Carnegie Mellon University School of Architecture

2015 Fabricating Customization Seminar sponsored by Centria

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Fabricating Customization

COURSE CONTEXT

Our ability to leverage materials and processes has grown exponentially over the past 70 years to place us in a current condition in which computational methods of design and fabrication allow us to construct nearly anything we can dream up, so long as we have the time and money.

The convergence between computational design and fabrication in architectural design over the past 15+ years has led to a resurgent interest in material performance at the building scale. Pre-occupations with “digital” form and visual complexity are giving way to material centric practices in which material behaviors and digital fabrication affordances meet to produce novel assemblies and spatial conditions. Derived in part out of a necessity to manage resources more responsibly, these processes of design rely upon an alchemic dialogue with matter and the fabrication processes through which standard material is transformed into a specific building component. A growing body of contemporary work illustrates how computationally driven fabrication processes equip the designer with an expanded repertoire of techniques. It is along this trajectory that the physical artifact is infused with characteristics of its “digital” origins, resulting in novel methods of assembly, performance, and ornamentation.

The allure of one-off customization (mass customization) offered through the use of digital fabrication tools is calling into question the long-standing reliance upon systems of mass production and standardized building components for one-off buildings. The impact of these interrelated streams is radically transforming the discourse and practice of architecture while, for better or worse, ushering in a phase of architectural investigation and production that relishes in complexity afforded through the use of sophisticated software and hardware tools.

Fabricating Customization

COURSE OVERVIEW

This course relocated the design process from the studio to the lab-workshop, moving design decisions upstream to include considerations of tooling and material processing as inputs for design experimentation. Students in this course worked in partnerships to explore novel methods of robotic metal sheet forming that were borne out of direct experimentation with industrial robotic arms and customized metal forming tools. The work of the students were in response to two primary motivations:

1. Explore novel methods of customizable robotic metal sheet forming.
2. Speculate upon the potential application of the results at the building scale.

This work leveraged the robustness and precision of industrial robotic arms in conjunction with rule-based, computationally generated geometry to explore highly customizable alternatives to long-standing mass-production metal forming techniques.

In situating this as an open-ended series of design experiments, rather than product designs, we have sought to produce artifacts that reveal the methods of their production and uniqueness of their material character, while suggesting potential applications at the building scale.

This course was conducted as an advanced research seminar in which design, prototyping and fabrication were interrelated and complimentary endeavors. It provides an opportunity to engage in prescient research in methods of robotic fabrication and the reciprocal relationship between design and fabrication. Students have explored, with substantial depth, various metal forming techniques that have been tested individually and as part of multi-step forming processes. The two ABB Industrial robotic arms located in the Applied Architectural Robotics Lab (AARL) in the School of Architecture have served as the platform for our research.

Phase One:

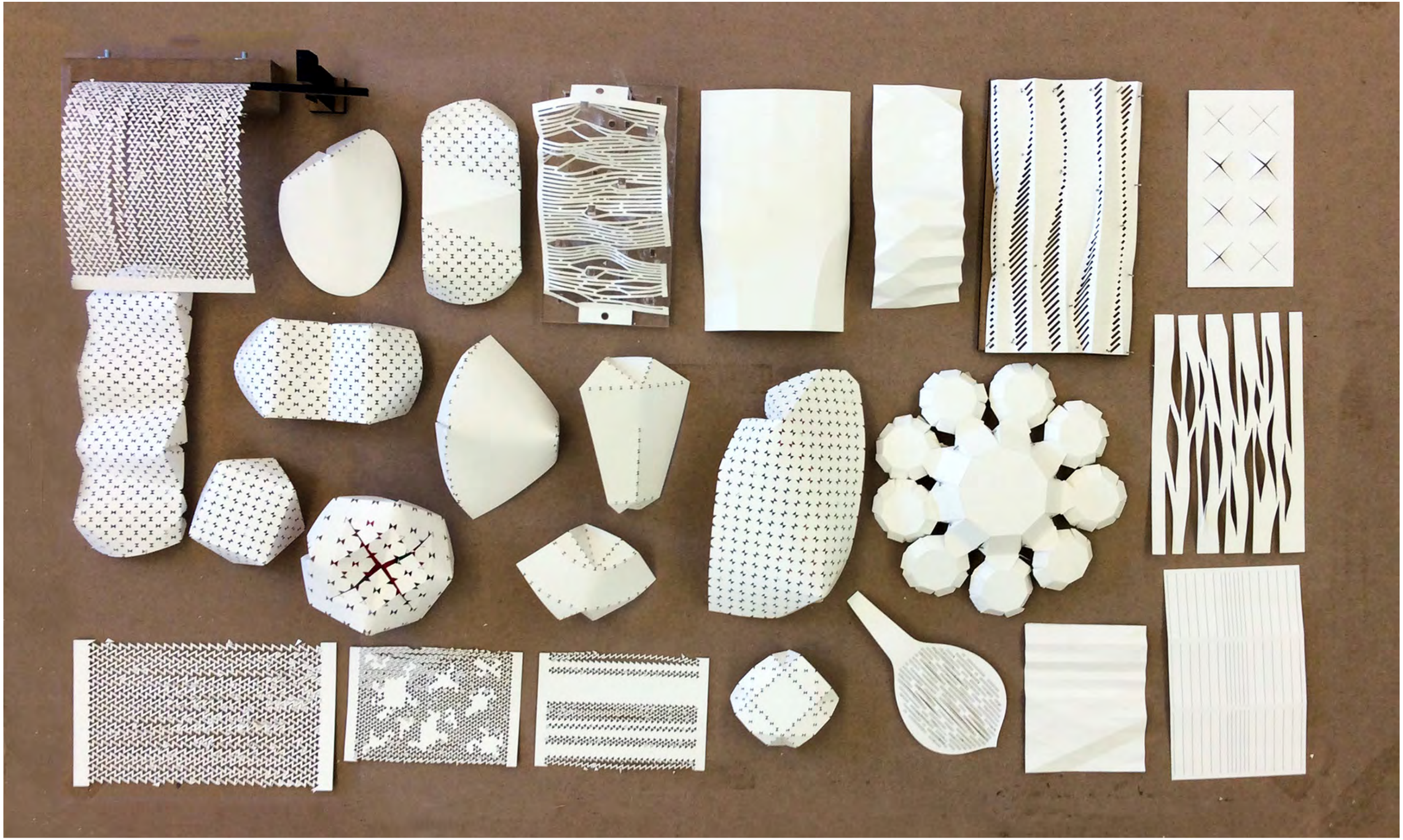
Early Studies in paper

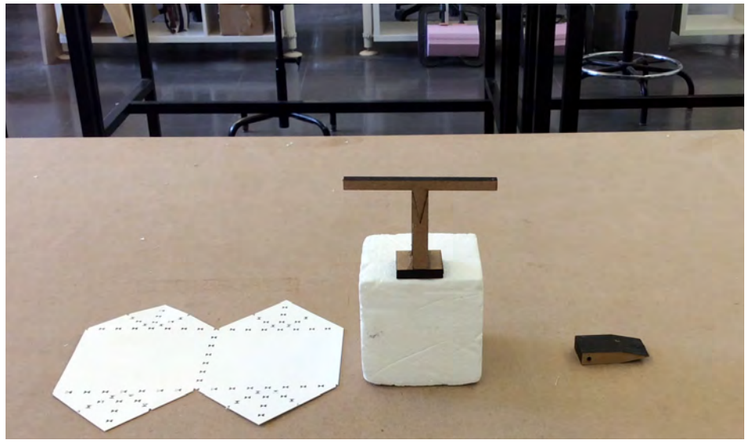
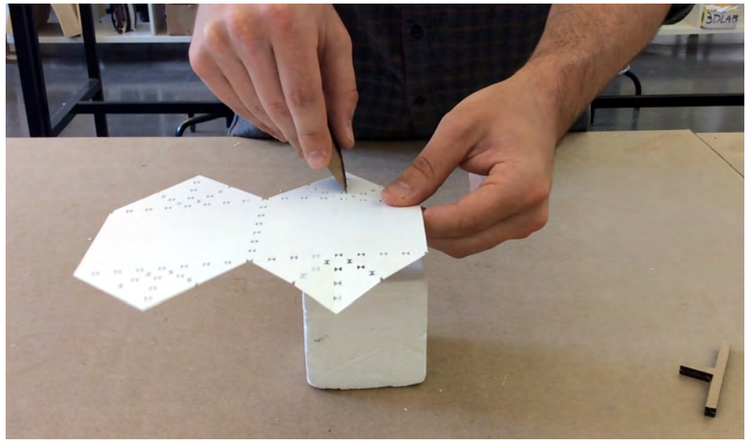
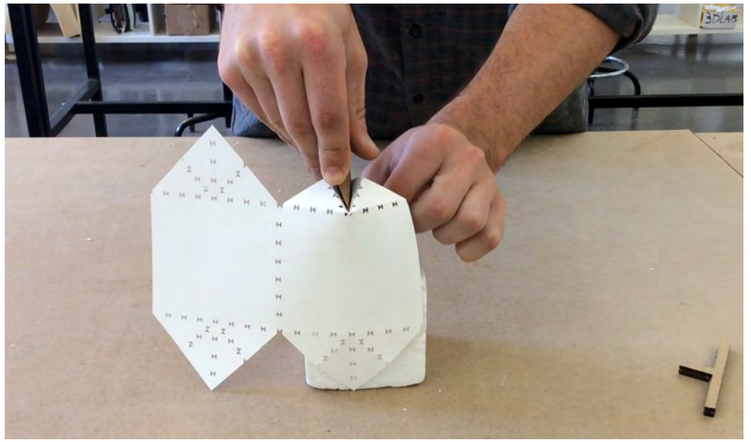
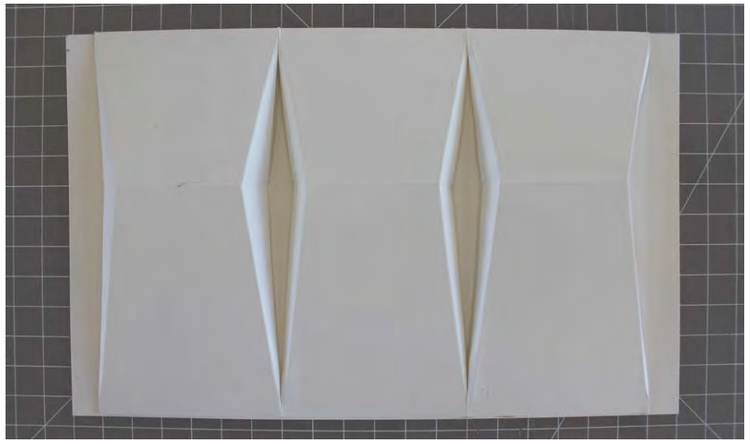
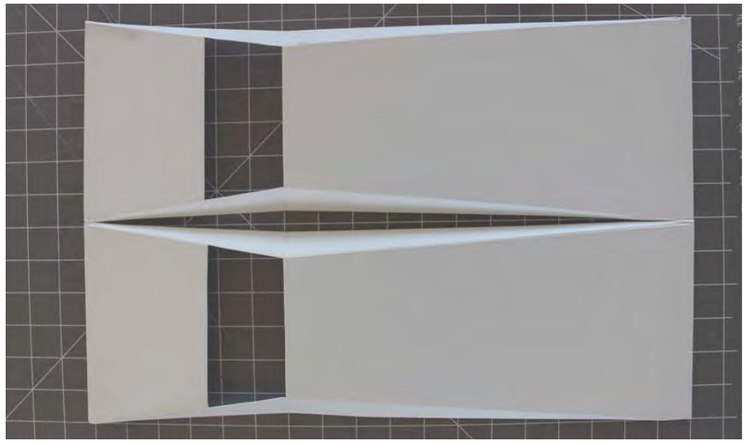
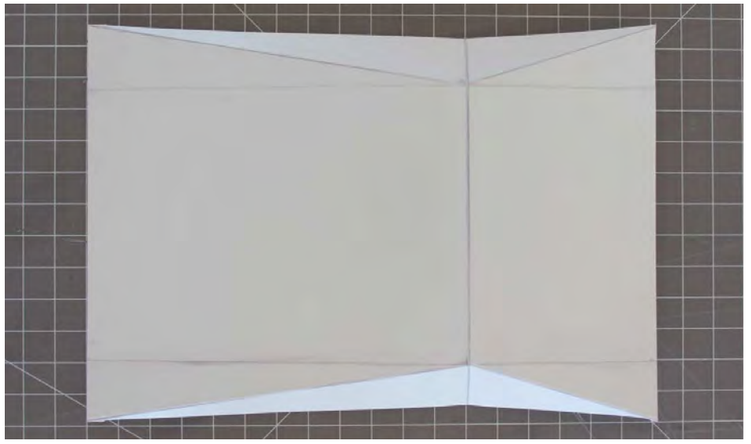
PROJECT INTRODUCTION

