**USER** DOCUMENTATION

# INTRA**LATTICE**

## CORE MODULES

v0.7.5

## PREFACE

VERSION **0.7.5** — BETA

INTRA**LATTICE** is a C# plugin for Grasshopper, used to generate solid lattice structures within a design space. It was developed as an extensible, open-source alternative to current commercial solutions. As an ongoing project developed at McGill's Additive Design & Manufacturing Laboratory (ADML), it has been a valuable research tool, serving as a platform for breakthroughs in multi-scale design and optimization.

By providing a modular approach to lattice design, and giving you full access to the source, we hope to collectively explore lattice design at a deeper level, and consequently, engineer better products.

**WEBSITE** — http://intralattice.com

**SOURCE CODE** — https://github.com/dnkrtz/intralattice/

**DEVELOPER DOCS** — http://intralattice.com/devdocs

## THE MIT LICENSE

OPEN SOURCE



## SUPPORT

If you have any issues, questions or feedback — please contact support@intralattice.com

## LEAD DEVELOPERS

This project was started in the summer of 2014. Although the process was a collaborative effort, the work load can be broadly categorized as follows:

**Aidan Kurtz** — Development of CORE modules, website and documentation.

**Yunlong Tang** — Development of OPTI modules (PhD Research).

**Prof. Fiona Zhao** — Project supervisor and head of the research lab.

## ACKNOWLEDGEMENTS

Many students/researchers have contributed to the project since its inception.

**Marc Wang** — Assisted in C# development, namely, GH_Goo wrappers and UI.

**Ken Nsiempba** — Currently developing a Laplacian-based frame component.

**Huiyuan Yang** — Currently developing a Voronoi-based frame component.

If you submit a pull request to the GitHub repository, and it is merged, your name and contribution will be listed. For more information on how to contribute, refer to the Developer Documentation.

Our mesh generation algorithms are inspired by Exoskeleton, an assembly by David Stasiuk.
And of course, a big thanks to David Rutten for his work on Grasshopper.

# TABLE OF CONTENTS

# 0.0 BACKGROUND

The freedom of form enabled by 3D printing has allowed engineers to integrate new orders of complexity into their designs. The goal of this research was to develop **a set of CAD tools for generating solid lattice structures** within a design space. The software would be used to:

- Reduce volume/weight while maintaining structural integrity.
- Increase surface area as a means of maximizing heat transfer.
- Generate porosity in bone scaffolds and implants.
- Serve as a platform for topology optimization.

In doing so, it should always output a watertight mesh suited for 3D printing. The lack of flexibility of current software solutions was the motive for this project. We wanted to develop a flexible platform more conducive to research, which would allow us to explore and experiment with lattice design at a deeper level. The obvious first step was to decide in which environment we would develop our system. Rhinoceros is known to be very open ended, having its own engine for interpreting scripts (Python, C# and VB), and a powerful plugin SDK (RhinoCommon). Its Grasshopper add-on is a visual programming tool widely used in architecture which provides an ideal interface for systematic design. In this visual interface, parameters and function components are combined sequentially to carry out the design of 3D models. By developing a set of custom components for Grasshopper, we could establish a modular workflow for generative lattice design.

That being said, if you are not familiar with Grasshopper, you are highly encouraged to have a look at the latest Grasshopper Primer, to bring you up to speed.

# 0.1 SYSTEM REQUIREMENTS

| | |
|---|---|
| **Operating System:** | Windows 7 or 8 (64-bit recommended) |
| **RAM:** | 8GB or more |
| **Video Card:** | OpenGL 2.0 capable video card |
| **CPU:** | No more than 63 CPU cores |

# 0.2 INSTALLATION

The following **required software** should be installed on your system.

- **Rhinoceros 5**
- **Grasshopper**

Next, if you haven't yet, download the latest version of INTRA**LATTICE**

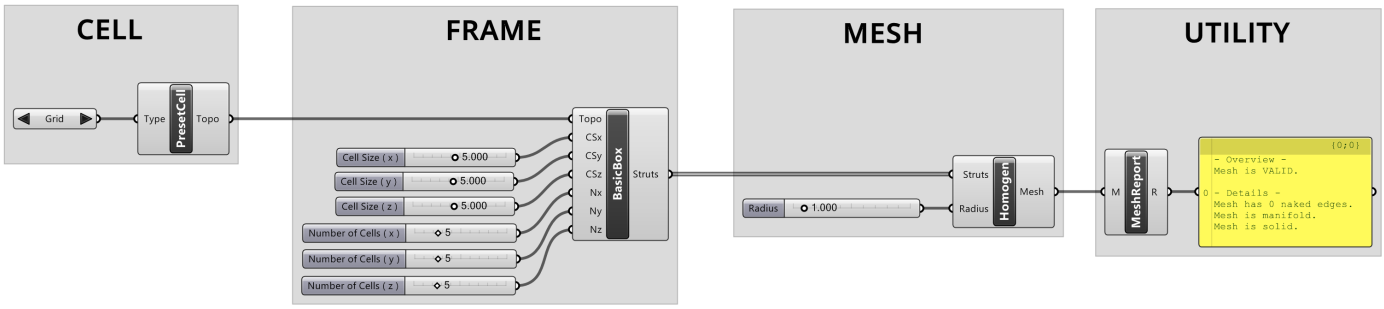
- **Intralattice**

To install, simply drag the 'IntraLattice.gha' file into your Grasshopper viewport. A new toolbar will appear.

Section 1

# CORE FRAMEWORK

This documentation covers the core modules—that is, the components concerned with modeling solid lattice structures, as opposed to the opti framework, which involves mechanical optimization. The core process is split into a set of modules, each carrying out a specific sub-process. Each of these modules includes a set of components to choose from. In Grasshopper, the modular approach looks like this.

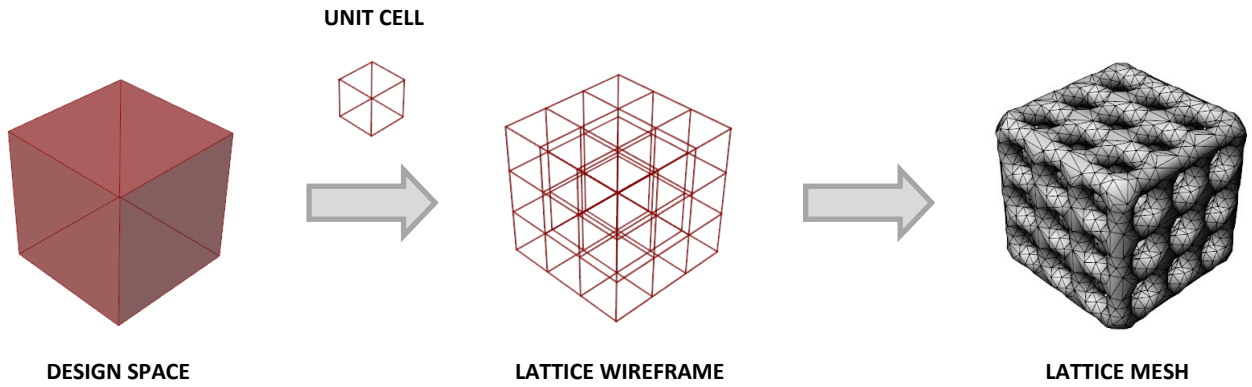



The **CELL** module generates the unit cell. The **FRAME** module takes in this unit cell, a design space and various lattice parameters, and outputs a wireframe of the lattice, as a list of curves. The **MESH** module then takes in the list of curves and outputs a single solid mesh, which can be baked and saved in any standard format (i.e. STL, OBJ, PLY, etc…). The **UTILITY** module is optional, and includes a set of tools for pre/post-processing. The benefits of defining a modular workflow include:

