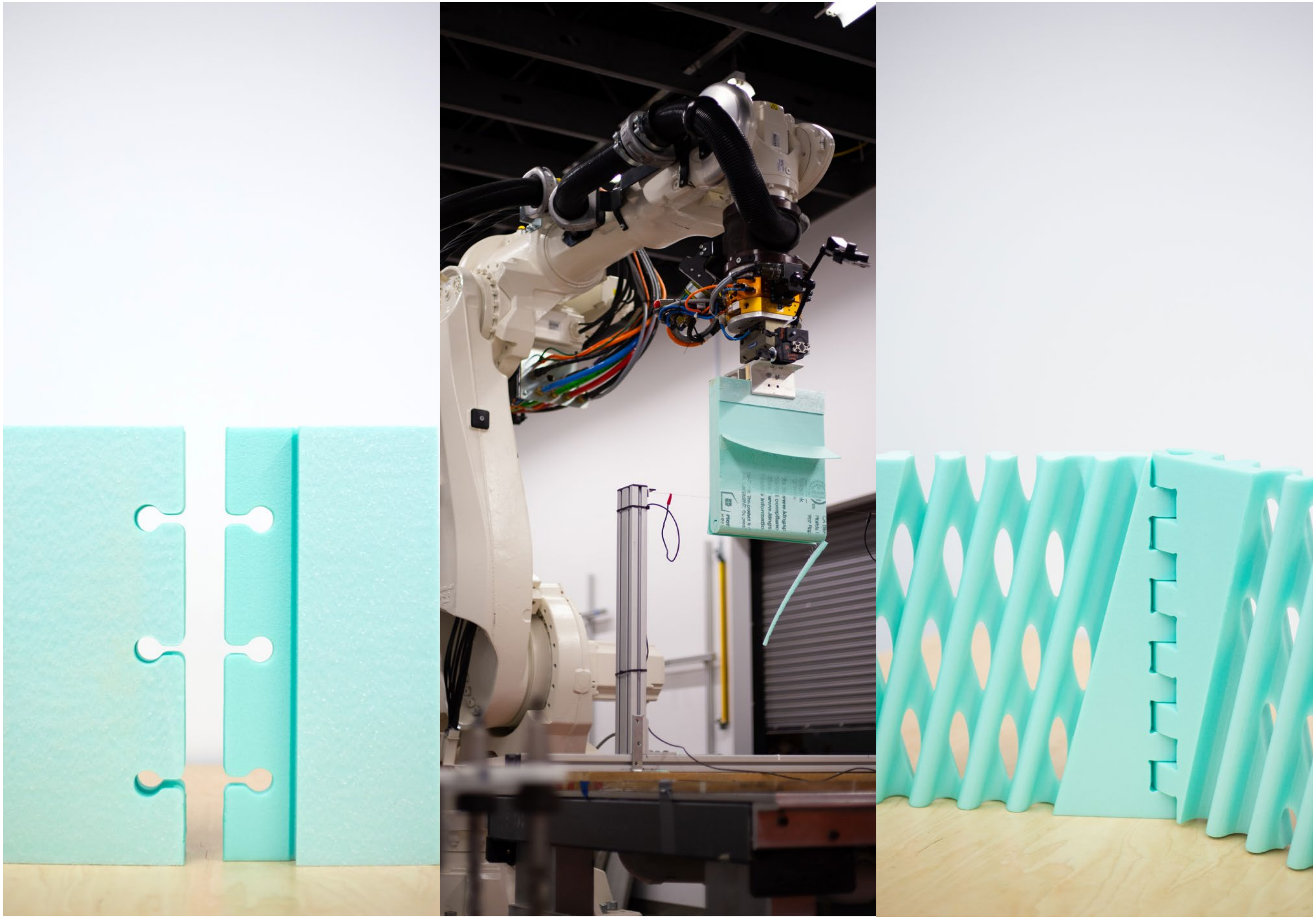


Robotically Manufactured Interlocking Modules

Jihoon Park & David Perry

Project Statement

Our goal in this project is to create a hot wire cutting workflow for generating unique, modular elements that will fit together into a larger structure via complex, robot fabricated joinery. There is a lot of precedent for hot wire cut geometries created with robots. Our project hopes to build on this prior work, but focus on creating modular elements that can fit together to create an emergent larger form. Generating these pieces will require cutting on all sides of a foam block which will take advantage of the 6 DOF of the robot arm. This project was conceived as a material study – as such the project applications and implications will emerge as we work.

