2020 ACSA CREATIVE ACHIEVEMENT AWARD SUBMISSION

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Fig. 1 Discussion with Centria R&D team member
Fig. 2 Student presentation to members of the Centria R&D team

COLLABORATION

Evolving modes of representation and communication continue to redefine the flow of information between designer, fabricator and manufacturer, while nimble means of fabrication recalibrate customization. As various types and scales of design practice reveal, opportunities for strategic collaboration between designer and fabricator abound. The work illustrated is the result of a two year university – industry partnership with Centria, a global manufacturer of metal façade systems and Autodesk. Centria sought to capitalize upon the alternate perspective the students and by extension the academy afforded to reconsider the standard metal façade panel that has served as the core of their business. We sought to structure a collaboration that strategically leveraged the material expertise of our industry partner while encouraging structured experimentation by the students, that was initially unconstrained from the myriad of technical and economic considerations associated with building cladding systems. The resultant sponsored 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. This first phase of the partnership decontextualized the work from the building façade and the technical challenges of enclosure systems, to provide student teams with sufficient opportunities to develop and refine processes of robotic metal forming.

Our partner was motivated by a desire to use the collaboration to stimulate a broader discussion within their organization about the business model and corporate culture of standardized production. Engaging future architects (students) in processes of procedural and material experimentation provided a means to understand generational values while also providing fresh perspective and vision to products that are often seen as conventional and pedestrian.

Our collaboration relied upon the robotic fabrication facilities at our university to develop workflows that afforded versioning processes to explore alternative ways of forming metal sheet. Our partnership sought to leverage the robustness and precision of industrial robots to explore a limited number sheet metal forming techniques that, by virtue of their recalibration, afford a subset of formed panels. Simple adjustments in robot tool position, rotation, force, etc. informed the behavior of the material and contributed to a range of possible outcomes or versions. Three distinct trajectories of research emerged that can be described through techniques of folding, buckling, and incremental forming. Each sought to reduce the need for material pre-processing, such as cutting or drilling of the sheets, in order to economize the workflow through the least number of tools or actions while yielding a range of potential versions.

The collaboration provided our student cohort with the perspective and rigor of industry and challenged the frequent desire for ultimate design freedom and its association with complete customization. The fabricated results and dialogue with our partner centered on the establishment and negotiation of constraints that were informed by the design motivations of our students and the seasoned expertise of industry. The partnership served as a means to explore alternative trajectories of design and fabrication that leverage material behavior and high fidelity fabrication to reveal a spectrum of possibilities.

The collaboration began in the fall of 2015 with Centria sponsoring the course, Fabricating Customization. This course established three distinct approaches to the transformation and forming of alloy surfaces. This was followed in the fall of 2016 by a second sponsored course offering of Fabricating Customization where students used the work from the prior year as a springboard. Their work was pursued within the area of incremental metal forming with the charge to address considerations associated with building enclosure such as panelization and scale. This course culminated with the fabrication of a large scale physical prototype, Tact(AL), on the campus of Carnegie Mellon. At the conclusion of these courses, Autodesk sponsored a workshop for Carnegie Mellon undergraduate and graduate students at their Boston Build Space, a world class fabrication facilitiy that aims to facilitate industry-academy partnerships while providing resident research teams opportunities to interact with the diverse expertise of their inhouse researchers and developers.

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.

CONTEXT

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 architecture’s materialty 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

Fig. 3 Autodesk Build Space workshop
Fig. 4 Student team prototype assembly

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.

RESEARCH BY DESIGN

This course was conducted as an advanced research seminar in which design, prototyping and fabrication were interrelated and complimentary endeavors. It provided 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.

COURSE ORGANIZATION

This course relied upon hands on experimentation with processes and materials. Studentsl worked in both the “final” material of steel and aluminum sheet as well as proxy materials such as papers and plastics, to allow for quicker experimentation at smaller scales.

Students were paired with a partner, with each team assuming responsibility for a primary forming process. While the processes and tools have been designed and fabricated, the student teams led investigations into the forming potential of each process. This initially occured as discrete experiments that established a rigorous set of baseline reference information and then moved into composite experiments that leveraged a range of available processes. Our intent was to establish a sophisticated understanding of material behavior relative to the processes at hand and to translate this knowledge into design parameters that embeded material and procedural considerations within a design ecosystem.

While each team led experimentation in a particular process, access to the collective knowledgebase was critical to the overall success of the course. Each team recorded their work through various forms of media and packaged the findings in accordance with the standards established at the start of the class. Rigorous documentation methods were paramount to ensure findings were useful for the entire group. The end result was a physical and digital catalogue of the work conducted during the semester.