- **Flexibility** : Each module can be changed independently; several components are available.
- **Progressive computation** : Users can preview each module before computing the next.
- **Malleability** : Data can be manipulated in between steps

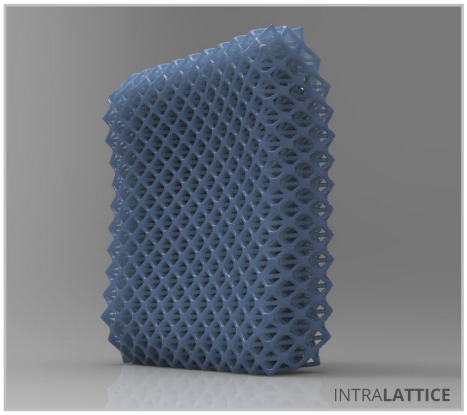
## 1.1 GENERATIVE PROCESS

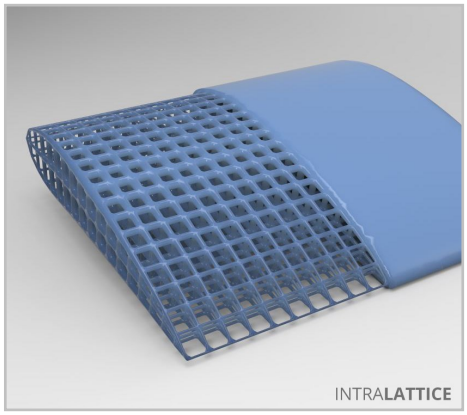
Here is a simple example to illustrate the generative process. The design space is populated with a unit cell, producing a lattice wireframe, which is then solidified as a solid mesh.

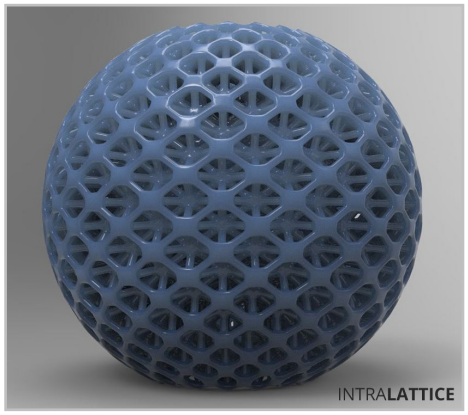


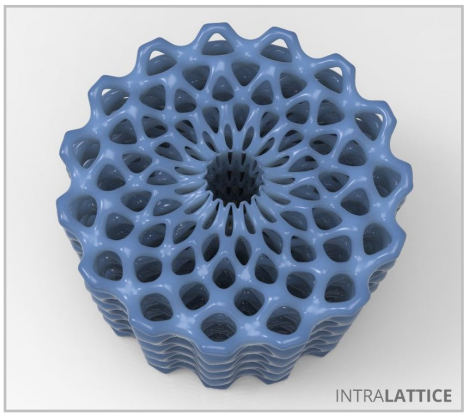

## 1.2 DESIGN CAPABILITIES

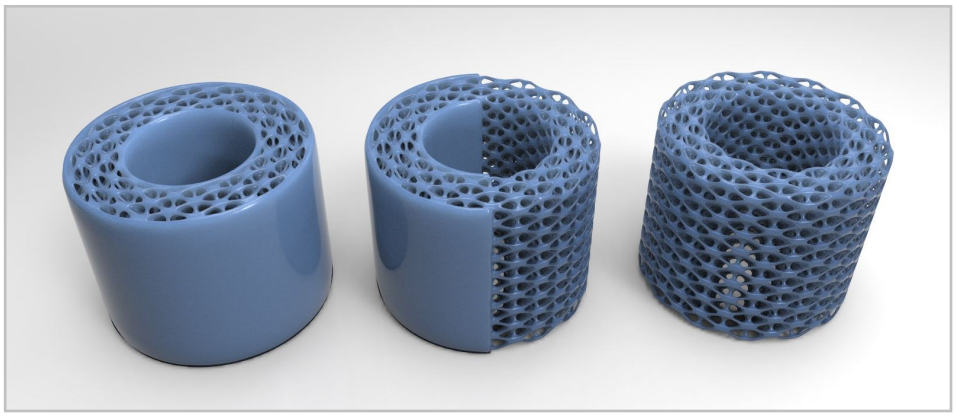
Some more complex designs are shown below, featuring various design spaces, unit cells and lattice mapping methods, as a testament to the functionality and versatility of Intralattice.



Section 2

# CELL MODULE

Intralattice generates **cellular** lattice structures, meaning the topology is based on a unit cell. Naturally, changing the unit cell structure will have a significant effect on the mechanical properties of the overall structure. And so this is where the parametric design process begins. The cell module is responsible for outputting a valid, formatted unit cell, which will then be used by the frame module to populate the design space.

## AVAILABLE COMPONENTS

**PresetCell** - Generates a unit cell from our preset cell library.

**CustomCell** - Converts a custom unit cell to a validated, formatted cell.

## WHAT IS A VALID UNIT CELL?

All unit cells generated by the PresetCell component are valid, and to that extent, the following information isn't useful. However, when designing custom unit cells, you need to keep in mind that the INTRALATTICE framework is built around a set of assumptions. The primordial assumption is that the cell has a cubic bounding box. Other requirements include:

**Requirement 1 :** All struts are linear.

**Requirement 2** : The bounding box of the cell is aligned with the World XYZ coordinate system.

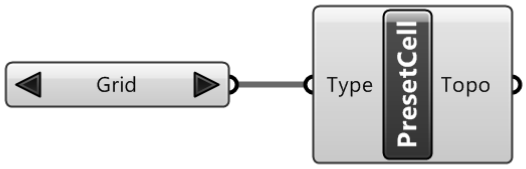
The next two requirements are concerned with continuity within the lattice.

