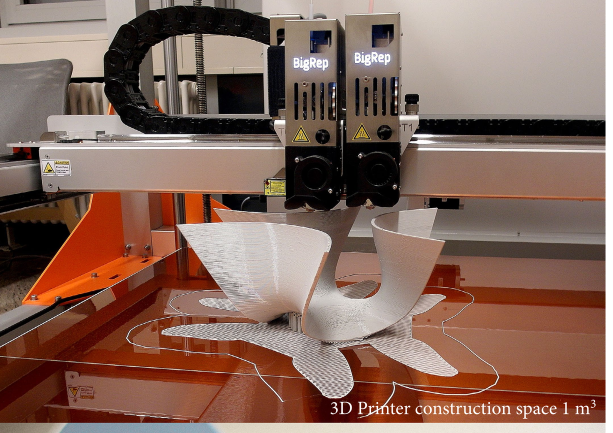
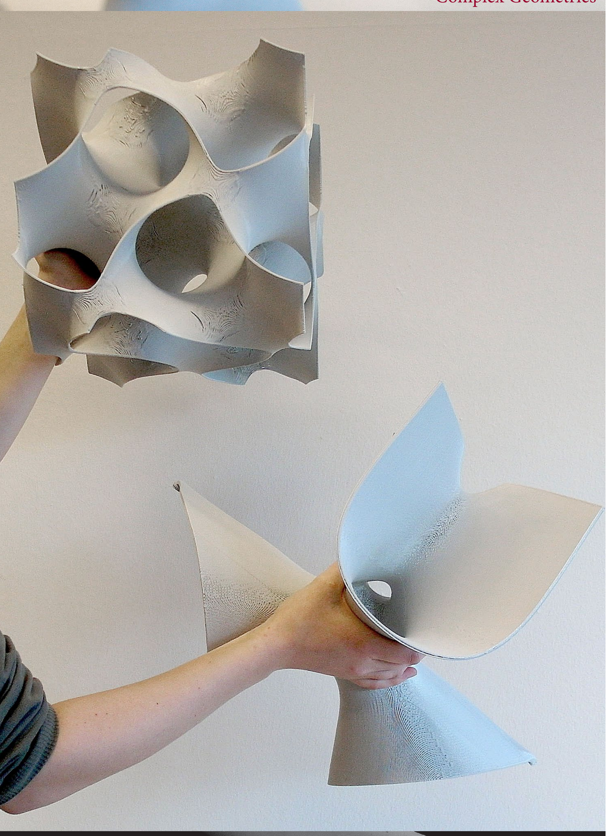
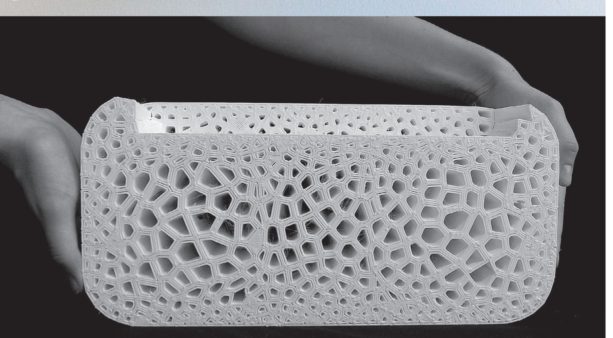

3D Printer construction space 1 m³


Large 3D print
Complex Geometries




Large 3D print
Artificial Sponge, optimized for structure and ductwork

SIZE MATTERS: New possibilities for architectural design via large-scale 3D printing

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1. Overview

We conduct an experimental student design project that investigates new possibilities for architectural design obtained via large-scale 3D printing technology.
We propose that the new digital technologies in modeling and manufacturing enable a much closer connection between designers' thoughts and their physical realization than previously possible and thereby a more humanistic architecture.

