ACSA Faculty Design Award

2015-2016 Winner Submission Materials

Durotaxis Chair

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University of Southern California

DUROTAXIS CHAIR
COMPLETION: November 2014
AREA: sqm
LOCATION(s):

The Durotaxis Chair is a fully 3D printed multi-material dual position rocking chair designed by Synthesis Design + Architecture and manufactured by Stratasys. The chair is inspired by the biological process of the same name, which refers to the migration of cells guided by gradients in substrate rigidity. The chair is an ovoid rocking chair which has two positions, as an upright rocking chair and as a horizontal rocking lounge. The volume of the chair is defined by a densely packed three-dimensional wire mesh that gradiates in size, scale, density, color, and rigidity. The chair capitalizes on the multi-material printing capabili-

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DUROTAXIS CHAIR

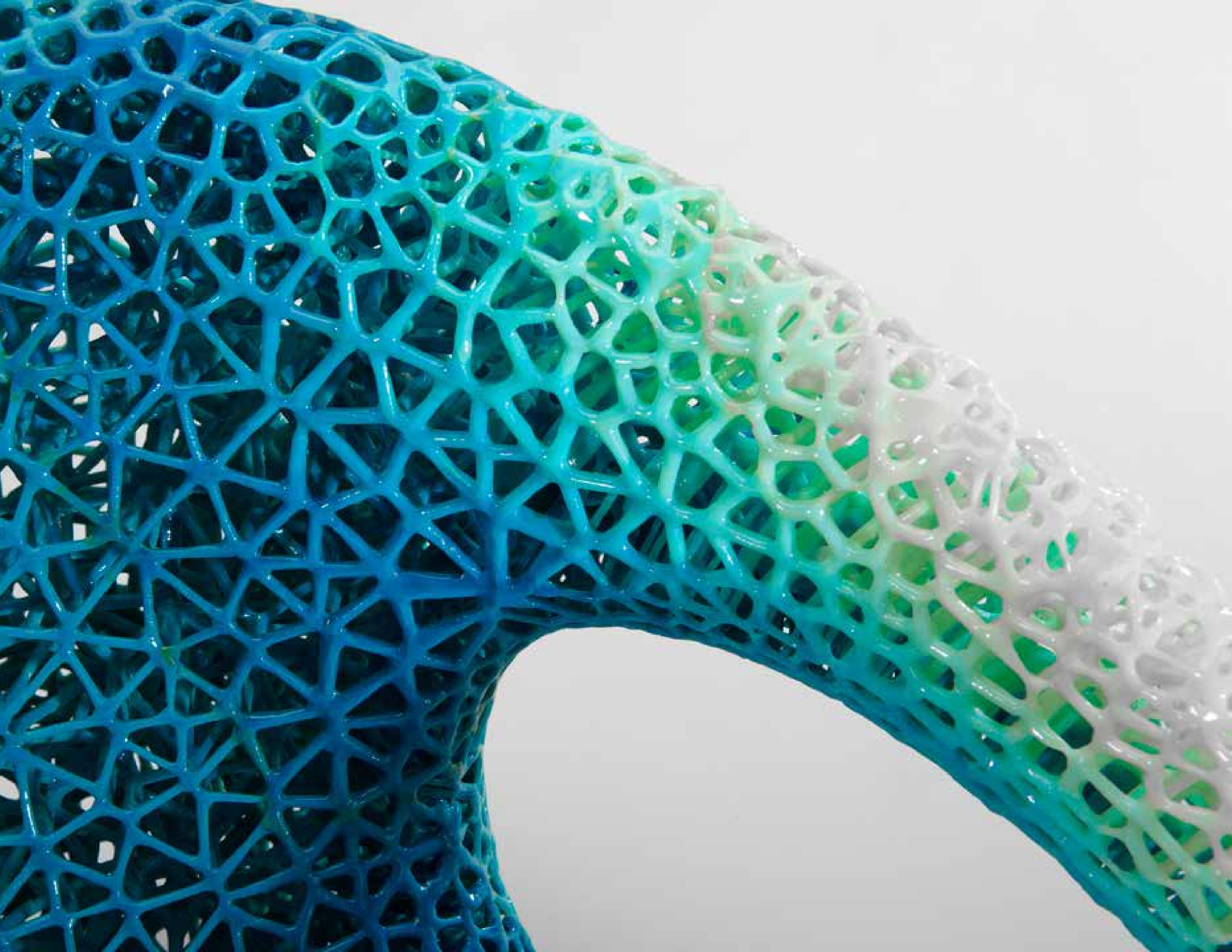
HOW DO YOU DESIGN A 3D PRINT RATHER THAN 3D PRINT A DESIGN?

Description: 3D printed multi-material dual-position rocking chair
Dimensions: 50cm x 60cm x 800cm
Materials: Objet VeroCyan Digital Material & Objet VeroWhite Digital Material
Designer: Synthesis Design + Architecture
Design Team: Alvin Huang (Design Principal), Yuan Yao, Alex Chan, Mo Harmon, Kais Al-Rawi, Joseph Sarafian, David O. Wolthers
Client: Stratasys
Fabricator: Stratasys
Photo credits: IMSTEPF Films

The Durotaxis Chair is a fully 3D printed multi-material dual position rocking chair designed by Synthesis Design + Architecture and manufactured by Stratasys. The chair is inspired by the biological process of the same name, which refers to the migration of cells guided by gradients in substrate rigidity. The chair is an ovoid rocking chair which has two positions, as an upright rocking chair and as a horizontal rocking lounge. The volume of the chair is defined by a densely packed three-dimensional wire mesh that gradiates in size, scale, density, color, and rigidity. The chair capitalizes on the multi-material printing capabilities of the Stratasys Objet 500 Connex3 to produce gradients of material performance. The varying gradient conditions are expressions of the combined formal, ergonomic, and structural properties of the chair.

Commissioned by Stratasys to produce a piece that would not be possible at all without 3D printing, Synthesis took the challenge a step further to produce a piece which more specifically would not be possible without the Stratasys Objet 500 Connex3. The complexity and density of the three-dimensional mesh of the Durotaxis Chair would be ridiculously laborious in any other conventional manufacturing process, however the gradient distribution of material properties and performance which would be impossible without the Objet Connex3.

As an extension to an on-going body of design research which explores the reciprocal relationships between form and performance - the chair provides an opportunity to explore a design and fabrication process that articulates both visually and materially what the chair is doing structurally and ergonomically.



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MULTIVALENT FORM

DOES FORM FOLLOW FUNCTION OR DOES FUNCTION FOLLOW FORM?

The multivalent form of the Durotaxis chairs allows for mutliple readings and uses of it's unique geometry. It is defined by an ovoid form which has two principle resting positions: as an upright rocking chair, and as a horizontal lounge chair.

The single curved belly and tighter radius of the upright position allows for a more dynamic rocking condition of rest, while the shallow curvature of the horizontal position provides for a more static resting condition.

In both cases, the chair is able to roll from one position to the next.

At a global scale, the geometry of the chair is defined by an ergonomic desire for mutiple positions, an aesthetic desire to express continuity between those positions, and a structural desire to produce a closed system for force distribution.

04) The Durotaxis chair shown in motion.

05) The Durotaxis as an upright rocking chair

06) The Durotaxis as a low horizontal lounge chair

HOW DO YOU STABILIZE AN IRREGULAR FORM?

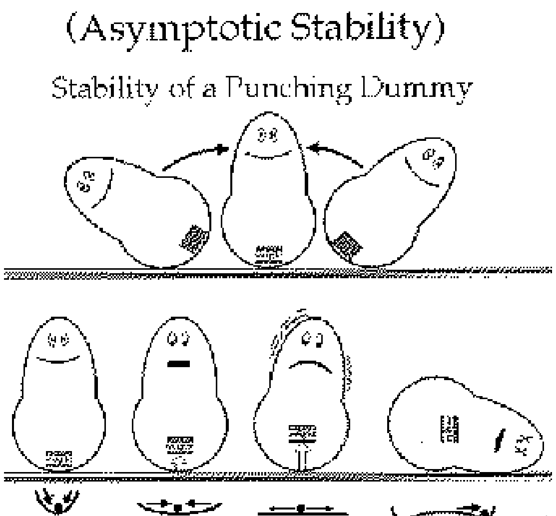
One of the primary concerns of the design of the chair was how to redistribute the center of gravity of the chair so that it would allow the chair to consistently return to the upright position while rocking.

To achieve this, the concept of “Asymptotic Stability” was applied. This is a strategy for using counterweighting forces through the re-distribution of mass to give a non-linear system a gravitation towards a particular orientation.

