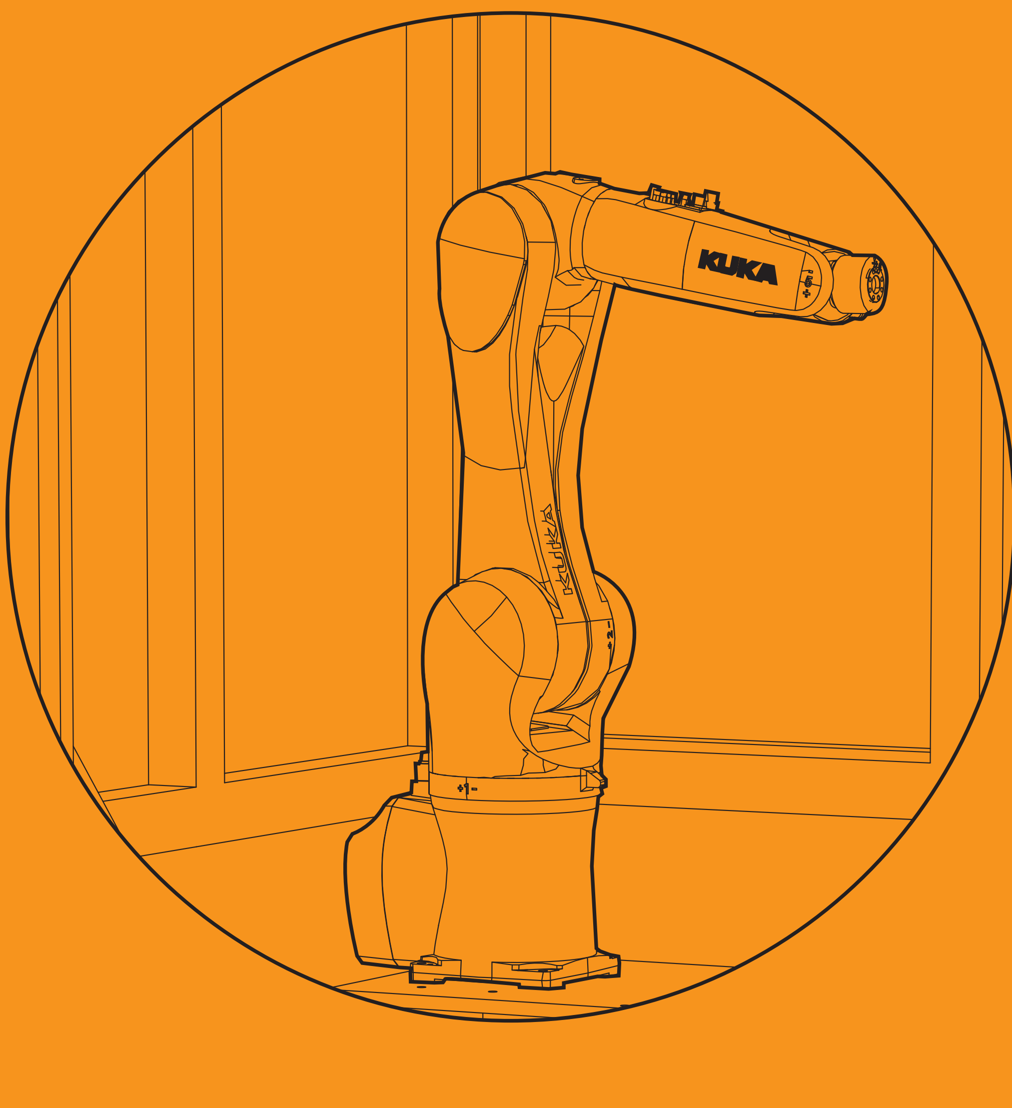
INTRO TO ARCHITECTURAL ROBOTICS



Myles Sampson

INTRO TO ARCHITECTURAL ROBOTICS

MIT Architecture

Abstract
The Robotic Arm is a common tool for automotive and engineering practices. However, the endless opportunities for architectural applications make it an up-and-coming tool for architects and designers. Understanding the fundamentals of robotic programming is key to unlocking the potential applications of robotics in architecture and design. This workshop is an introduction to the MIT Department of Architecture robotic arm. We will explore architectural robotics through the Shape Grammar formalism, a rule-based design schema.

The primary objective is to use robotic manipulators to perform the same tasks that designers execute physically by hand. The workshop utilizes a three-step process to achieve a thorough process to architectural robotics. Step 1 includes physical execution of the design and documentation through the shape grammar formalism. Step 2 comprises robot execution of the design: students work through robotic path planning, robotic programming, and digital design. Step 3 consists of iterating, debugging, and refining the design for robotic manipulation. Through the workshop, students learn the necessary skills to execute their ideas on robotic manipulators.

Instructor
Myles Sampson

Advisor
Larry Sass
George Stiny

Students
Arthur Rodrigues
Carolyn Tam
Emma Jurczynski
Jin Gao
Natalie Pearl
Tim Cousin

Critics
Caitlin Mueller
John Ochensdorf
Diego Pinochet
Sandy Curth
Gil Sunshine
Zain Karsan

01

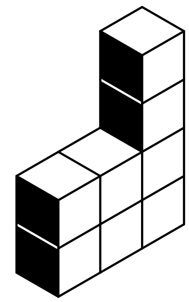
Background

George Stiny's *Kindergarten Grammars 1980* provide a solid foundation for the class's approach to design robotics. A constructive approach to languages of designs is proposed in the paper as a placeholder for future ideas around the vocabulary for constructive languages.

This placeholder extends the original ideas around architectural composition considered by George Stiny and his shape grammar formalism.

Overview

In a shape grammar, the construction of designs begins with a fixed initial shape that shape rules can be applied on a given vocabulary, typically a set of specified shapes or objects and spatial relations. Shape grammars may also contain combinations of shape rules. Using these rules, languages of designs are created. Rules assist in the creation of designs and open new directions for design with a give category. These rules can be arranged systematically using shape grammars and these rules shift the from individual designs to languages of designs which can be studied with ease.



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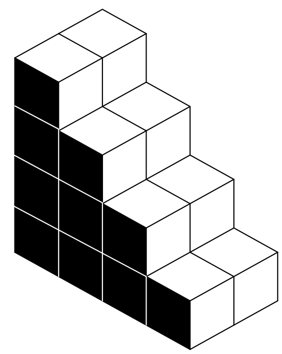

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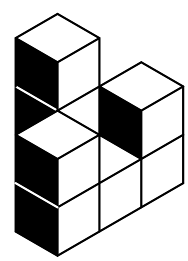

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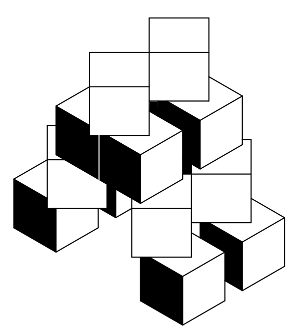