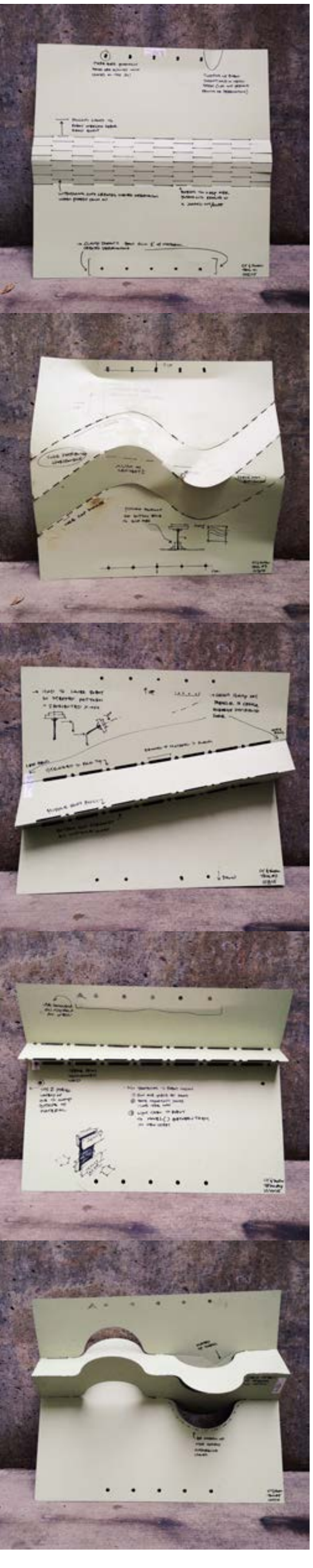

Fig. 5 Sheet transformation tests

ROBOTIC FABRICATION

Robotic fabrication processes differ most significantly from traditional "single task" methods of digital fabrication in their inherent task flexibility. Given the fact that industrial robotic arms are not only capable of operating within a larger spatial zone but can also command a range of tools, how one utilizes these machines, is distinct from established methods of digital fabrication.

Three fundamental distinctions of fabrication can be observed; subtractive, additive, and transformation. Subtractive processes are well established and utilized for direct and indirect production of architectural components. While additive fabrication is typically associated with 3d printing processes, it also extends into methods of accretion and assembly and has emerged as a significant area of research and experimental practice that rely upon various forms of robotic workflows.

Transformative processes, by their very nature, utilize material (molecular) and/or geometric alterations for the production of an altered artifact. They rely upon nuanced understandings of material properties and ultimately, control over material behavior for the production of a desired outcome. Transformative processes afford the prospect of embedded complexity through action upon material (transformation) rather than aggregation alone.

Transformative 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.

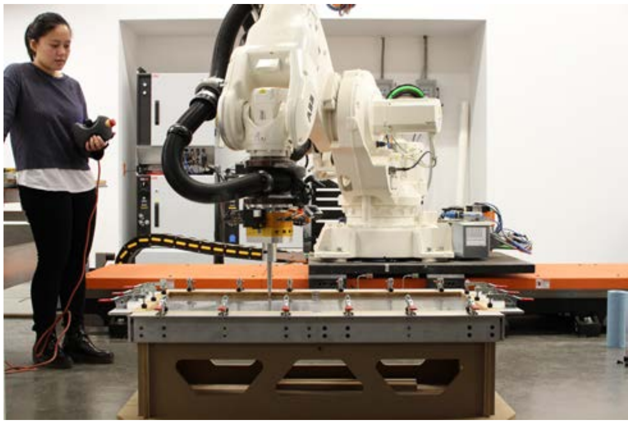

Fig. 6 Incremental forming tools
Fig. 7 Incremental forming robotic workcell

FABRICATING CUSTOMIZATION FALL 2015

PHASE ONE: CREASE / FORM / CUT / EXPAND

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.