2. Background & Motivation: Removing the detour of small-scale representations

In its short history [since 1981] 3D printing has evolved rapidly and will continue to do so [Ref 1]. For architectural education this means that it is not only essential for students to be familiar with the latest techniques, but to be able to accommodate future developments. For architectural design the effects are manifold. To name but a few: quasi-custom materials, rapid prototype production and the possibility to fabricate buildings or parts of buildings from one piece without having to assemble separate elements.
We focus on the issues brought along by the ever-increasing size of 3D printers (as opposed to those resulting from printing speed or cost): When until recently, small construction spaces restricted their use to scale models of architecture or objects like door handle prototypes, now, larger construction spaces of around 1 cubic meter allow for the production of 1:1 objects like chairs or complete building parts.
We propose that this difference in size matters enormously, as it in fact removes a detour that the design of architecture traditionally has always taken for granted, namely that prior to its time and labour-consuming building, architecture has to be presented in smaller scale representations. Now, architecture can be thought and digitally modeled 1:1, and then directly manufactured (printed) 1:1 for ‚end-use' [Ref 2].
In an experimental student design project, we investigate and discuss five implications of this.

3. Five implications of 3D printing with construction spaces >1m³

(i) Custom materials

Variations in both the source material that is being printed and how it is printed allow for many possible customizations of the material properties of the printed objects. The printable source materials are manifold, with wood, various metals and synthetics as bases.
The possibility to define and control micro-structure (resolution measured in micrometers and above 25x magnification) allows to adjust resultant material properties like porosity, plasticity and elasticity. This frees designers from the constraints of pre-defined building materials (wood, metals etc).

(ii) Rapid 1:1 prototype loops

Being able to have a 1:1 prototype produced in a matter of hours - especially overnight - means that more prototypes can be produced sooner and influence the design process much more than previously. While design fields like for example vehicle or object design rely heavily on feedback from prototypes testing to improve designs as a matter of course, architecture so far could not, because of the efforts involved to build prototypes. This changes with larger and faster printers. Thus, architecture can now benefit from the feedback of the study of multiple prototypes during the design process.

(iii) Integration of different functions into one building element

3D printers make the complexity of the geometry of the printed objects negligible. Apart from the new formal properties that have been the focus of study in recent years, this also allows to integrate functionalities that have traditionally be assigned to separate building elements into one piece - like for example various ducts and pipes for transport of power or fluids in wall systems. This extends to joints for connecting different building elements. Such integration promises less material waste and faster building processes.

(iv) Possibility to fabricate buildings or parts of buildings from one piece without having to assemble them

As a corollary of (iii), larger units of buildings can be fabricated as single pieces, making the assembly of separate parts taking for granted in the construction of buildings obsolete. For example, doors, door frames, hinges and door handles and the wall around them, or sanitary units including washbasins, wcs and all the necessary ductwork can now be printed as one piece.

With a construction space of 1 cubic meter or more, furniture objects like chairs or small tables can be produced, or modules of larger structures.

(v) On-site-Production

A lot of effort in building goes into transport of materials, machinery and people to the building sites from specialized production or storage spaces located at considerable distances. Installing a number of large-scale 3D printers on a building site would restrict the transport to the printing source material, saving a lot of energy and space.

4. Hardware

The recent acquisition (2016) of a BigRep ONE v3 printer with a construction space of 1 cubic meter (1005 mm x1005 mm x1005 mm) allows our school of architecture to investigate and test the above mentioned possibilities with students.
The application of additive manufacturing processes, such as fused deposition modeling (FDM – formerly copyrighted by Stratasys), equivalent to fused filament fabrication (FFF - coined by the RepRap community), of the BigRep ONE v3, allows the materialization of objects within a resolution of 400 to 900 micrometers.
The structural properties of the produced objects do not have to be the same as the used source filament material. Digital methods and thereby applied and processed geometries may enhance certain physical aspects within design and production of objects.

5. Material

The materials used for printing are specially modified thermoplastic filaments with a diameter of 3 mm deposited on spools. With the use of thermoplastics comes a certain range of potential modifications by introduction of functional composites. These are still compatible to the printing nozzles of the BigRep when printing parameters like speed, temperature, ventilation etc. have been calibrated according to the complexity of geometry to be printed.
The printing machine producer currently offers popular and biodegradable polyactid acid (PLA) which has been used for testing and calibration purposes.
Composite filaments with ingredients like wood will be tested and calibrated in future projects. Also, technical modification of the printing nozzles and bed for better calibrated printing results are thinkable. Finally, filaments can be produced in-house with an additional extrusion machine for filaments with new composite characteristics.