Arch

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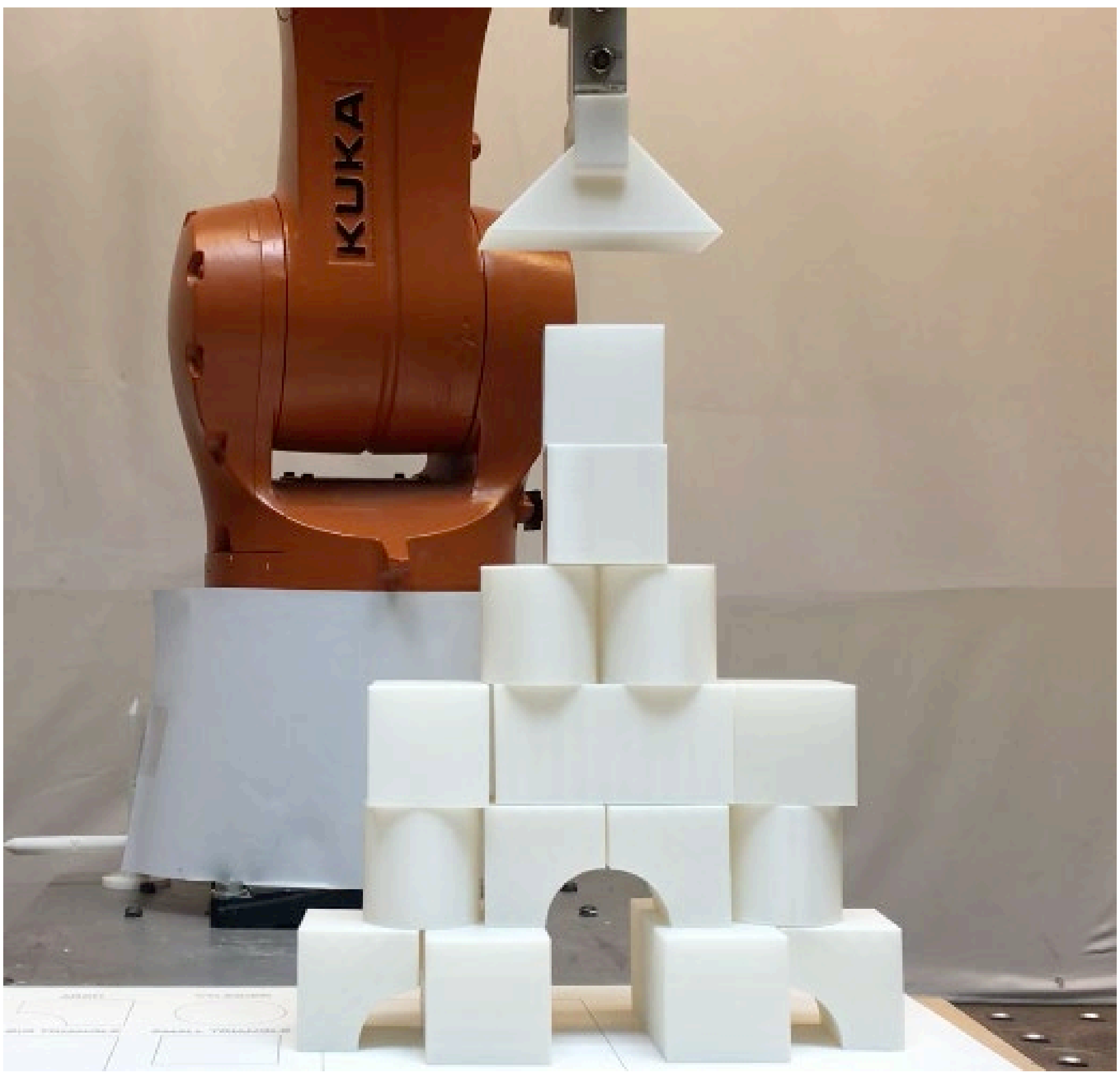
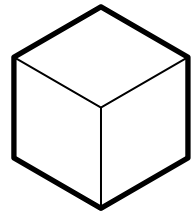
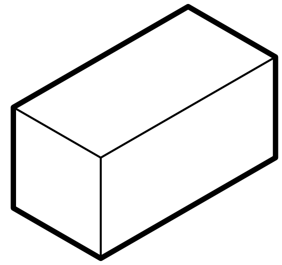




Gift 3

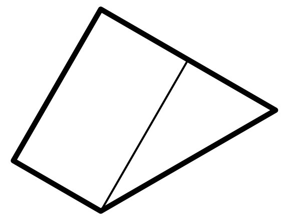


Gift 4

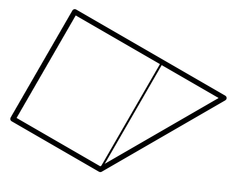
Frobel's Gifts

Child's play is central to architectual design, and Froebel's kindergarten method illustrates this exact quality. The Kindergarten method is based on series of geometrical gifts as a series of geometrical forms. The gifts are passed to the child in sequence as the child progresses through each gift. There are three categories that Frobel uses with each gif: forms of knowledge which involve logical and mathematical ideas; forms of life represent things seen in the outside world; and forms of beauty which can be described as ornament. Children are encouraged to play with each of the gifts in combination.

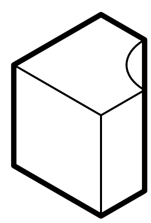
The nature of Froebel's categories of form, the child learns to solve his design problems with the gifts to discover the possibilities with them. This process is similar the processes a young designer experiences as they mature to a mastery of the discipline. Both cases leverage a vocabulary of construction elements to suggest new possibilities for young designers.



Gift 5



Gift 5



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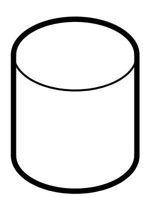


Cylinder

03

Assignment 1- Physical Design

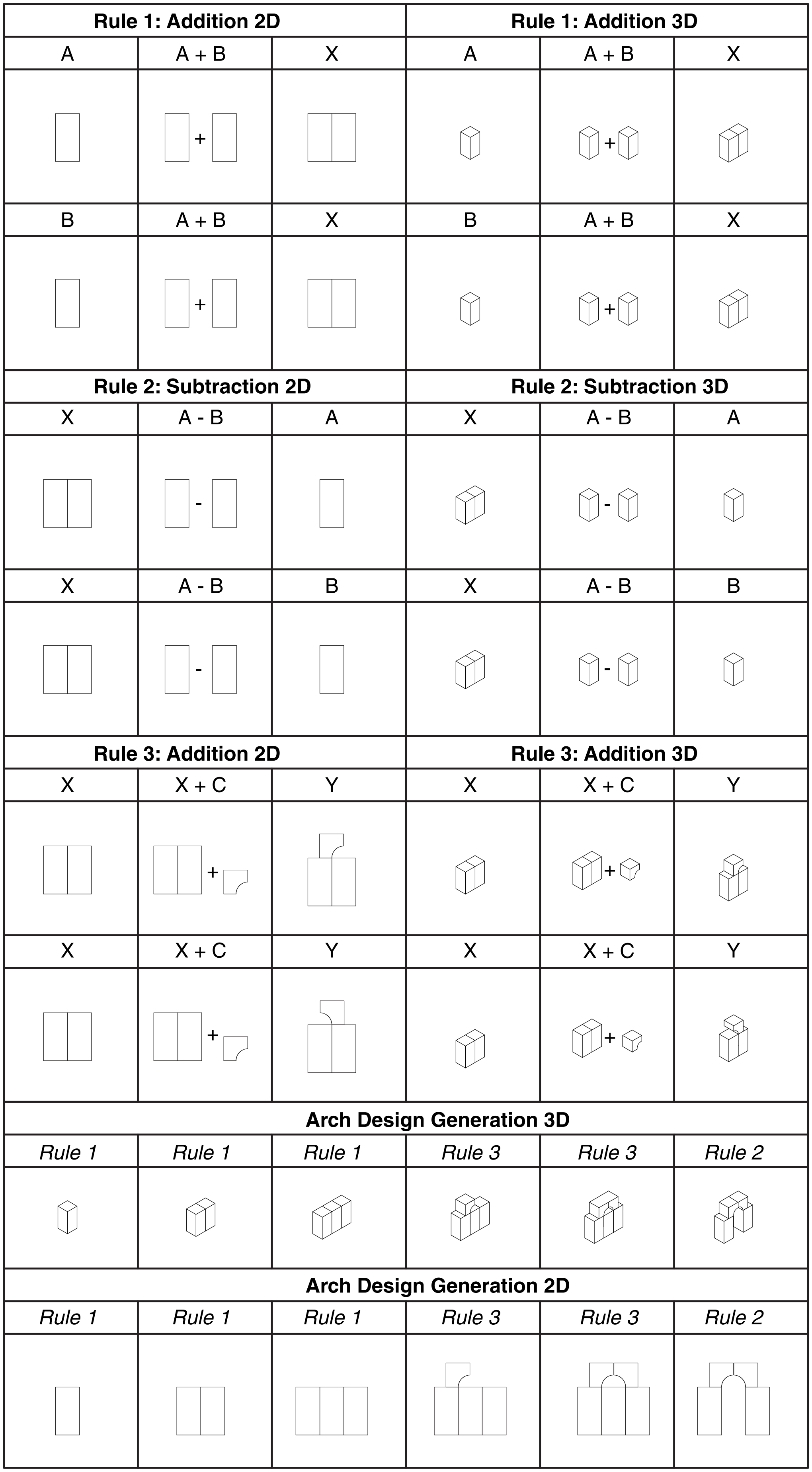
Each group will be given a set of 2 inch square blocks. As a group, write a set of rules to describe the physical construction of one of the following designs: church, armchair, staircase, arch.
Each group will be given a set of 2 inch square blocks. As a group claim one of the designs in the document below:

Come up with your own design, and repeat the process. Create a set of rules, and describe how these objects are assemebled using the rules you created.   Rules should illustrate the follwing actions: Input — Current State—Output. Present both your designs using a diagram.

Lastly, in Rhino begin setting a up simulation and workspace for the pick and place assembly operation. Start by modeling the components and determining a sequence of movements for the final configuration of the objects.

Learning Objectives

1. 3D Object Manipulation
2. Rule Based Design
3. Physical to Digital Workflow
4. Kuka Programming Language



Example Rule Diagram: How to Construct An Arch

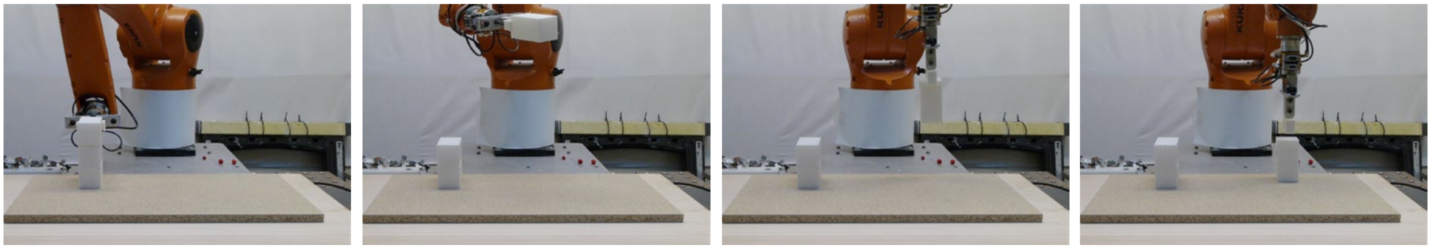
04

Assignment 2 - Robotics in Action

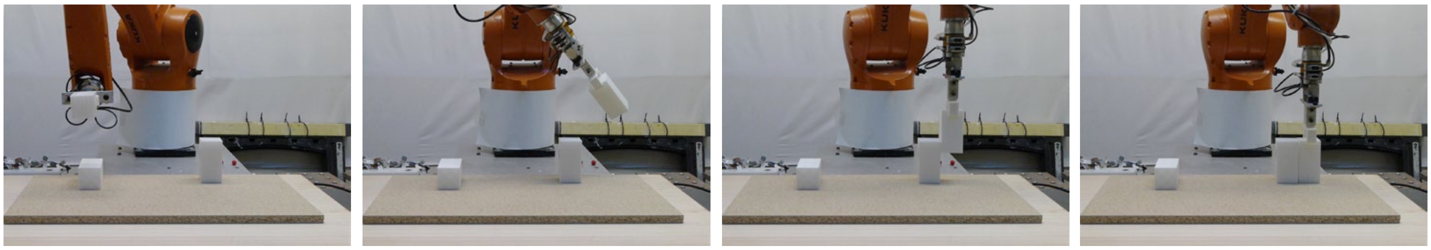
Use your design from your previous by hand iterations. Iteratively execute the design on the robotic arm. Document the successes and failures of each attempt. Photograph each attempt, and present these findings along with a minute long video of the objects final construction. In the video answer the following questions: What went wrong? What your expectations of the robotic execution? How did you overcome those obstacles?

Learning Objectives

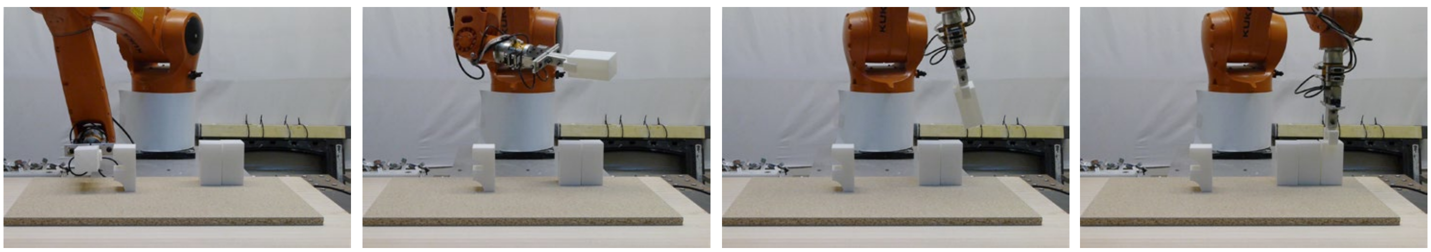
1. Base Calibration
2. Tool Calibration
3. Robotic Pick and Place
4. Spatial Poses (Rotating Planes)
5. Visual Computation
6. Kuka PRC
7. Basic Grasshopper Data Structures