This project will be divided into three parts – each part will change in scale depending on time. First we will do introductory studies: calibrating our designs with kerf, developing basic, but necessary, workflows for cutting in various orientations, and more. Second we will move onto creating complex joinery — we'll explore how to take full advantage of the robot's 6 degrees of freedom through the design of joinery. Finally we will move to designing fully modular, robot manufactured elements that can be easily constructed into some larger form.Other than foam block this project will use pre-existing tools and materials in the lab.

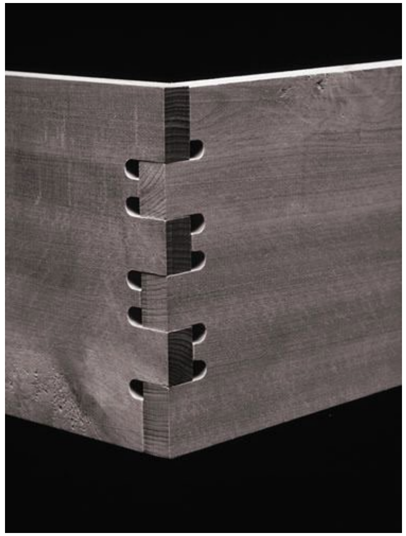

RolandSnooks, RMIT Architectural Robotics Lab, 2013

Precedent

The level of precision that comes from attention to detail and craftsmanship is considered one of the most important qualities that make fine joinery. Meanwhile, precision maybe an architectural robotics' biggest strength. However, if a craftsman's joinery were to be identically reproduced through the robotic workflow, it would not have the same ethos as its original. Which perhaps is why there seems to be a void in researching traditional joinery using the robotic arm. However, once we embrace the fact that though we may not reproduce the soul of a craft, we open our options to taking a different tectonic approach focusing on the morphology of the joinery system that carries a sense of digital poetics.

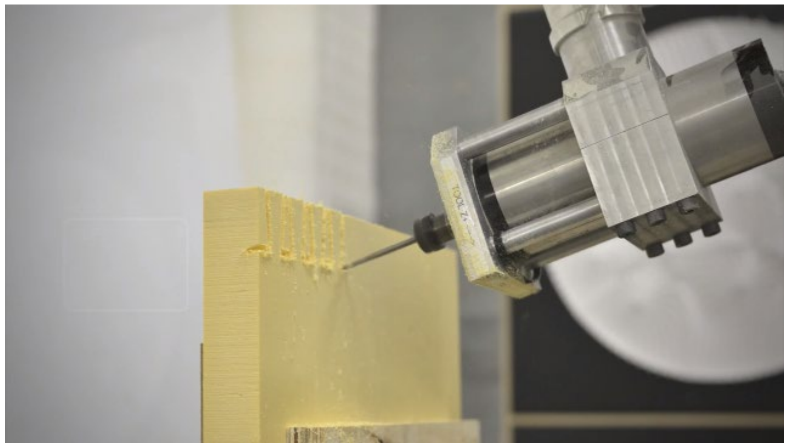
Previously, much has been explored in an effort to create a simple joinery system by CNC milling. for most cases, it's inherent two-dimensionality and the disability to create straight corners has given birth to a punctured joint finish. Although highly precise, it still seems to present limitations in complex 3 dimentionally varying joints. This is an opportunity for a 6-axis robot which is explored in Mitchell Page's research. His robotic dovetail fabrication done in the University of Sydney utilizes software plugin 'Dove' to generate milling paths for dovetails that require an angled joint. The robot's ability to cut at varying angles and orientations allow complex fabrication in a short amount of time.

