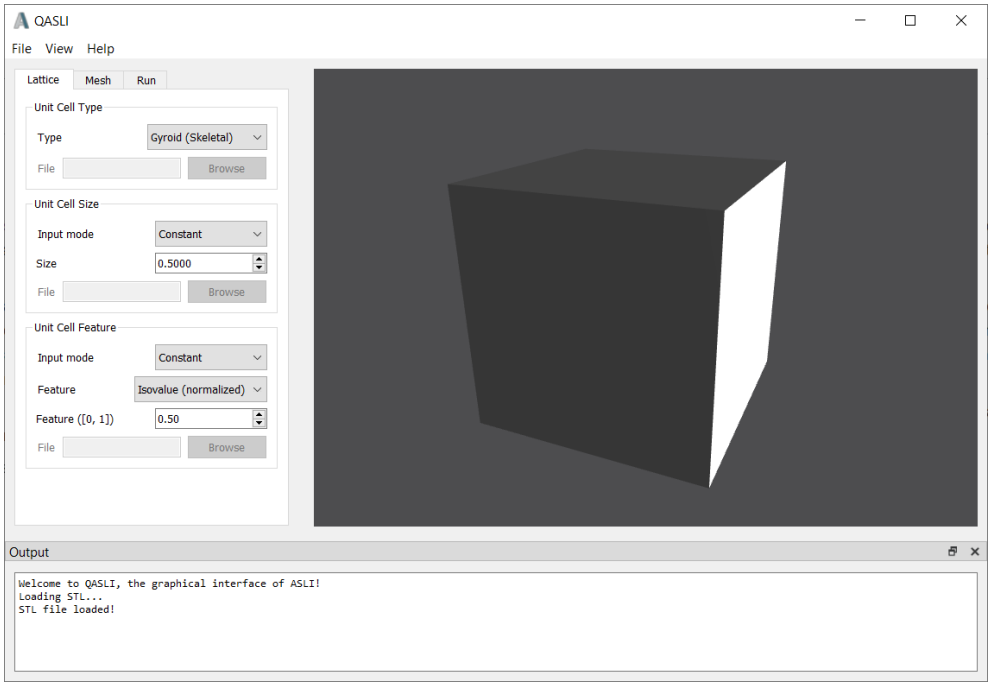
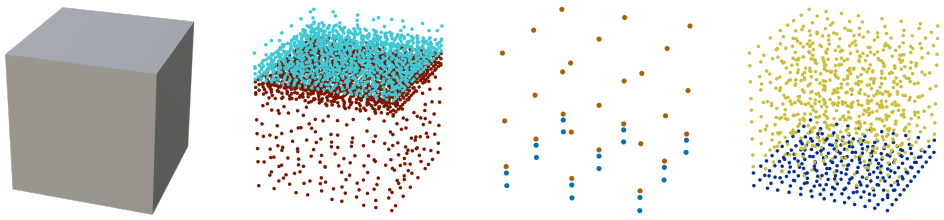


Figure 2: QASLI, the graphical user interface of ASLI.

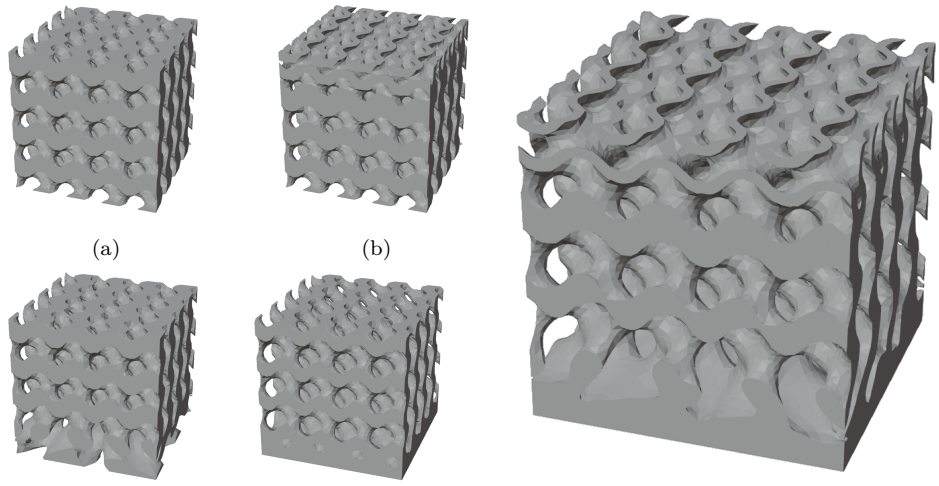
- Set `sap` to `inputs/cube.sap`
- Set `fap` to `inputs/cube.fap`
- Set `lt_type` to `hybrid`
- Set `lt_size` to `0`
- Set `lt_feature_val` to `0`

Save the modifications made and execute ASLI by calling `./ASLI config.yml` if using Linux or `ASLI.exe config.yml` if using windows. The generated lattice will be stored as an `.stl` file in the outputs folder.