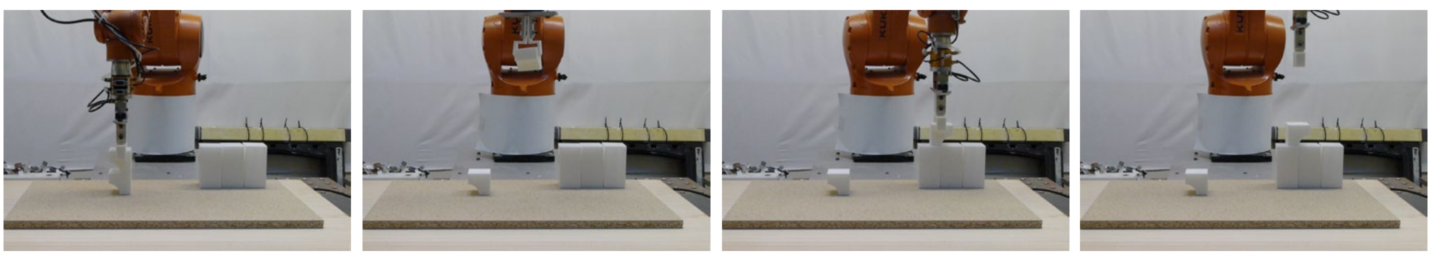
Rule 1



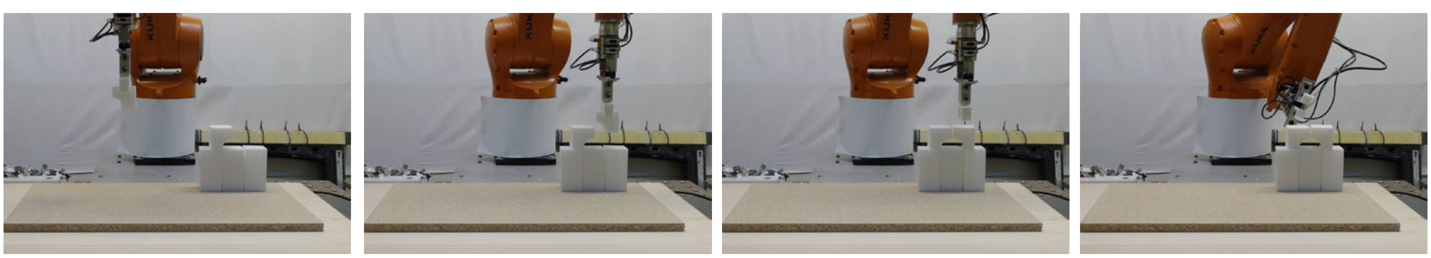
Rule 1



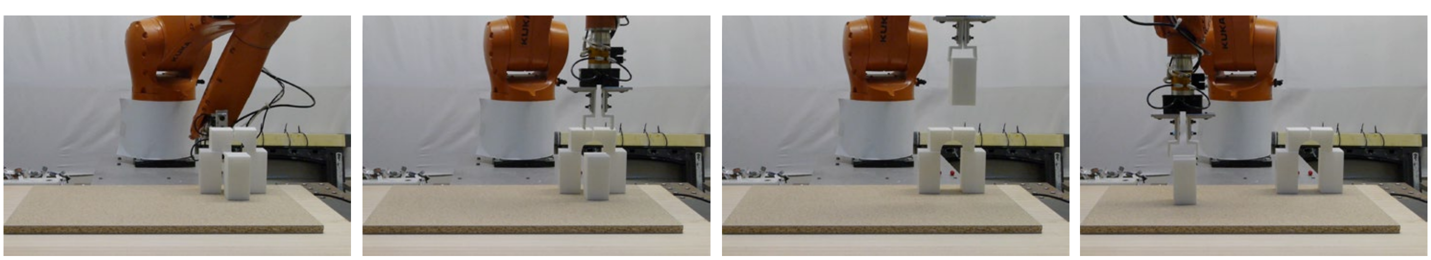
Rule 1



Rule 2



Rule 2



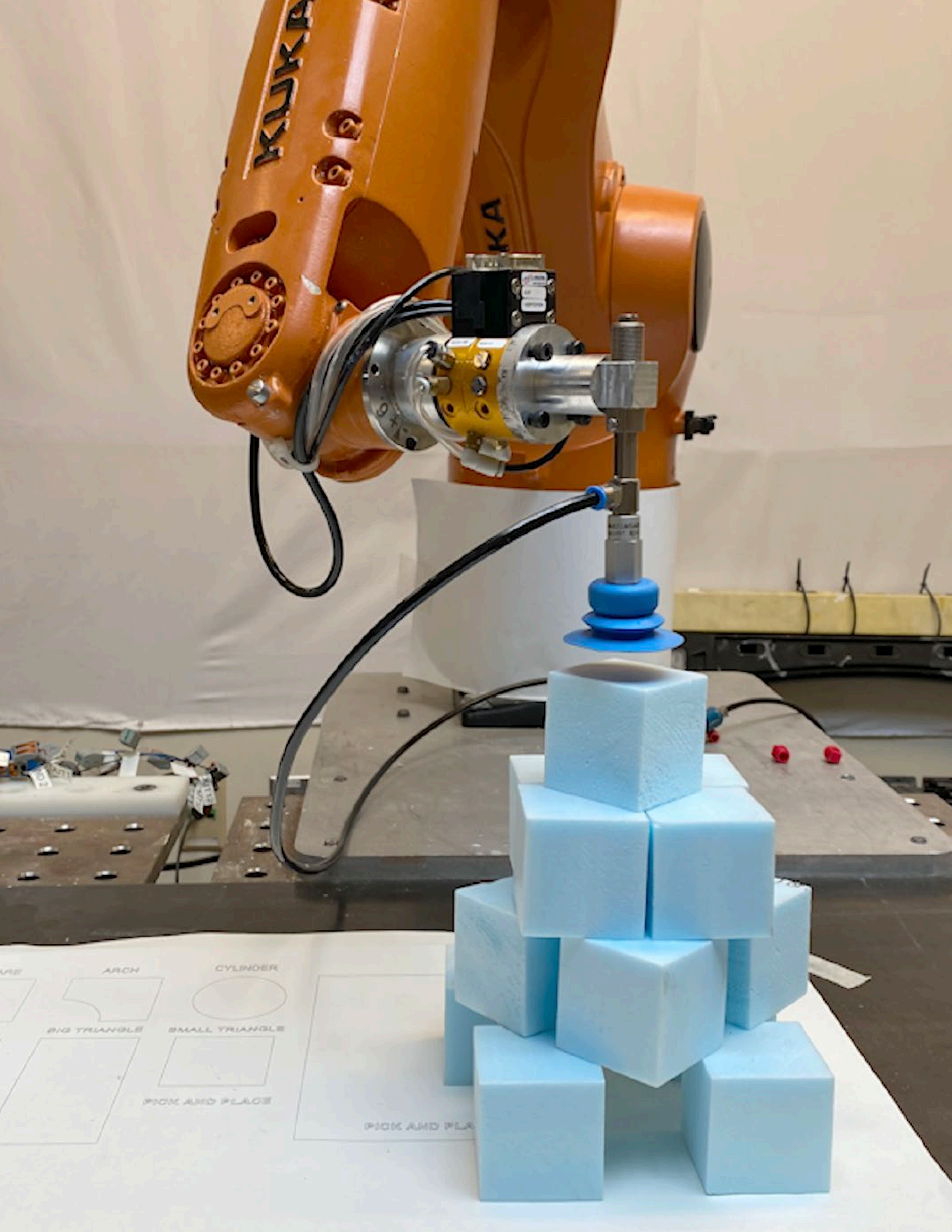
Rule 3

05

Tower of Power

This project examines discrete object stacking through a simplified tower design. The design employs three rules. Rule one sets up the initial spatial relationship between two cubes—the cubes must have parallel faces. Either they can contain a gap or operate with no spacing, containing surface faces that touch. Rule two adds another cube to the design by applying a rotation and stacking procedure to cubes in the scene from rule one. The rule calls for the cube to be placed directly on \another cube. Lastly, rule three applies a similar rotation and stacking maneuver on the series of cubes, but instead of the cube placed aligned and centered on one cube, the rule rotates and places a cube at the intersection of two parallel cubes. Through these simple rules, the student executes the design of a creative tower on the robot. With architecturally designed rules, the physical features of structurally sound design come naturally. The challenge, in fact, lies in the robotic assembly.