There still are challenges untouched by these precedents that could be solvable with hotwire cutting. The issue of sharp corners and complex curvature may be resolvable if we build upon these researches, and thus introduce a new tool-driven aesthetic.



left: Jochen Gros, Friedrich Sulzer, Hochschule für Gestaltung Offenbach Research Lab

below: Mitchell Page, University of Sydney Robotic Dovetail Fabrication, 2017

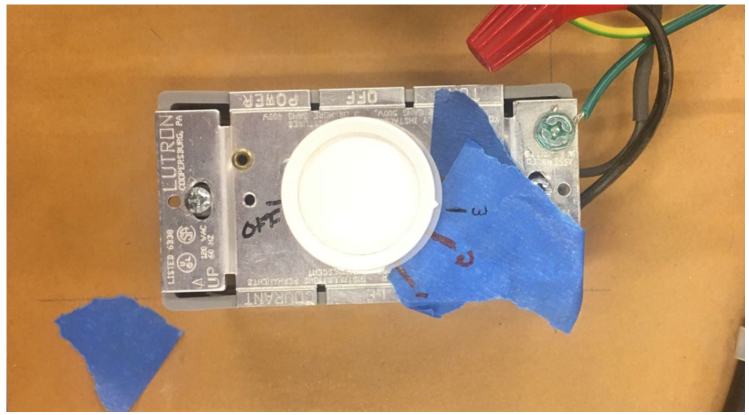


Calibration

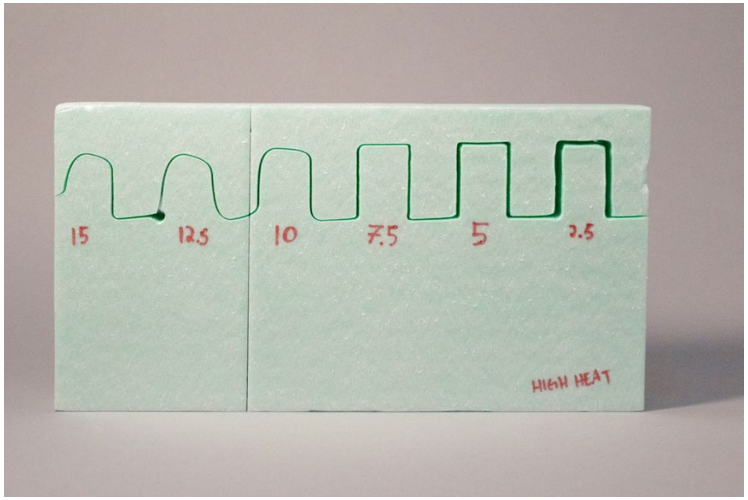
In order to create precise and well fitting joinery we had to calibrate our cutting paths with the geometry of the hotwire cutter kirf. To calibrate we tested the hotwire cutter at various parameters which are:

speed
temperatures
tension on hotwire.

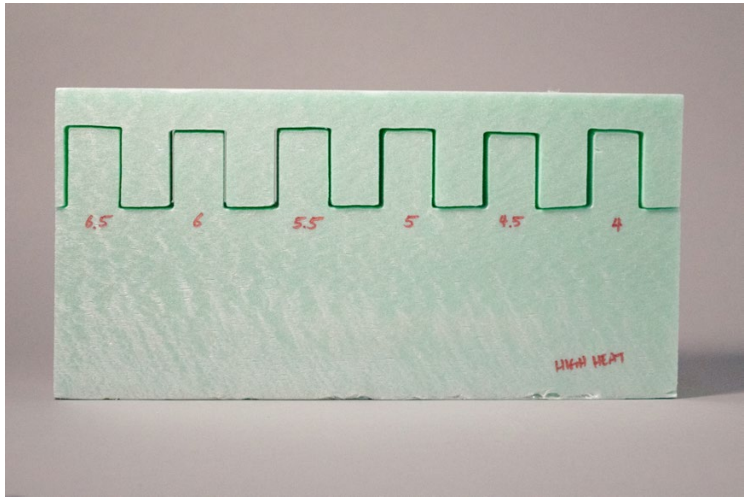
Varying these factors, we were able to find the most relatively consistent and accurate speed and temperature. In our experiments we found that using a relatively low temperature, marked in the photo below, and running at about 3mm/s gave some of the best results. The kerf of the hotwire cutter at this speed was 0.5461 mm. In order to compensate for this geometry we will have to offset all future curves by this value.