Trans-formative processes of sheet material forming served as the foundation of research and experimentation within the course. Initially, students explored planar processes of creasing, rolling and cutting as methods to geometrically transform the sheet and serve as an introduction toward procedural transformation that could be replicated with the use of an industrial robot. This course expanded initial experimentation in robotic expanded metal forming conducted by students in the fall of 2014.

PROJECT METHOD

Preliminary experimentation in paper afforded expediency and economy. While paper has its own unique material properties and does not replicate the behavior of metal, it did afford exploration of correlations between cut and crease patterns and subsequent surface geometry. This initial phase established methodical processes of testing that relied upon reciprocities between incremental changes and observation of results to establish rules based procedures for forming of the material.



Phase Two:

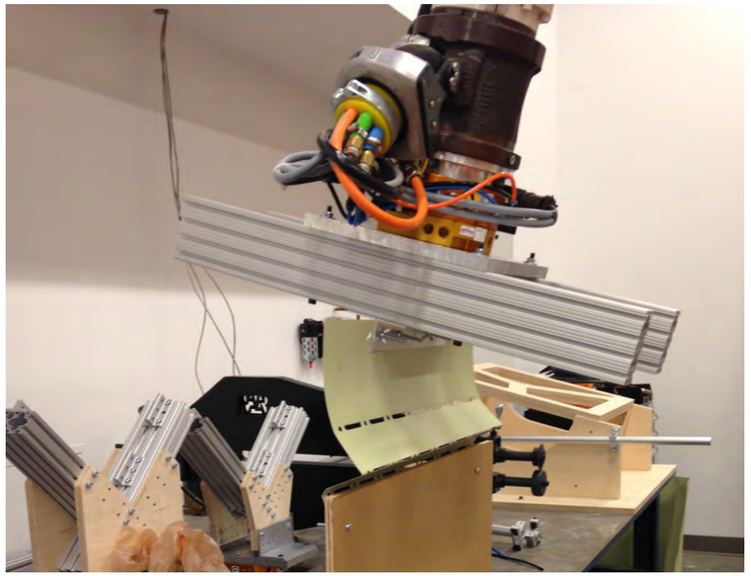
Aluminum and Steel forming

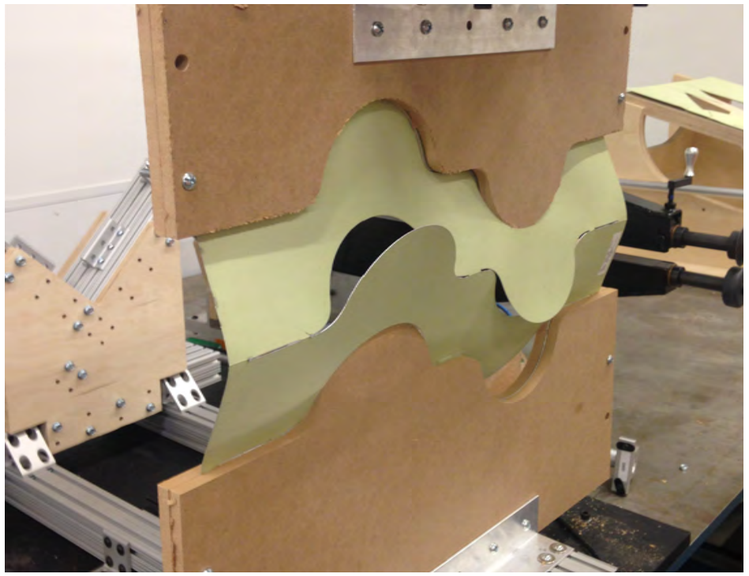
PROJECT INTRODUCTION

The second phase of the course involved the use of the 24” x 24” aluminum and steel sheets provided by Centria. Depending upon the processes, teams occasionally utilized manual forming techniques in the early stages to approximate robotic motion. This soon transitioned to fully robotic processes. Teams utilized both on-line and off-line robot path planning to develop the work and understand basic material behavior in relation to robot motion. All three teams eventually established programmed and repeatable robotic motion that afforded results with an acceptable degree of consistency given the nature of the course.

ROBOTIC METAL FOLDING

Student Team 1:
Cy Kim | Yaakov Lyubetsky





CREASE BIASED SHEET FOLDING

Forming of aluminum sheets began with the strategic removal of material through plasma cutting and the subsequent superimposition of creases through manual bead rolling. The sheet perforations achieved through the plasma cutting process proved to be an effective means of controlling sheet folding while the creases biased directionality of folding based upon the hill and valley orientation of the crease.

FOLDING PROCESS OBSERVATIONS

- Introducing cuts between creases creates a gradual curve

- Bead-rolling with too much pressure cuts through thinner aluminum

- The clamps that the aluminum mounts to doesn't span the full two feet of the sheet, resulting in deformations when the sheet is rotated.

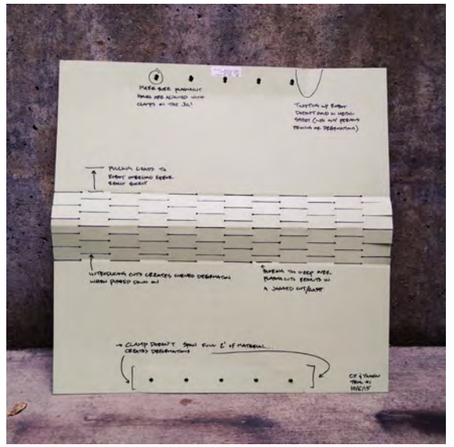
- Pulling or twisting without properly placed cuts results in robot overload error very quickly

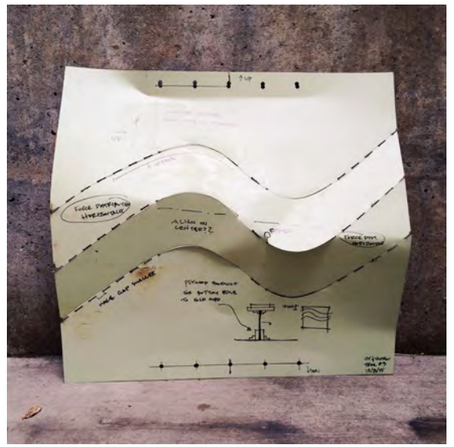
- Placing the clamp not parallel to cuts unevenly distributes the forces

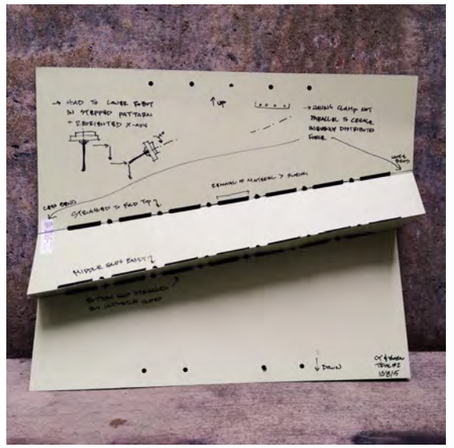
- The middle perforation line folded the easiest, the bottom struggled but ultimately folded