By conceiving of the chair neither as a homogenous solid (with a consistent distribution of mass through an irregular volume) or as a hollow skin (with a consistent surface mass distributed by an irregular surface area distribution), we are able to re-distribute the mass of the chair through a variable density and variable thickness three-dimensional mesh matrix. **The resulting hierarchichal cellular structure allows us to place the center of gravity of the chair (both pre- and post-occupant) in a position which naturally gravitates towards a vertical position.**

07) Conceptual diagram illustrating the concept of Asymptotic Stability in an inflatable punching dummy - by Albert K. Harris (http://www.albertkharris.com/2013_symmetry.html)

08) Sectional diagram of the redistributed center of gravity of the densely packed three-dimensional mesh structure.



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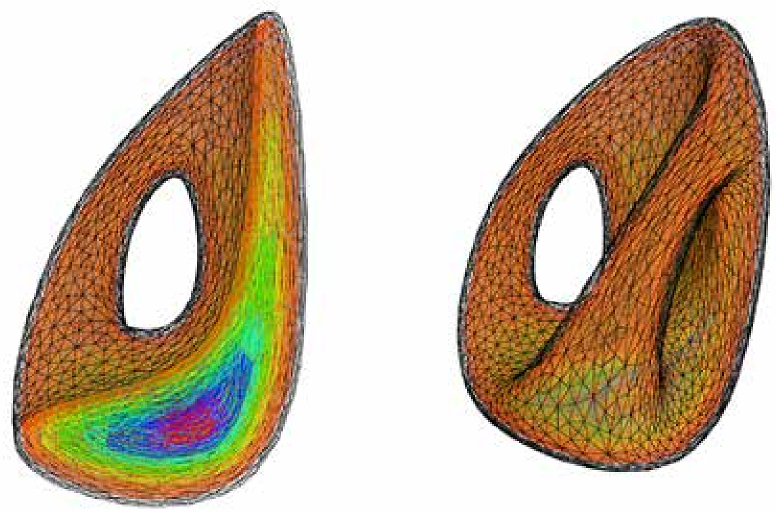
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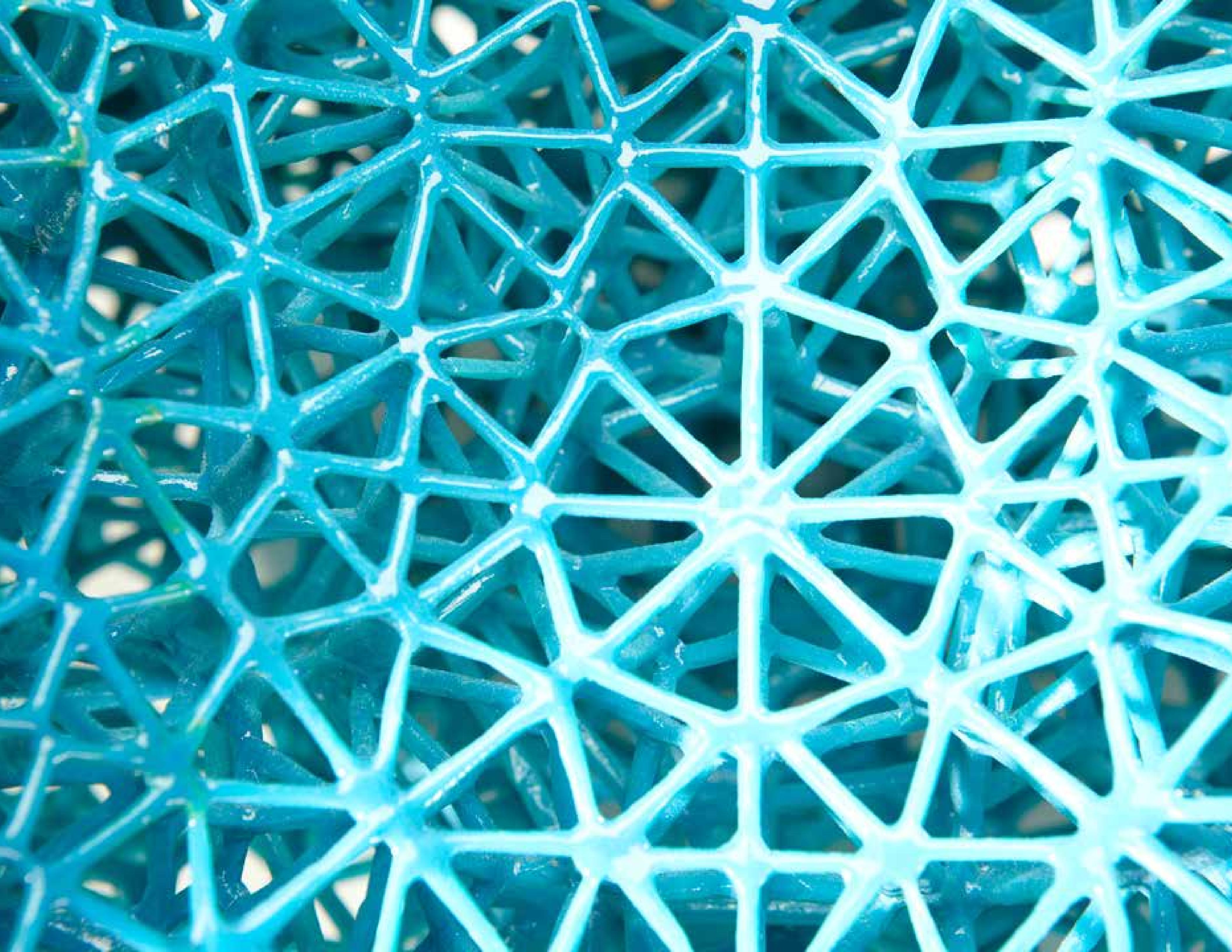


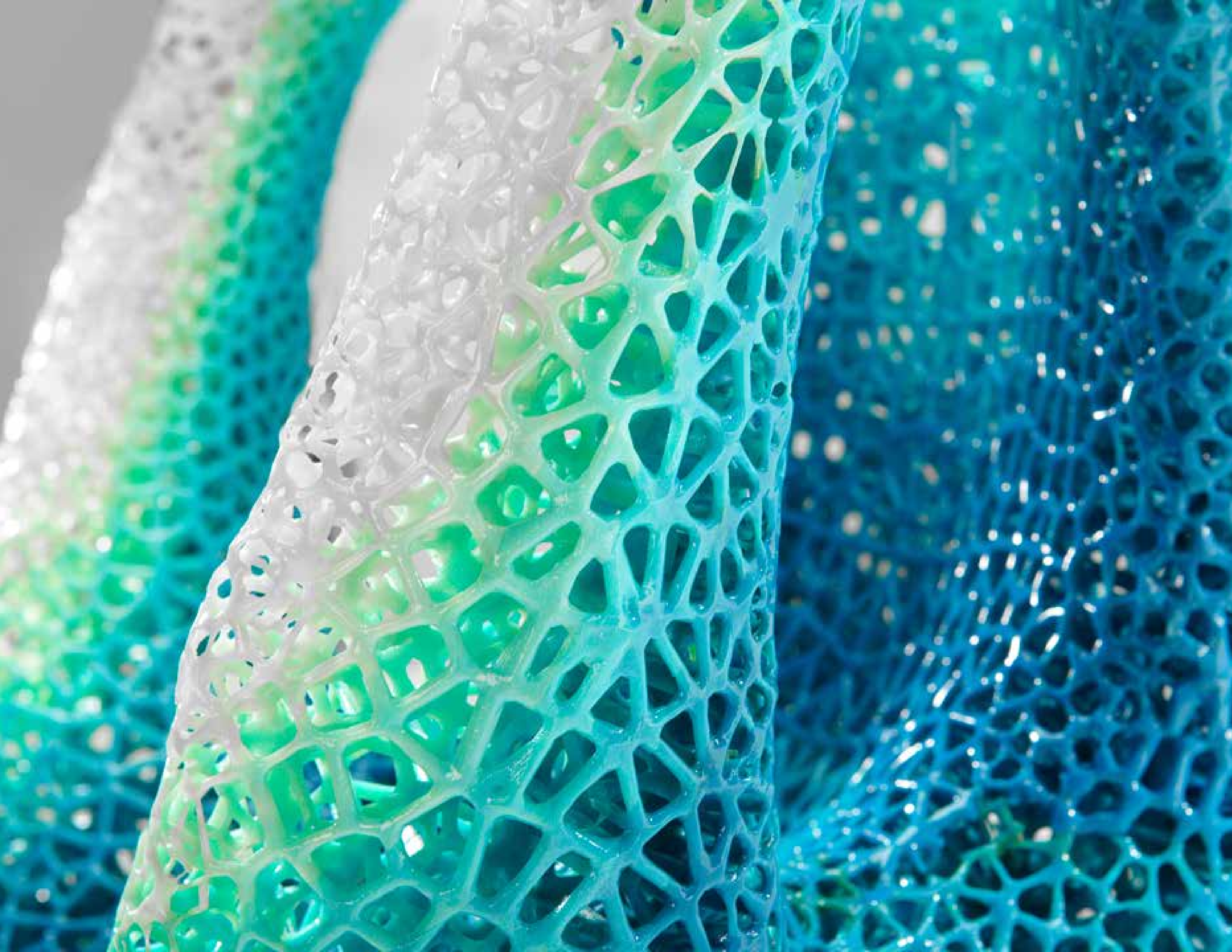
CAN WE THINK ABOUT MATERIALITY AS A CONTINUOUSLY VARIABLE CONDITION?