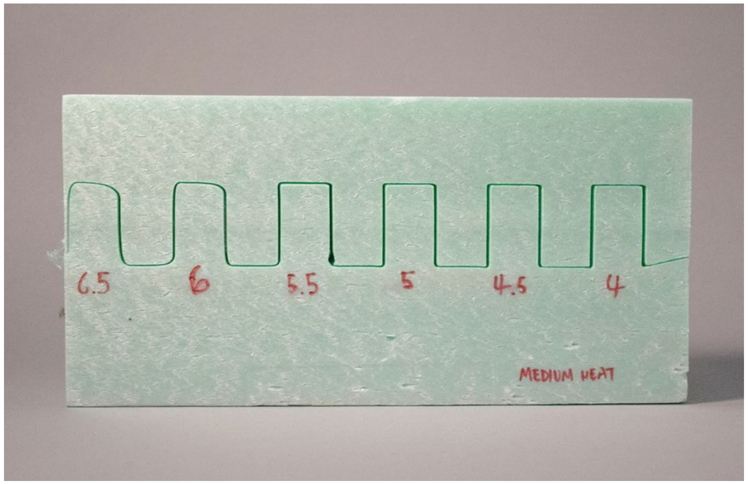
Calibration cont’



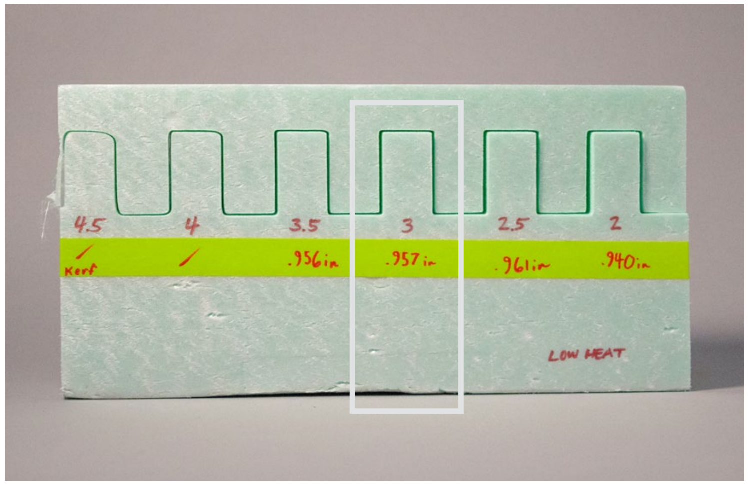
High heat, speeds 2.5 - 15.0



High heat, speeds 4.0 - 6.5



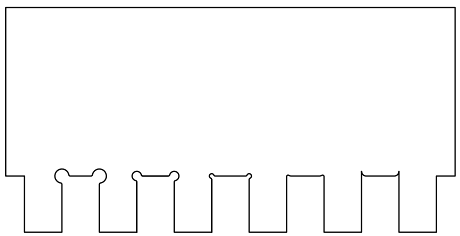
Medium heat, speeds 4.0 - 6.5

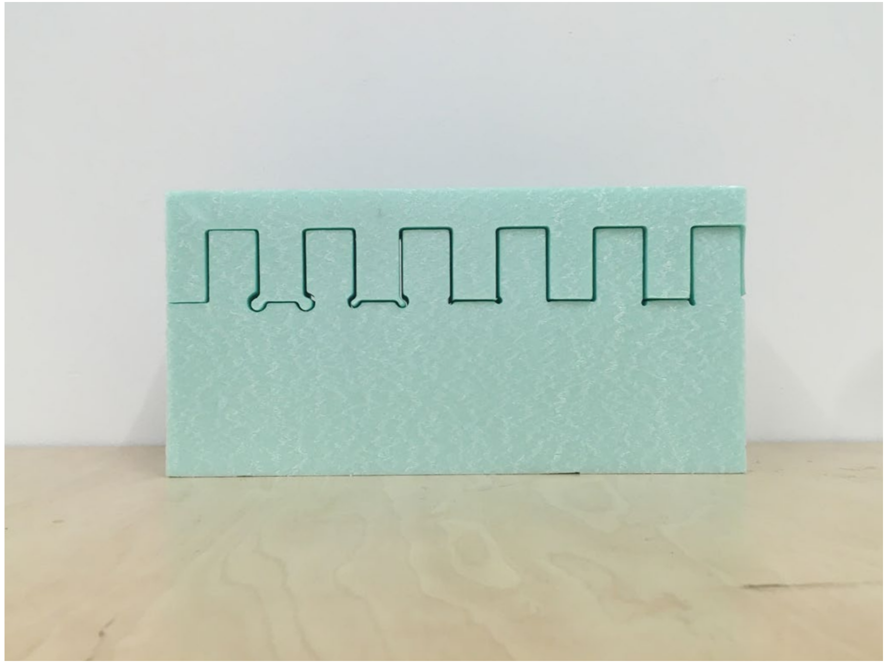


Low heat, speeds 2.0 - 4.5

Turning the corner

Cutting sharp angles is another challenge in Robotic hotwire cutting because factors such as zoning and wire tension prevent the wire from precisely touching the corner. This corner test was done with ears with various radius to find out what would be the optimal distance the wire had to cut past the corner while still keeping the maximum surface area of contact for the joints.



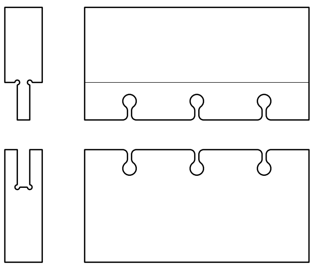


Multi-directional cut

As an initial test to create pieces for an end to end joinery, a simple mortise-and-tenon joint was incorporated with dowel joints that will reinforce the locking mechanism to a simple friction joint system. This workflow required cutting in two directions, one of the short edge and one on the long edge, combined with one pick-and-place operation.