(a) (b) (c) (d)

Figure 3: Input files of the demo problem (a) input geometry, (b) type at point data [• sheet-gyroid • strut-gyroid], (c) size at point data [• 0.25 • 0.5] and (d) feature at point data (isovalue) [• 0.35 • 1].



(a) (b) (c) (d) (e)

Figure 4: $1 \times 1 \times 1$ cube with an (a) constant infill, (b) hybrid infill, (c) pseudo-periodic infill, (d) heterogeneous infill and (e) hybrid pseudo-periodic heterogeneous infill.

3.3.2 Running the demo making use of the GUI

To run the demo using the GUI the first step, after opening QASLI, is to load the `.stl` file containing the geometry to be provided of an infill. To do so go to File > Load Surface (.stl), open the folder `inputs`, select the file named `cube.stl` and click Open.

Next, set the lattice and mesh parameters depending on the infill you would like to obtain following the instructions below.

a) Constant infill (Fig. 4a)

1. Set **Lattice** > Unit Cell Size > Size to `0.25`

b) Hybrid infill (Fig. 4b)

1. Set **Lattice** > Unit Cell Type > Type to '*From file*'
2. Click on the corresponding Browse button, navigate to the `inputs` folder, select the file `cube.tap` and click Open.
3. Set **Lattice** > Unit Cell Size > Size to `0.25`
4. Set **Mesh** > Mesh Engine > Mesher to '*CGAL*'

c) Pseudo-periodic infill (Fig. 4c)

1. Set **Lattice** > Unit Cell Size > Input mode to '*From file*'
2. Click on the corresponding Browse button, navigate to the `inputs` folder, select the file `cube.sap` and click Open.
3. Set **Mesh** > Mesh Engine > Mesher to '*CGAL*'

d) Heterogeneous infill (Fig. 4d)

1. Set **Lattice** > Unit Cell Size > Size to `0.25`

2. Set **Lattice** » Unit Cell Feature » Input mode to '*From file*'
3. Click on the corresponding Browse button, navigate to the `inputs` folder, select the file `cube.fap` and click Open.
4. Set **Mesh** » Mesh Engine » Mesher to '*CGAL*'

e) Hybrid pseudo-periodic heterogeneous infill (Fig. 4e)

1. Set **Lattice** » Unit Cell Type » Type to '*From file*'
2. Click on the corresponding Browse button, navigate to the `inputs` folder, select the file `cube.tap` and click Open.
3. Set **Lattice** » Unit Cell Size » Input mode to '*From file*'
4. Click on the corresponding Browse button, navigate to the `inputs` folder, select the file `cube.sap` and click Open.
5. Set **Lattice** » Unit Cell Feature » Input mode to '*From file*'
6. Click on the corresponding Browse button, navigate to the `inputs` folder, select the file `cube.fap` and click Open.
7. Set **Lattice** » Mesh Engine » Mesher to '*CGAL*'

Finally, go to the **Run** tab and click Run. Once finished you will be notified, dismiss the notice by clicking on Ok. The generated lattice will be displayed automatically in the viewer and stored as an `.stl` file in the outputs folder.

3.4 Other examples

A few examples that showcase ASLI capabilities are shown in Fig. 5.