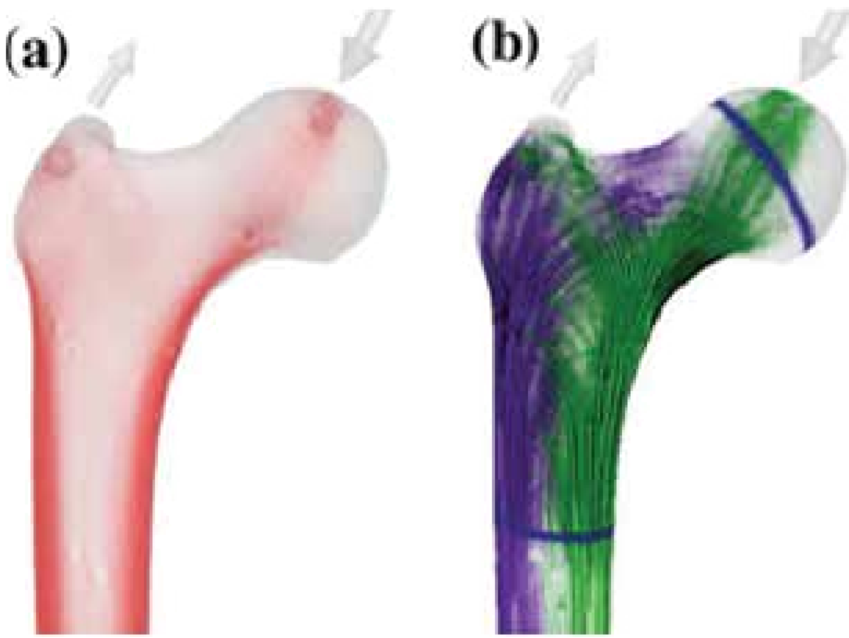
The Objet Connex500 3D Printer provides hi-resolution multii-material printing. The typical 3D printer has one head and one nozzle which allows it to print one material with a typical build resolution of .1mm.

The Connex500 has two heads, each with 96 nozzles, and builds at a resolution of 16 micron (.016 mm). Not only are each of the heads able to print different materials, the 96 nozzles allow the two heads to simultaneously print variable matrices of the two material types thus instantaneoulsy printing hybrid material compounds.

Currently the machine is only able to print the proprietary resin based Objet “Digital Materials”. These materials host a wide range of variation in color, stiffness, and transparency. By mixing and gradiatiing between these conditions various performative properties of material can be produced.

We wanted to capitalize on this innovation as a design opportunity to think of materiality as a gradient condition of constant but subtle change.





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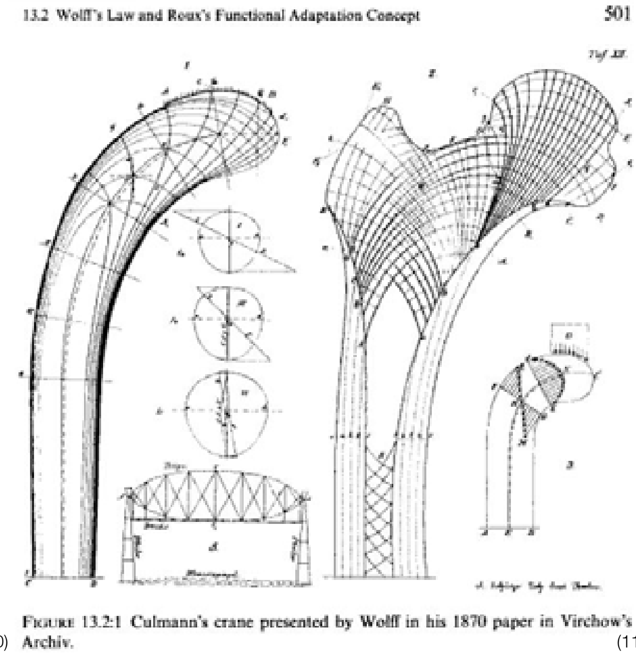

13.2 Wolff's Law and Roux's Functional Adaptation Concept 501

FIGURE 13.2:1 Culmann's crane presented by Wolff in his 1870 paper in Virchow's Archiv.

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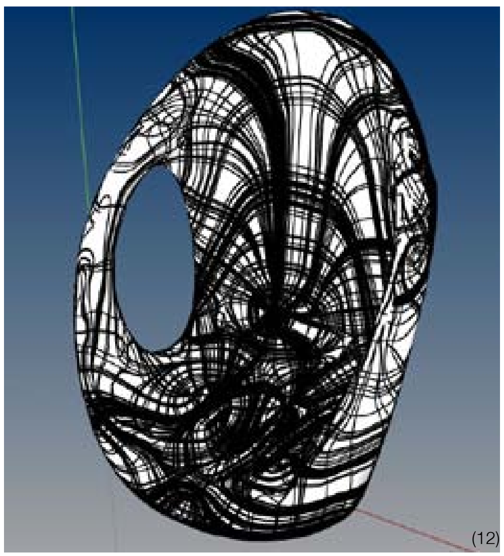

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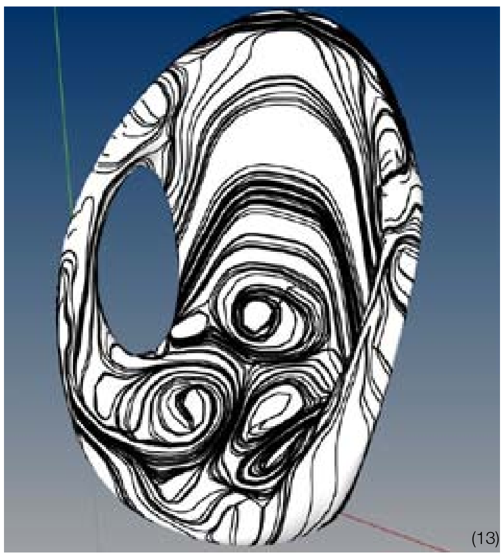

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INFORMED GROWTH

CAN WE THINK OF 3D PRINTING AS A MANUFACTURING PROCESS OR A GROWTH PROCESS?

As 3D printing is a layer-based additive manufacturing process where each subsequent layer is placed upon the previous one, a fundamental paradigm shift in the way we conceived of the chair was to relate it towards the growth and performance of bones.

Bones are thought of as solid homogenous elements, yet at a microscopic level they are anything but. They are actually a variable density structure of spongy cellular tissue, with increased material and density placed in areas of the greatest principal stress. This is defined as a hierarchical rather than homegenous structure.

We approached the analysis of the Durotaxis chair as an opportunity to take a similar strategy. Through the use of the Karamba structural analysis plug-in, we were able to analyze the geometry of the chair to discover it's principal stress flow lines.

These principal stress lines illustrate the flow of vectors through the geometry in both tension and compression, and serve as a the basis for generating a gradient heat map that informs the redistribution of mass, and reorientation of structure to accommodate and respond to structural force.