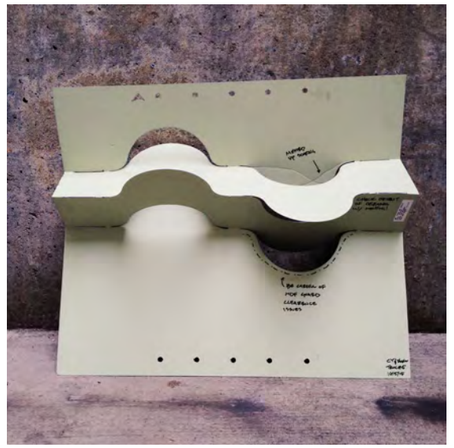
- Removing / cutting material creates a much more flexible fold than bead-rolling

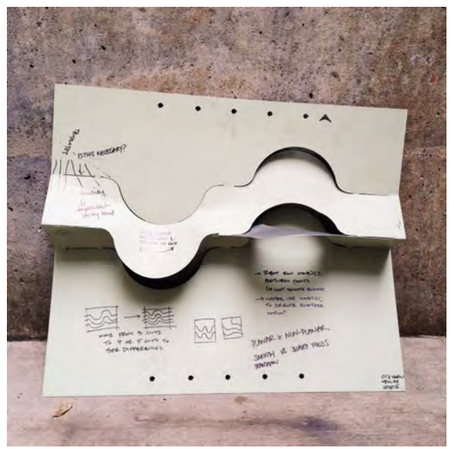
- Plywood material clamps worked well when extending to the full sheet width

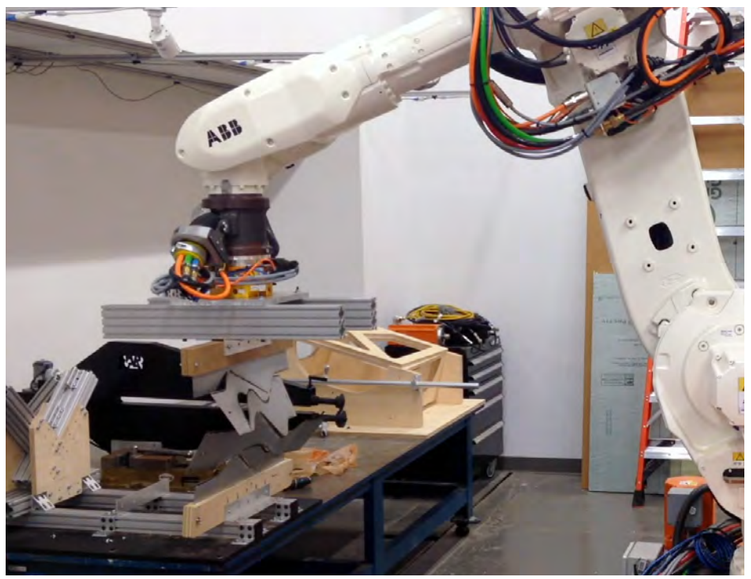


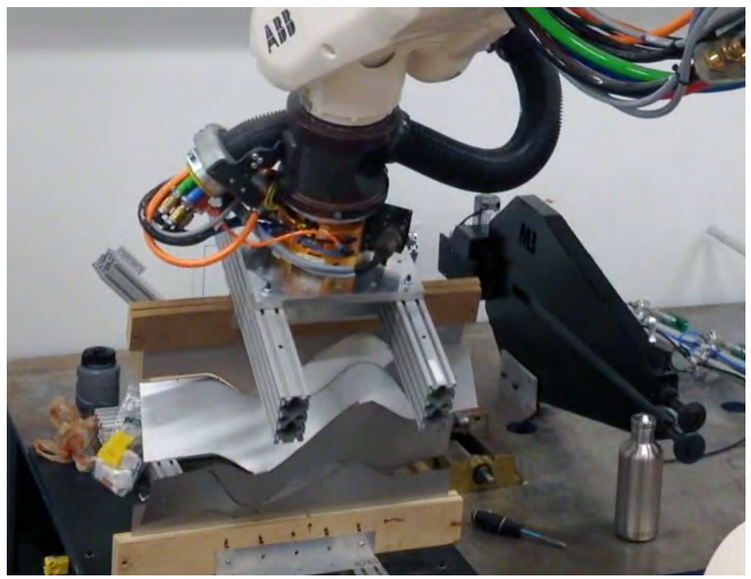












MULTI-FOLD SHEET FORMING

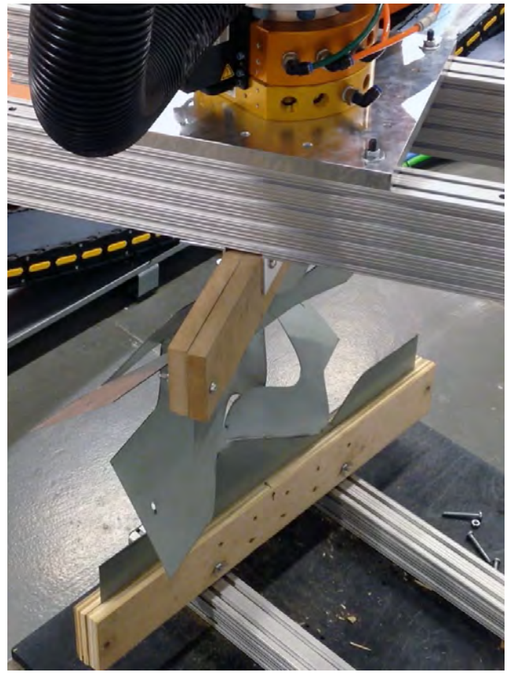
As work progressed, the students were motivated by the following considerations:

Create a form with many folds, all in a single robotic action

Define a process where the cut and the fold patterns can have variations, while the robotic motion remains the same

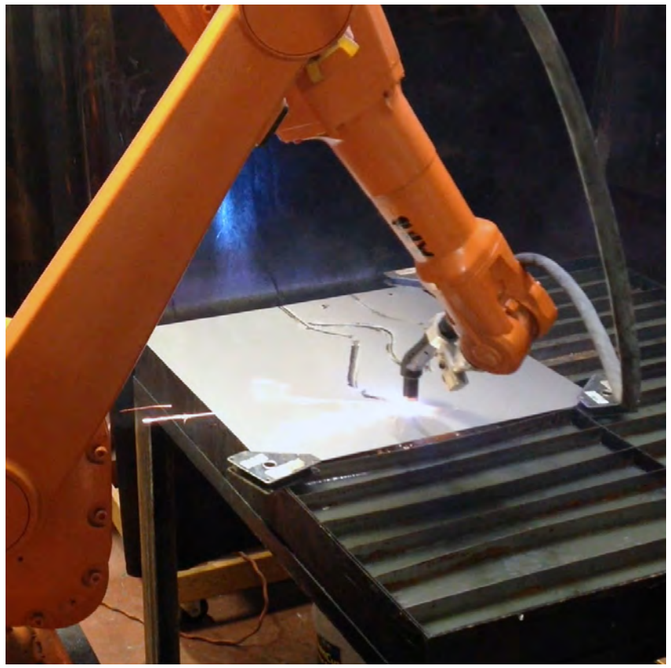
Tile individual panels to create a larger dynamic form

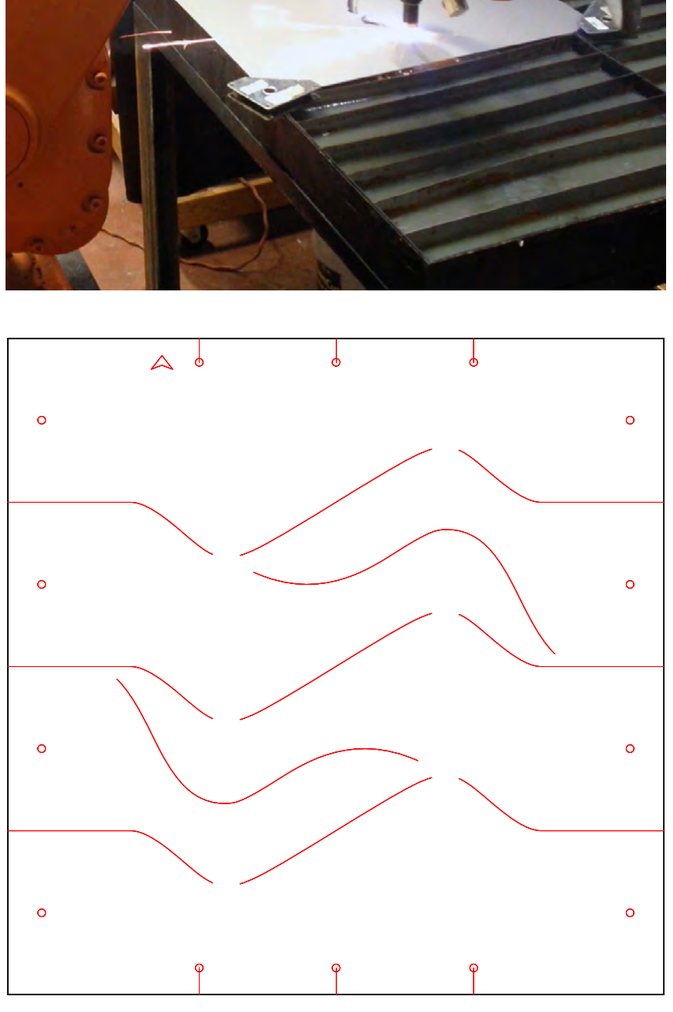
Refine a process for the creation of compound curves that create a more visually complex and intriguing form