6. Constraints

Long printing times are quite cumbersome and can only be reduced with a loss in printing resolution. The accompanying loss of surface quality can be equalized by additional post-processing such as surface filling, sanding and painting which define new artistic qualities for exhibition purposes [Ref 4]. New printer prototypes with an additional 3-axis tiltable printing bed show that otherwise necessary printing and removing support structure in a post-process can be omitted and hence speed up the printing process overall [Ref 5].

7. Software

The software used for design modeling and production of architecture objects by the students are a mathematical modeling software (MathMod) that visualizes implicit and parametric surfaces, McNeel´s Rhino 3D with its graphic scripting interface Grasshopper 3D and a state of the art slicing software (Simplify 3D).
The use of prepared implicit and parametric surfaces as well as Grasshopper scripts support a compact learning curve with fast results for the initial stages of the student´s 3d modeling experience with new software in a school of architecture [Ref 3].

8. Experimental Student Design Course: *Polyfunctional walls*

Traditionally, design courses have been mirroring the structure of real-world projects in that they more or less followed a clear sequence of separate steps: theoretical study of subject, design presented with 2D media and perhaps occasional 3D models, presentation to final design in 3D media and 3D scale model.
In contrast, our course is set up as a series of iterative loops consisting of brief study and then quick - digital - design in 3D and production of 3D prototypes, be they 1:1 prototypes or scale models. This sequence is repeated several times within the course. Knowledge, skill and understanding of the possibilities existing today and those coming are thus obtained in waves, each one building upon the previous ones. The learning process thus set up in the course can continue for the students even after the course itself is finished.

In our first study and research project shown here, we develop **polyfunctional wall elements**. They **integrate** several functions conventionally distributed over various building elements (structure, electrical installations, ductwork, lighting fixtures, acoustic functionalities, seating and storage furniture) into single elements. The overall geometry and the built-up of the walls are controlled via a custom grasshopper definition.