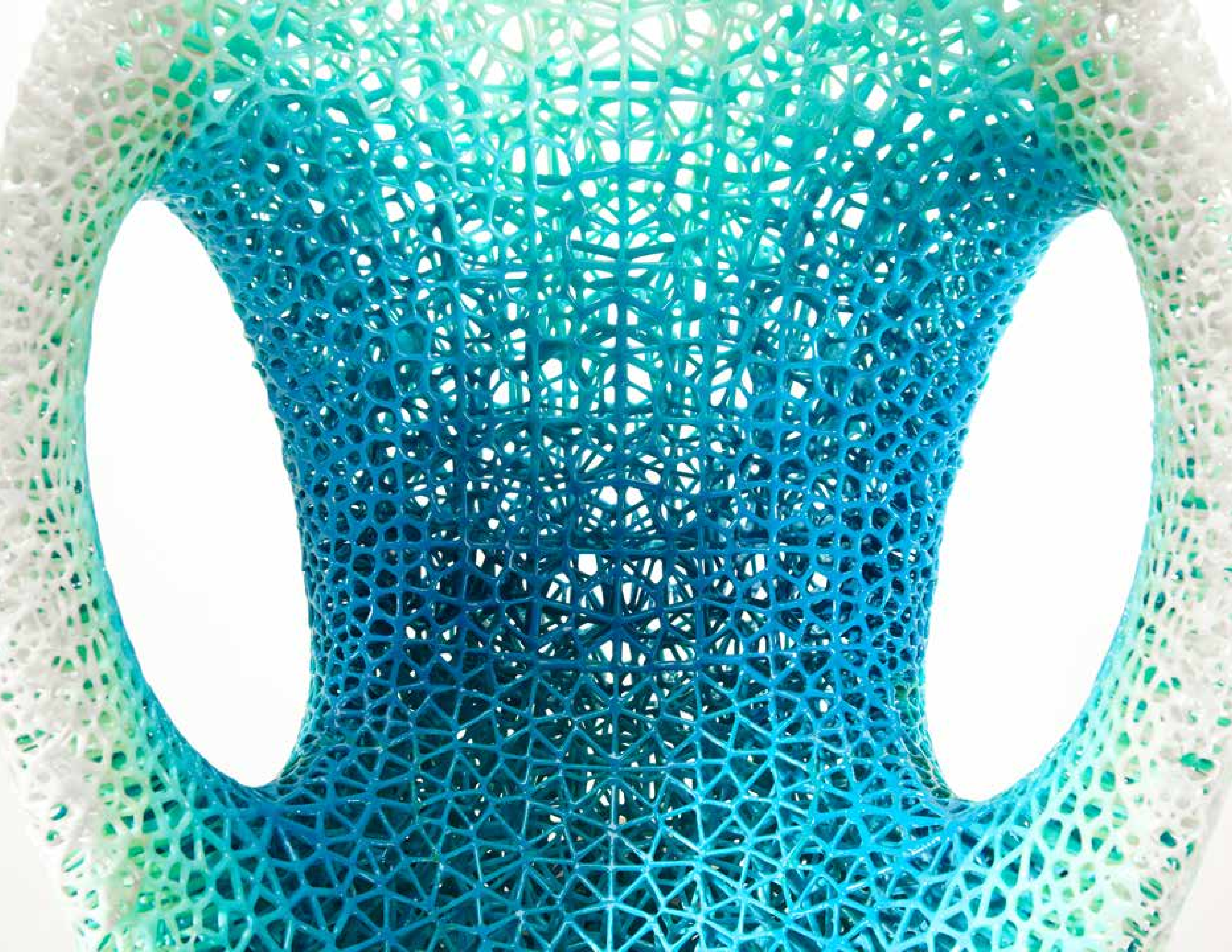
10) von Mises stress distribution of the femur under tension and compression loading (a), principal stress lines: green - compression, purple - tension (b) - by Martin Ruess http://www.simced.de/research-profile.html

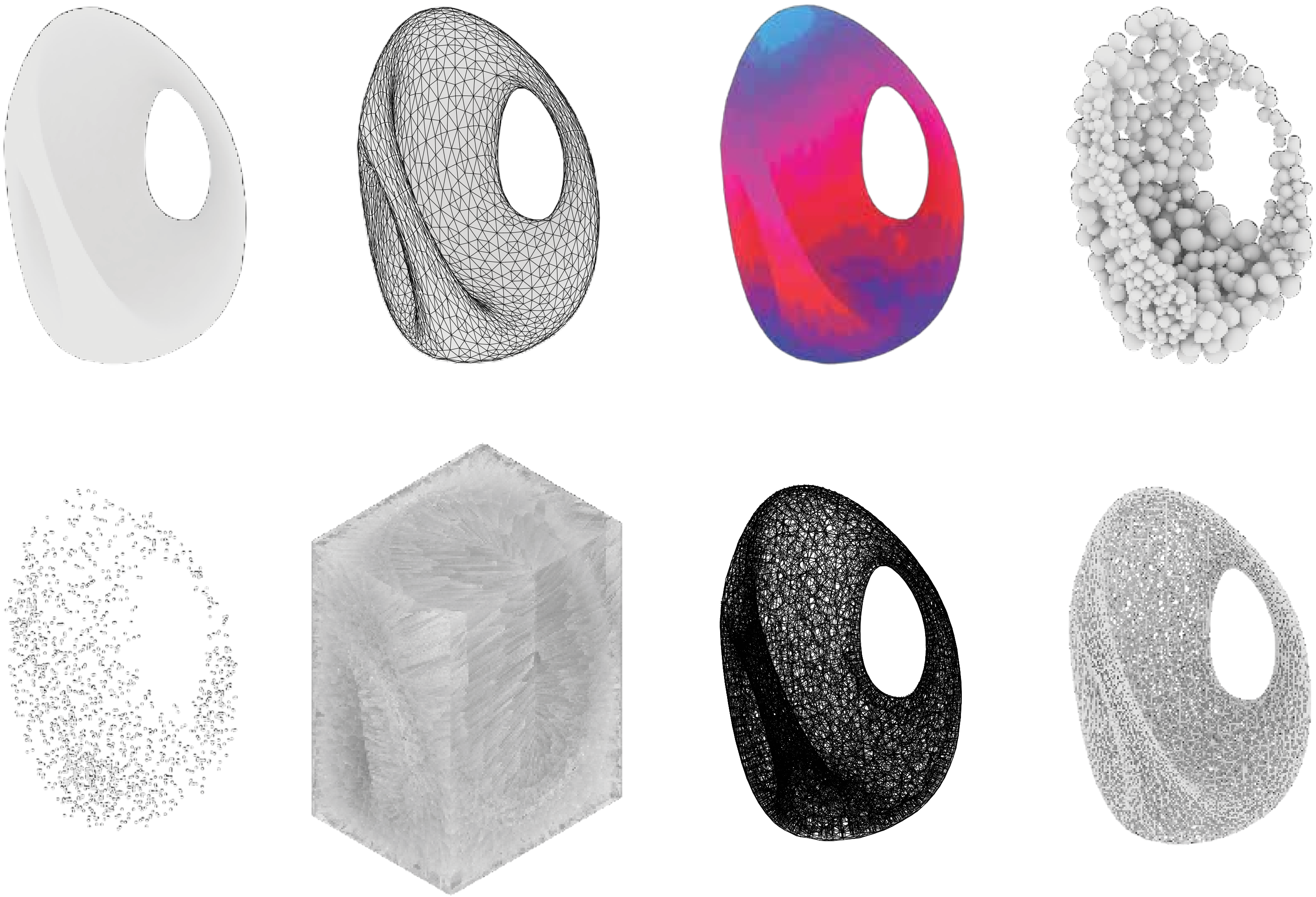
11) Diagram of Wolff's Law of Bone Adaption illustrating the trabecular bone and the way its structure grows most where needed, ending up following principal stress trajectories - by Julius Wolff https://spacesymmetrystructure.wordpress.com/2009/02/06/rheotomic-surfaces/

12) Composite principal stress analysis of the chair done in the Karamba structural analysis solver for Rhino.

13) Tensile principal stress analysis of the chair done in the Karamba structural analysis solver for Rhino.

14) Compressive principal stress analysis of the chair done in the Karamba structural analysis solver for Rhino.