**Requirement 3 :** Each face of the bounding box of the cell has at least 1 node lying on it.

**Requirement 4 :** Opposing faces of the bounding box have mirror nodes.

# 2.0 PRESET CELL

**Description** — Built-in selection of unit cell topologies.




## INPUTS

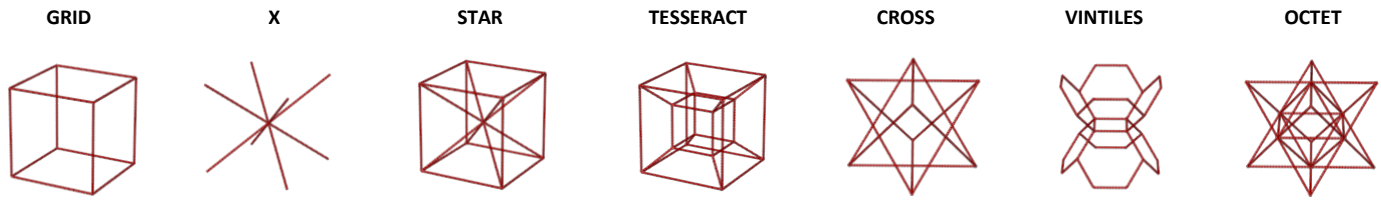
**Type** Integer representing the unit cell topology selection.

## OUTPUTS

**Topo** Cell topology as a UnitCell object (custom data type).

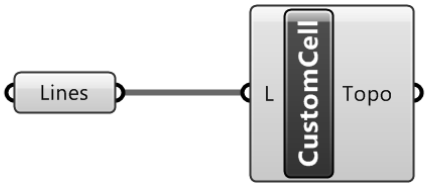
## EXAMPLES

This example shows some of the built-in unit cell topologies included in our library. If you can't find what you're looking for in our library, use the CustomCell component (next page) to process your custom unit cell designs.



# 2.1 CUSTOM CELL

**Description** — This component is used to pre-process a custom unit cell. It will verify that the cell is valid, and return an error if it fails any of the validity tests. Otherwise, it will output a valid UnitCell data object.




## INPUTS

**L** List of curves representing your unit cell. (*note:* must be linear curves)

## OUTPUTS

**Topo** Cell topology as a UnitCell object (custom data type).

## EXAMPLE 1 **— Import custom cell from any CAD software**

Once you've created a unit cell as a set of lines, save it in a universal format.

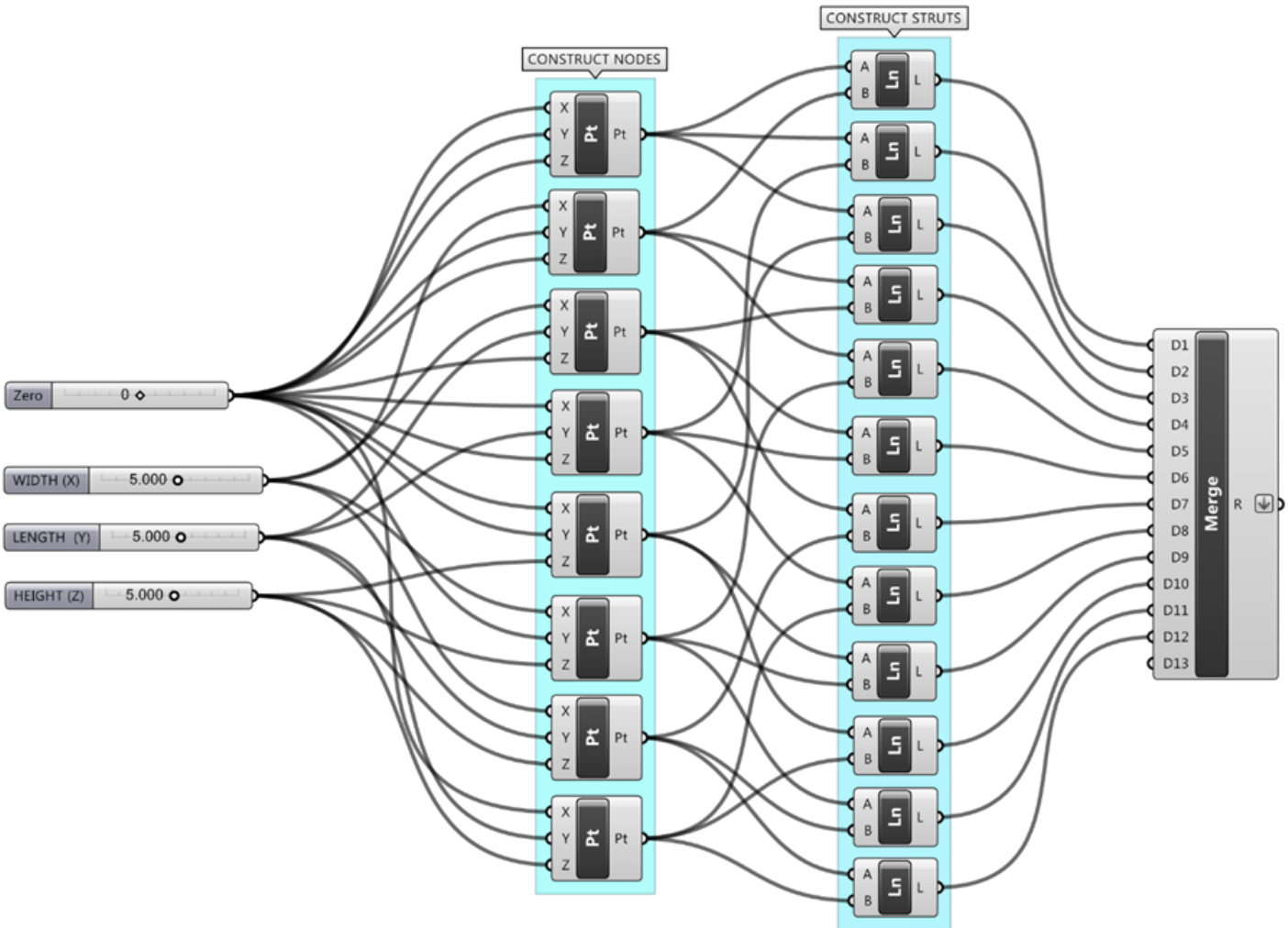
1) **Open the file** in Rhinoceros.
   - A) In Rhinoceros, go to "File -> Open".
   - B) Select your file.
2) **Set the curves** in Grasshopper.
   - A) In Rhinoceros, select all lines that make up your unit cell.
   - B) In Grasshopper, right-click on the 'L' input of CustomCell, then choose "Set multiple curves".
3) **Internalise the data** on the CustomCell component.
   - A) In Grasshopper, right-click on the 'L' input, then choose "Internalise data".
     The unit cell geometry is now being stored inside Grasshopper.
4) **Remove curves** from Rhinoceros.
   - A) In Rhinoceros, select all the lines and click Delete.

## EXAMPLE 2 — **Create custom cell in C#/VB/Python script**

Grasshopper has built-in scripting components for C# and VB. You may also extend the scripting capabilities to Python by downloading/installing **GhPython**. Just make sure your script is outputting a list of lines, and input this list into the CustomCell component.

## EXAMPLE 3 — **Create custom cell in Grasshopper**

Another efficient way of designing unit cells is directly in Grasshopper. The figure below shows a simple example of how this could be done for the simple grid topology. Essentially, we create a set of nodes, and then connect pairs of these nodes as lines.



Section 3

# FRAME MODULE

The frame module generates a wireframe of the lattice structure, based on the unit cell generated by cell module, and a design space. It will output a list of curves, which can be solidified with the mesh module.