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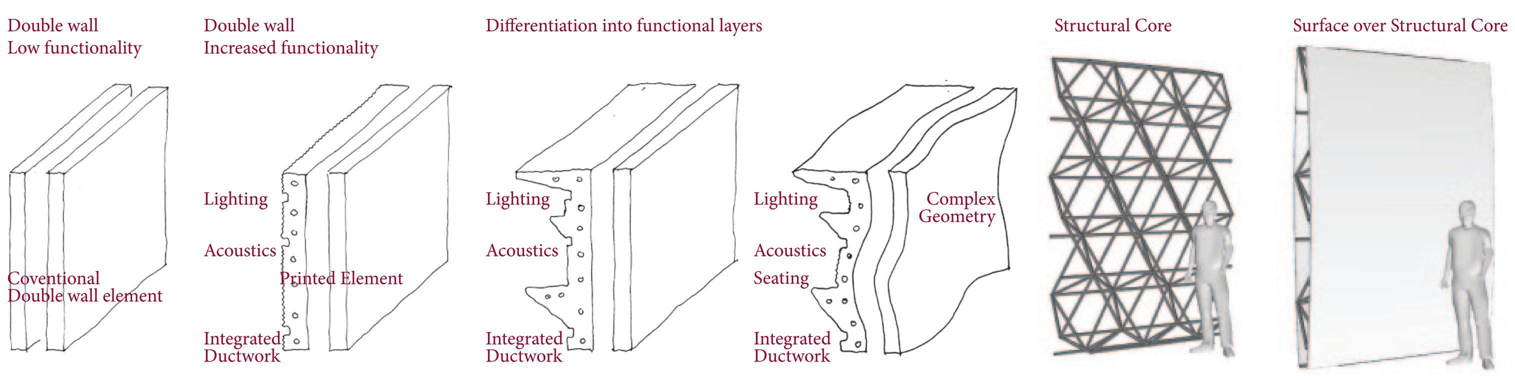
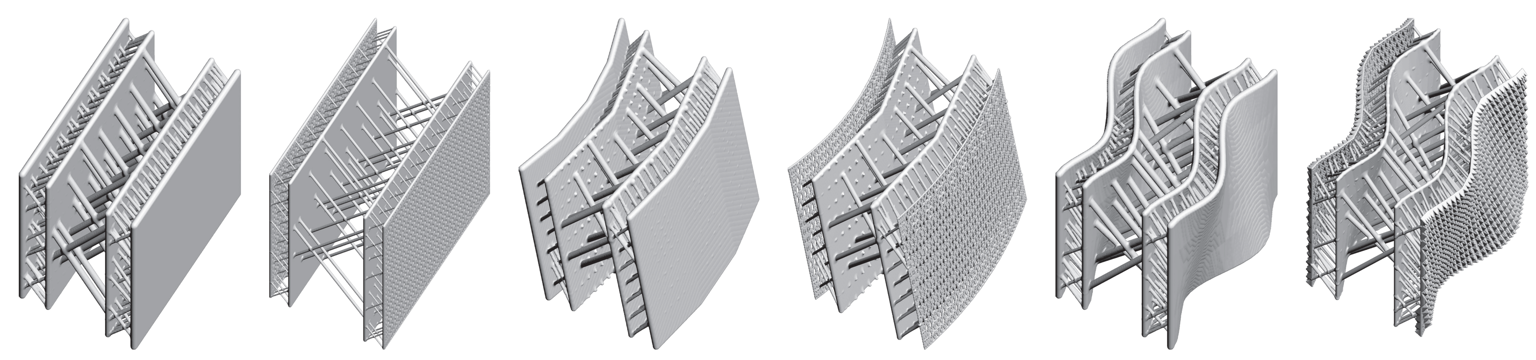