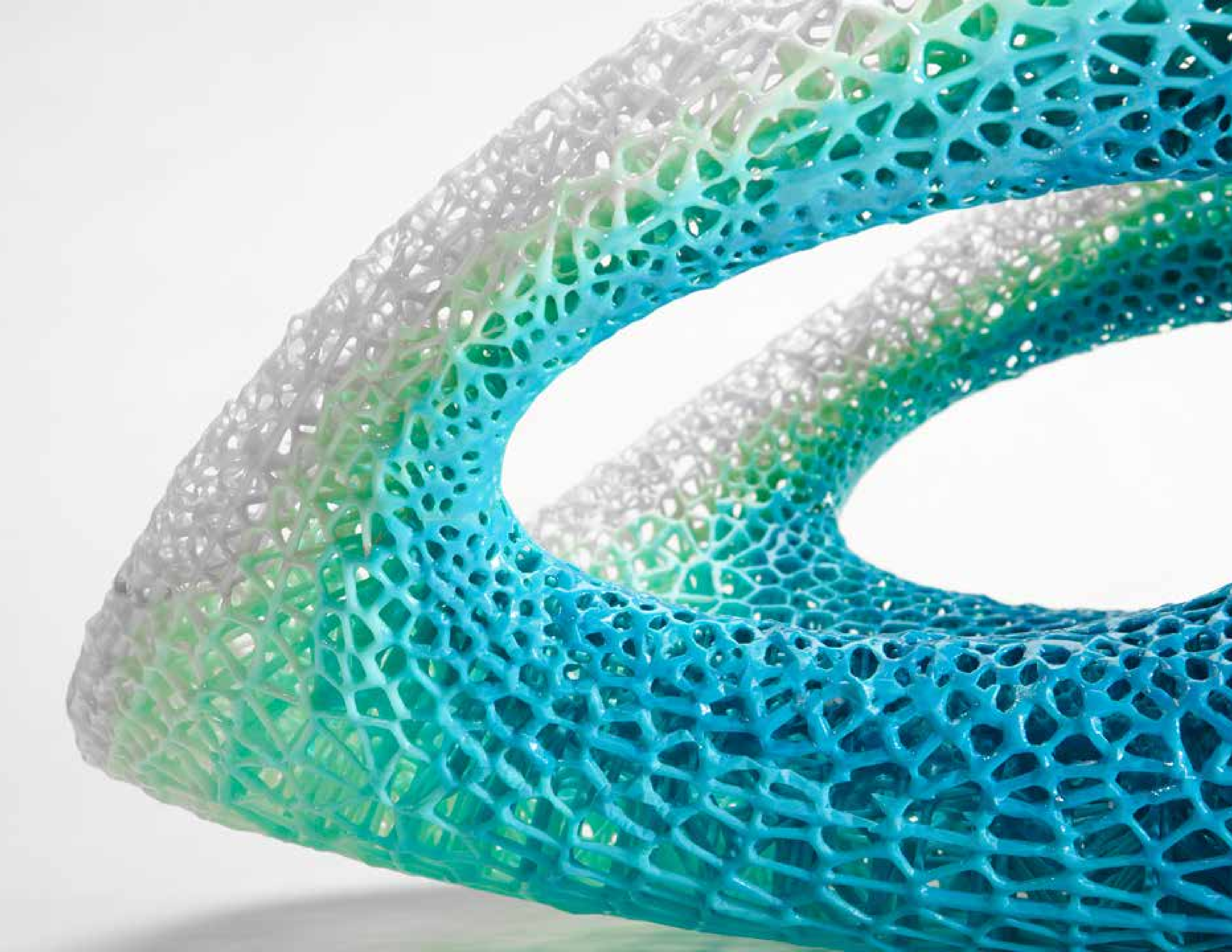
GENERATIVE SPHERE PACKING (WHAT WE WANTED TO DO)

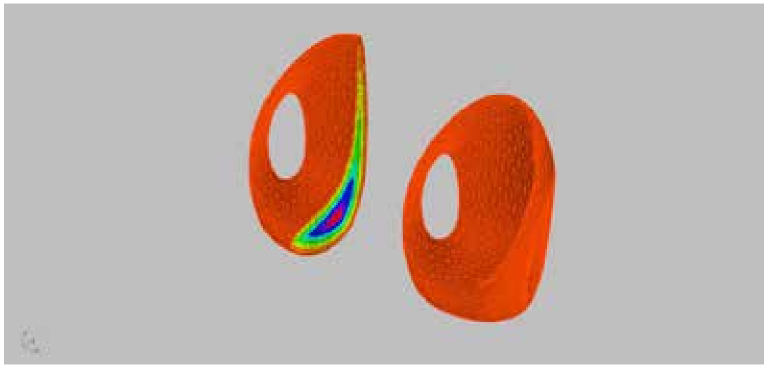
HOW CAN THE STRUCTURAL & ERGONOMIC PERFORMANCE OF FORM BE ARTICULATED?

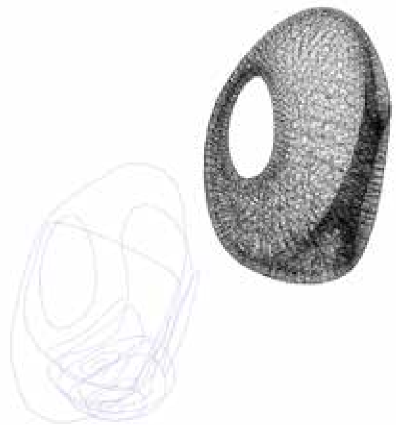
Given the design intents In order to achieve the desired effects of a variable density three-dimensional space frame The workflow for generating the variable densely packed 3D mesh jumped between a number of software packages and oscillated between the manual and intuitive modeling of the form of the chair, to the analytical study of structural forces, to the generative articulation of gradient conditions into a cellular matrix.

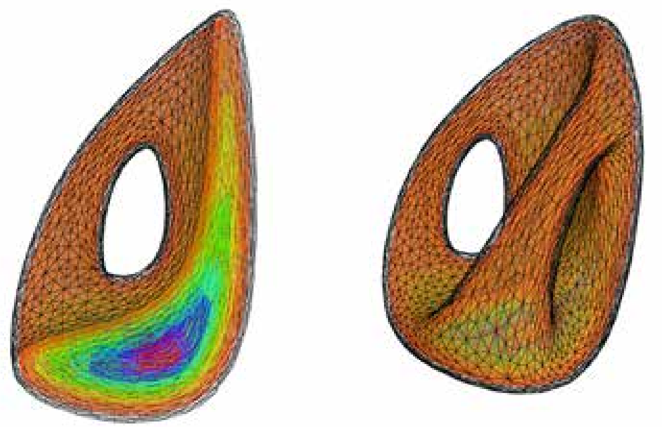
- The chair geometry is developed through low-poly subdivision modelling in Maya.
- The subdivision mesh is exported to Rhino, and the mesh topology is processed through a plug-in called Weaverbird.
- The refined mesh is analyzed in the structural analysis plugin-in Karamba to discover principal stress distributions.
- The structural analysis is converted into a gradient heat map through the associative modeling plug-in Grasshopper.
- A dynamic springs & nodes is utlized to "sphere pack" a variable density cloud of points within the boundary of the mesh utilizing the gradient heat map as scalar distribution map..
- Each of the nodes of the network (the centers of the spheres) is extracted as a point cloud, including the centroids of all boundary mesh faces.
- The composite point cloud of both sphere-packed volume and the boundary mesh topology are used to generate a three-dimensional voronoi network.
- All voronoi cells outside of the original boundary condition are removed, and the wireframe network of the cells is extracted to create the underlying topology of the new mesh.
- The wireframe network is given a variable thickness and color gradient in relation to the heat map of it's principal stress analysis through plug-in Exoskeleton.

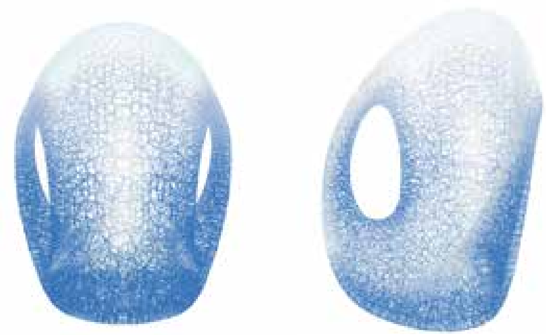
This process was explored with limited succes. Though we were able to produce each step of the process - we were extremely limited by the resolution of the packed mesh (number of points in the cloud) and the computational power required to manipulate & generate them.