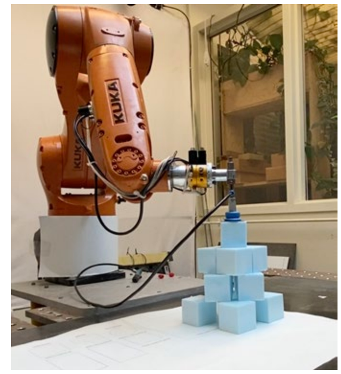
As the first project of the workshop, this project allowed participants to experiment with the workflow between the human and computer interface. For novice roboticists, understanding plane rotation is essential. While rotating blocks by hand are straightforward, executing this manipulation procedure through a robotic manipulator is challenging. Designers built their designs by hand, modeled their intended forms in the CAD environment in Rhinoceros, and conducted their trajectory planning in Grasshopper. Relying on Grasshopper and the KUKA PRC plug-in, students learned new concepts around poses and their relationship to more fundamental concepts around planes to execute their robotic planning.


KUKA
ARCH
CYLINDER
BIG TRIANGLE
SMALL TRIANGLE
PICK AND PLACE

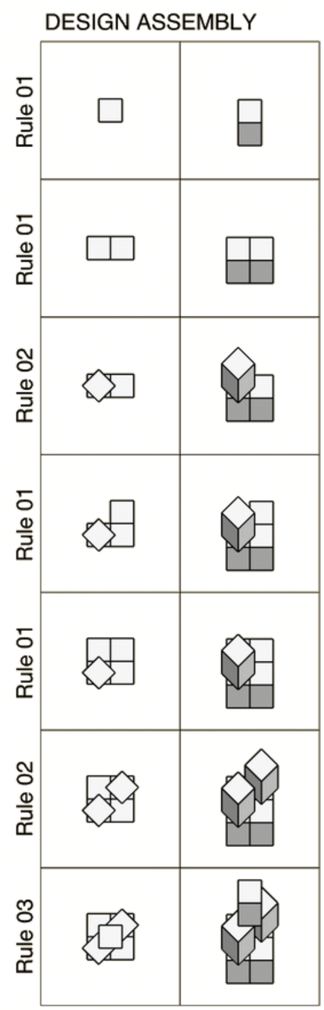
Tower of Power

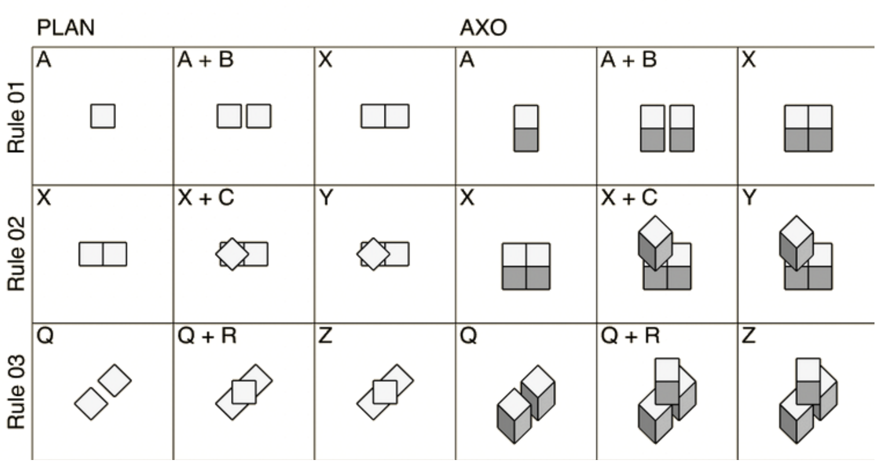
Natalie Pearl

06



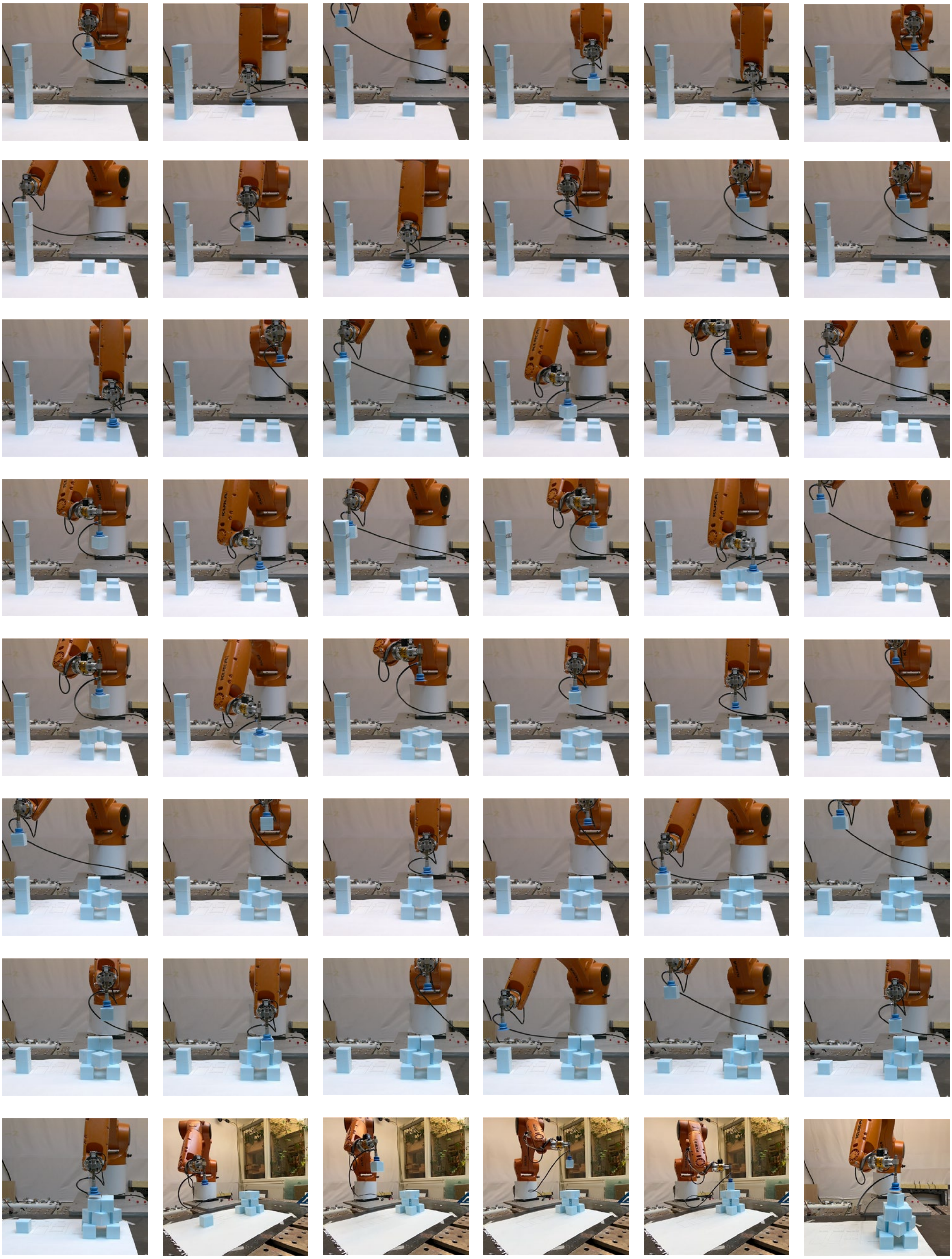
As the first project of the workshop this project allowed participants to experiment with the workflow between the human and computer interface. For novice roboticists, understanding plane rotation is essential. While rotating blocks by hand is very straightforward, executing this manipulation procedure through a robotic manipulator is challenging. Designers built their designs by hand, modeled their intended designs in the CAD environment in Rhinoceros, and conducted their trajectory planning in Grasshopper. Relying on Grasshopper and the KUKA PRC plug-in, students learned new concepts around poses and their relationship to more fundamental concepts around planes to execute their robotic planning.