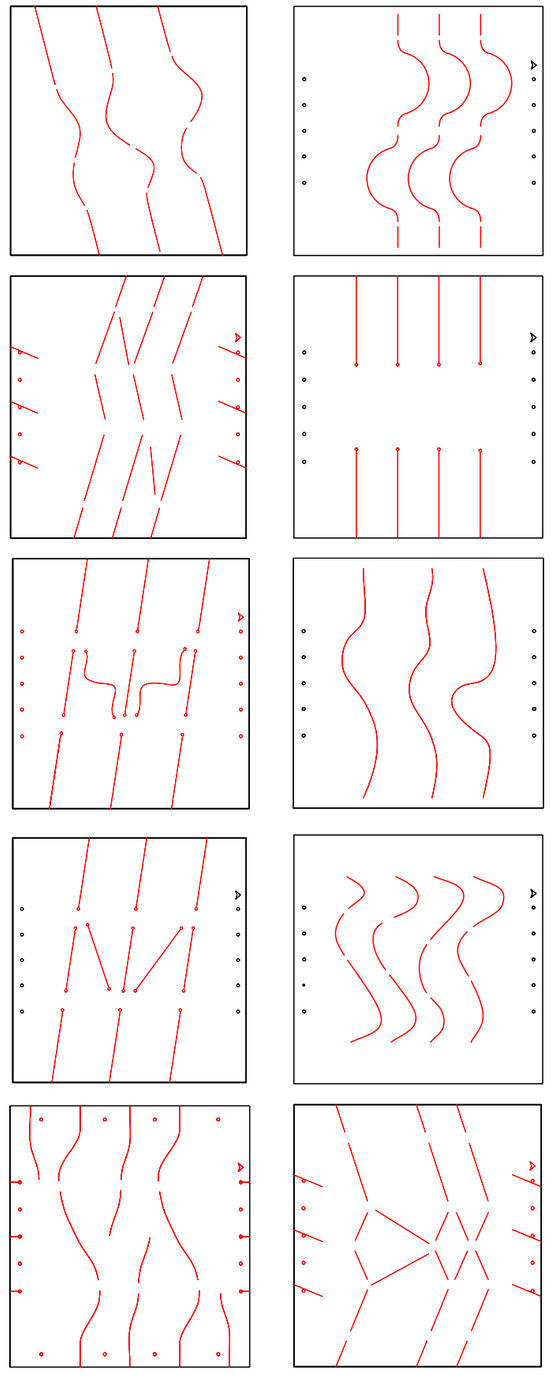


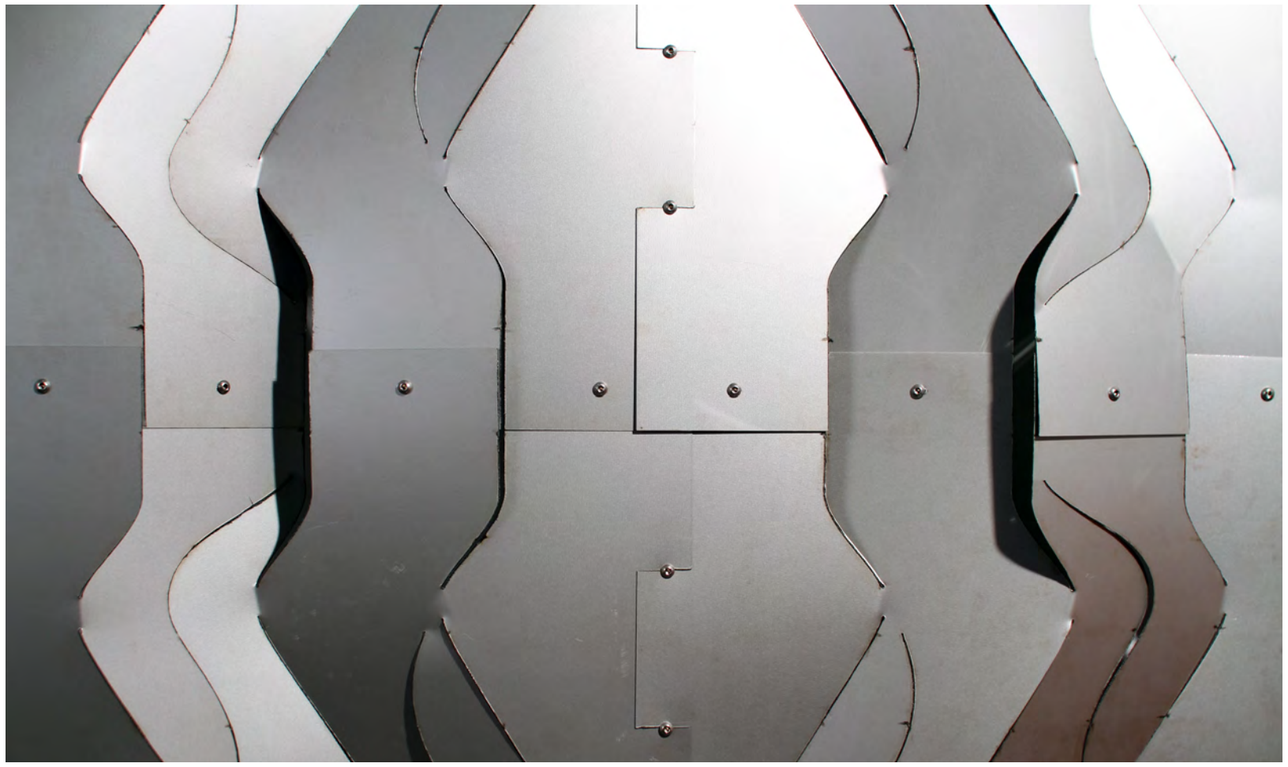
PLASMA CUT PERFORATIONS

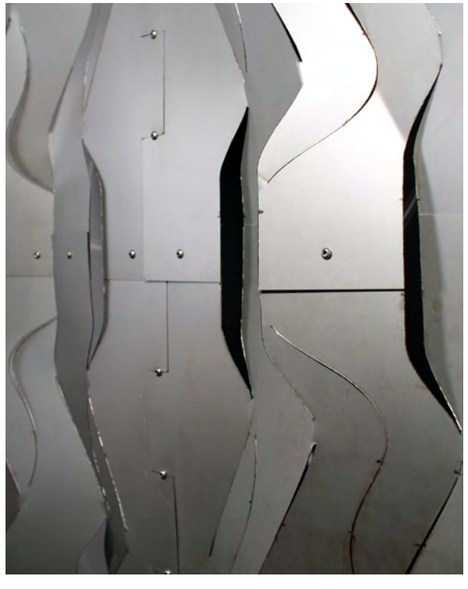
Robotic plasma cutting proved to be an effective and economical means of perforating sheet material for subsequent folding. Burning of the paint coating was observed. While most of this residue could be removed, other means of cutting, such as laser or water-jet would provide a cuts of a substantially higher quality.