This test uncovered a few more challenges that comes with robotic hotwire cutting. First of all, we had to restructure the path offset script to address the different orientations of the paths. Then, the level of precision regarding the hotwire location and vector relative to the robot target had to be refined in order to locate the joints precisely as modeled. Third, a secondary and tertiary safe location had to be input in between cuts to reassure that the block does not cross the hotwire while reorienting.

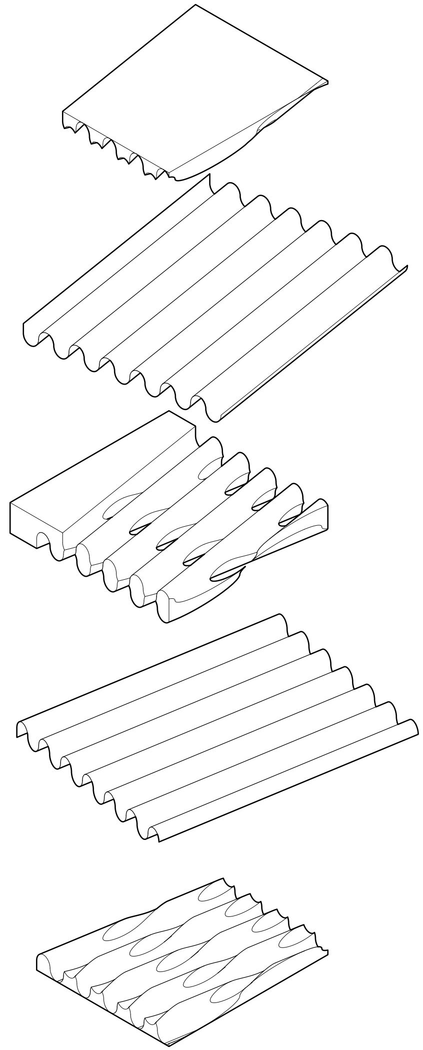
Through a series of these tests, we were able to refine HAL and RobotStudio scripts into a more robust definition that will allow more complex cutting.



Multi-directional cut cont’

The same workflow was applied to cutting larger surfaces on both sides of the block to experiment with forms that can yield a degree of structural integrity along with aesthetics, weight, and porosity.

By transposing a sine wave-cut pattern on two sides with different orientations, we were able to create a complex waffle geometry that starts to test the abilities of robotic hotwire cutting that cannot be shared with other digital fabrication techniques.