Tower of Power

Natalie Pearl



Emma Jurczynski & Carolyn Tam

07

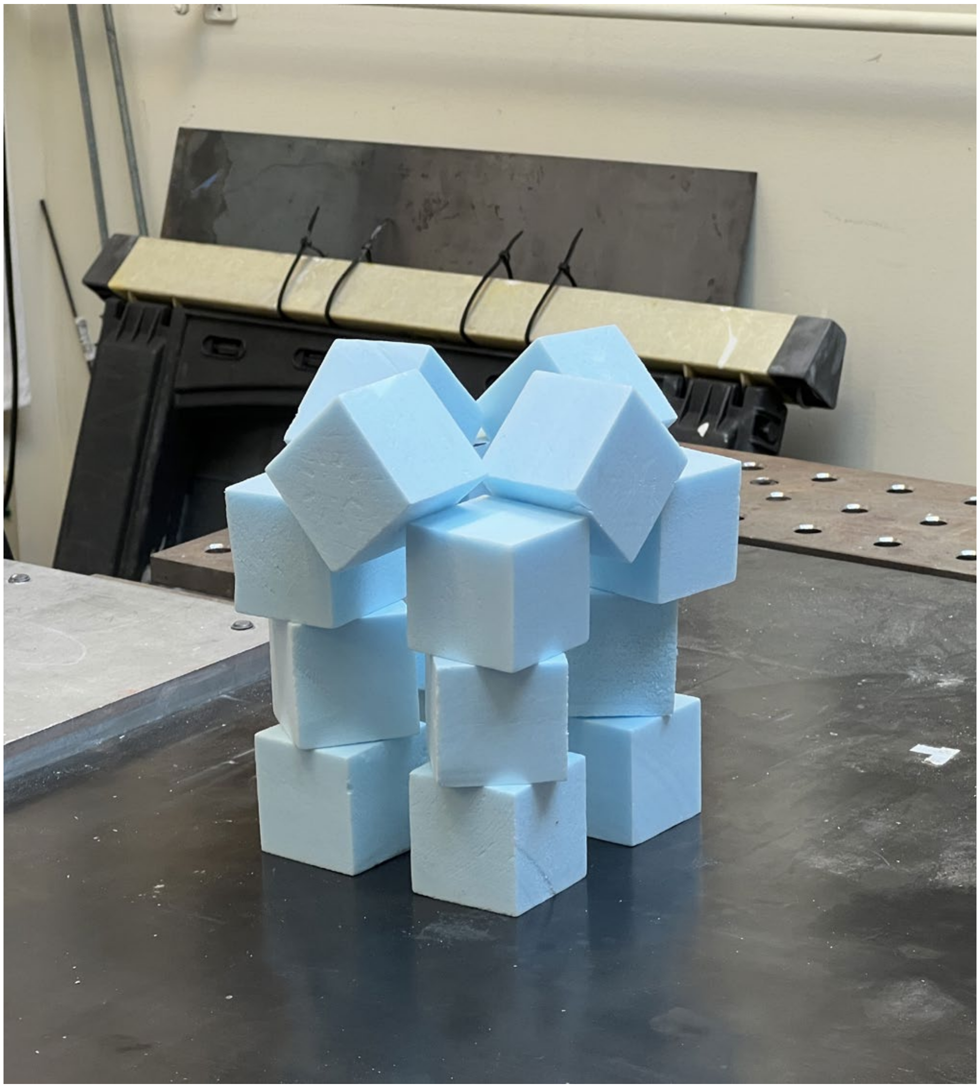
Archy

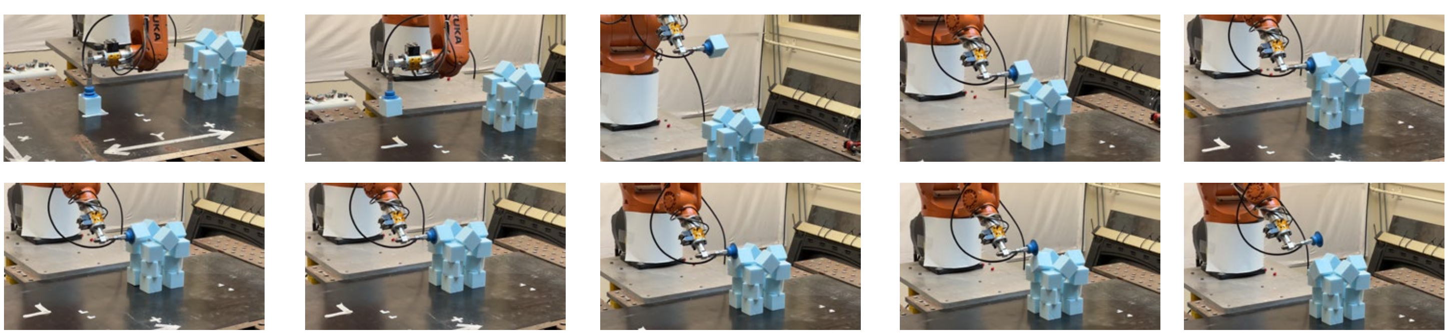
Archy examines the structural possibilities of architectural construction using a robotic manipulator. Designed using a series of three simple rules, the students designed and built a false arch using two inches foam cubes. The first rule initializes the spatial relationships between the objects by placing cubes in parallel at a fixed distance. Later in the assembly process, rule one allows for stacking capabilities. Rule two describes the addition of a cube. By stacking and rotating the cube forty-five degrees, a rhythmic design effect materializes while maintaining the structural capacity of the structure. Rule three rotates a cube forty-five degrees along its y-axis and places it between the gap between two cube towers with parallel top stacks as if it were a keystone. The resulting structure is a false arch.

The main issue to resolve in this design is establishing the spatial relationship on the bottom stacks, so the space between towers, before the robot places the keystone cube, contains enough space for the placement of the final object. This spatial tolerance in the gap must overcome the pressure created during the release of pressure from the suction cup tool on the keystone cubes. This design provides a foundation for additional creative exploration of architectural structures through robotic arms.