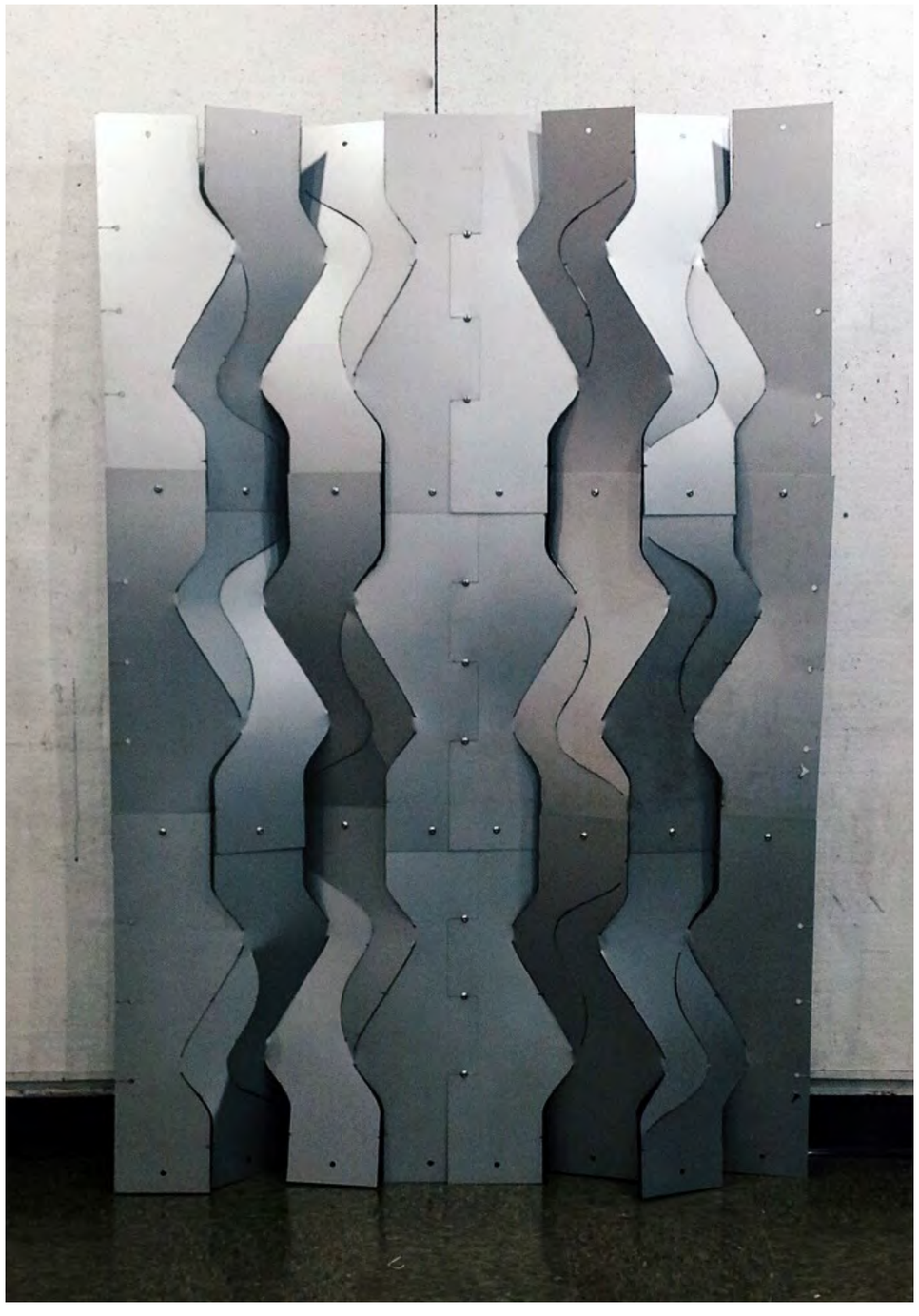






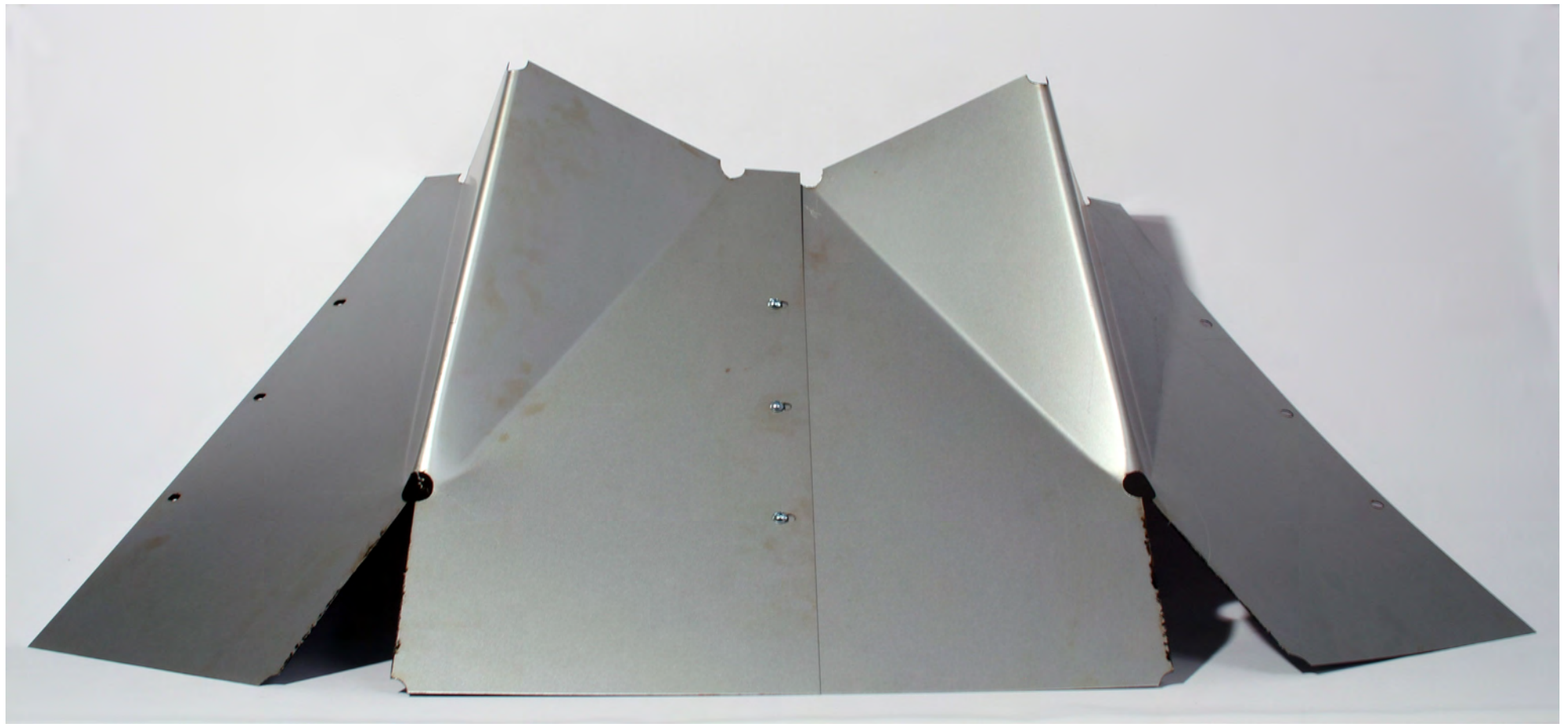


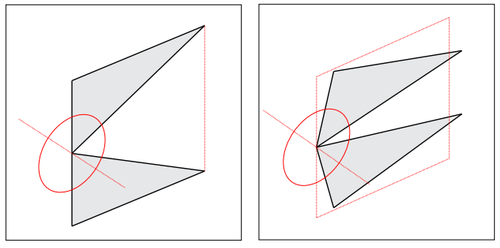




ROBOTIC METAL BUCKLING

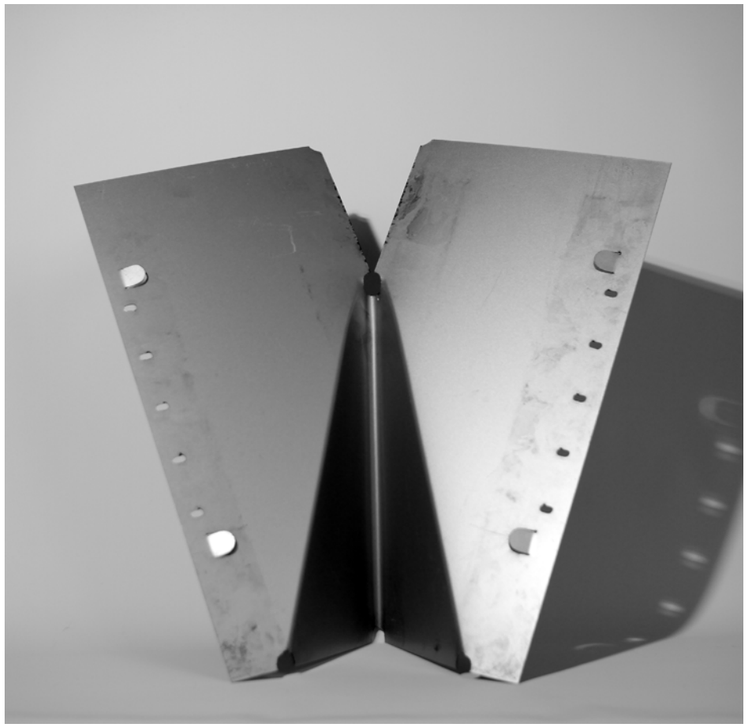
Student Team 2:
Kirk Newton | Matt Porter

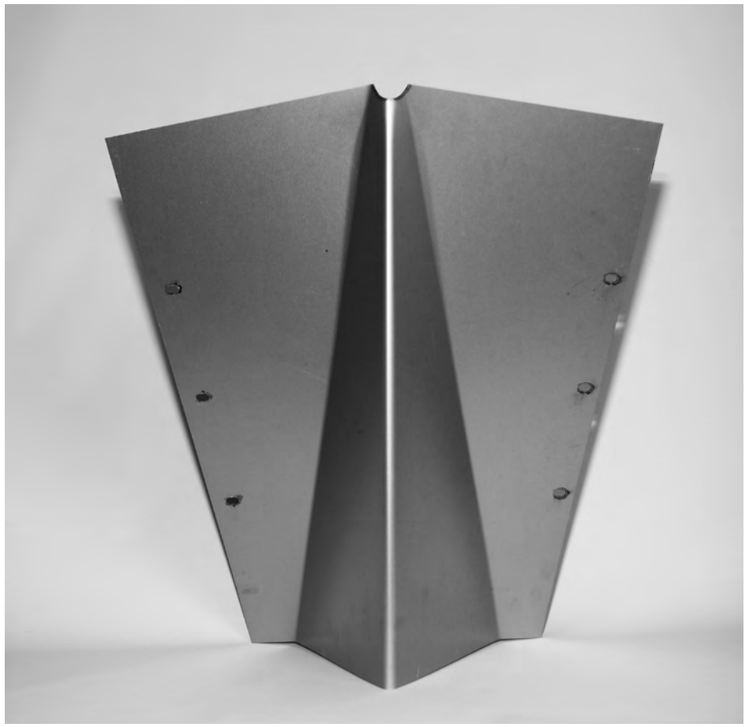




ROTATIONAL BUCKLING

As perhaps the least process heavy of the three work-flows explored, the work was motivated by a desire to establish a process that afforded a range of crisply folded sheets through simple rotational movements of the sheet. By carefully buckling the steel, the sheet could take on form with a range of folding radius. Interchangeable MDF clasps served as a means to preserve planarity of portions of the sheet and establish edges along which the material was folded.