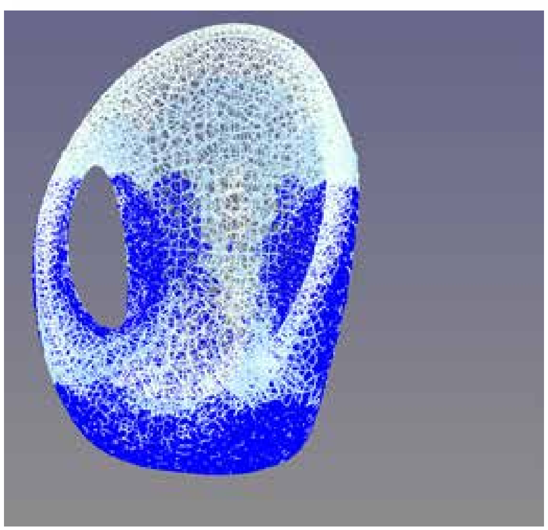


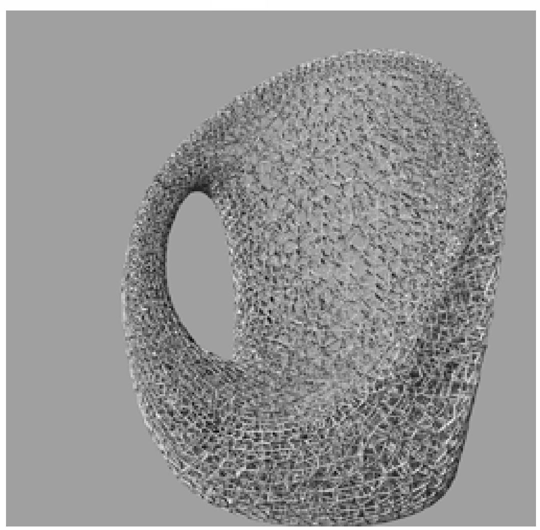


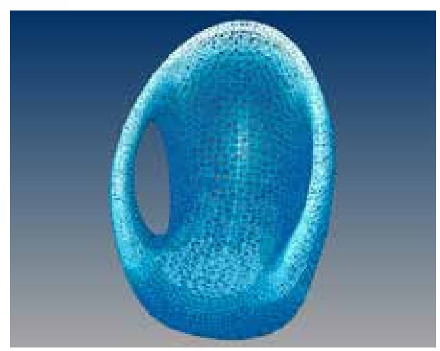












MANUAL GENERATION OF A VARIABLY ARTICULATED CELLULAR STRUCTURE (WHAT WE ACTUALLY DID)

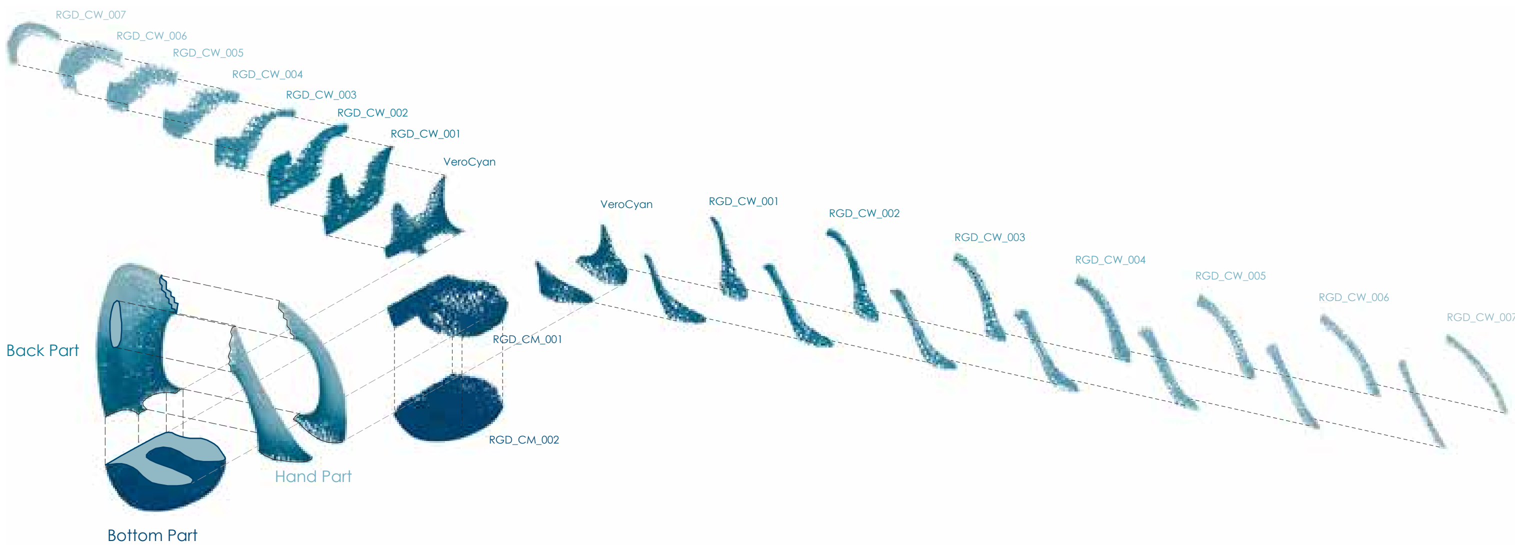
HOW DO WE FIGURE ALL OF THIS OUT AND MAKE THIS THING IN ONLY TWO MONTHS?

With a pressing deadline to have a piece ready for the 2014 ACADIA Conference in Los Angeles, CA time was limited and we needed to deliver a ready to print 3D file to Stratasys in less than one month in order to meet the deadline for the project. As a result, the computationally generated process was abandoned and a highly laborious manually generative process was applied.

1. Boundary Topology
   The base subdivision mesh is imported to Rhino via Maya to use as the boundary topology of the model, with a series of mesh refinements with the plug-in Weaverbird.
2. Stratified Layers
   A sequence of 3D offsets creates a series of “onion” like layers of skin, with both intersecting and self-intersecting areas of each mesh being removed. As such, the layers continuously shrink as they offset towards the center of the volume.
3. Variable Densities
   Grasshopper is used to extract the vertices of each layer of the meshes. In particular, the organization of the exterior layer’s points are important and as such are extracted through a separete process as a means of maintaining the topology of the surface structure. The points within the inner volume of the boundary mesh are extracted at variable densities towards the center.
4. Wireframe Extraction
   The resulting composite point cloud is processed as a 3D voronoi structure. The wireframe of the 3D voronoi is extracted as a wireframe network.
5. Gradient Generation
   A series of attractor curves are manually constructed at specific places of the chair in order to create gradient effects within the chair that would visually simulate the principal sress analysis of the shell as a means of producing the desired results.
6. Variable Thickness & Color
   Using Grasshopper the attractor curves drive the variable thickness of the wireframe as a set of 3D pipes of varying radial dimension, as well as the color gradient of the individual mesh components. Pipe elements scale in dimension and color in relationship to distance from attractor curves.
7. STL Preparation
   Z-brush was used to merge and smooth the individual pipes into a single closed STL ready mesh.

GRADIENT LOGICS

HOW MANY STEPS DOES IT TAKE TO PRINT A GRADIENT?



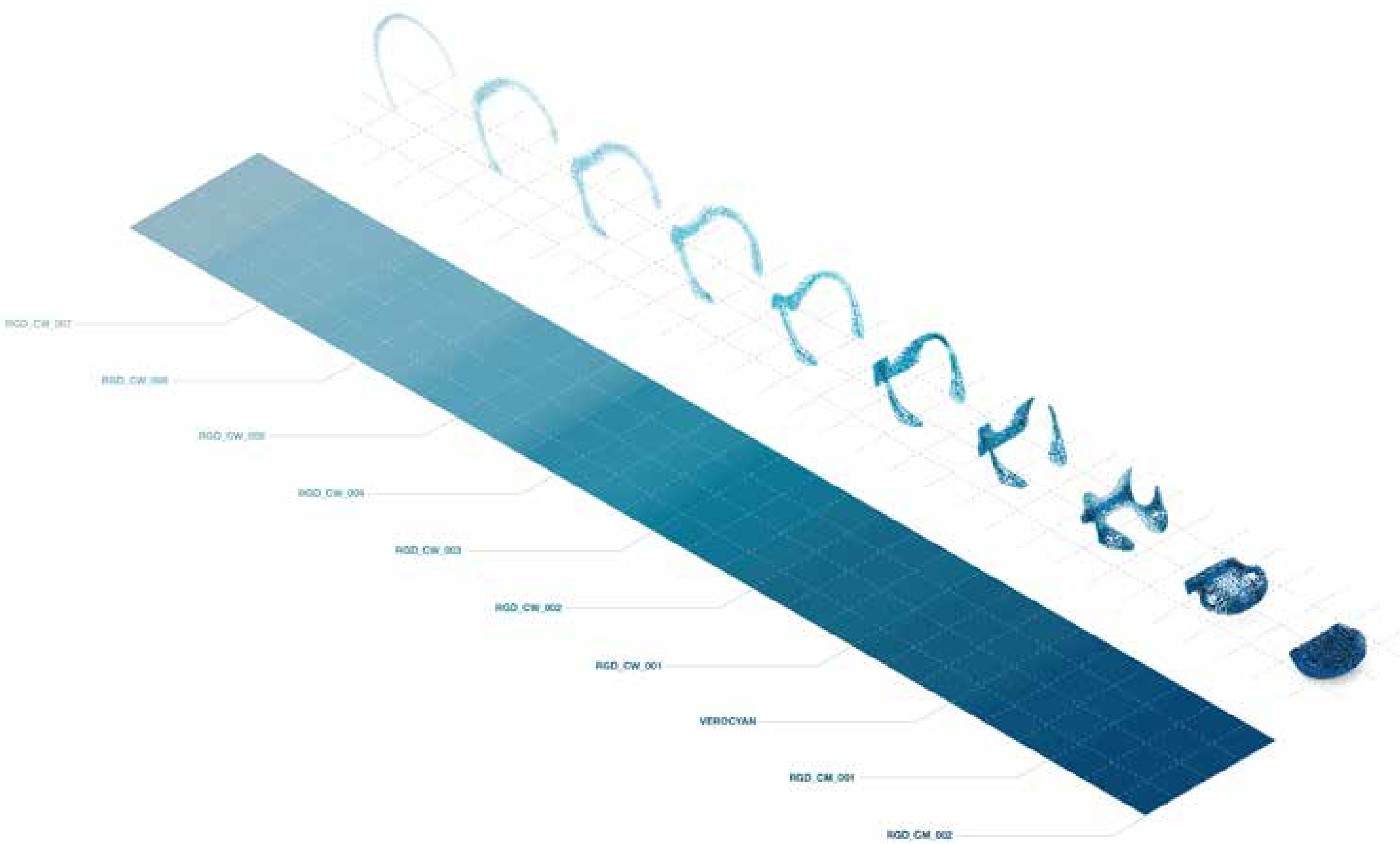
To meet the demands of the exhibition deadline, it ws decied that a 1/2 scale prototype would be produced rather than a full scale version. This would save in both printing time and post production time

