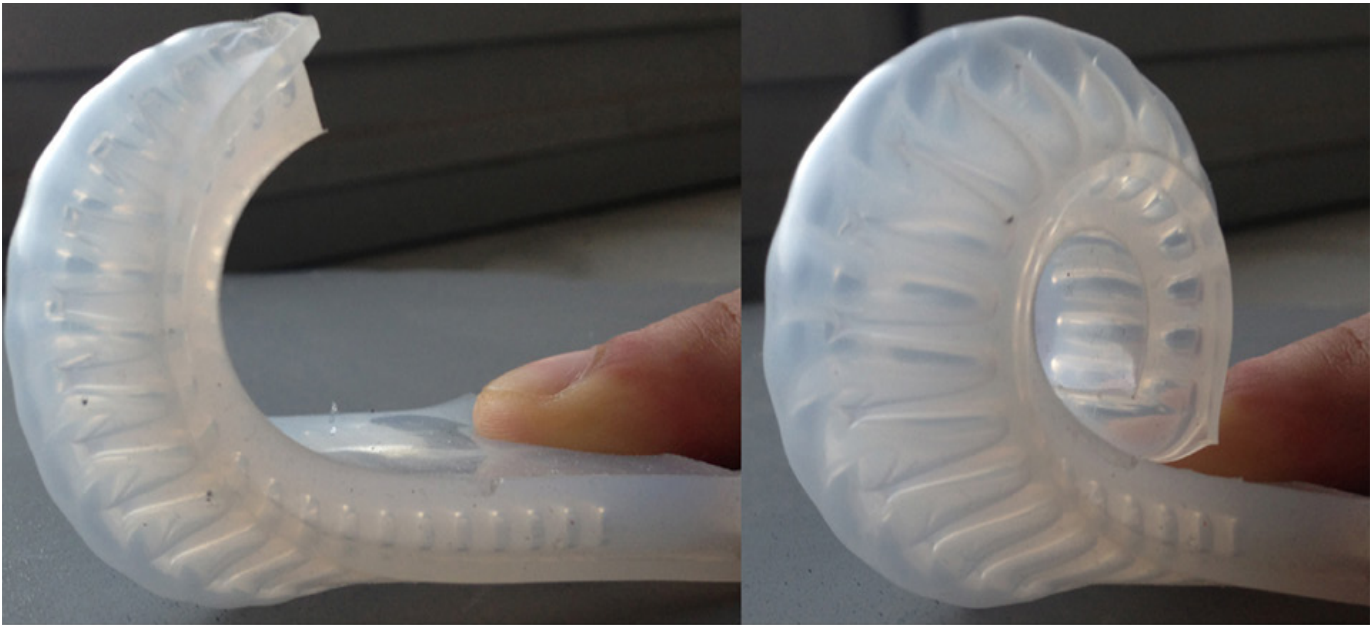


TOWARDS A DIGITAL ANISOTROPIC MATERIALITY

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1 Defined material properties leading to material computation - pneumatic experimentation (Pindeus, 2013)

ABSTRACT

We are witnessing the dawn of additive manufacturing in the one-to-one environment. This is subsequently allowing us to gradually depart from the idea of assembly as a way of designing and building. The ongoing research project presented in this paper is dedicated to developing a digital design process that can generate an anisotropic digital material, which stands in negotiation between the design intent, structural optimization and the possibilities of the fabrication method.

An accessible tool for the *Grasshopper*® environment is being developed which encourages the design conception of such a materiality and incorporates the native translation into the equivalent machine code for an extrusion based printer.¹

PREMISE

The new possibilities of computer-guided production are closing the gap between the seamlessness of the digital model and its built physical form. The gradient of the digital is becoming literal as blends replace joints for transitions. Methods of material-based design computation are paving the way for this conception of anisotropy in tectonics.² The resulting digital models describe the local conditions within a form as a result of an ascribed material behavior reacting to set conditions. The constraints of the means of fabrication are fed into this negotiation of digital processes in the first instance, embedding the fabrication strategy in the design conception (Figure 1).

The topology and local material properties of the outcome stand as an optimized result of this looping process accomplishing a higher structural efficiency and a decrease of excess material. The rise of variable property fabrication methods affects these models allowing the heterogeneity of the calculated digital material to be translated into physical form.