## AVAILABLE COMPONENTS

The first two components populate a predefined design, which is ideal for quickly testing new cell topologies, and 3D printing samples for mechanical testing.

**BasicBox** - Generates a simple lattice box.

**BasicCylinder** - Generates a simple lattice cylinder.

The following components are for user-defined design spaces.

**ConformSS** - Generates a conformal lattice between two surfaces.

**ConformSA** - Generates a conformal lattice between a surface and an axis.

**ConformSP** - Generates a conformal lattice between a surface and a point.

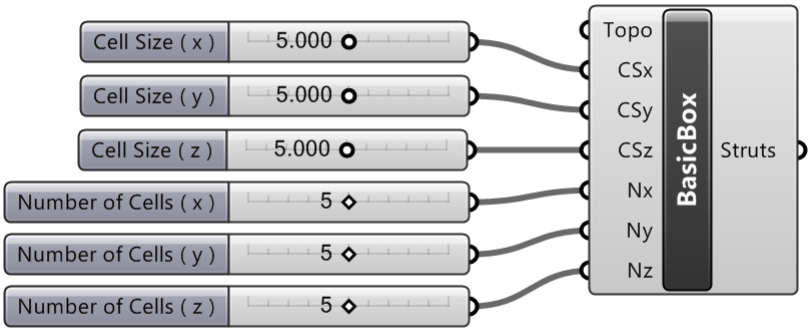
**UniformDS** - Generates a uniform, trimmed lattice within a closed Brep/Mesh design space.

## FUTURE COMPONENTS

We are also in the process of developing a relaxation-based conformal algorithm, and a voronoi-based algorithm for emulating trabecular structure in bone.

# 3.0 BASIC BOX

**Description** — Generates a lattice box.




## INPUTS

| | |
|---|---|
| **Topo** | Topology data, output by cell module. |
| **CSx, CSy, CSz** | Size of unit cells in each of the xyz Cartesian coordinates . |
| **Nx, Ny, Nz** | Number of unit cells in each of the xyz Cartesian coordinates. |

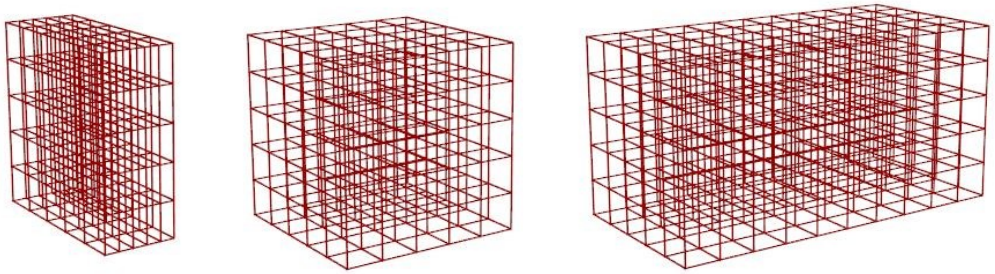
## OUTPUTS

| | |
|---|---|
| **Struts** | List of curves representing the lattice struts. |

## EXAMPLES

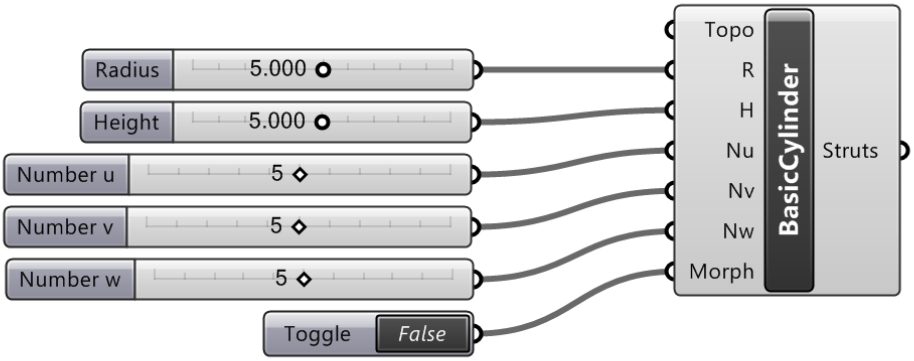
At this point, everything is pretty straight-forward. You can play with the size of unit cells, and also the number of cells in each direction.

Note that **all examples in this documentation will use the grid unit cell topology**, for clarity.



# 3.1 BASIC CYLINDER

**Description** — Generates a uvw-conforming lattice cylinder.




## INPUTS

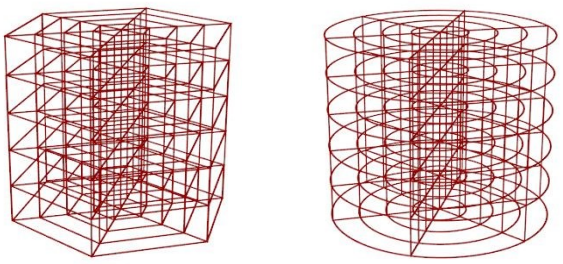
| | |
|---|---|
| **Topo** | Topology data, output by cell module. |
| **R, H** | Cylinder radius and height, respectively. |
| **Nu, Nv, Nw** | Number of unit cells in each of the UVW-map coordinates. (u—axial, v—theta, w—radial) |
| **Morph** | Strut morphing. (if true, struts are morphed into curves) |

## OUTPUTS

| | |
|---|---|
| **Struts** | List of curves representing the lattice struts. |

## EXAMPLE

The example shown here illustrates **the effect of morphing**. While the nodes conform to the design space whether the structure is morphed or not, struts will not necessarily conform like we want them to. To morph the struts to the design space, the algorithm discretizes the struts, and maps sets of control points to the uvw-space, which are then interpolated as curves.



## 3.2 HOW TO DEFINE YOUR DESIGN SPACE

The last two components generated lattice frames within a predefined design space. Next, we're going to look at frame components that support user-defined design spaces.

### UNIFORM

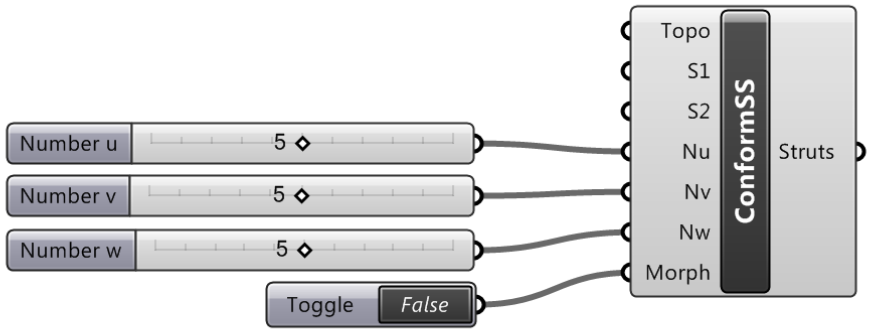
COMING SOON...

### CONFORM

COMING SOON...