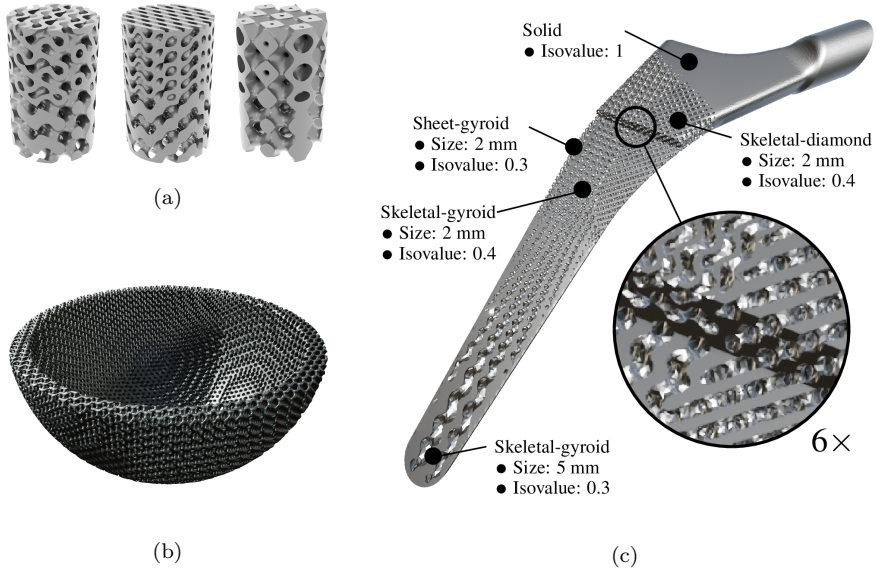


Figure 5: Examples of lattice structures generated with ASLI: (a) functionally graded cylinder test samples, (b) functionally graded acetabular cup and (c) functionally graded femoral implant with stem cut in half to show internal structure.

4 Support

If you have questions or encounter any bugs there are a number of resources listed below you can use.

- Bugs can be reported using the ASLI issue tracker on GitHub.
- Questions and suggestions can be posted in the discussions section on GitHub
- Alternatively questions and bugs can also be send to `asli@kuleuven.be`.

Appendix A: Input parameters

ASLI requires multiple parameters to be specified by the user. Most of these parameters have default values that work well for many use cases and are therefore considered a good starting point. The remaining parameters need to be specified by the user. A list of the different parameters including a description is found bellow. Moreover, parameters have been labelled as "Standard" or "Advanced" depending on the whether they are required relatively frequent or only in rare cases. For convenience, all input parameters are indexed in the Section "Index of input parameters" found at the end of the manual.

A.1 Input/output files

- *Parameter name:* `stl` [Standard]
  Default: -
  Description: STL file containing the object to be provided of an infill.
  Possible values: String value

- *Parameter name:* `internalGeometry` [Standard]
  Default: -
  Description: String specifying the internal geometry (*cuboid* w d h, *cylinder* h r_x r_y or *spheroid* r_x r_y r_z) to be provided of an infill. Parameter is only active in the absence of the `stl` parameter.
  Possible values: String value

- *Parameter name:* `tap` [Standard]
  Default: -
  Description: Type at point file containing local unit cell type specifications.
  Possible values: String value

- *Parameter name:* `sap` [Standard]
  Default: -
  Description: Size at point file containing local unit cell size specifications.
  Possible values: String value

- *Parameter name:* `fap` [Standard]
  Default: -
  Description: Feature at point file containing local unit cell feature specifications.
  Possible values: String value

- *Parameter name:* `output` [Standard]
  Default: ./outputs/
  Description: Location were the output file(s) will be stored. If a specific output filename is desired it can be included in the string.
  Possible values: String value

A.2 Lattice parameters

- *Parameter name:* `lt_type` [Standard]

  Default: -

  Description: Parameter specifying the unit cell type (*gyroid*, *sheet_gyroid*, *diamond*, *sheet_diamond*, *primitive*, *sheet_primitive*, *IWP*, *sheet_IWP* or *cubic*). To specify multiple unit cell types set to *hybrid* and provide a .tap file (see `tap` parameter).

  Possible values: String value

- *Parameter name:* `lt_type_side` [Standard]

  Default: scaffold

  Description: Parameter specifying the side of the scaffold to discretize (*scaffold*, *void* or *all*).

  Possible values: String value

- *Parameter name:* `lt_type_filterRadius` [Advanced]

  Default: 1.0

  Description: Radius specifying the size of hybrid regions. The radius scales automatically with local unit cell size. Only active if `lt_type` is set to *hybrid*.

  Possible values: Non-negative floating point number

- *Parameter name:* `lt_type_correctionFactor` [Advanced]

  Default: 0.25

  Description: Correction factor to compensate for the thinning effect of hybridization. Only active if `lt_type` is set to *hybrid*.

  Possible values: Non-negative floating point number

- *Parameter name:* `lt_size` [Standard]

  Default: -

  Description: Parameter specifying the unit cell size. Set to a value larger than 0 for a constant unit cell size. To prescribe a variable unit cell size set to 0 and provide a .sap file (see `sap` parameter).

  Possible values: Non-negative floating point number

- *Parameter name:* `lt_feature` [Standard]

  Default: -

  Description: Parameter specifying the unit cell feature for which a value will be specified (*volumeFraction*, *wallSize* or *poreSize*).