Archy

Emma Jurczynski & Carolyn Tam

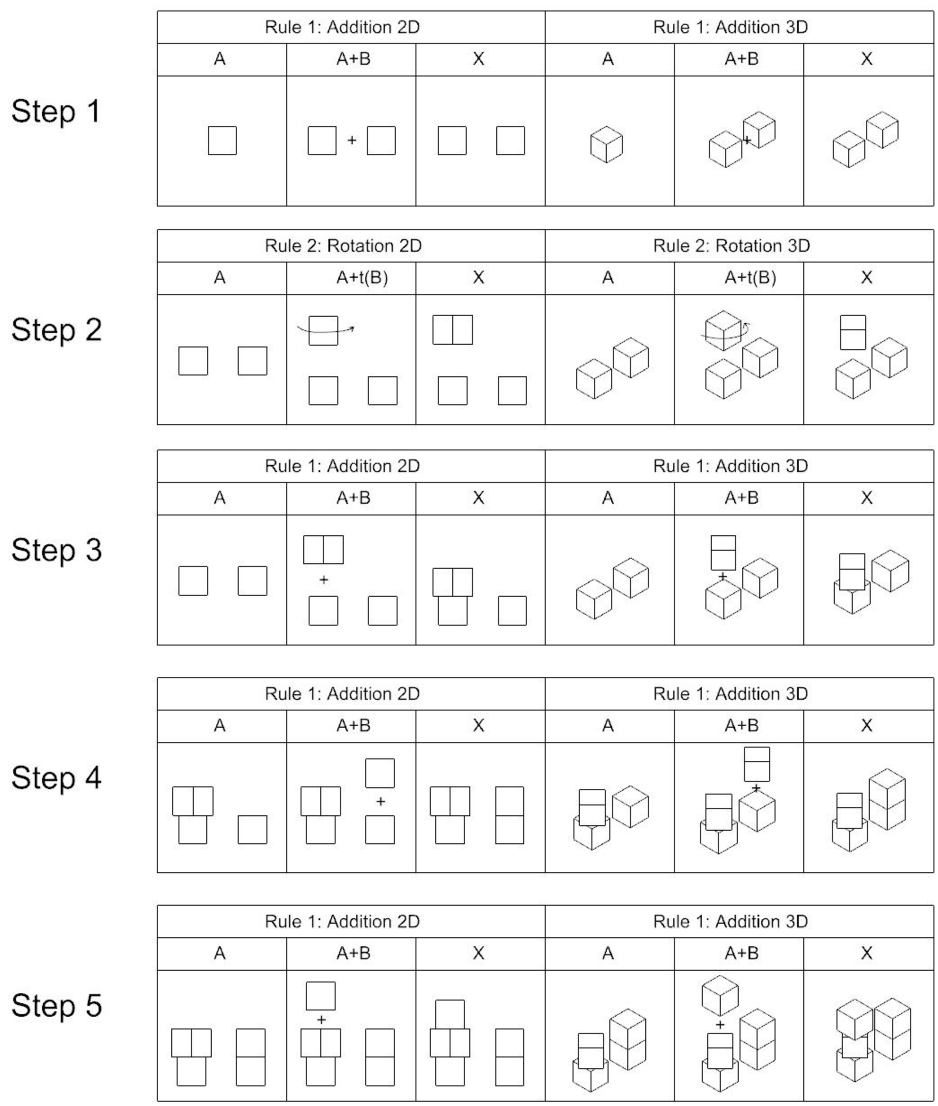




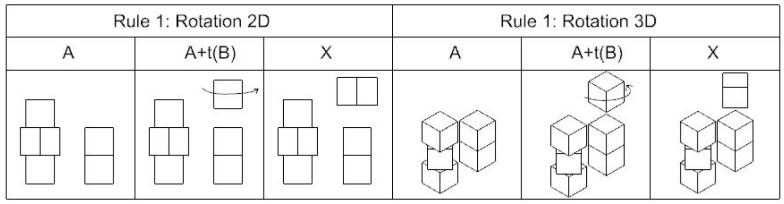
Archy

Emma Jurczynski & Carolyn Tam

08



Step 6



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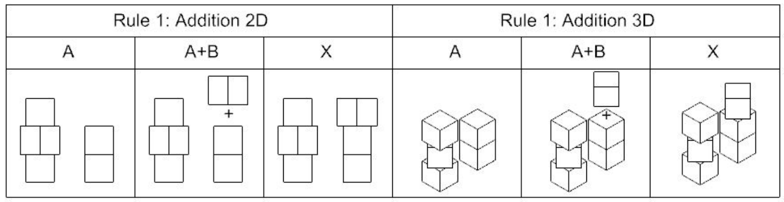
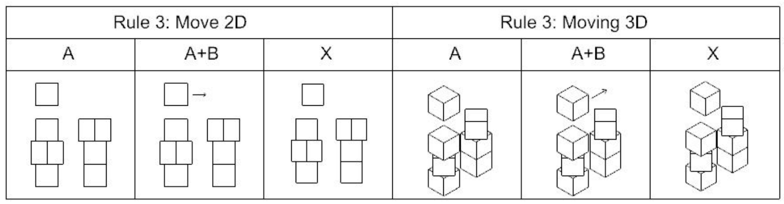
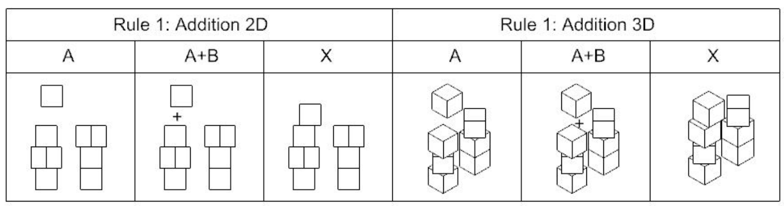


Step 8



Step 9



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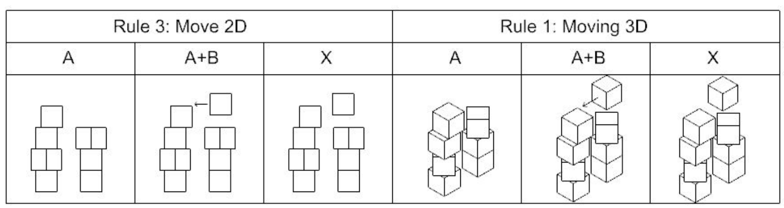

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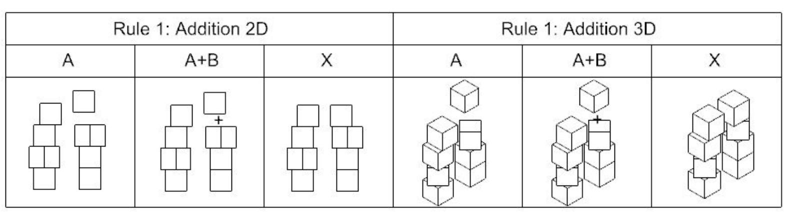

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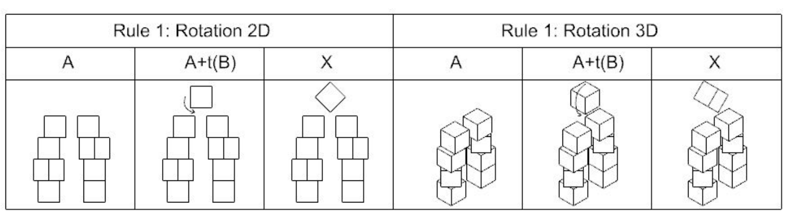

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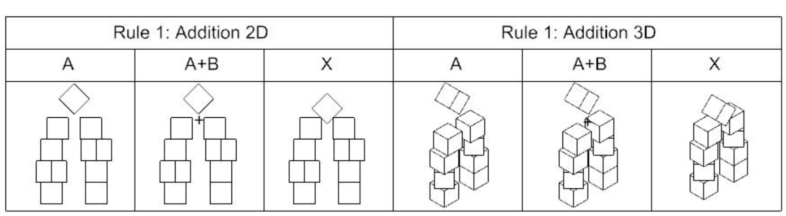