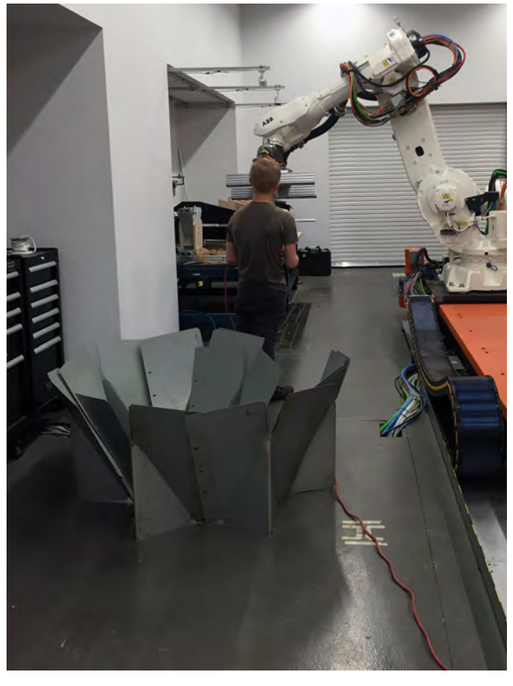


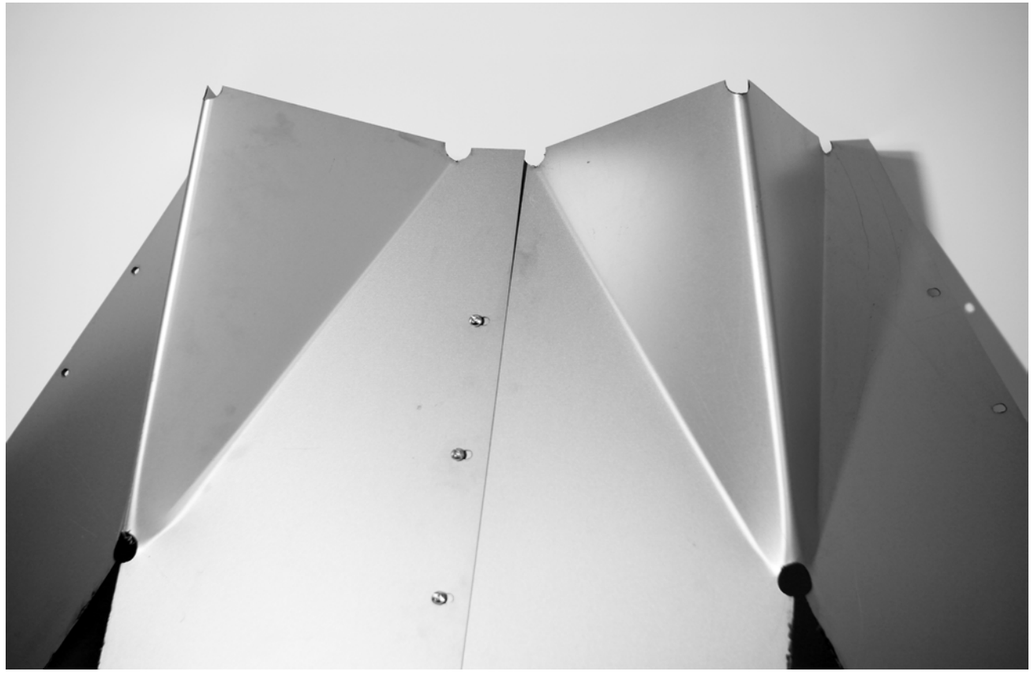
ROTATIONAL BUCKLING

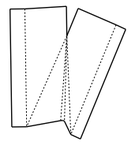
Sheet material removal was reduced to a minimum in an attempt to leverage the rotational robotic motion in conjunction with tooling and fixturing to achieve the desired the results. Strategically located holes and cuts provided tooling registration and mounting locations, tabs for joining of sheets, and circular holes that facilitated the resolving of forces across the sheet to reduce the likelihood of sheet tearing.

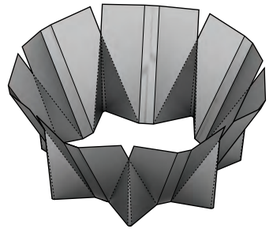
PANEL ARRAYS AND AGGREGATIONS

The panel shape, number and degree of folds, and location of joining tabs allows for a wide range of sculptural forms.