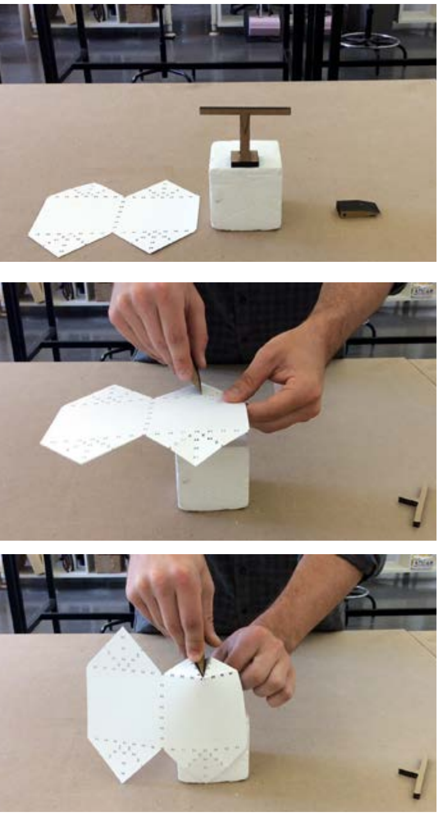

Fig. 8 Forming tests anticipating robotic proceedures

Fig. 9 Scaled sheet transformation models

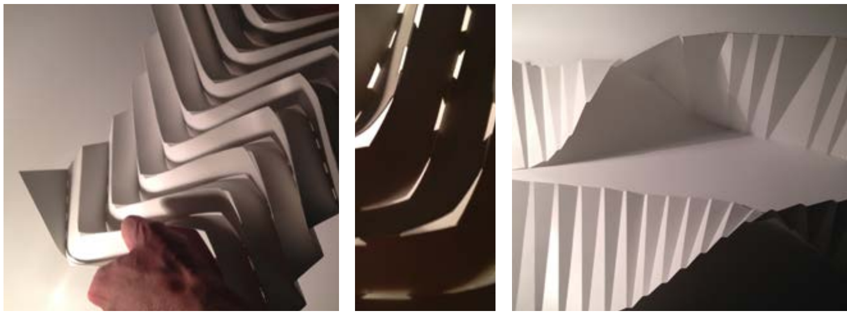

Fig. 10,11 Crease and fold models

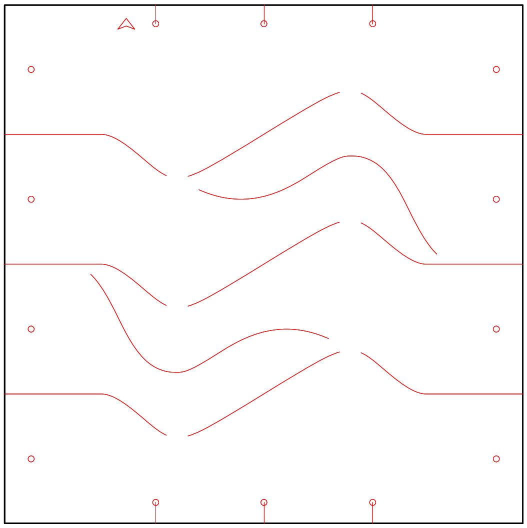

Fig. 12 Sheet reflief lines for plasma cutting

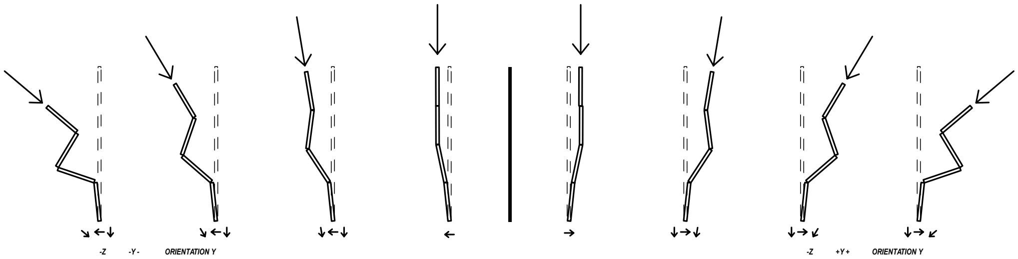

Fig. 13 Crease and folding bias force vector diagram

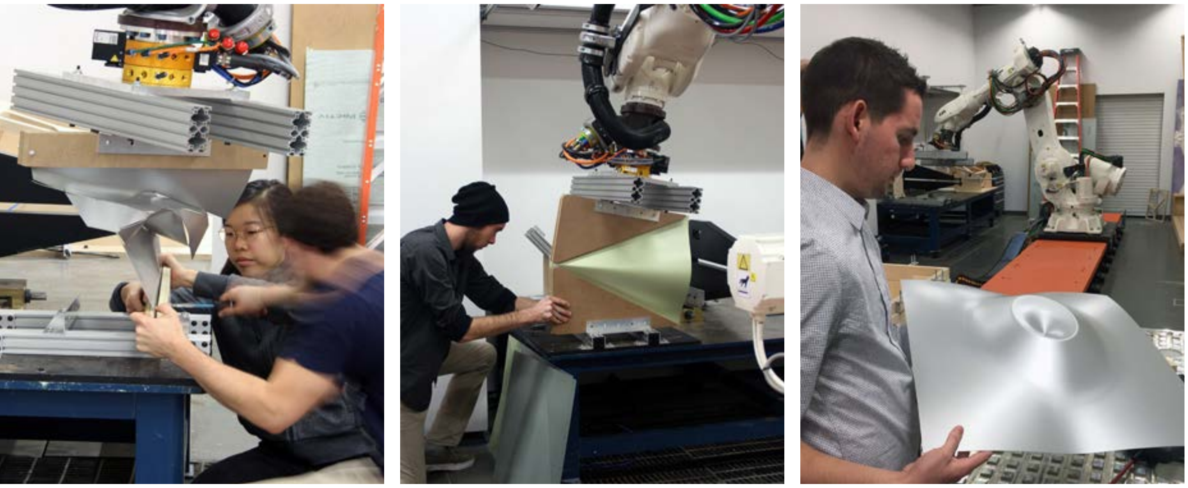

Fig. 14 Initial robotic forming tests

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PHASE TWO: FOLD / BUCKLE / STRETCH

The second phase of work sought to translate initial “analog” proceedures conducted by hand and through a proxy material to the industrial robots and and through steel and aluminum sheet.

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.

FOLDED SHEET

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.

BUCKLED SHEET

As perhaps the least process heavy of the thre 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.

STRETCHED SHEET

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.