Though the Objet500 is able to print in a smooth gradient, the process of providing gradient information to the machine to print was a much more painful process then expected.

At the time of production, the only process for printing the multi-material conditions of the chair was to break the file into a series of stepped gradient conditions as separate closed mesh's.

Grasshopper was used to break the color and scale gradient into precisely ten color/scale steps, each resulting in a single closed mesh...or so it seemed. Though the process of gradient selection was able to be automated through Grashopper, the process of cleanly closing the resulting meshes was highly manual and laborius, with a solid two weeks of manual modeling.

The resulting ten step file is composed into a single STL file, which is broken down into exactly 4 pieces: a back rest, seat, and two arm rests. These pieces are split to be able to fit the bed of the Connex500.

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DIGITAL CRAFT

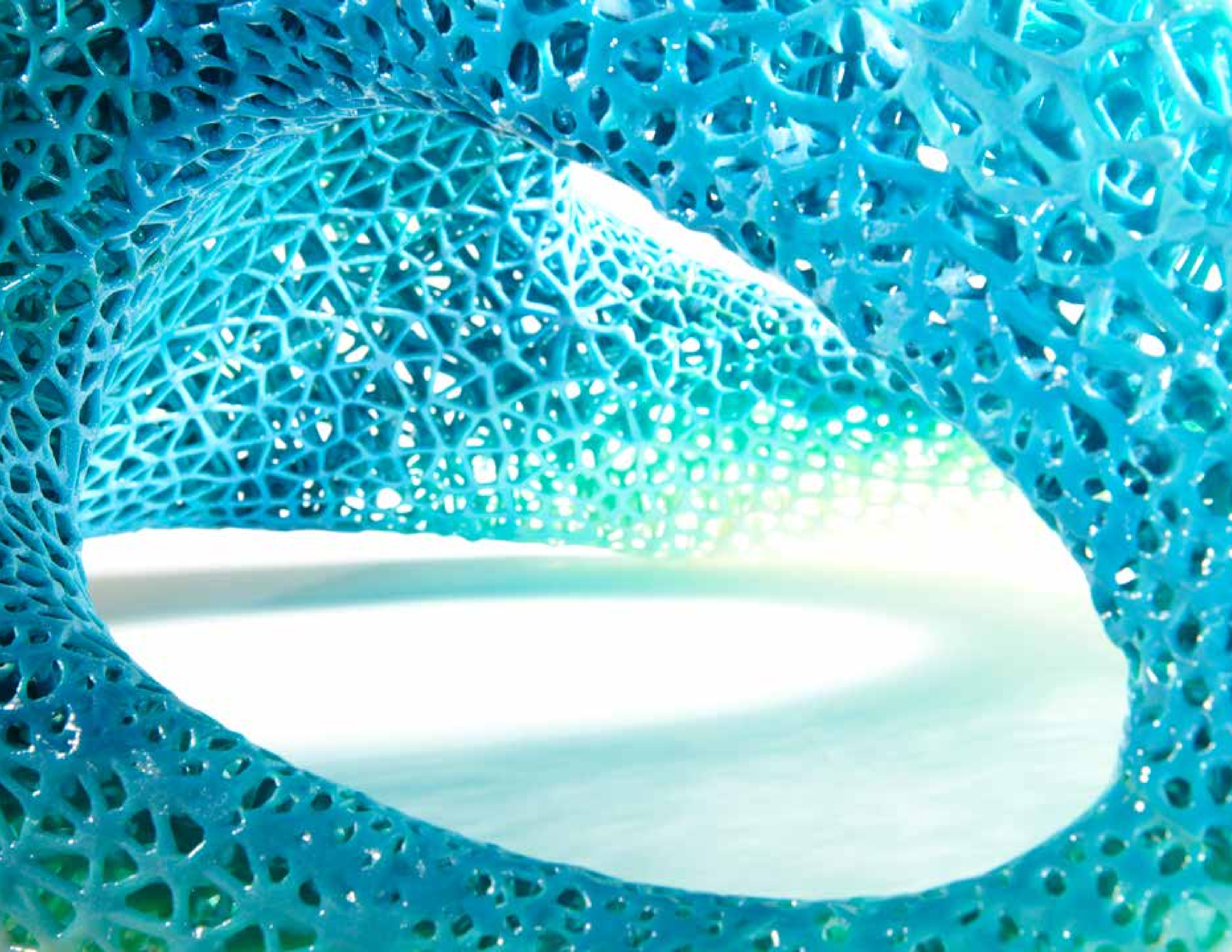
DOES THE CONCEPT OF CRAFT EXIST IN THE ERA OF DIGITAL FABRICATION?

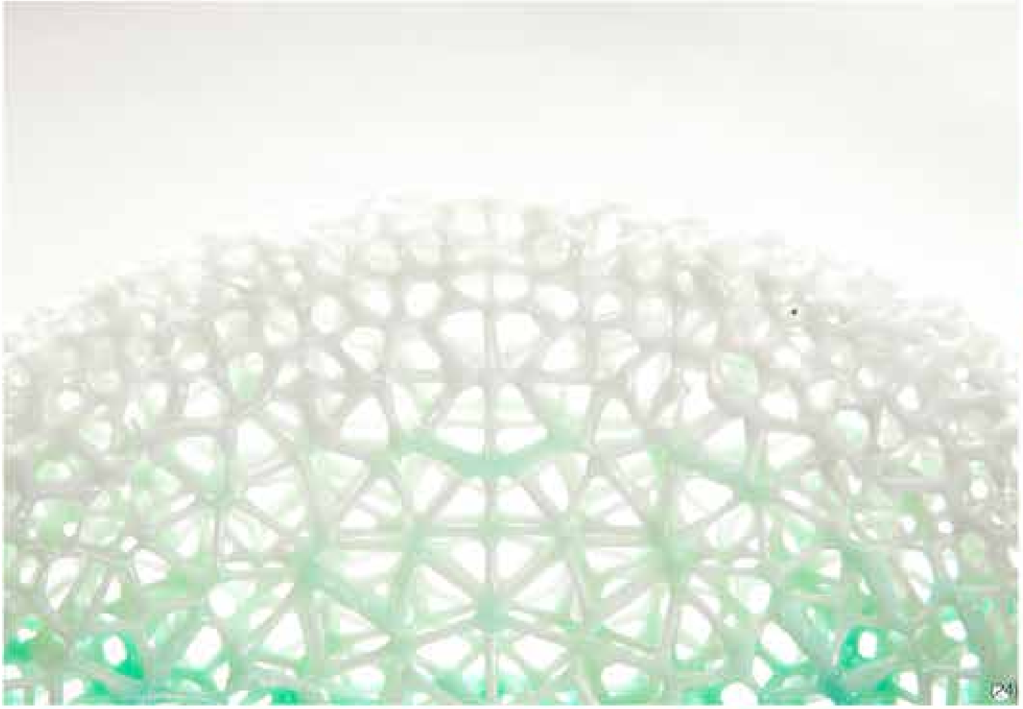
Though the translatiion of information to matter is an automated translation of computational protocols, the end result involves much manual labor and the precision of hand craft.

18-20) The individual pieces are 3D printed with full support material on the Connex500. You can see here that volume of the chair is printed as a solid object with the support material filling the voids of the model.