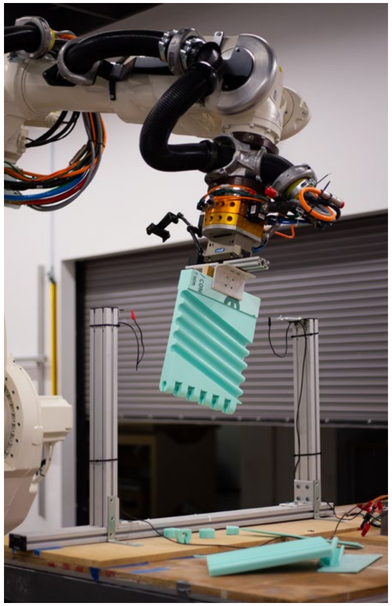


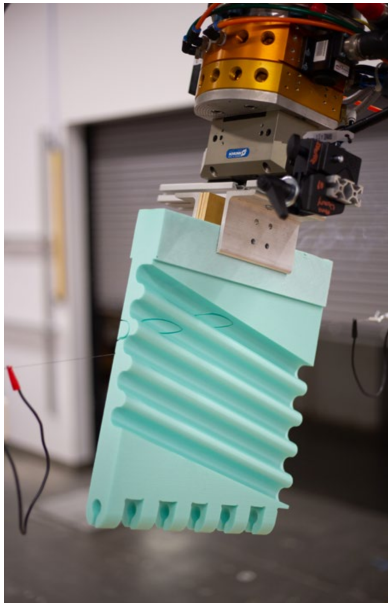
Joinery and Lattice Combined

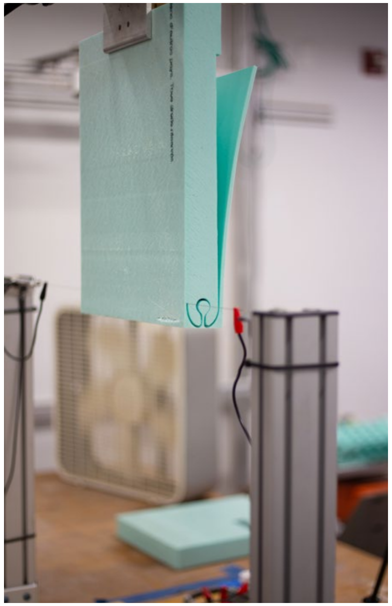
As a final demonstration of the cababilities of our manufacturing technique we cut a set of foam blocks with both the waffle geometry and finger joints to interlock at the edges. The joinery was additionally unique in that it was designed to allow rotation, similar to a hinge.

It was in this workflow that we really to see the emergence of a reasonable amount of error. This started when we realized the hot wire cutting cable had lost tension over time. The second point of error, which we had predicted, emerged from how the robot was holding the block. We midigated these errors by both tightening the hotwire bettween each run as well as cutting the block to a standard size once on the gripper.

An additional point of error that we hadn't considered was the fact that the waffle cut drastically changed the elastic properties of the overall material. With the complex cuts on just one side, the block became much more springy and likely to bend under load. All of this resulted in non - negligeable bending of the block when the hotwire was being passed through it. When cutting the lattice we observed significant error in the cutting path. This error could be mitigated by finding ways to support the foam as it's cut in these complex ways, or by reducing speed even more so that the force applied to the foam stock is further reduced.

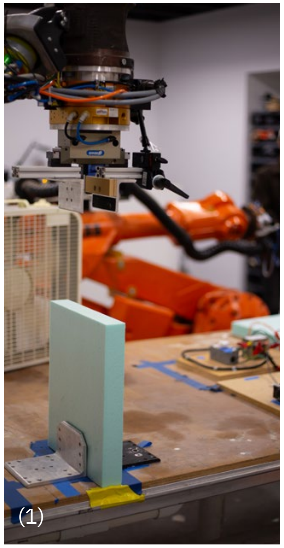






Joinery and Lattice Combined cont’