INTRODUCTION

The project's aim is to create an accessible tool for generating and fabricating functionally graded materials while keeping design intention in mind. In terms of software, the goal is to develop a generative component for the node based scripting environment of *Grasshopper*.³ It should encourage an intuitive workflow for the generation of optimized topology and anisotropic materials on one hand and the equivalent direct guidance of extrusion-based 3D printers on the other. In terms of hardware we are developing hacks for common extruders to allow for the fabrication of heterogeneous material properties and distributions in accordance with the digital file generated with the *Grasshopper* component.

THE COMPONENT

The *Grasshopper*® community has shown a tendency where developers have pushed towards the optimization of material.⁴ Components such as Kangaroo Physics, Millipede, or Karamba have enabled users to design with digital material computation.^{5,6} .⁷ The HAL Project, developed by Thibault Schwarz, is an example to incorporate fabrication into the same.⁸ The development of the component stands in the same tradition. It is about bringing a design methodology to a wider audience and natively combining it with a contemporary fabrication technology. Form and materiality can be simultaneously created in correlation with each other while being informed with the fabrication constraints and the designer's intentions. A simulated model in the viewport and the generation of the equivalent machine codes are the results of the operation.

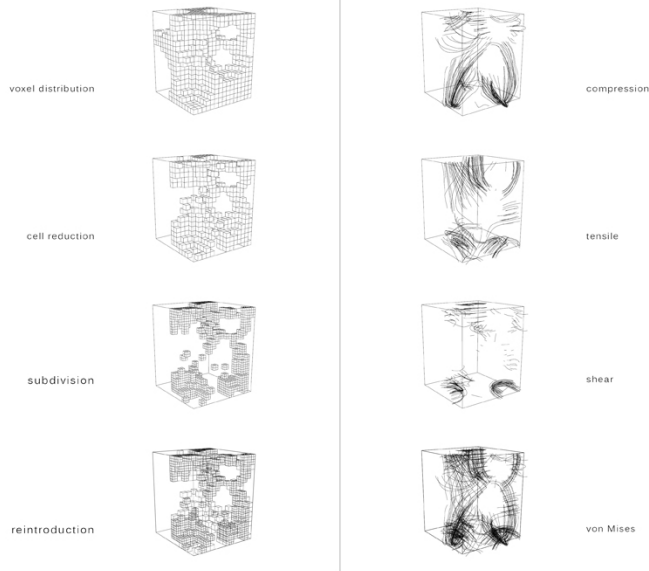


2 A 3D printed model showing the geometrical negotiation between a predefined void and a density function (Rhombberg 2014)

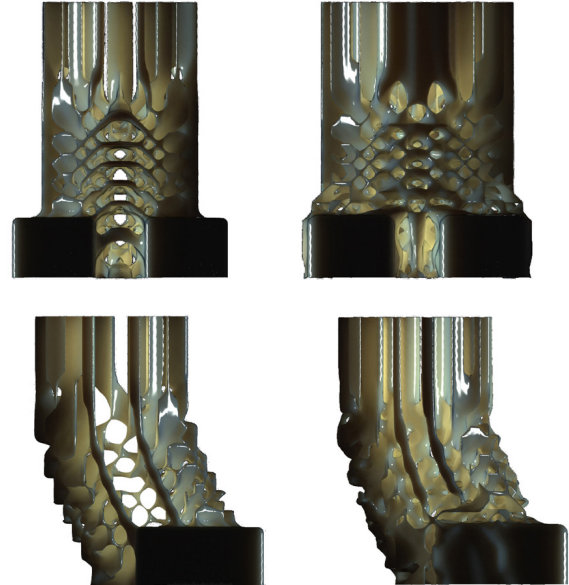
IMPULSION

The component's point of departure is the definition of the build space and an initial resolution of spatial division. The voxelation method can be on the basis of either cubes or tetrahedrons with each method leading to specific qualities. Volumes may be ascribed with an incipient zero density value. This makes it possible to define spaces as voids where no material shall be deployed (Figure 2).

These predefined values can also be used to affect the tendentious material and tectonic qualities of a specific volume. Areas of high density can carry more apertures or have a thinner wall thickness allowing for more transparency. These values are basic tendencies for the distribution of material and stand in negotiation with the following processes. They can be defined



3 The bi-directional Evolutionary Optimization Solver – material distribution around a predefined void and force tensors (Buckler, Rhomberg, Thanei 2013)



4-5 Compositional tendencies developed with a radial falloff function propagating from a curve and the topology optimization package (Rhomberg 2014)

manually or by describing a function in space. The latter allows giving the formation a relative habit such as enclosing areas or opening towards a given vector. This assents the possibility to define spatial relationships or a coded semiotic readability.