# 3.3 CONFORM SURFACE-SURFACE

**Description** — Generates a uvw-conforming lattice between two surfaces.




## INPUTS

| | |
|---|---|
| **Topo** | Topology data, output by cell module. |
| **S1, S2** | The surfaces that define the design space. In some cases, you may need to pass one of the surfaces through the 'AdjustUV' component to fix UV alignment issues. |
| **Nu, Nv, Nw** | Number of unit cells in each of the UVW-map coordinates. |
| **Morph** | Strut morphing. (if true, struts are morphed into curves) |

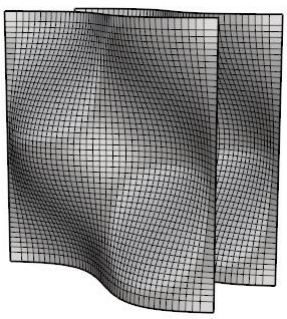
## OUTPUTS

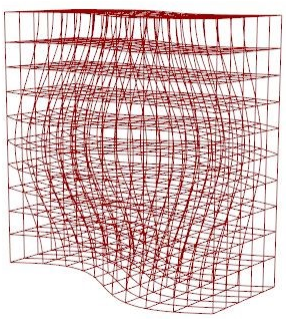
| | |
|---|---|
| **Struts** | List of curves representing the lattice struts. |

## EXAMPLE

The example shows a pair of identical sinusoidal surfaces, and the space between them is filled with lattice. Of course, your surfaces do not need to be identical.

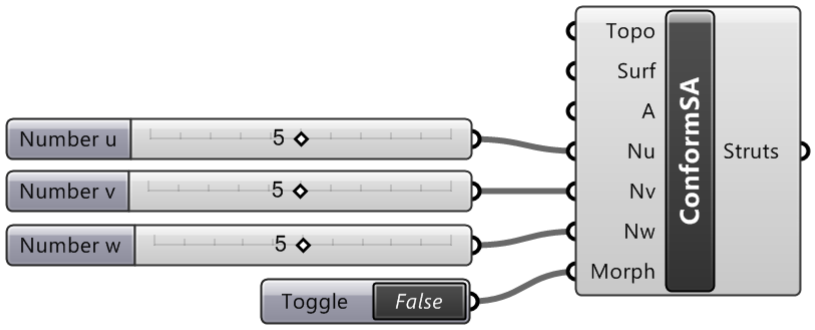
The lattice is conformed to the surfaces with the help of their UV maps, which are used to define a single UVW-map. You may input open or closed surfaces, such as spheres.





# 3.4 CONFORM SURFACE-AXIS

**Description** — Generates a uvw-conforming lattice between a surface and an axis.




## INPUTS

| | |
|---|---|
| **Topo** | Topology data, output by cell module. |
| **S1, A** | The surface and axis that define the design space, respectively. In some cases, you may need to pass the surface through the 'AdjustUV' component to fix UV alignment issues. |
| **Nu, Nv, Nw** | Number of unit cells in each of the UVW-map coordinates. (u—axial, v—theta, w—radial) |
| **Morph** | Strut morphing. (if true, struts are morphed into curves) |

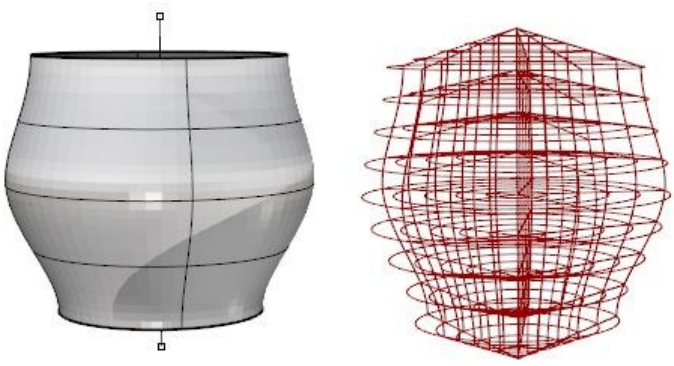
## OUTPUTS

| | |
|---|---|
| **Struts** | List of curves representing the lattice struts. |

## EXAMPLE

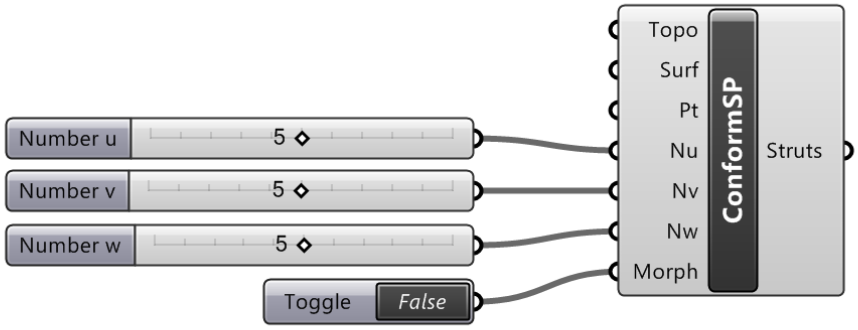
The lattice is conformed to the space between the axis and the surface by using the UV-map on the surface, and letting the axis be a U-map. The axis can be an open or closed curve. The surface can also be open or closed.

This example shows lattice being mapped to the space between a cylindrical surface and a linear axis which is slightly longer than the surface.



# 3.5 CONFORM SURFACE-POINT

**Description** — Generates a uvw-conforming lattice between a surface and a point.




## INPUTS

| | |
|---|---|
| **Topo** | Topology data, output by cell module. |
| **S1, Pt** | The surface and point that define the design space, respectively. |
| **Nu, Nv, Nw** | Number of unit cells in each of the UVW-map coordinates. |
| **Morph** | Strut morphing. (if true, struts are morphed into curves) |

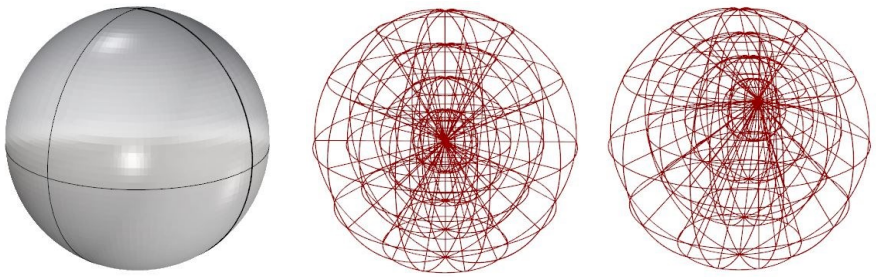
## OUTPUTS

| | |
|---|---|
| **Struts** | List of curves representing the lattice struts. |

## EXAMPLE

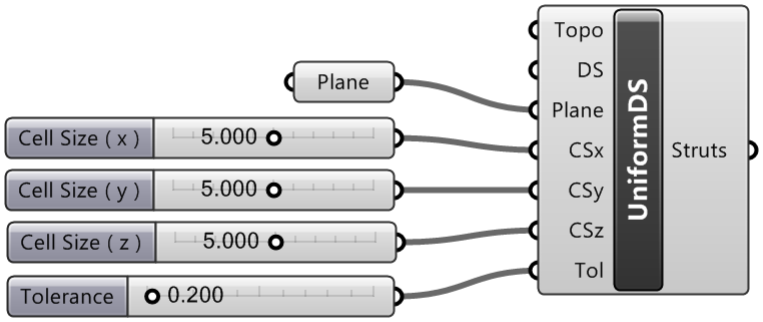
This example shows the space between a spherical surface and a point being populated with conformal lattice. As shown, the point does not need to be centered.