Fig. 15-17 Final student forming technique demonstration prototypes

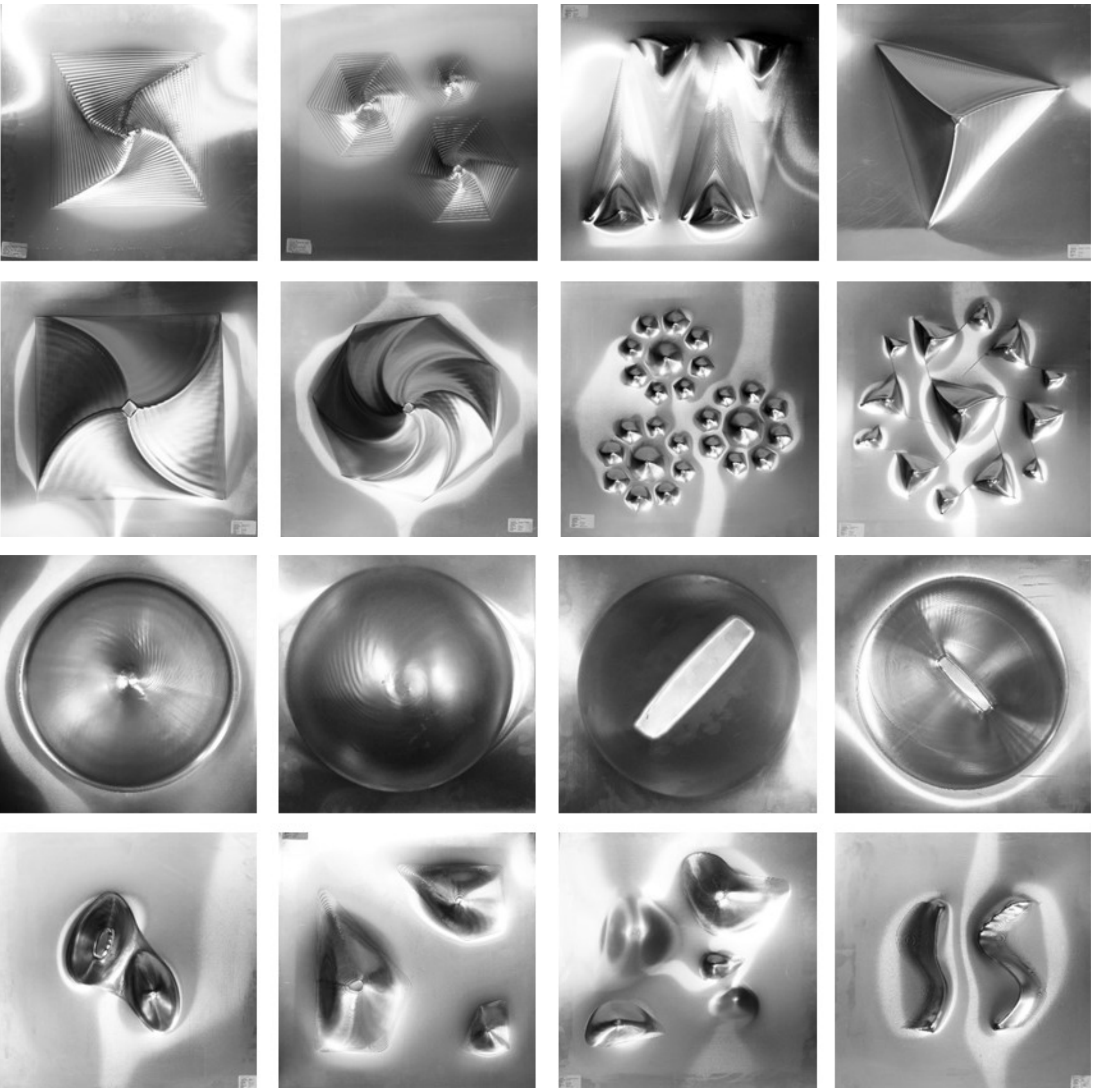


Fig. 18 Matrix of aluminum incremental forming tests

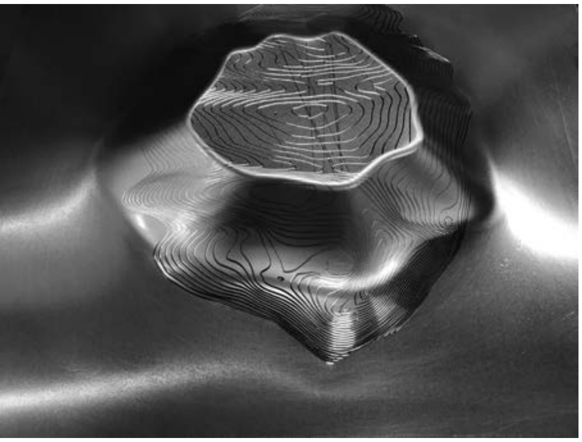


Fig. 19 Aluminum test of combined engraving and forming

FABRICATING CUSTOMIZATION FALL 2016

SURFACE DUCTILITY THROUGH INCREMENTAL FORMING

The Carnegie Mellon - Centria collaboration continued through the 2016-2017 academic year with Centria's sponsorship of Fabricating Customization in the fall of 2016. This course leveraged the prelimenary research from the students in the preceeding year to explore processes of incremental forming with greater rigor. Of particular interest to Centria was the development of low relief forming techniques with the use of standard industrial robots. Students sought to probe the affordances of incremental forming techniques which are effectively methods of drawing across the surface of the sheet. The resulting work revealed both drawn surface engraving across the sheet as well as deep draw forming that demonstated the domain limits of the forming techniques deployed.

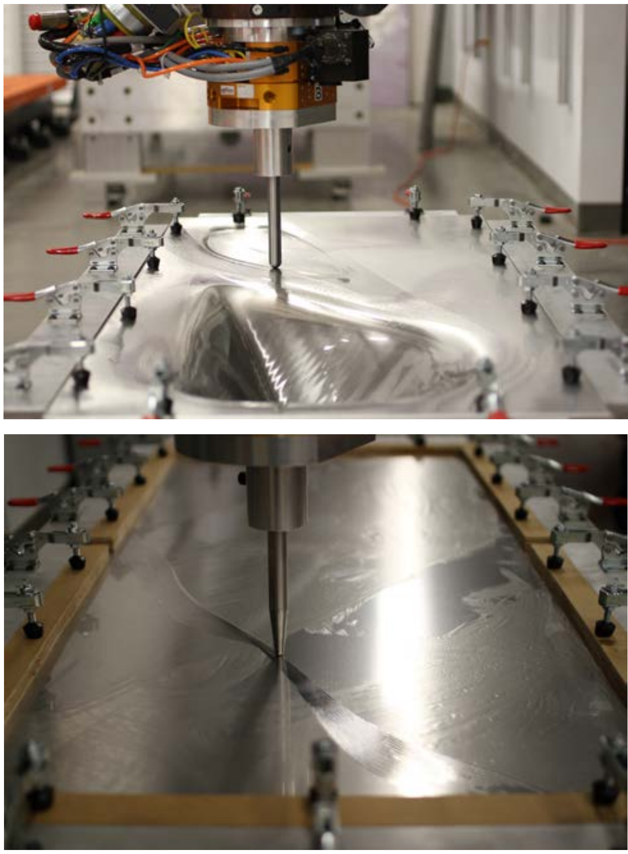


Fig. 20-21 Robotic forming and engraving process detail

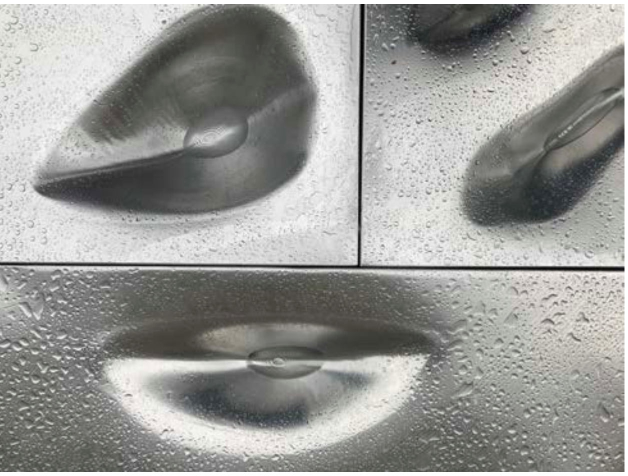


Fig. 22 Tact(AL) installation at Carnegie Mellon University
Fig. 23 Tact(AL) installation panel detail