The cutting process started with a basic pick workflow, then the robot proceded to cut the hinge, fingers, and then lastly the waffle geometry.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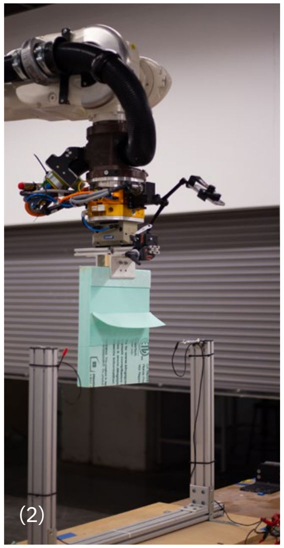
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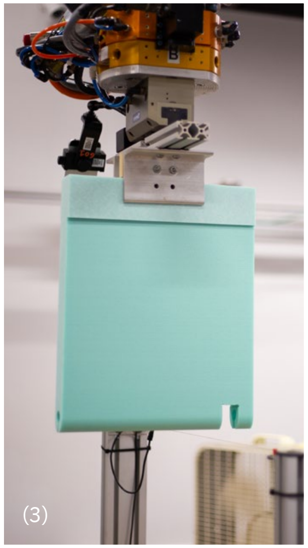
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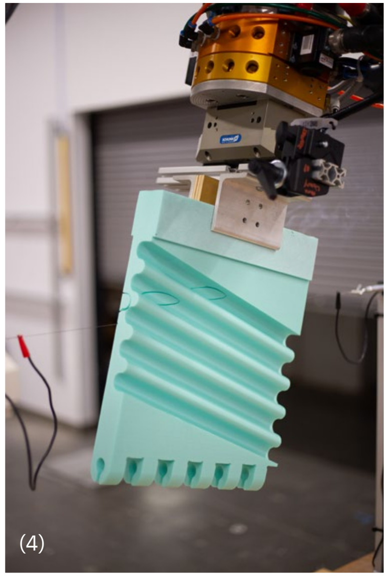
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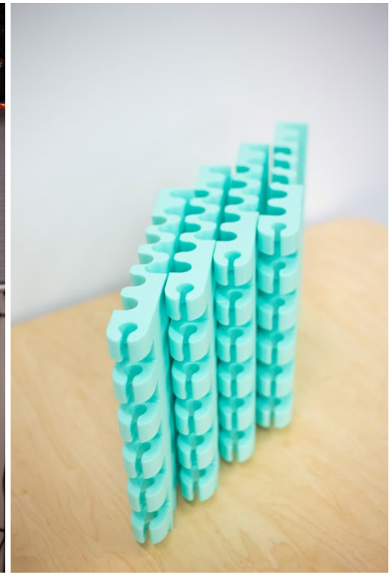

