# Embodied Computation:

## Advancing New Processes for Robotic Fabrication of Custom Components through the Understanding of Material Behavior

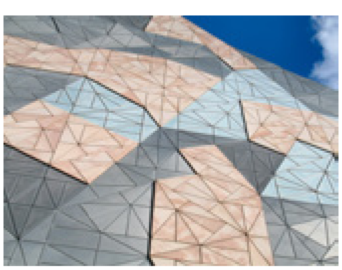
Alex Fischer
Project Statement Draft
Due 9/3/2013

This proposed project seeks to advance a more diverse, responsive, and site specific architecture. It is the multiformity of architecture that creates its beauty in our world. How boring would the world be if all buildings were made of the same parts, or clad in the same panel? Who could draw inspiration from a uniform built environment? Buildings themselves should not be uniform in form and structure either. Every element in a structure is acted upon by differing forces depending on its orientation, structural load, and program type. This should be made clear in the articulation and visual appearance of the structure, especially in with the advent of digital manufacturing technolgies. In his essay **Integral Formation and Materialisation: Computational Form and Material Gestalt**, Achim Menges writes,

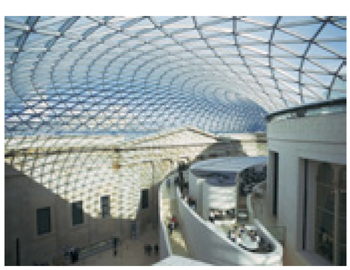
> *"Architecture, as a material practice, attains social, cultural and ecological relevance through the articulation of material arrangements and structures. Thus, the way we conceptualise these material interventions- and particularly the technology that enables their construction - presents a fundamental aspect in how we (re)think architecture."*

By leveraging computational design and robotic fabrication, it is possible to increase the variation and environmental responsiveness of an architecture, down to its components. The real challange is to create workflows that keep material and labor costs to a reasonable level. All too often digital fabrication methods for creating building components are too wastefull and/or labor intensive to be realistically used in a building scale project. With this in mind, I will be comparing material and labor cost tradeoffs between the processes I use and commonly used equivalent processes.

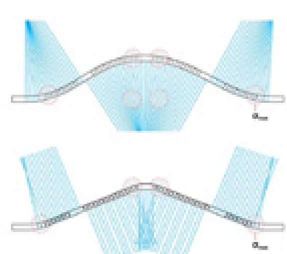
I am proposing a two part thesis, each part encompassing one full semester. The first project is meant to be leveraged to increase knowledge and skill requried to tackle the second project. Both are expansions on processes that I have worked with before, so the time it takes to really get going should be minimal. If either project still has the opportunity for expansion at the end of each semester, I have an additonal year of masters school in Computational Design at CMU in which I can continue developing that project.



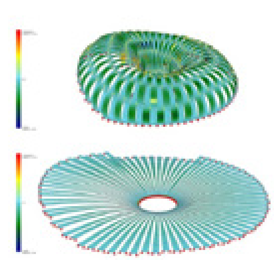
Federation Square - Lab



British Museum - Foster



Kerfing - Menges



Research Pavilion 2010 - Menges

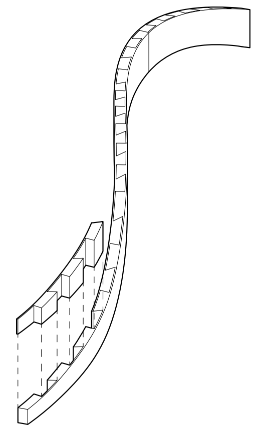
In the Fall 2013 semester I will work to develop a new computational toolset and robotic fabrication process for creating curved wood components. The process I will be developing was inspired by Schindler Salmeron's **ZipShape** technique, which I worked with in the Fall 2012 Semester with Eugene Wong in Professor Ficca's studio. The essence of Schindler Samlermon's project was the ability to take two flat sheets of wood and mill out a teeth pattern on each sheet such that when you put the two sides together they form a predetermined curvature. He believed this technique could be used to create flat pack furniture that could be assembled at home and sold the idea to Ikea. However, due to the great about of uniform pressure needed to be applied to the two sides to glue them together, his idea does not quite work. You either need a huge amount of clamps or a vacuum bag to hold the two sides together, both of which the average household does not have.