Tact(AL) CARNEGIE MELLON INSTALLATION SPRING 2017

The second offering of the sponsored course, Fabricating Customization, culminated with the installation of Tact(AL) a student designed and fabricated aluminum panel wall system that illustrated the affordances of the techniques explored by students over the preceeding industry-academy partnerships. The installation served as a physical demonstration that was subsequently shared with the leadership team at Centria. Following the installation at Carnegie Mellon and the subsequent Autodesk sponsored workshop at the Autodesk Build Space, a portion of the wall was included in the show, BuildingForward at the Boston Society of Architects.

Rick Rundell, technology and innovation strategist and senior director at Autodesk describes the show:

"BUILDing Forward offers a glimpse into the future of building through the experiences of the Autodesk BUILD Space research, project, and startup teams as they design, build, and test prototypes. We are pleased to partner with the BSA Foundation to share this vision of the future of the built world around us."

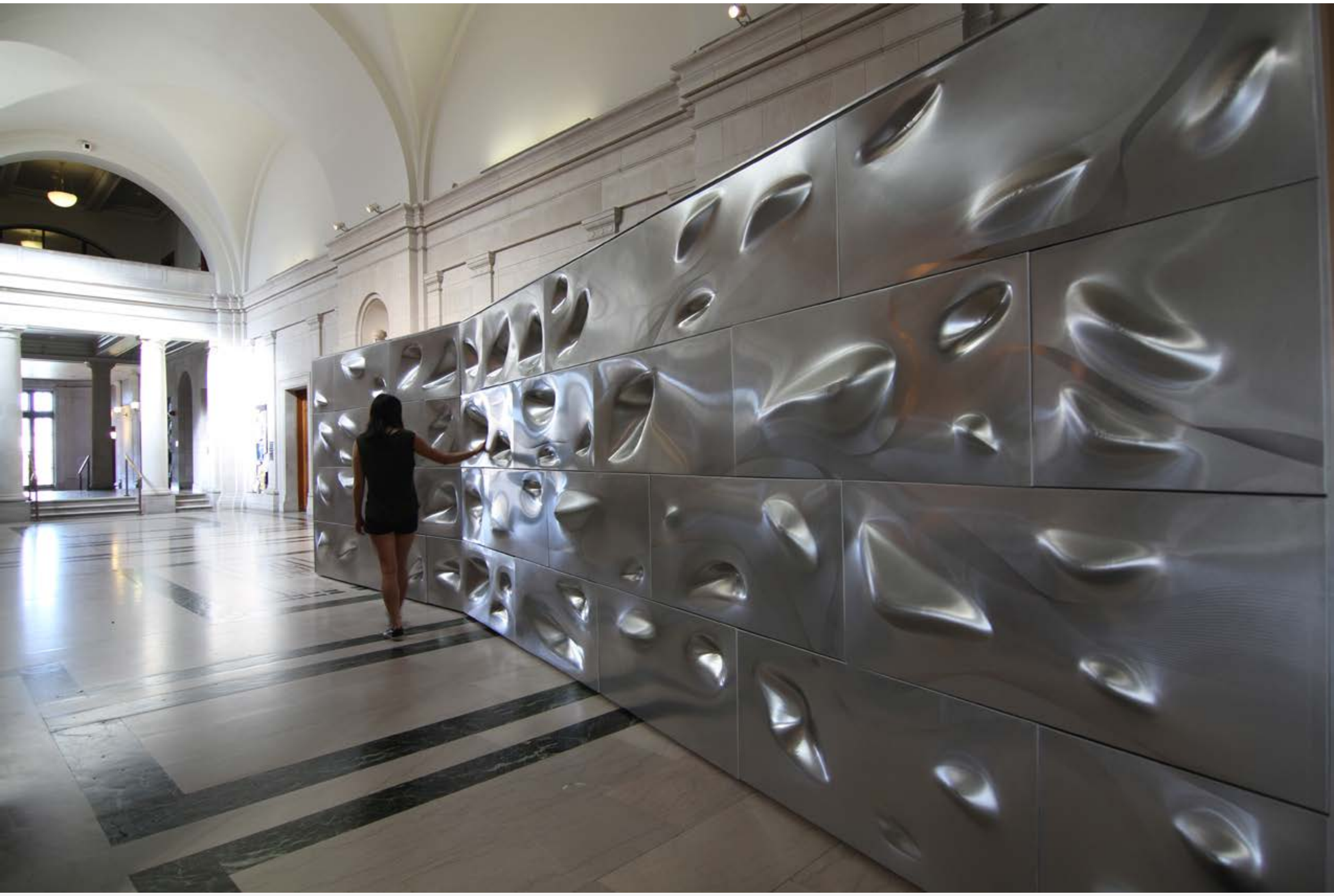
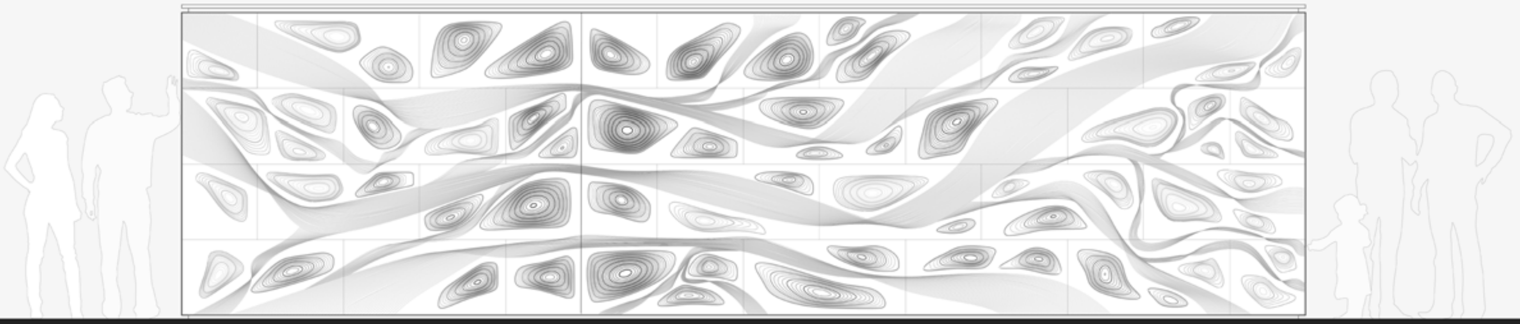
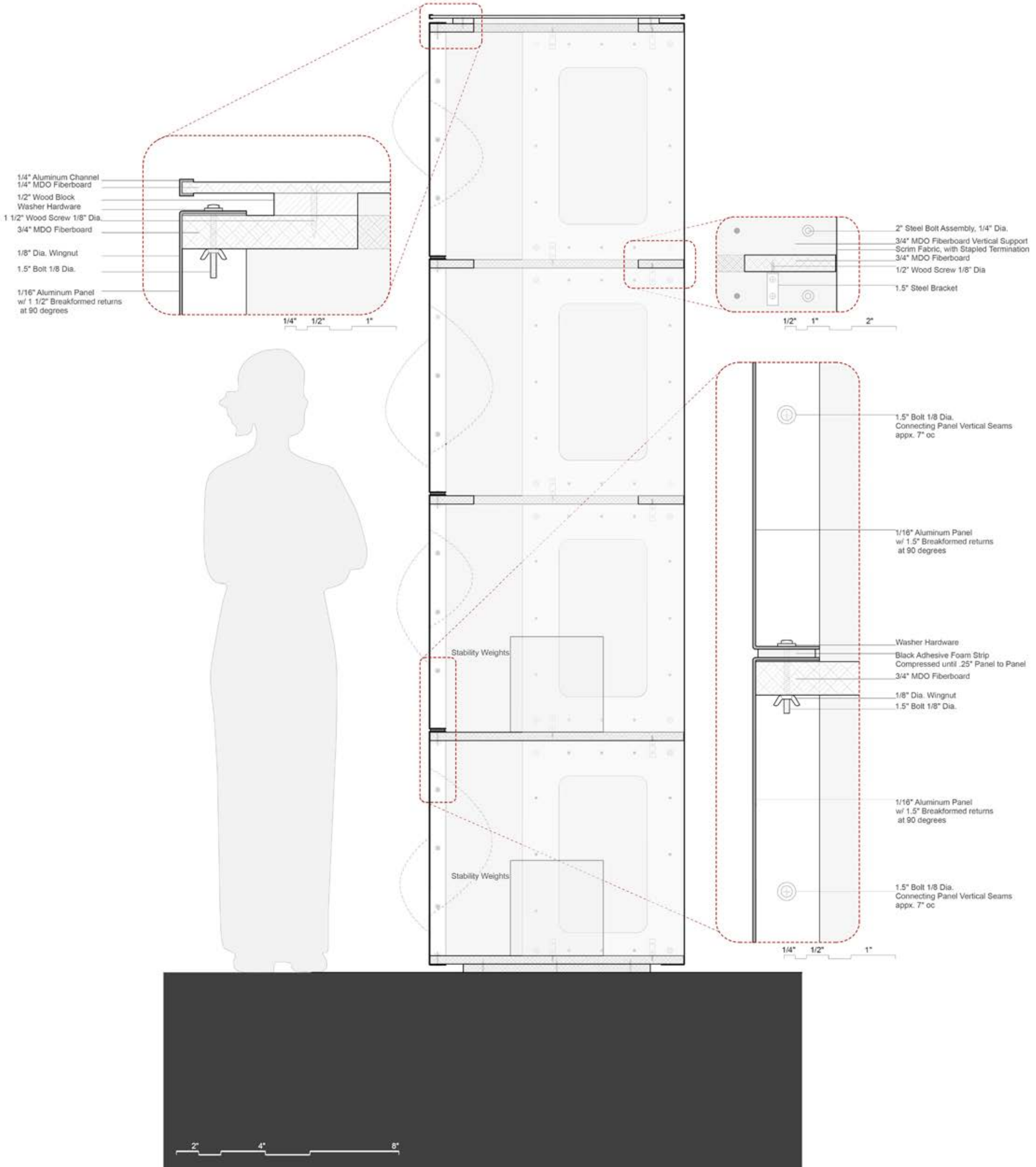
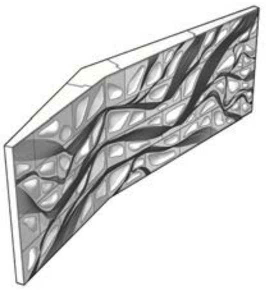
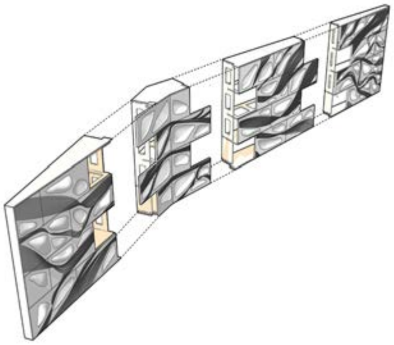