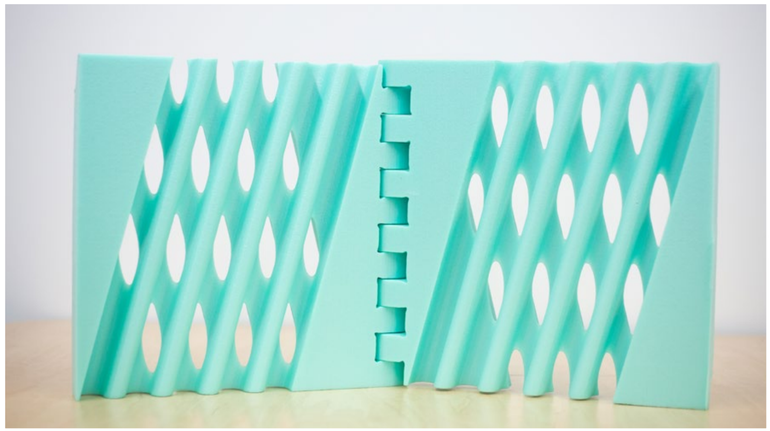

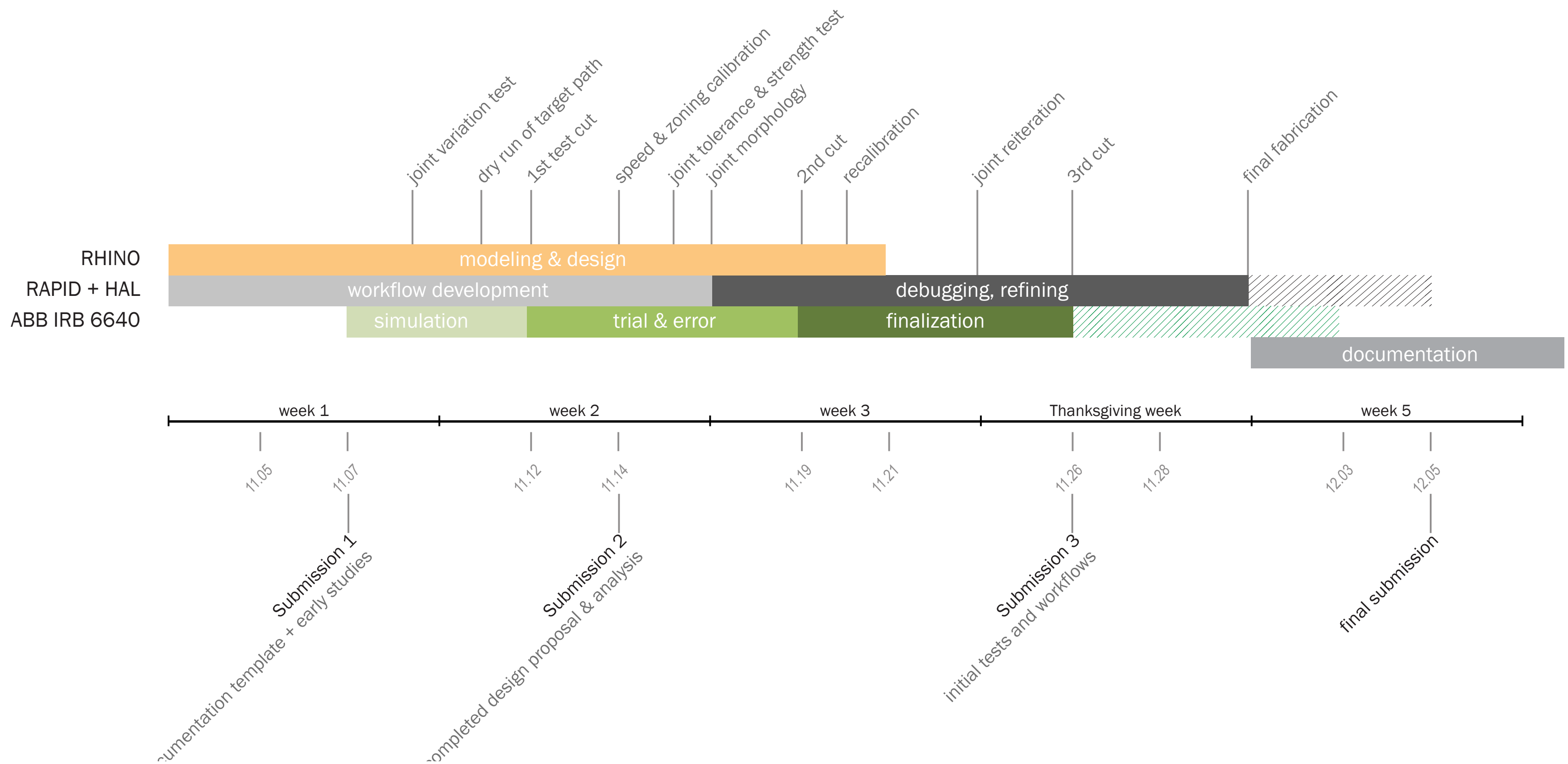
joint variation test
dry run of target path
1st test cut
speed & zoning calibration
joint tolerance & strength test
joint morphology
2nd cut
recalibration
joint reiteration
3rd cut
final fabrication
RHINO
RAPID + HAL
ABB IRB 6640
modeling & design
workflow development
debugging, refining
simulation
trial & error
finalization
documentation
week 1
week 2
week 3
Thanksgiving week
week 5
11.05
11.07
11.12
11.14
11.19
11.21
11.26
11.28
12.03
12.05
Submission 1
umentation template + early studies
Submission 2
ompleted design proposal & analysis
Submission 3
initial tests and workflows
final submission

References

Japanese joinery
https://imgur.com/r/mechanical_gifs/Q98Aj
https://cmu.primo.exlibrisgroup.com/permalink/01CMU_INST/19i49l9/alma991004380609704436
https://cmu.primo.exlibrisgroup.com/discovery/fulldisplay?vid=01CMU_INST:01CMU&search_scope=MyInst_and_CI&tab=Everything&docid=alma991008300519704436&context=L&virtualBrowse=true

CNC Joinery
https://www.youtube.com/watch?v=mSxCIMVJXOA

Wire cutting
https://jordanberta.com/Spatial-Wire-Cutting
https://www.youtube.com/watch?v=_qv9LUX3mTg
https://www.youtube.com/watch?v=cIrXC4uE2ko
https://www.youtube.com/watch?v=LmWePxTlWRw