But these predetermined qualities are subordinate to the latter processes that actuate the integrity of performance and can be overridden in case of extreme inefficiency. This gives the project a controlled design tendency and still allows for inherence and coherency towards the system.

TOPOLOGY OPTIMIZATION

The main process governing the distribution of material is the topology optimization package (Figure 3). It is based on the Bi-directional Evolutionary Optimization Solver of the Karamba project.⁹ It recognizes set anchor points, the accumulation of acting forces, Eigenweight and the mentioned preloaded density tendencies (Figure 4, 5).

The combined situation is compiled and voxels are deployed where the forces are below an interchangeable threshold value resulting in a higher structural efficiency to material use ratio. An overview of the forces present in the entire structure is directly visualized with an iso-surface hull created with a marching cubes solver (Figure 6).

ADAPTIVE SUBDIVISION

The system strives towards an optimized buildup. Each voxel stores information about its material tendency and the forces that are at play. This allows for local differentiation in the entire geometrical solution ensuring an anisotropic material distribution. One proposed strategy for densification is to recursively subdivide the voxels over their centroid. The amount of fractal subdivision that should occur in a voxel is defined by a threshold derived from the local principal stresses. In the case of cubic voxels, this concludes an octree subdivision which plainly stays

orthogonal in its directionality (Figure 7). A tetrahedral subdivision yields a more effective use of space and creates a multidirectional densification when it is subdivided.

An alternative strategy is to use the principal stresses to inform local geometrical morphologies, which are capable of adapting to each voxel's situation individually. A series of Batwing Surfaces were the first family of geometry that was tried. These surfaces work within a cube and allow for a high amount of control over their directionality.

A collection of Batwing Surfaces was selected upon their ability to cope with a selection of generic stress situations. Each voxel is now categorized into one of these situations and the according surface from the collection is applied (Figure 8).

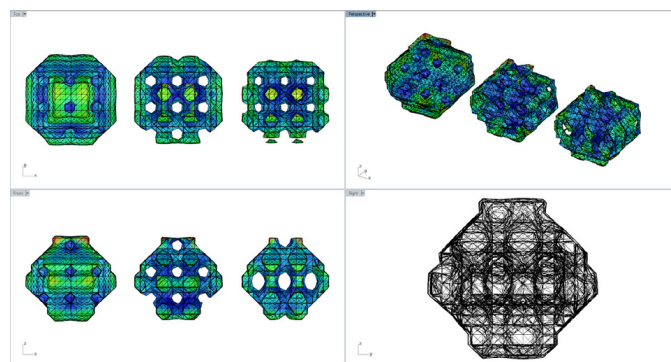
A further step, which allows the selected surfaces to act as genotypes, which morph and adapt phenotypically to the precise local stresses is still under development.

TRANSLATING LOCAL PROPERTIES INTO G-CODE

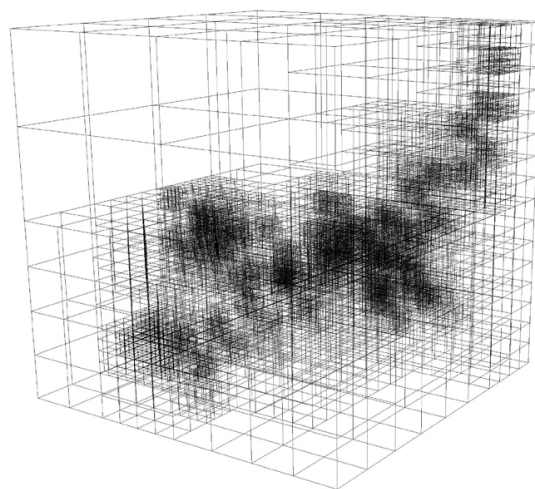
The experimentation is currently on the basis of common polymer extrusion technologies. This permits a set amount of possibilities. For now we have been creating material differentiation by altering the nozzle heats and flow rates on a dual extruder head setup. The qualities that are possible with the available fabrication method become the degrees of freedom for the variation of material properties. The information of the material build related to these properties inscribed locally into each voxel. This idea relates to the concept of the material voxel or maxel proposed by Neri Oxman.¹⁰ In the final stage of the setup these are translated directly into the machine code. It is the aim to take this translation as well as the slicing of geometry into tool paths and integrate these processes natively in the Grasshopper environment.