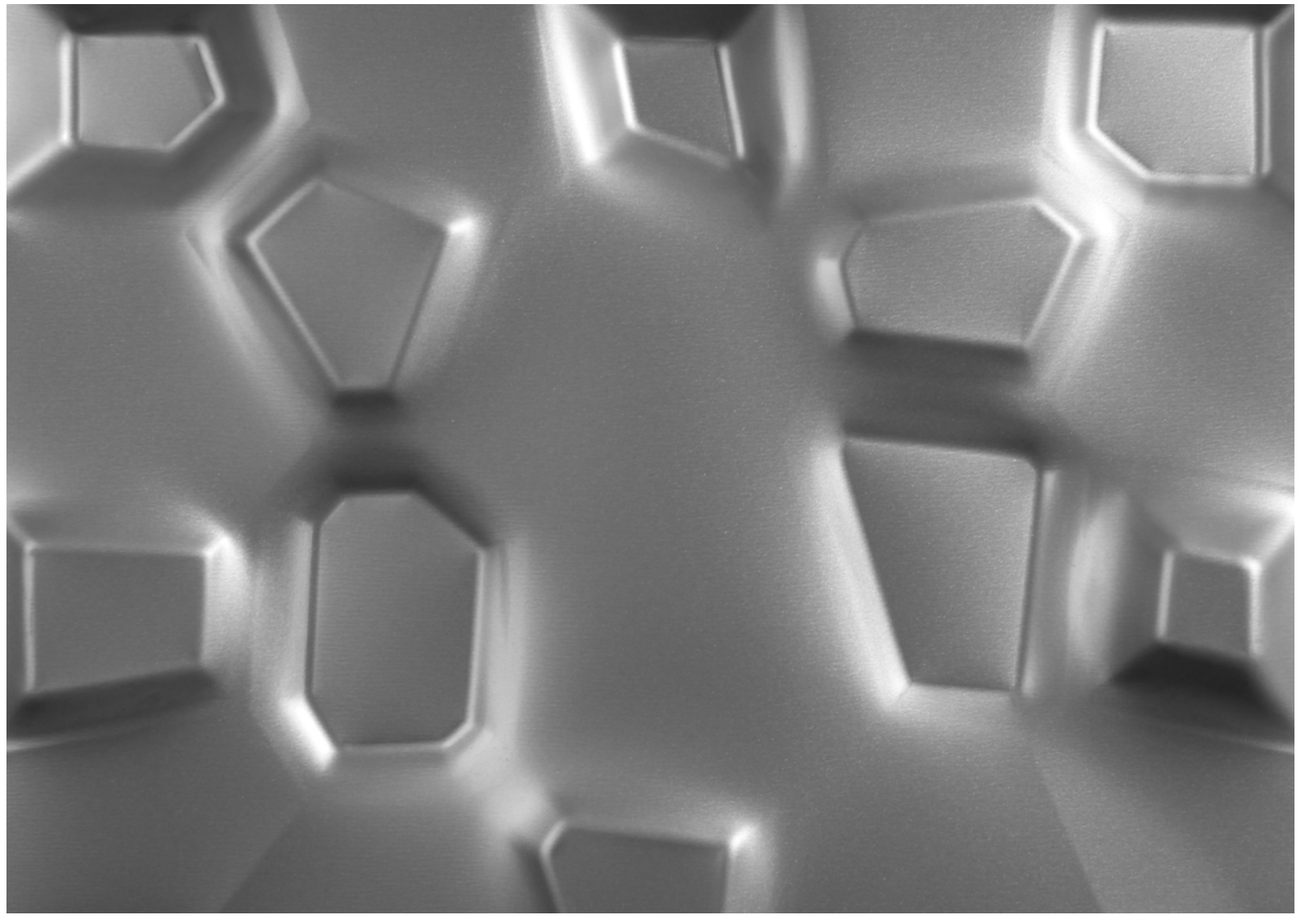


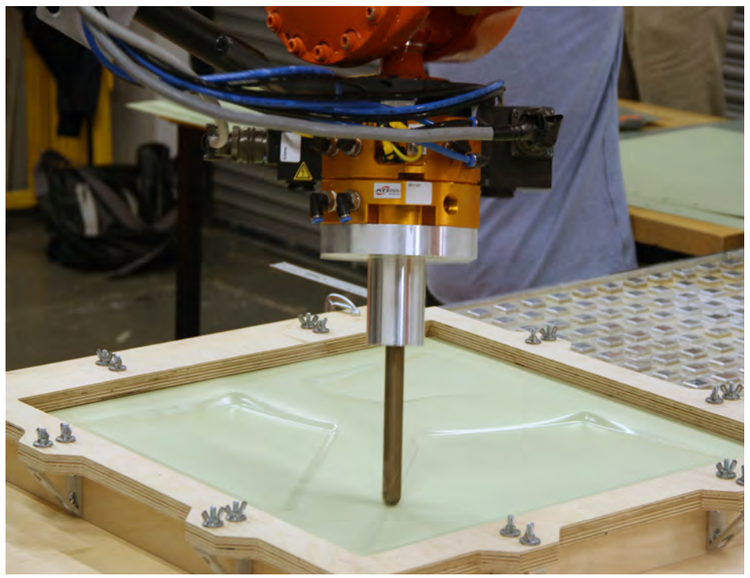


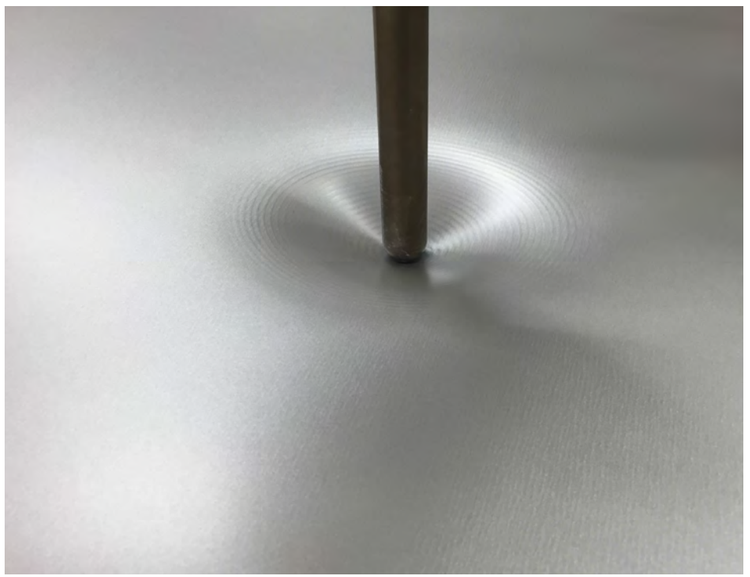


ROBOTIC
METAL FORMING

Student Team 3:
Scott Holmes | Dan Russo

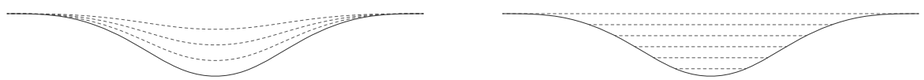






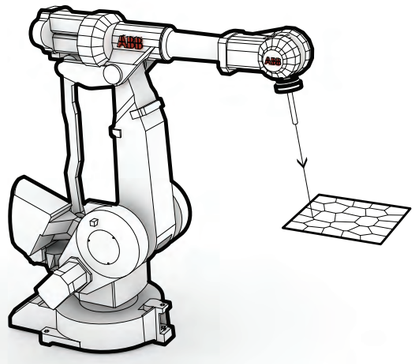
Applying a Path

Scaled ***vs.*** ***Incremental***



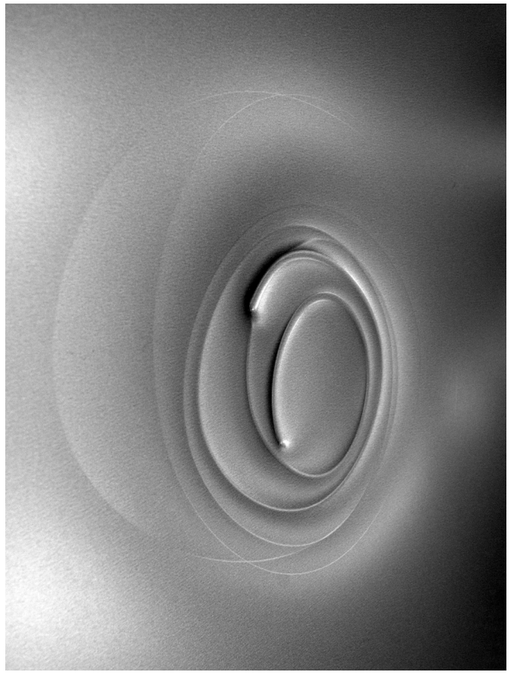
PATH SCALED METAL FORMING

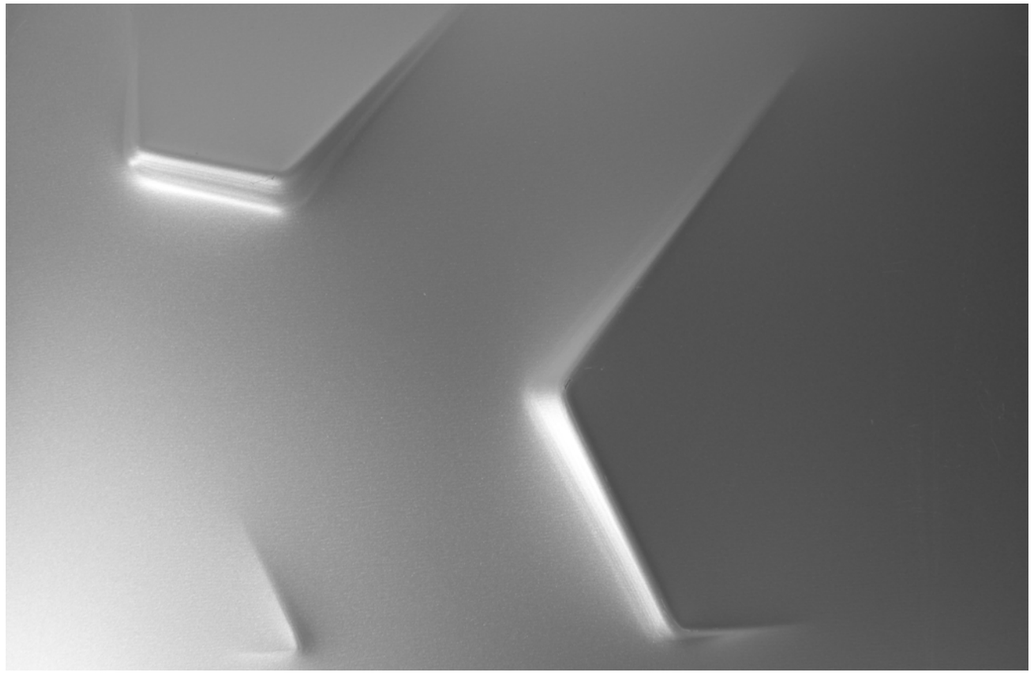
The path scaled forming process affords the development of complex three-dimensional sheet form through the consistent and controlled displacement of the metal sheet. A case hardened metal stylus tool affixed to the end of the industrial robot is moved across the metal sheet at progressive scaled depths in the z-axis, to expand the sheet in accordance to the pre-determined robot motion path. A plywood fixture registers the sheet relative to the robot and elevates the sheet above the table surface. The ‘floating’ metal sheet is subsequently formed down toward the table surface.

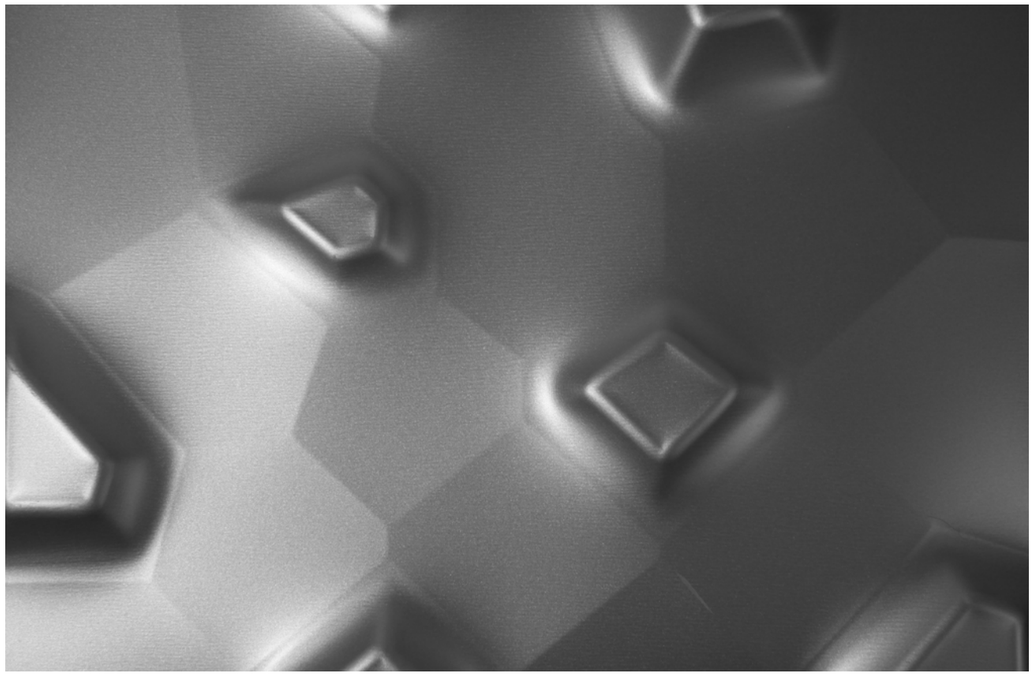


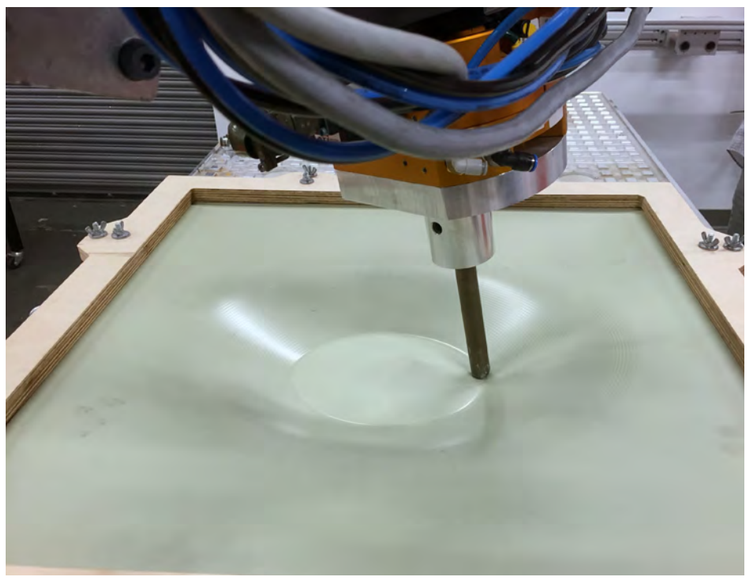
EMBOSSING AND FORMING

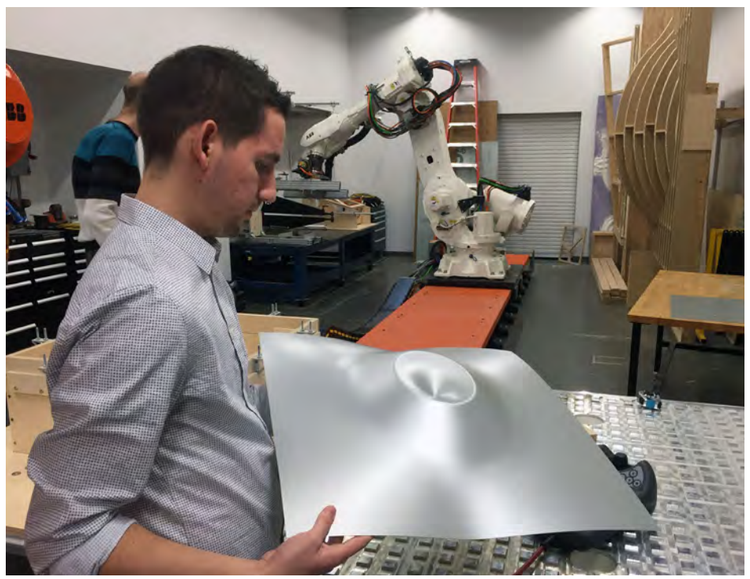
The motion path accuracy, position repeatability and rigidity of the industrial robot afforded both subtle and significant metal sheet deformation. The tracery of surface paths of a constant depth along the sheet produced extremely subtle surface patterns with an embossed appearance. Subsequent tooling along the sheet and registered to these embossed patterns resulted in significant forming depths, while largely preserving the initial embossed patterns.