21-22) The raw 3D prints are placed in a chemical bath which dissolves the support structure. Nearly 70% of the printed material is wasted. This waste is non-recyclable and cannot be repurposed or recovered.

23) The invididual pre-fabricated pieces of the chair are removed from the bath and post-processed to clean off any remaining support structure. The invididual pieces are carefully and precisely welded together by hand using chemical adhesives.





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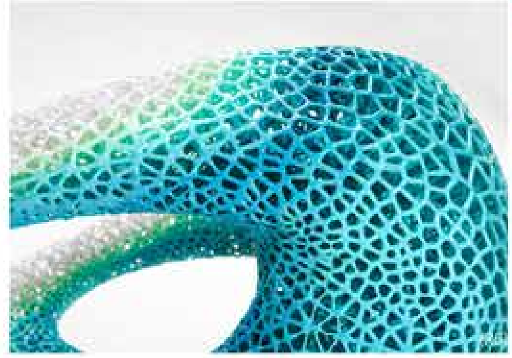

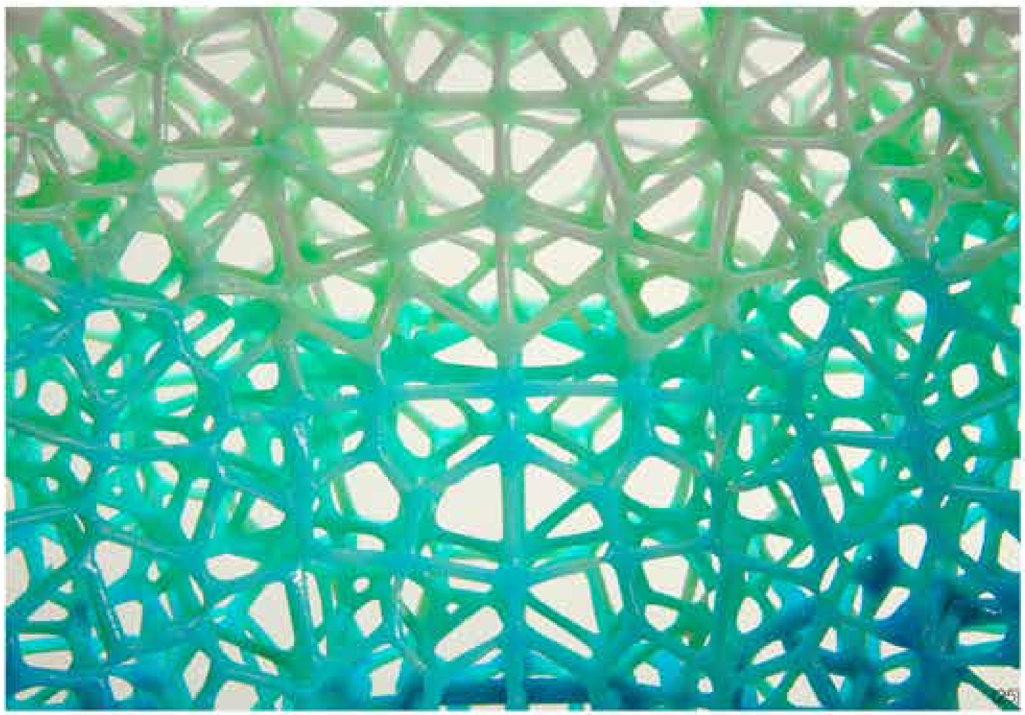

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NEXT STEPS

WHERE IS ALL OF THIS GOING?

The resulting half scale prototype of the Durotaxis Chair was printed and exhibited at the 2014 ACADIA Conference in Los Angeles, California at the University of Southern California. It has been widely published and is currently being exhibited at the ZKM Centre for Art and Media Karlsruhe, Karlsruhe, Germany.

We are now working with Stratasys and Walter P. Moore Consulting Engineers on the second version of the chair, which we are attempting to print at full scale. The second version of the chair will bz


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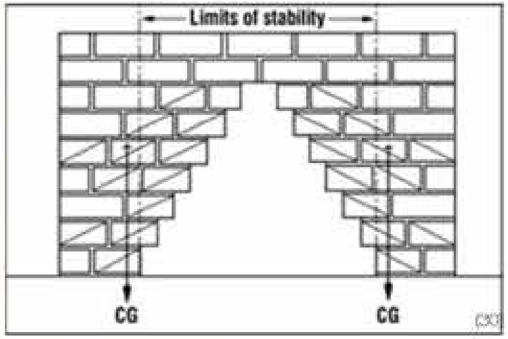

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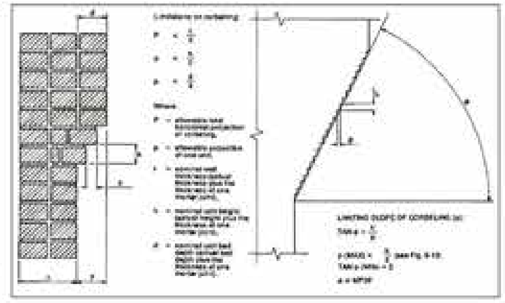
Limitations on Corbelling
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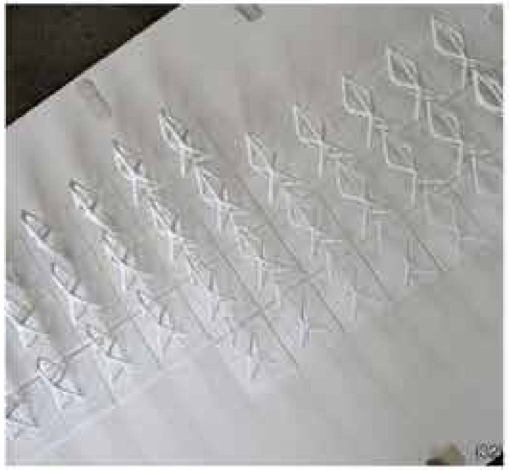
SUPPORTLESS 3D PRINTING

CAN A BIOLOGICAL PROCESS PAIRED AGAINST A MEDIEVAL CONSTRUCTION TECHNIQUE INFORM A HIGH TECH FABRICATION PROCESS?

We are now in the midst of producing the full scale version of the Durotaxis Chair 2.0.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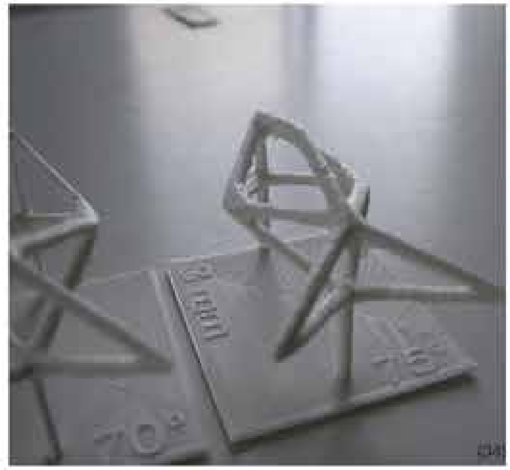
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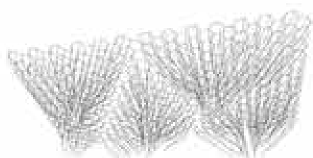
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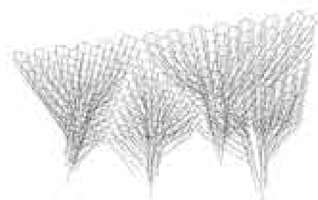
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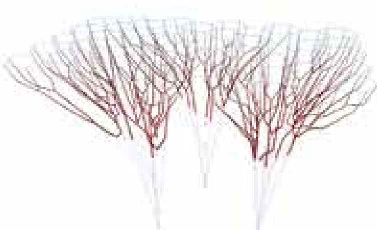
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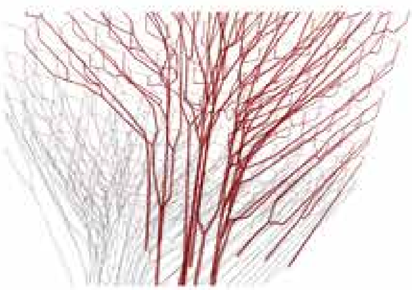
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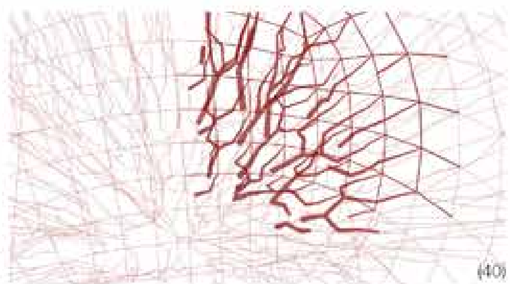
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