HARDWARE

It is not the intention here to suggest the fabrication of architecture in building scale by extruding polymers in the way we see it with common plastic extruders. Neither is it our goal to remain tied to this material in the long run. But since this technology has taken over our desktops by storm it conjures a popular training ground for experimentation. Full-scale extrusion technologies such as D-Shape™ are yet to become the standard.¹¹ In the meantime, cheap polymer extruders remain a great opportunity to explore the possibilities of building architecture with an anisotropic materiality.



6 Formations developed with a trigonometrical function and the topology optimization package. The colors indicate the Von Mises Stresses (Rhombert, Thanei)

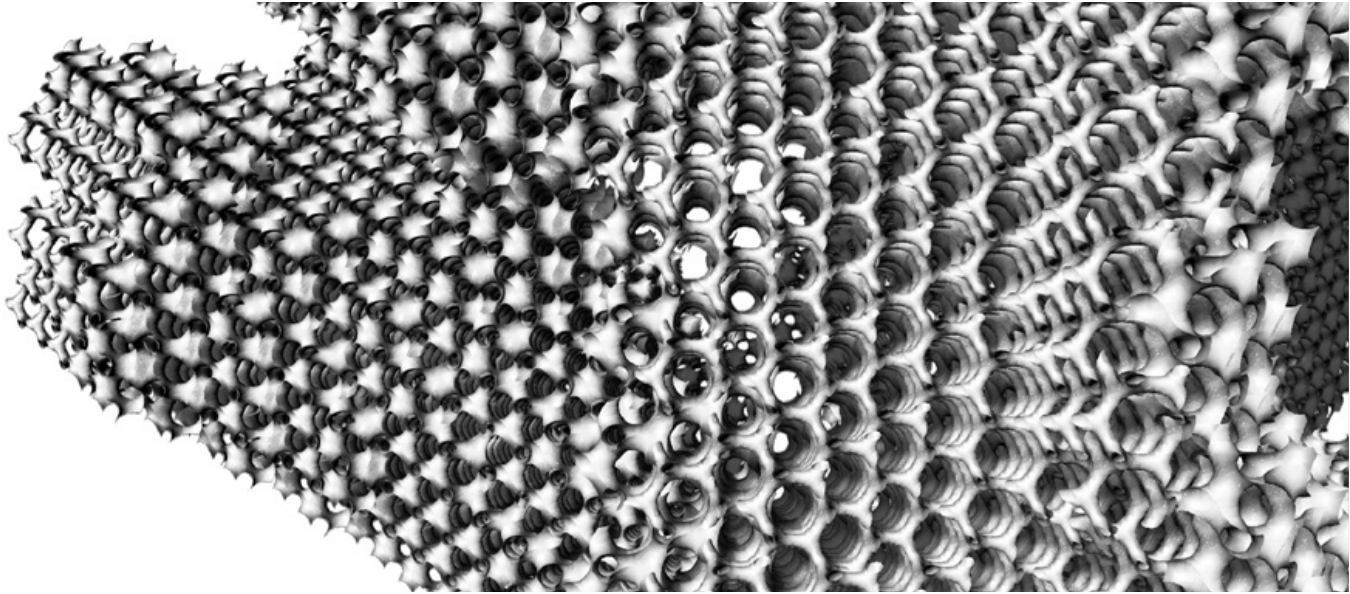


7 A recursive and adaptive octree subdivision according to stress values (Rhombert and Thanei 2013)

The proposed design tool should encourage the conception of tectonics, which is based on this notion of heterogeneous material distributions and properties. The design should flow freely into production so the fabrication can fully play of the virtue of the machine.

FUTURE

Extrusion technologies rely on supporting material when the geometry's inclination goes beyond a certain degree. We would like to incorporate a set of algorithms, which push towards solutions in the generative phase that require a minimum or no support material. We are currently looking into developing hardware, which enables further ways to blend between material states. Combining multiple extrusion heads into one or injecting additives could give rise to new methods to alter material properties at will.¹²



8 Morphologies of Batwing Surfaces according to local stress situations (Rhomberg and Thanei 2013)

As we master the set challenges, it is becoming obvious that a realistic simulation of the generated material qualities should become a part of the research (Figure 9). The information of the material voxel can be stored in vertex colors or translated into maps, which correlate with the material qualities in common render engines. This greatly supports a more direct workflow between generating and representing tectonics and anisotropic materiality.