Moreover, the surface does not need to be closed.



# 3.6 UNIFORM DESIGN SPACE

**Description** — Generates a uniform lattice trimmed to the shape of the design space.




## INPUTS

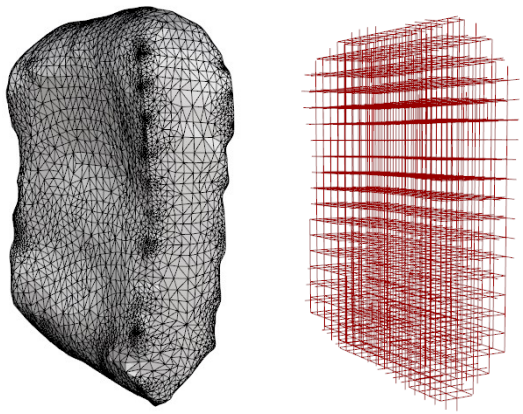
| | |
|---|---|
| **Topo** | Topology data, output by cell module. |
| **DS** | The design space, as a Brep or a Mesh. |
| **Plane** | Orientation plane of the uniform lattice. (3 degrees of freedom) |
| **CSx, CSy, CSz** | Number of unit cells in each of the plane coordinate directions. |
| **Tol** | Minimum strut length. (trimming can result in very small struts) |

## OUTPUTS

| | |
|---|---|
| **Struts** | List of curves representing the lattice struts. |

## EXAMPLE

The example here shows a craniofacial bone mesh, extracted from a CT scan. The design space is populated with a uniform lattice. Orientation of the lattice can be optimized using the Plane input. The design space may also be a Brep.



## UNRESOLVED ISSUE

Meshes with many coplanar faces are **error prone**. Rhinoceros has trouble determining if a point is inside or outside the mesh in these cases.

Section 4

# MESH MODULE

The mesh module takes in a lattice wireframe, as a list of curves, and converts it to a solid mesh, which can be exported as a .stl and 3D printed. The underlying mesh generation methods are inspired by Exoskeleton, a fantastic assembly by David Stasiuk. We've extended functionality to curves, modified various aspects of the algorithm, and encapsulated the process with a data structure.

However, robustness is still an issue: if the strut radii are ill-defined, meaning that they result in any parts of the mesh overlapping , the output will be invalid. This is illustrated on the next page. Moreover, as you increase the number of struts in your lattice, runtimes and memory usage increase dramatically. Unless you have a powerful workstation, we don't recommend attempting to solidify lattices of more than 500,000 struts.

## AVAILABLE COMPONENTS

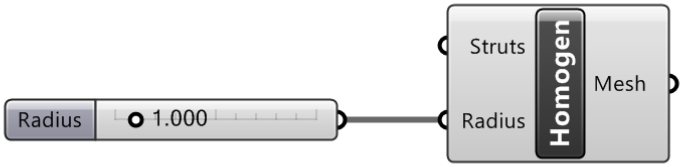
| | | |
|---|---|---|
| **Homogen** | - | Generates a homogeneous mesh. (constant strut radius) |
| **HeterogenGradient** | - | Generates a gradient-based heterogeneous mesh. (variable strut radius) |
| **HeterogenCustom** | - | Generates a fully customizable heterogeneous mesh. (variable strut radius) |

## FUTURE COMPONENTS

To address the robustness issue, one idea is to use a voxel-based approach. Once again, David Stasiuk has led the way, recently releasing Cocoon, a meshing component based on implicit surfaces and the marching cubes algorithm. This approach seems to be much more robust, but also much more computationally expensive (i.e. very long runtimes). We are hoping to explore this avenue in the near future.

# 4.0 HOMOGENEOUS

**Description** — Generates a homogeneous mesh of the lattice. (constant strut radius)




## INPUTS

**Struts** List of curves representing the lattice struts.

**Radius** Radius of the struts. Note that the actual thickness of the struts is double this value.

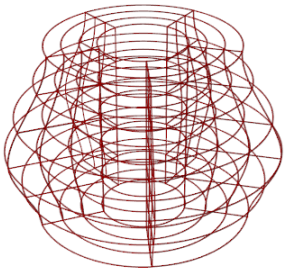
## OUTPUTS

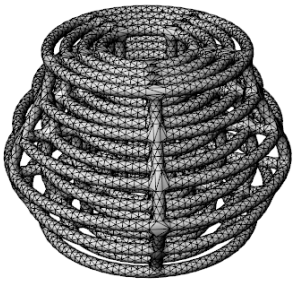
**Mesh** Solid mesh of the lattice.

## EXAMPLE

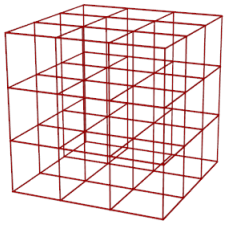
The meshing components work for both lines and curves. In this example (right), a morphed lattice is solidified with constant radius.

**Choose your radius wisely**—the component will return an invalid mesh if any parts of your mesh overlap. The overlap issue is illustrated in the example below.