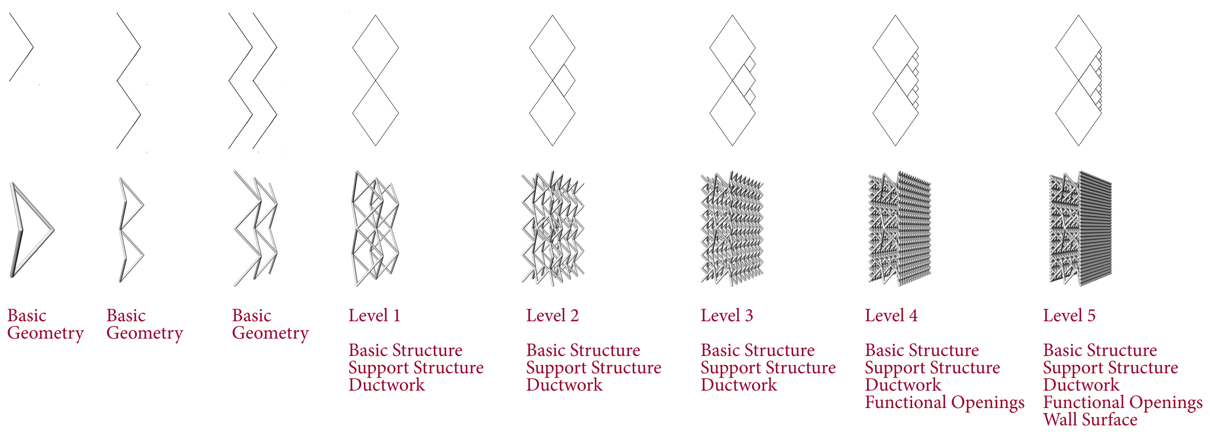
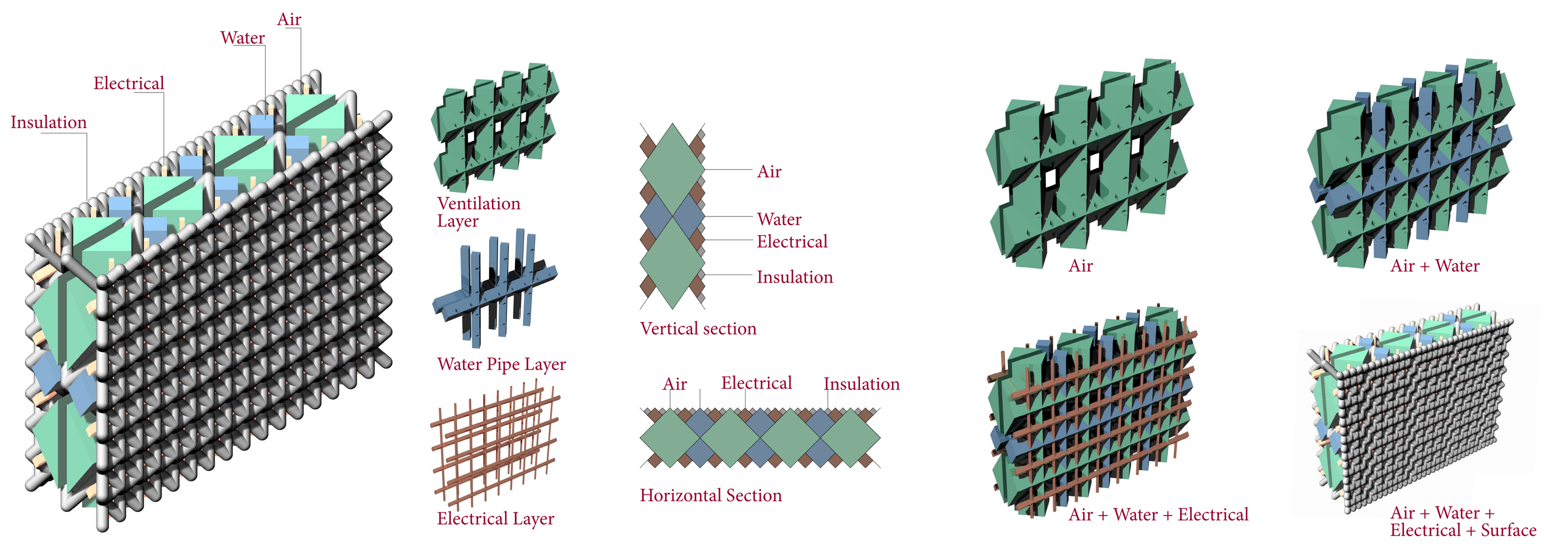
3D Print of Multifunctional Wall Elements