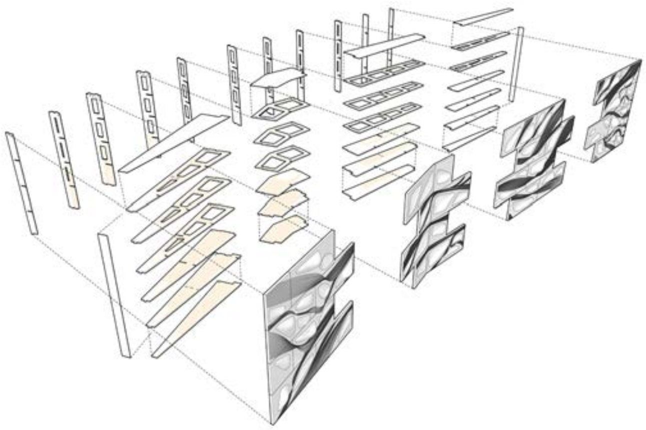
Fig. 24 Tact(AL) installation at Carnegie Mellon University
Fig. 25 Tact(AL) installation engraving and forming curves




1/4" Aluminum Channel
1/4" MDO Fiberboard
1/2" Wood Block
Washer Hardware
1 1/2" Wood Screw 1/8" Dia.
3/4" MDO Fiberboard
1/8" Dia. Wingnut
1.5" Bolt 1/8 Dia.
1/16" Aluminum Panel
w/ 1 1/2" Breakformed returns
at 90 degrees
1/4"
1/2"
1"
2" Steel Bolt Assembly, 1/4" Dia.
3/4" MDO Fiberboard Vertical Support
Scrim Fabric, with Stapled Termination
3/4" MDO Fiberboard
1/2" Wood Screw 1/8" Dia
1.5" Steel Bracket
1/2"
1"
2"
1.5" Bolt 1/8 Dia.
Connecting Panel Vertical Seams
appx. 7" oc
1/16" Aluminum Panel
w/ 1.5" Breakformed returns
at 90 degrees
Washer Hardware
Black Adhesive Foam Strip
Compressed until .25" Panel to Panel
3/4" MDO Fiberboard
1/8" Dia. Wingnut
1.5" Bolt 1/8" Dia.
1/16" Aluminum Panel
w/ 1.5" Breakformed returns
at 90 degrees
1.5" Bolt 1/8 Dia.
Connecting Panel Vertical Seams
appx. 7" oc
1/4"
1/2"
1"
Stability Weights
Stability Weights
2"
4"
8"







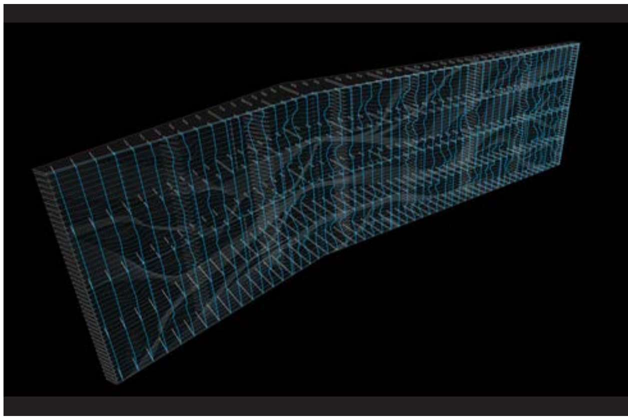


Fig. 26-28 Tact(AL) installation modularized assembly details

Fig. 29 U-shape channel between panels. It adds rigidity and absorbs deformations due to the strech of the material.

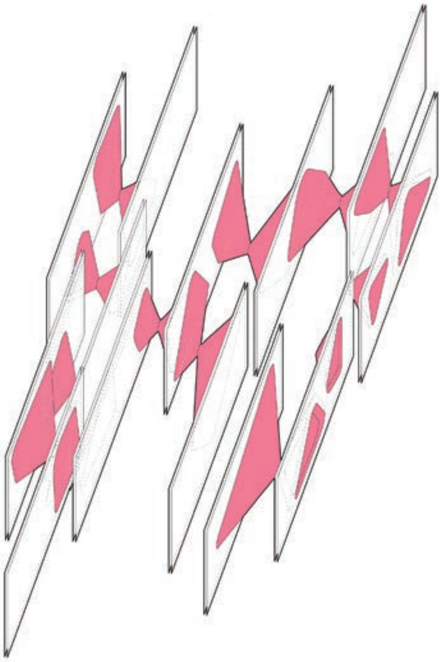


Fig. 30 Parallel view of the robotically incremented metal forming ceiling installed at Autodesk BUILD Space, Boston.

INCREMENTAL FORMING WORKSHOP AUTODESK BUILD SPACE SUMMER 2017

Autodesk generously sponsored and hosted an Incremental Forming Workshop for 2.5 weeks over the summer of 2017 at their recently opened Building, Innovation, Learning and Design (BUILD) Space located along Boston's revitalizing eastern harbor front. Autodesk's unique industrial workshop and innovation studio 'focus on the future of making things in the built environment – the places we live in, the buildings we work in, and the infrastructure we rely so heavily upon.' This facility provided participants access to world-class fabrication equipment, including industrial robotic arms and a design studio that served as our temporary home. The workshop provided participants an opportunity to interact with a community of future oriented designers, researchers, fabricators and software developers working in the architecture, design and engineering communities.

The workshop was co-led with Manuel Rodriquez Ladron de Guevara, a graduate student under advisment of Ficca at the time.