Schindler Salmeron's ZipShape

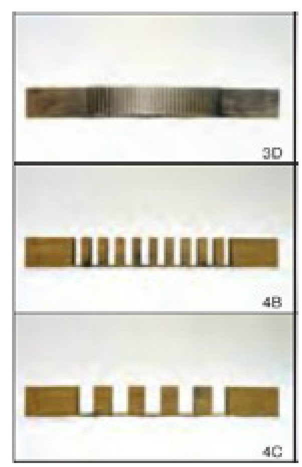

Clamps (Fischer & Wong)

This is where my thesis idea comes in. If I could write a script that could predict/simulate how those angles change as you bend the sheet, I believe I could mill out both sides such that as you bend them, they form the exact angle needed to slide them together and hold together without the need for clamps or vacuum bags.

The research method I use will follow closely to Achim Menges' students' project **Kerf-Based Complex Wood Systems** where I will begin with controlled experiments, which will lead to a script, then prototypes and a final structure/installation. Professor Ficca brought in one of Menges' students, Marshall Campos, last year to give a talk about his kerfing project, and it was one of the main sources of inspiration for my thesis project. Hopefully I will be able to interface with him throught the semester so he can give me some guidance.

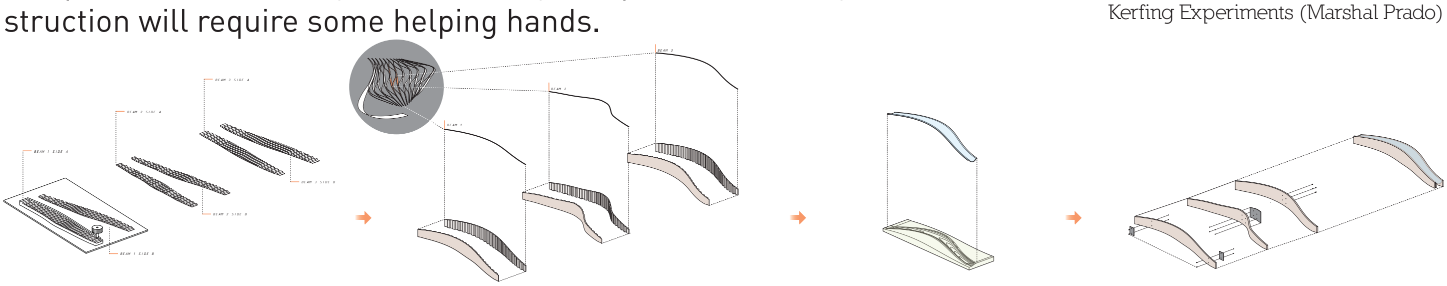

Dovetail Teeth (Fischer & Wong)

The experiments will test to see what the variables are in this technique. I imagine the curvature of the piece, uniform curvature vs varied curvature, thickness, springback, and wood type will all be needed to be factored into the script. This piece of software will be similar to the program Menges' team wrote for the **ICD/ITKE Research Pavilion 2010**. Menges was able to simulate the behavior of plywood as it is bent and distorted by forces. However, he had a team of PhD's working for him so inevitably my program will be much more crude, but will hopefully still do the job I need.



Kerfing Experiments (Marshal Prado)

The final output will be an occupyable structure, about the size of our Materials and Assembly Catenary projects. If I do my job right, each curved component will be easily assembled by one person, and only the final construction will require some helping hands.

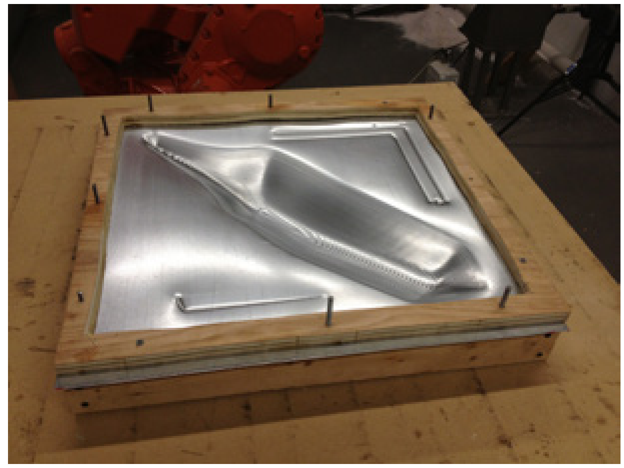

Curved Wood Beams (Alex Fischer and Eugene Wong)

In the Spring semester I will look at the process of multi-robot-based Asymetrical Incremental Sheet Forming (AISF). Last spring, I worked with Matt Adler to come up with a workflow that invloved the 6-axis robot in the dfab lab and the plasma cutter robot. We were able to achieve some pretty interesting and groundbreaking results. Without the use of a mold, we were able to form a flat sheet of steel into a 3-dimentional form simply by incrementally pressing down on the sheet with a spherical toolhead attached to the robot.