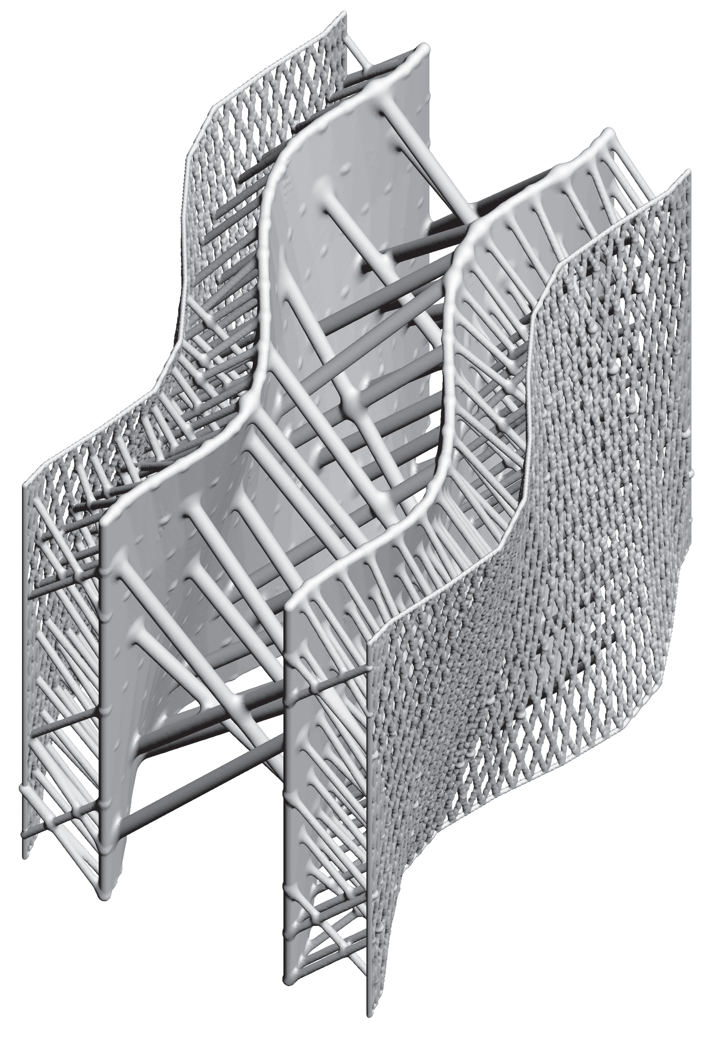


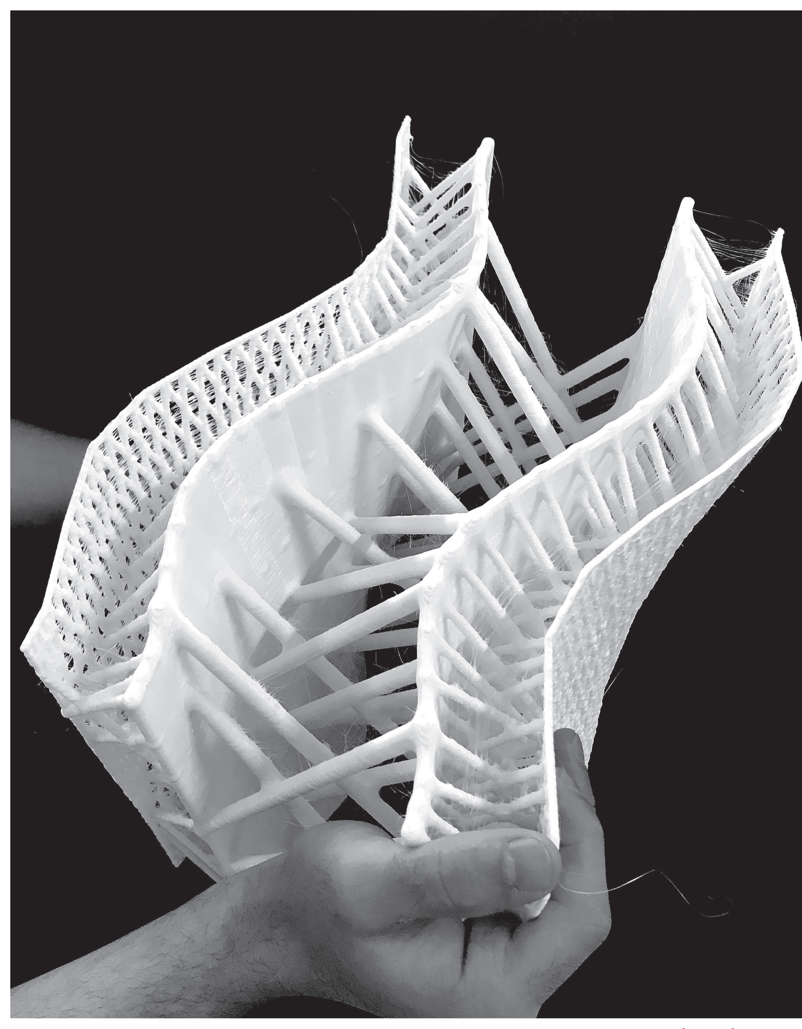
Varying Wall Element Geometries, Internal Structures and Perforation Levels generated via custom Grasshopper Definition

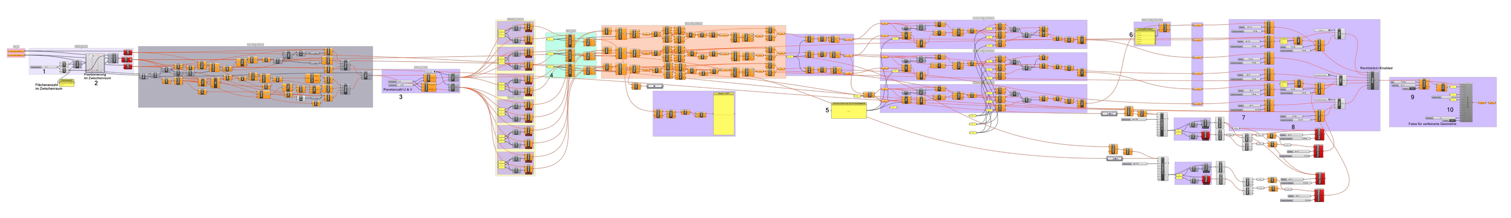









3D printed sample piece



Two set of curves to define the outside surface geometry of a precast or in-situ 3d-printed wall which are tweened and positioned to define spatial layers for different materials and HVACR. A diamond panelling scheme (Proving Ground´s Lunchbox Add-On) is used to discretize the surfaces into line geometry. Line connections between the layers are introduced to stabilize and enforce the wall, all without the need for support structures in the printing process, since arbitrary angles are filtered. David Stasiuk Cocoon Add-On enables the line geometry as axis for a marching cube geometry to get a fully enclosed and directly printable mesh geometry. In a last step Daniel Piker´s Mesh Machine is used to equalize and reduce the mesh face count of the cocoon mesh.

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