  Possible values: String value

- *Parameter name:* `lt_feature_val` [Standard]

  Default: -

  Description: Parameter specifying the unit cell feature value. Set to a value larger than 0 for a constant feature value. To prescribe a variable feature value set to 0 and provide a .fap file (see `fap` parameter). If the feature value being

provided is an isovalue, it should be specified as a normalized isovalue

Possible values: Non-negative floating point number

- *Parameter name:* `lt_feature_mode` [Advanced]

  Default: relative

  Description: Parameter specifying the feature value mode (*absolute* or *relative*). Only active if `lt_feature` is set to *wallSize* or *poreSize*. If set to *relative*, provide wall and pore sizes relative to a $1 \times 1 \times 1$ unit cell.

  Possible values: String value

A.3 Mesh parameters

- *Parameter name:* `me_mesher` [Standard]

  Description: Parameter specifying the mesh library to use (*CGAL* or *MMG*).

  Default: -

  Possible values: String value

- *Parameter name:* `me_nThreads` [Standard]

  Default: 1

  Description: Number of threads to use. Parallel mode is only available when `me_mesher` is set to *CGAL*.

  Possible values: Positive integer

- *Parameter name:* `me_elementSize` [Standard]

  Default: $0.5 \times$ [local wall size]

  Description: Size of elements relative to the local wall or pore size depending on the side discretized. When using the CGAL library `me_elementSize` represents an upper bound on the circumradii of the mesh tetrahedra. When using the MMG library `me_elementSize` represents the elements edge lengths.

  Possible values: Positive integer

- *Parameter name:* `me_volumeMesh` [Standard]

  Default: FALSE

  Description: Parameter specifying if a volume mesh is also required. Set to TRUE to obtain a volume mesh in addition to the surface triangulation, otherwise only a surface triangulation is generated.

  Possible values: Boolean value (TRUE or FALSE)

- *Parameter name:* `me_edgeProtectionAngle` [Advanced]

  Default: 70

  Description: Edge protection angle in degrees. If set to 0 edge protection is disabled.

  Possible values: Non-negative floating point number

- *Parameter name:* `me_threshold` [Advanced]

  Default: 0.033

Description: Smallest permitted mesh size as a fraction of the local unit cell size.

Possible values: Positive floating point number

A.3.1 CGAL specific parameters

- *Parameter name:* `CGAL_facetDistance` [Standard]

  Default: 0.1 × [local unit cell size]

  Description: Surface approximation error as an upper bound for the distance between the circumcenter of a surface facet and the center of the surface Delaunay ball of this facet. Scales with the local unit cell size.

  Possible values: Positive floating point number

- *Parameter name:* `CGAL_relativeErrorBound` [Advanced]

  Default: 1e-3

  Description: Relative error bound used to compute intersection points between the implicit surface and query segments. The bisection is stopped when the length of the intersected segment is less than the product of the relative_error_bound by the diagonal of the mean unit cell size.

  Possible values: Positive floating point number

- *Parameter name:* `CGAL_facetAngle` [Advanced]

  Default: 30

  Description: Surface facet shape quality as lower bound for the surface facets angle in degrees.

  Possible values: Positive floating point number

- *Parameter name:* `CGAL_cellRadiusEdgeRatio` [Advanced]

  Default: 3.0

  Description: Tetrahedron shape quality measure as an upper bound for the ratio between the circumradius of a mesh tetrahedron and its shortest edge. Only active if `CGAL_volumeMesh` is set to TRUE.

  Possible values: Floating point number larger than 2

- *Parameter name:* `CGAL_facetSize` [Advanced]

  Default: `me_elementSize`

  Description: Surface facet size as an upper bound for the radii of surface Delaunay balls. Scales with the local wall or pore size depending on the side discretized.

  Possible values: Positive floating point number

- *Parameter name:* `CGAL_edgeSize` [Advanced]

  Default: `me_elementSize`

  Description: Upper protected edge length bound. Scales with the local wall or pore size depending on the side discretized.

  Possible values: Positive floating point number

- *Parameter name:* `CGAL_minEdgeSize` [Advanced]

  Default: 0

  Description: Lower edge size bound. If set to 0 the option is disabled. Use with caution!

  Possible values: Positive floating point number

A.3.2 Mmg specific parameters

- *Parameter name:* `MMG_hausd` [Standard]

  Default: 0.3 × [mean unit cell size]

  Description: Surface approximation error as a maximal Hausdorff distance. Scales with the mean unit cell size.

  Possible values: Positive floating point number

- *Parameter name:* `MMG_hgrad` [Advanced]

  Default: 1.3

  Description: Gradation value. Only active if `MMG_volumeMesh` is set to TRUE.

  Possible values: Floating point number larger than 1

- *Parameter name:* `MMG_hinitial` [Advanced]

  Default: 0.36 × [smallest local feature size]

  Description: Size of mesh used to compute the level-set. Scales with the smallest local feature size.

  Possible values: Positive floating point number

Index of input parameters