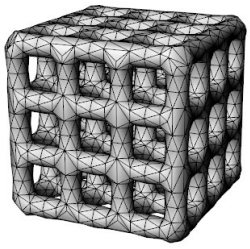




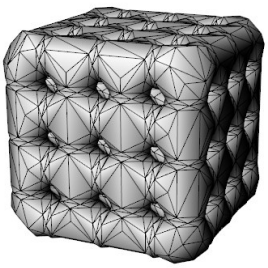
**BASE FRAME**
Struts input



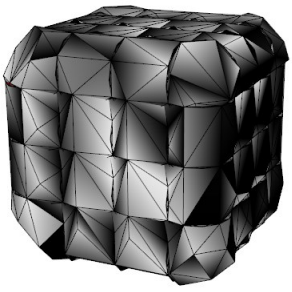
**RADIUS = 1mm**
Valid mesh



**RADIUS = 2mm**
Valid mesh (borderline)

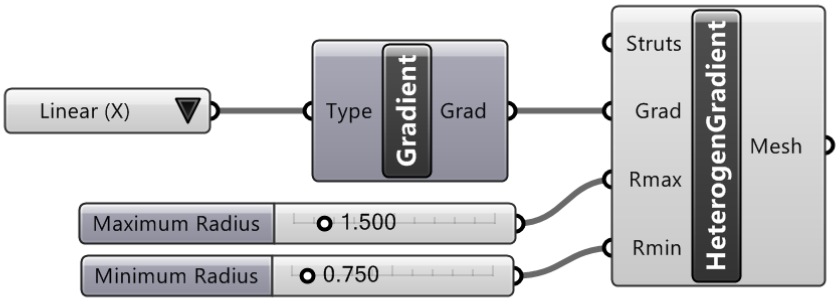


**RADIUS = 3mm**
Invalid mesh



# 4.1 HETEROGENEOUS GRADIENT

**Description** — Generates a heterogeneous mesh of the lattice. (gradient strut radius)




## INPUTS

**Struts** List of curves representing the lattice struts.

**Grad** Mathematical expression (string) representing a spatial gradient.

**Rmax, Rmin** Maximum and minimum strut radius.

## OUTPUTS

**Mesh** Solid mesh of the lattice.

## GRADIENT FUNCTION

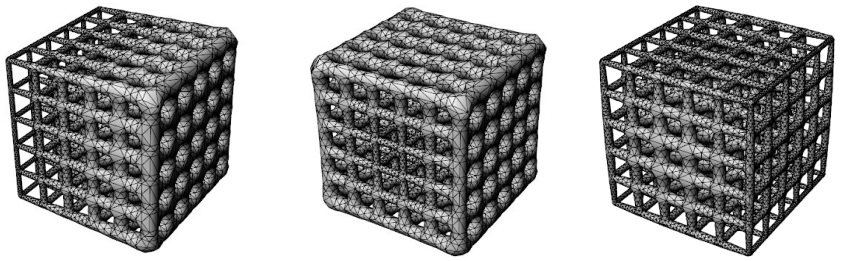
The spatial gradient (Grad) is a mathematical function g(x,y,z) with a unitized domain

0 < **x** < 1
0 < **y** < 1
0 < **z** < 1
0 < **g(x,y,z)** < 1

The radius of the struts at each node is directly proportional to value g(x,y,z), such that

**g(x,y,z)** = 0 → Radius = Rmin
**g(x,y,z)** = 1 → Radius = Rmax

## EXAMPLE



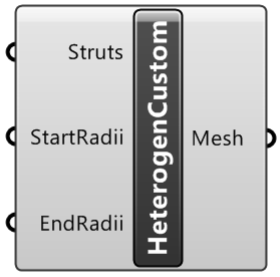
Linear gradient
g(x,y,z) = x

Cylindrical gradient
g(x,y,z) = Sqrt(Abs(2*x-1)^2 + Abs(2*z-1)^2)/Sqrt(2)

You can reverse the gradient by swapping Rmin and Rmax.
The PresetGradient component includes a library of gradients.
Of course, you may also define your own gradient functions.

## 4.2 HETEROGENEOUS CUSTOM

**Description** — Generates a heterogeneous lattice. (custom strut radii)




### INPUTS

| | |
|---|---|
| **Struts** | List of curves representing the lattice struts. |
| **StartRadii** | List of radii at the start of each strut, parallel to the Struts list. |
| **EndRadii** | List of radii at the end of each strut, parallel to the Struts list. |

### OUTPUTS

| | |
|---|---|
| **Mesh** | Solid mesh of the lattice. |

### EXAMPLE

With this component, you have complete freedom in defining the strut radii. This is of particular interest when combined with FEA, in the sense that the strut radii lists can be optimized for a specific real-world applications. We currently have proprietary modules that do this — if you are interested, please contact us.

Section 5

# UTILITY MODULE

The utility module provides a set of pre/post-processing components. For the most part, these components are optional. But in some cases, you'll find yourself using one or more of these.

## AVAILABLE COMPONENTS

The current components are summarized below.

**1. AdjustUV** - Adjusts the UV-map of a surface.

**2. CleanNetwork** - Removes duplicate curves from a list, within tolerance.

**3. MeshReport** - Verifies that the mesh represents a solid, and returns a comprehensive report.

**4. MeshPreview** - Displays detailed preview of a mesh.

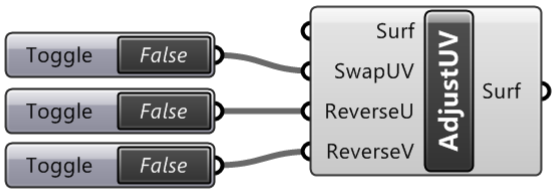
## FUTURE COMPONENTS

Since this module doesn't serve any single purpose, the possibilities for future components are pretty diversified. For one, we plan on extending the MeshReport component to include information relevant to particular 3D printer technologies and systems. Another component we'd like to develop involves generating external skins to cover the lattice, without the need for Boolean unions of meshes.

Generally, the users' needs will direct development, so don't hesitate to contact us.

# 5.0 ADJUST UV

**Description** — Adjusts the UV-map of a surface for proper alignment with other surfaces/axes.




## INPUTS

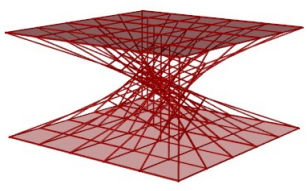
| | |
|---|---|
| **Surf** | Surface to adjust. |
| **SwapUV** | Swap the uv parameters. |
| **ReverseU** | Reverse the u-parameter direction. |
| **ReverseV** | Reverse the v-parameter direction. |

## OUTPUTS

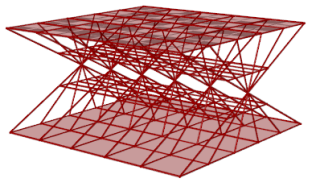
| | |
|---|---|
| **Surf** | Adjusted surface. |

## EXAMPLE

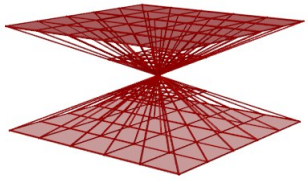
Suppose you wanted to generate a conformal lattice between two surfaces. As mentioned, the UV-maps of your surface are used as a basis for the UVW cell grid. The various UV-map misalignment issues are illustrated below.



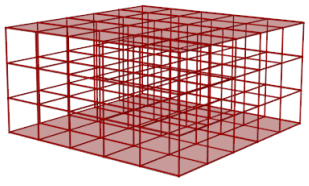
**Swapped UV-directions**



**Reversed U or V-direction**



**Reversed U and V-directions**

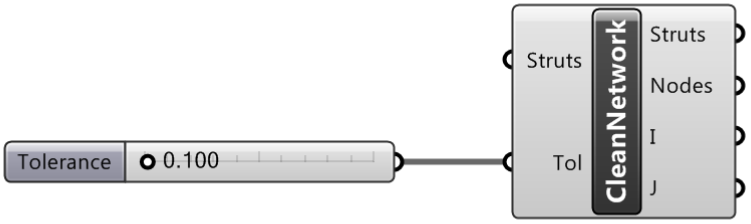


**Matching UV-maps** (desired)

If you run into these kind of issues, pass one of the surfaces through the AdjustUV component. This also applies to misalignments between an axis and a surface (as in the ConformSA component).