Excerpt from workshop brief

Our design process relies upon methods of representation such as drawing, modeling, and simulation to develop the 'project' through the lens of various design techniques. These abstractions each present particular methods to understand and communicate the project. Our work is rarely centered on the product itself, but rather upon the instructions and documentation of the desired intent. The techniques we utilize typically don't tell the whole story and occasional present unachievable fictions. The translation of these abstract notations of the project into the tactile, built realm affords unique opportunities to leverage and respond to the unanticipated behaviors of materials and processes. Less a process of validation than provocation, it is here in which "the designer must recognize that there is a fundamental difference between what they made through drawing and what the drawing made, and how there is a world of difference in-between."

As we have seen now for over a decade, digital fabrication techniques have ushered in not only novel methodologies of making and modes of translation, but also reinvigorated languages of form and geometry largely abandoned through modernist methods of mass production. While the promise of mass-customized manufacturing has yet to be widely realized, the techniques of bespoke and nimble fabrication are increasingly deployed at small scale.

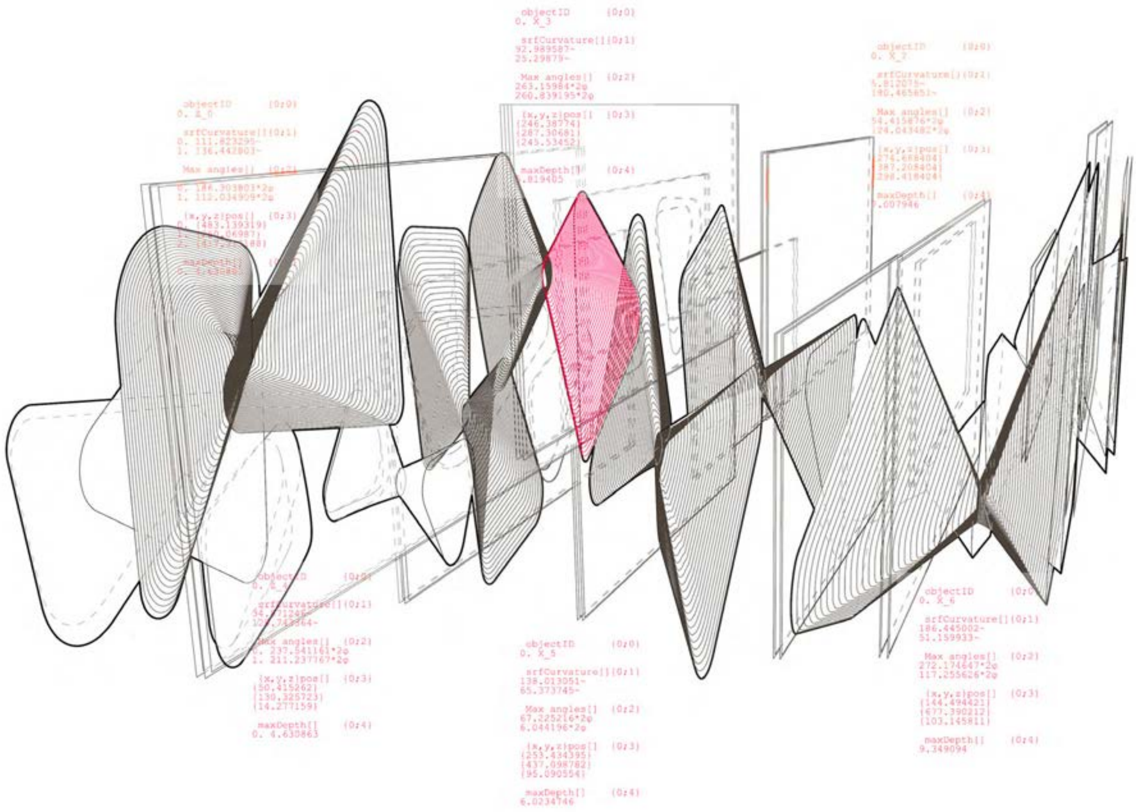


Fig. 31 Composition of the assembly of the pieces. Each pair correspond to different tested angles to ensure the maximum separation at strategic areas responding to the context of the room it was hung.

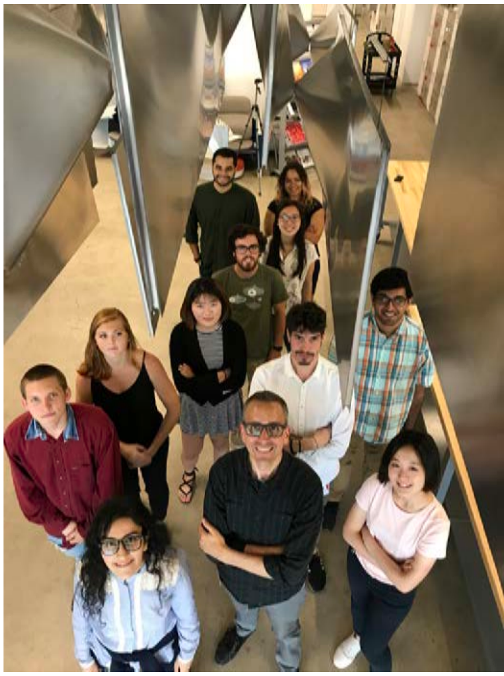


Fig. 32 Workshop team below final ceiling

Fabricating Customization F2015

Participating Students:
Scott Holmes
Cy Kim
Yaakov Lyubetsky
Kirk Newton
Matt Porter
Daniel Russo

Fabricating Customization F2016

Participating Students:
Marnfah Kanjanavanit
Joselyn Macdonald
Anthony Nitche
Dyani Robarge
Rachel Sung

Autodesk Build Space Workshop

Workshop Leaders:
Jeremy Ficca
Manuel Rodriguez Ladron de Guevara

Participating Students:
Meghan Chin
Jack Fogel
Erin Fuller
Zain Islam-Hasmi
Min Young Jeong
Zhuoying Lin
Atefeh Mahdari
Ryan Smith
Nitesh Sridhar
Annabelle Swain