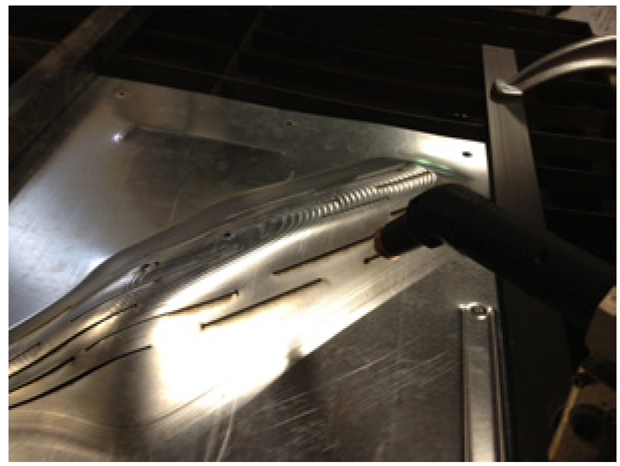
The result is much the same as you would get from using the CNC router on foam, but you do not lose any material. It is not a subtractive process. Instead the sheet is stretched and deformed. We even proved that you could have localized deformations without the need for a mold. However, the result is not exactly what the digital file describes since there is some springback without anything pushing behind the sheet.

This is where my second thesis idea comes in. The dfab lab now has two large 6-axis robots in the same room that can interact with one another. I would like to explore how this AISF technique could be improved if there was a second robot pushing against the sheet on the opposite side. I believe this multi-robot process could eventually be used to do exactly that a CNC is able to create, but without any waste and in rigid metal.

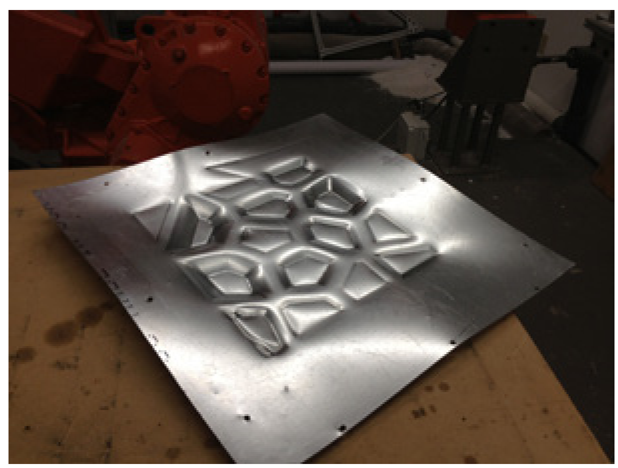
In the begining of the semester I would be performing a series of experiments to see how the two robots acting on the same sheet affects the deformation. This would hopefully lead to a piece of software that can take a file that would have otherwise run on the CNC, and create a toolpath using this Multi-robot-based Asymetrical Incremental Sheet Forming technique. This is a lofty goal but I have been taking a lot of CS courses at CMU and would like to apply them to architecture and fabrication. At the end, I would have a series of tests to display along with videos of the process and maybe a script or program that I described. If I could get assistance, maybe even a full scale prototype of a facade system.