ACKNOWLEDGEMENTS

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NOTES

1. Rutten, D. and McNeel, R. & Associates (2014) Grasshopper. <http://www.grasshopper3d.com/>
2. Oxman, N (. 2010). Material-based Design Computation. Massachusetts: Massachusetts Institute of Technology
3. Rutten, D. and McNeel, R. & Associates (. 2014). Grasshopper. <http://www.grasshopper3d.com/>
4. Rutten, D. and McNeel, R. & Associates (s. 2014). Grasshopper. <http://www.grasshopper3d.com/>
5. Pirker D (., (2014). Kangaroo Physics. <http://www.food4rhino.com/project/kangaro>
6. Sawako, K. and Panagiotis M. (2014). Millipede. <http://www.sawapan.eu/>
7. Preisinger, C. and Grohmann-Schneider ZT GmbH. (2014). Karamba3d. <http://www.karamba3d.com/>
8. Schwarz, T. (2014). HAL Robot Programming and Control. <http://hal.thibaultschwartz.com/>
9. Preisinger, C. and Grohmann-Schneider ZT GmbH. (2014). Karamba3d. <http://www.karamba3d.com/>
10. Oxman, N (. 2010). Material-based Design Computation. Massachusetts: Massachusetts Institute of Technology
11. Monolite UK Ltd. (2014). D.Shape™ Technology Presentation. http://www.d-shape.com/d-shape_presentation.pdf
12. RichRap. (2014). "Three extruder's and One Nozzle – RepRap material blending". <http://richrap.com/?p=121>

REFERENCES

- Monolite UK Ltd. (2014). D.Shape™ Technology Presentation. http://www.d-shape.com/d-shape_presentation.pdf.
- Oxman, N. 2010. Material-based Design Computation. Massachusetts: Massachusetts Institute of Technology.
- Pirker D., (2014). Kangaroo Physics. <http://www.food4rhino.com/project/kangaroo>.
- Preisinger, C. and Grohmann-Schneider ZT GmbH. (2014). Karamba3d. <http://www.karamba3d.com/>.
- RichRap. (2014). "Three extruder's and One Nozzle – RepRap material blending". <http://richrap.com/?p=121>.
- Rutten, D. and McNeel, R. & Associates. (2014). Grasshopper. <http://www.grasshopper3d.com/>.
- Sawako, K. and Panagiotis M. (2014). Millipede. <http://www.sawapan.eu/>
- Schwarz, T. (2014). HAL Robot Programming and Control. <http://hal.thibaultschwartz.com/>.

IMAGE CREDITS

Figure 1. Pindeus, Maya (2013) Synthetic Skin: Pneumatic Study.

Figure 2. Rhomberg, Daniel (2014) SMART3DPrint, Geometric Negotiation.

Figure 3. Buckler P., Rhomberg D., Thanei S., (2013) SMART3DPrint, TopOpt Diagram.

Figure 4. Rhomberg, Daniel (2014) SMART3DPrint, Tectonic Study Front.

Figure 5. Rhomberg, Daniel (2014) SMART3DPrint, Tectonic Study Side.

Figure 6. Buckler P., Rhomberg D., Thanei S. (2013) SMART3DPrint, Density Functions.

Figure 7. Buckler P., Rhomberg D., Thanei S., (2013) SMART3DPrint, Recursive Subdivisions.

Figure 8. Rhomberg D., Thanei S., (2013) SMART3DPrint, Batwing Genotypes.

Figure 9. Rhomberg D., Thanei S., (2013) SMART3DPrint, Material Qualities.



9 Material qualities calculated in Grasshopper® translated into renderable materials via mesh vertex colors (Rhomberg and Thanei 2013)

DANIEL RHOMBERG, born in 1991 in Austria, is a student of architecture at the University of Applied Arts Vienna. From 2009 to 2011 he studied under Wolf D. Prix and from 2011 to current he has been a student in the Studio of Hani Rashid. His mutual interests with Peregrin Buckler and Stefan Thanei in digital materiality, computational design and production led them to form the SMART3DPrint Group with Maya Pindeus which has been supported by Mag.Arch. MArch Andrei Gheorghe and Dipl.-Ing. Dr. Clemens Preisinger. The SMART3DPrint Group was formed at the Institute of Architecture, University of Applied Arts Vienna with the financial support of the Hochschuljubiläumsstiftung / City of Vienna. The current members Peregrin Buckler, Andrei Gheorghe, Daniel Rhomberg, Maya Pindeus and Stefan Thanei share mutual interest in digital materiality, computation and production. The project is supervised and mentored by Ass. Prof. Andrei Gheorghe and Dipl.-Ing. Dr. Clemens Preisinger.