# 5.0 CLEAN NETWORK

**Description** — Removes duplicate curves from a list, within specified tolerance.




## INPUTS

| | |
|---|---|
| **Struts** | List of curves to be cleaned. |
| **Tol** | Tolerance for combining nodes/curves. |

## OUTPUTS

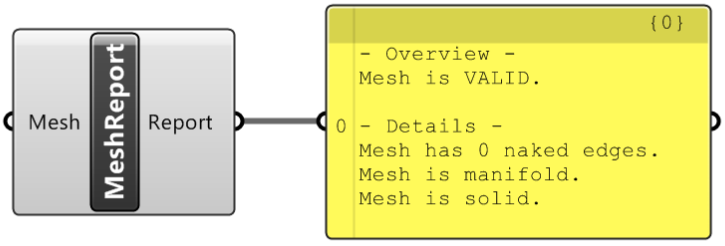
| | |
|---|---|
| **Struts** | Cleaned list of curves. (no duplicates) |
| **Nodes** | List of unique nodes. |
| **I** | List of *Nodes* indices for start of each curve in *Struts*. |
| **J** | List of *Nodes* indices for end of each curve in *Struts*. |

## EXAMPLE

The tolerance input allows you to remove struts which are very close to one another. Note that all the mesh components (seen in next section) run this method internally, so you don't need to run your lattice frame through this unless you want to make use of the tolerance input to combine struts. Also, note that this component compares curves based on their endpoints and midpoints—it may not distinguish similar (yet noisy/oscillating) curves.

# 5.0 MESH REPORT

**Description** — Verifies that the mesh represents a solid, and returns a comprehensive report.




## INPUTS

**Mesh** The mesh to inspect.

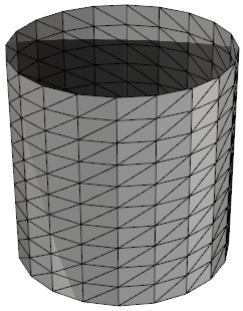
## OUTPUTS

**Report** Validity report, concerning 3D printability.

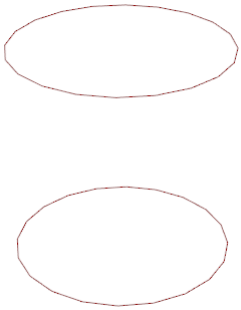
*Naked edges are visible in the viewport (as dark red polylines).*

## EXAMPLE

The most fundamental requirement of a mesh if it is to be 3D printed, is that it must represent a solid. As an example, consider the following cylindrical mesh, which is left open. Naturally, this model does not represent a solid — it has naked edges all along the loose ends. Our component will highlight naked edges, in dark red. This can be very useful when you have complex lattice meshes, and want to find the problem areas in your mesh. We used this simple example, because at this stage, it's actually quite difficult to generate meshes with naked edges with Intralattice (which is a good thing!).



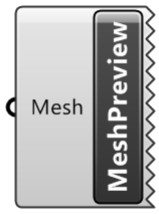
**MESH**



**NAKED EDGES**

# 5.0 MESH PREVIEW

**Description** — Displays a detailed preview of a mesh.




## INPUTS

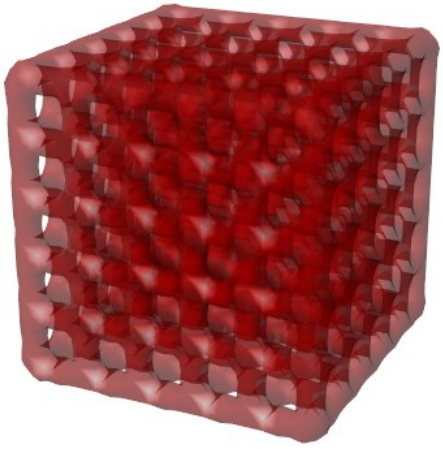
**Mesh** The mesh to preview.

## OUTPUTS

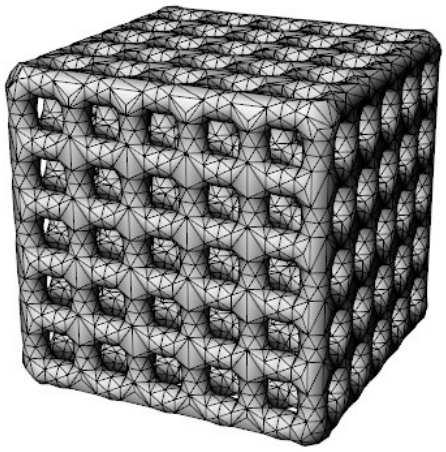
*A colored mesh and its edges are visible in the Rhinoceros viewport.*

## EXAMPLE

The example below shows the default and detailed previews for a simple box lattice.



**Default Grasshopper preview**



**Detailed preview**

Section 6

# CASE STUDIES

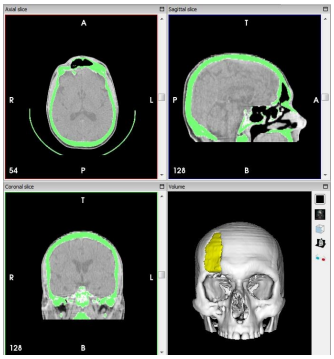
In this section, we look at a few case studies.

**WIP**

# 6.0 BONE GRAFTS

Bone tissue, unlike most other tissues, has the ability to regenerate when provided a space in which to grow. Bone grafting is a surgical procedure which aims to implant scaffold materials for reparative bone growth. The success of a bone graft relies on three biologic mechanisms: osteoconduction, osteoinduction and osteogenesis. Osteoconduction occurs when the graft serves as a scaffold upon which bone cells spread and form new bone. Naturally, the structural properties of this scaffold play an important role in this process.
Through the use of lattice structures, we can manipulate the porosity and strength of the implant. First and foremost, defining the design space requires some form of medical imaging of the patient's fracture. Below, we will walkthrough the design process of a craniofacial bone graft implant.

## **STEP 1** - CT SEGMENTATION



Based on a CT scan of the patients fractured skull, InVesalius reconstructed the set of medical images into a 3D representation. Then, by manually selecting voxels where cranial bone was missing, an implant space was defined (seen in yellow) and exported as a mesh (.stl).

For the record, this process was quite tedious and a more efficient approach is needed.

## **STEP 2** - GRAFT DESIGN

The next step was to open the implant mesh in Rhino3D and select it as the design space in our Grasshopper algorithm. From here, experimenting with various lattice topologies and cell sizes allows us to manipulate the porosity and strength of the implant. Note that we are currently developing a topology generation algorithm which emulates the trabecular structure of bone. We are very interested in working with specialists to fine-tune these structures.

In the example below, a simple grid-uniform-homogeneous lattice is generated:

**I** Fractured Skull → **II** Solid Implant → **III** Porous Implant

## 6.1 CELLULAR TIRE

Airless tires are of particular interest in offroad, military and extra-terrestrial vehicles. In general, the quality of such tires is largely based on resilience. However, since this property is hard to evaluate through FEA, extensive physical testing is required to validate the quality of a design. In this case study, we simply show prototypes which would be tested, the quality of these designs is unknown.

As usual, the first step was to define a design space, which in this case, was the space between the tire thread and the wheel rim.

Next, we set the various design parameters, such as unit cell type, conformal iteration values and strut radius.

By changing the design parameters, we easily obtain diversified structures. In the figure shown here, you can see, in order of appearance:

1. Bare design space
2. Grid conformal lattice
3. Octet conformal lattice
4. Vintiles conformal lattice