AISF result (Alex Fischer and Matt Adler)



3D Plasma Cutting (Alex Fischer and Matt Adler)



Localized Deformations (Alex Fischer and Matt Adler)

Multi-Robot AISF at Univeristy of Michigan

# Schedule

Project 1
September: Experimentation in 2D via Lasercutter and CNC knife
October: Script Writing
November: Prototyping
December: Final Assembly

Project 2
January: Fabrication of Frame to hold Sheet Metal
Febuary: Experimentation with Multi-Robot AISF
March: Software Coding
April: Software Coding
May: Fabrication of Final Pieces

# Advisors

Requested Advisors:
Jeremy Ficca: AIA, Associate Professor of Architecture, Director: Digital Fabrication Lab (jficca@andrew.cmu.edu)
Joshua Bard: Assistant Professor of Architecture (jbard@andrew.cmu.edu)
David Kosbie: Assistant Teaching Professor of Computer Science (koz@cmu.edu)

Likely Support:
Dale Clifford: Assistant Professor (dalec@cmu.edu)
Dana Cupkova: Ing.Arch., M.Arch, Assistant Professor, Lucian & Rita Caste Chair (cupkova@cmu.edu)
Madeline Gannon: Adjunct Instructor (mgannon@andrew.cmu.edu)
Michael Jeffers: Digital Fabrication Fellow (mjeffers@andrew.cmu.edu)
Ramesh Krishnamurti: PhD, Professor (ramesh@cmu.edu)
Arthur Lubetz: AIA, Adjunct Professor (al4d@andrew.cmu.edu)
Frank Melendez: George N. Pauly, Jr. Fellow (frankmelendez@cmu.edu)
Marshall Prado: Research Associate - The Institute for Computational Desgin (ICD) - Stuttgart

# Bibliography


Brell-Çokcan, Sigrid, and Johannes Braumann. *Rob/Arch 2012: Robotic Fabrication in Architecture, Art and Design*. Wien: Springer, 2013. Print.

·A compilation of recent projects involving robotic fabrication. Includes a chapter on AISF with usefull information including equations, pictures, and explainations of the process.

Crane, Brad, Andrew McGee, Marshall Prado, and Yang Zhao. *Kerf-Based Complex Wood Systems*. Prof. Achim Menges. *Kerf-Based Complex Wood Systems*. Harvard University Graduate School of Design, 2010. Web. 02 Sept. 2013. <http://www.achimmenges.net/?p=5006>.

·A material exploration project that will closely mirror my process. Specifically, a research pro cess looking into the affect of kerfing on the plyability of wood pieces.

Fischer, Alex J., and Eugene Wong. "Rivulet." *Alex J Fischer*. Carnegie Mellon University, Dec. 2012. Web. 03 Sept. 2013. <http://www.alexjfischer.com/portfolio/rivulet/>.

·A past project of mine that utilized the ZipShape technique to produce 3 unique curved wood beams. I will be incorporating parts of the script I wrote for this project into my thesis.

*ICD/ITKE Research Pavilion 2010: Project Video*. Prod. Achim Menges. Perf. Andreas Eisenhardt, Manuel Vollrath, Kristine Wächter. *ICD/ITKE Research Pavilion 2010: Project Video*. ITKE, 27 Oct. 2012. Web. 02 Sept. 2013. <https://vimeo.com/48374172>.

·A video of the assembly process for a pavilion that was formed through material computation.

Menges, Achim, Andreas Eisenhardt, Manuel Vollrath, and Kristine Wächter. "ICD/ITKE Research Pavilion 2010 « Institute for Computational Design (ICD)." *ICD/ITKE Research Pavilion 2010 « Institute for Computational Design (ICD*). University of Stuttgart, 2010. Web. 02 Sept. 2013. <http://icd.uni-stuttgart.de/?p=4458>.

·Details about the pavilion along with photos and references.

Menges, Achim. "Integral Formation and Materialisation: Computational Form and Material Gestalt." *AD Reader* Computational Design Thinking (2011): 198-210. Print.

·An essay about material computation that I will use to back my thesis argument.

Schindler, Christoph, and Margarita Salmerón Espinosa. *ZipShape Mouldless Bending II: A Shift from Geometry to Experience. Schindler Salmeron*. ECAADe, 2011. Web. 3 Sept. 2013. <http://www.schindlersalmeron.com/images/schindlersalmeron/publications/2011_Schindler Salmeron_ZipShapeII.pdf>.

·A paper explaining the ZipShape process.

Schindler, Christoph. *ZipShape: A Computer-Aided Fabrication Method for Bending Panels without Molds. Schindler Salmeron*. Www.designtoproduction.com, 2008. Web. 3 Sept. 2013. <http://www.schindlersalmeron.com/images/schindlersalmeron/publications/2008_Schindler_Zip Shape.pdf>.

·An expanstion on the paper explaining the ZipShape process.