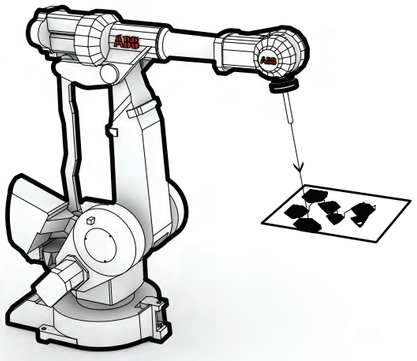






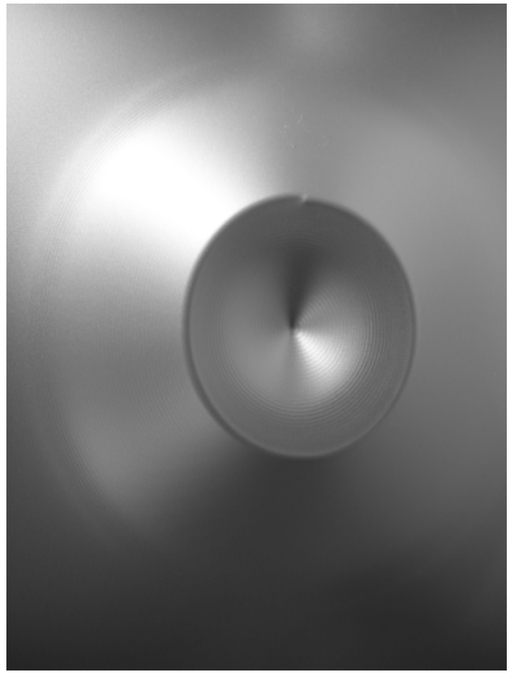
DOUBLE-SIDED METAL FORMING

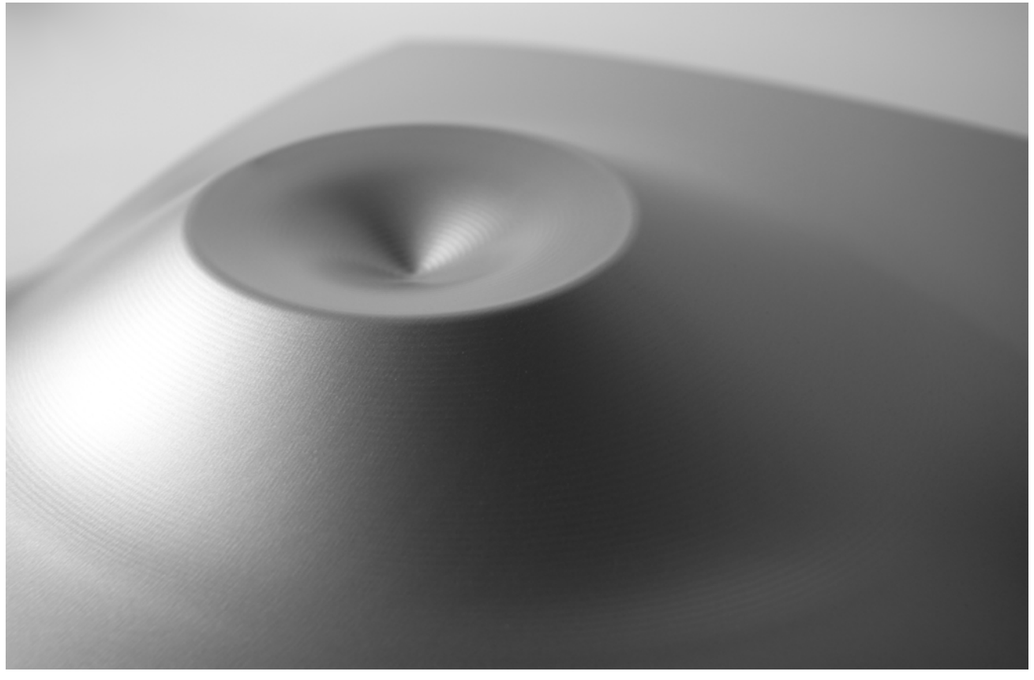
While the table mounted fixture proved to be an effective means of registering the sheet relative to the robot its box-like form only allowed forming of the sheet on one side and with one robot. Progressive experiments led to explorations in surface geometry that undulated along the sheet, utilizing ridges and valleys to expand the range of potential surfaces. These surfaces necessitated flipping of the metal sheet between forming processes to achieve the desired results.

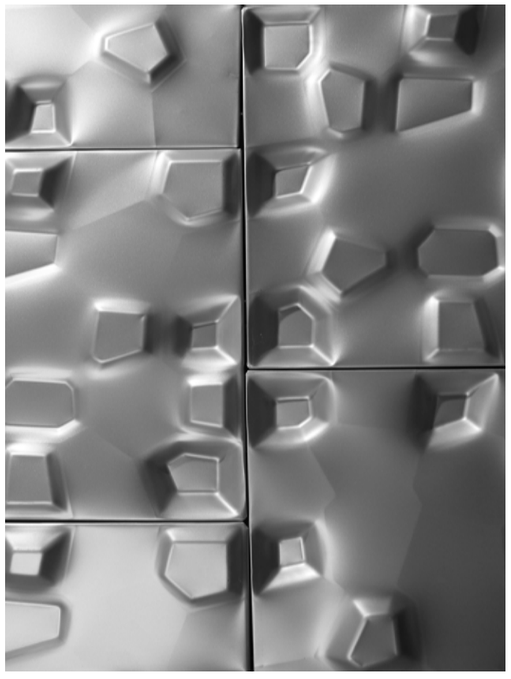


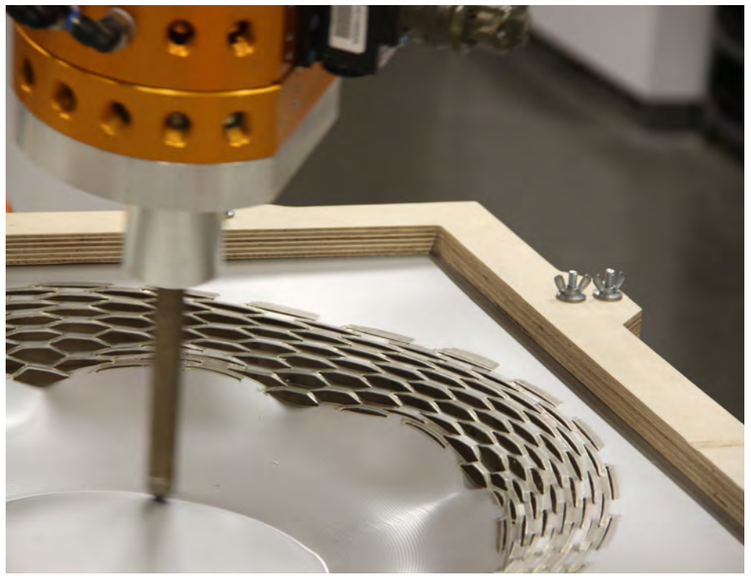
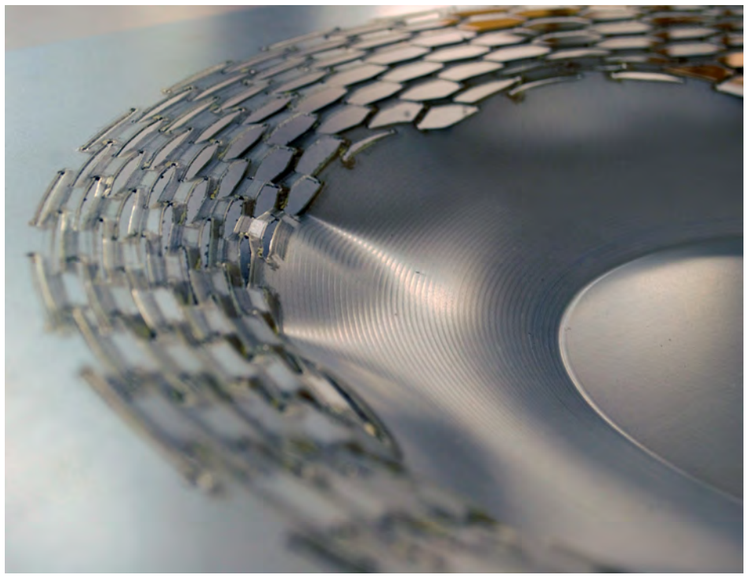
DOUBLE-SIDED METAL FORMING

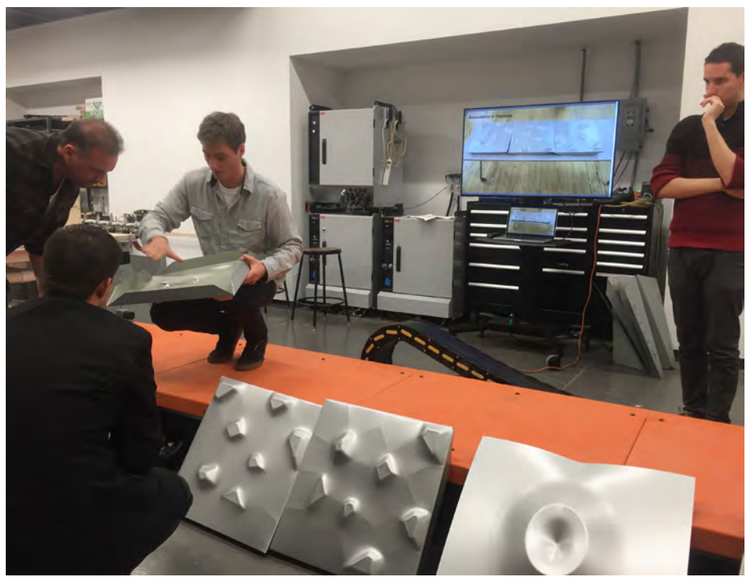
As with the processing of any double-sided surface, registration of the material to the fixture and tool while flipping the material is critical to achieve controllable and repeatable results. For the purposes of this preliminary research, the fixture and ply-wood containment rim produced acceptable results, occasionally with startling visual appearance.









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