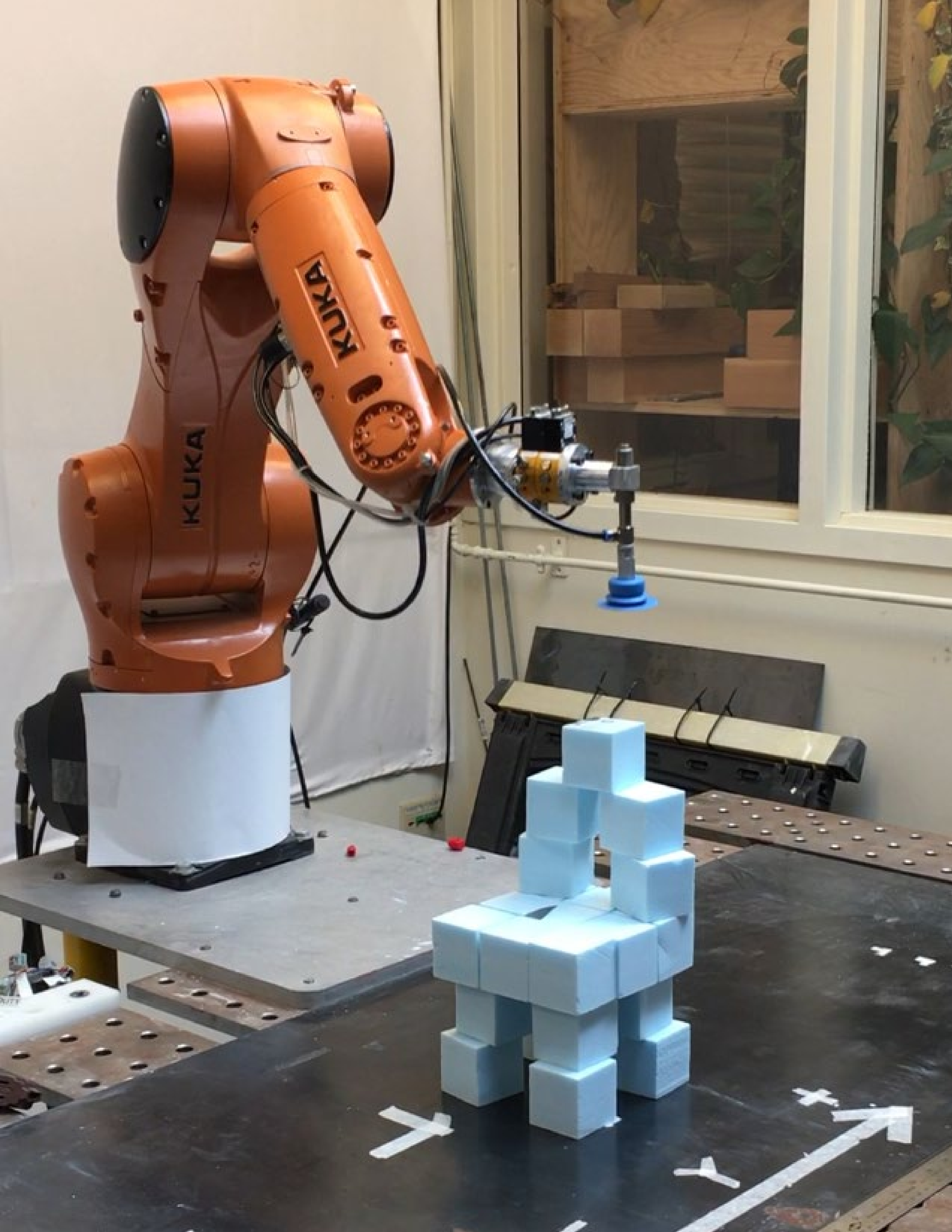
09

Take a Seat

Take a Seat is a design that examines robotic manipulators and their ability to make architecturally sound objects. Following the workshop's three-part formula—physical design, digital design, and robotic execution—the project accomplishes a design that embodies simplicity and structural soundness. The designer builds the chair in a series of steps that directly relate to the robot's ability to manipulate the foam cubes using the MIT Rapid Prototyping Lab's suction cup tool. The tool is custom milled out of aluminum and contains a spring that allows for imperfections and greater control in the assembly process. The suction tool employs Festo suction cups which are pneumatically controlled at 60 psi using a Vaccon Venturi Vacuum Pump.

Throughout the workshop, the students manipulate their discrete objects through pick-and-place operations to execute their designs. In the workshop, we discovered that designs that contain building blocks that are in horizontal contact are almost impossible to assemble, and designs must include a horizontal gap to prevent unwanted collisions. Robotically created forms need these spaces because strictly position-based manipulators do not employ computational perception systems, such as lidar cameras, required for adaptive assembly.

Still, by iterating on our three-part process—physical-to-digital-to-robotic—we discovered designers reduce robotic pose inaccuracies, tolerances, and structural instability when the robotic manipulator uses the consistent pickup location for objects. Through this method, the designer found working the tolerance distances from 2mm to 5mm, when incorporated into the digital design process for the robot. The design and assembly process of the seat clearly illustrates the need for tolerance distances; students digitally design in CAD a 3mm tolerance gap on all parallel sides for the robotic assembly procedure.


KUKA
KUKA

10

Spatial Relations and Sequencing

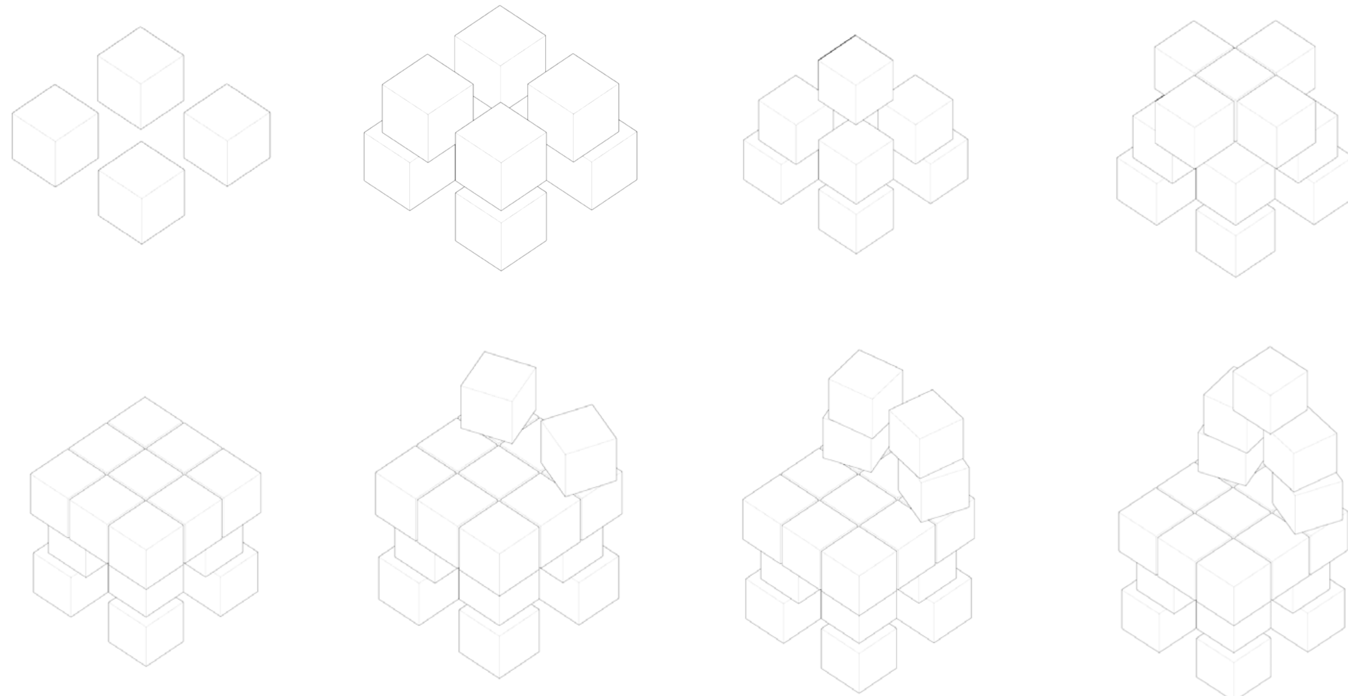
Take a Seat relies on static spatial relationships to control the robotic assembly. The designer used an intuitive bottom-up approach to build the chair. Essentially, the robotic construction of the chair closely mimicked the physical creation of the chair by hand. The primary difference to this design is that it navigates around the limitations of the robotic end-effector. Here, spatial relationships dictate the design rules required for the assembly while operating within the limits of the suction tool.

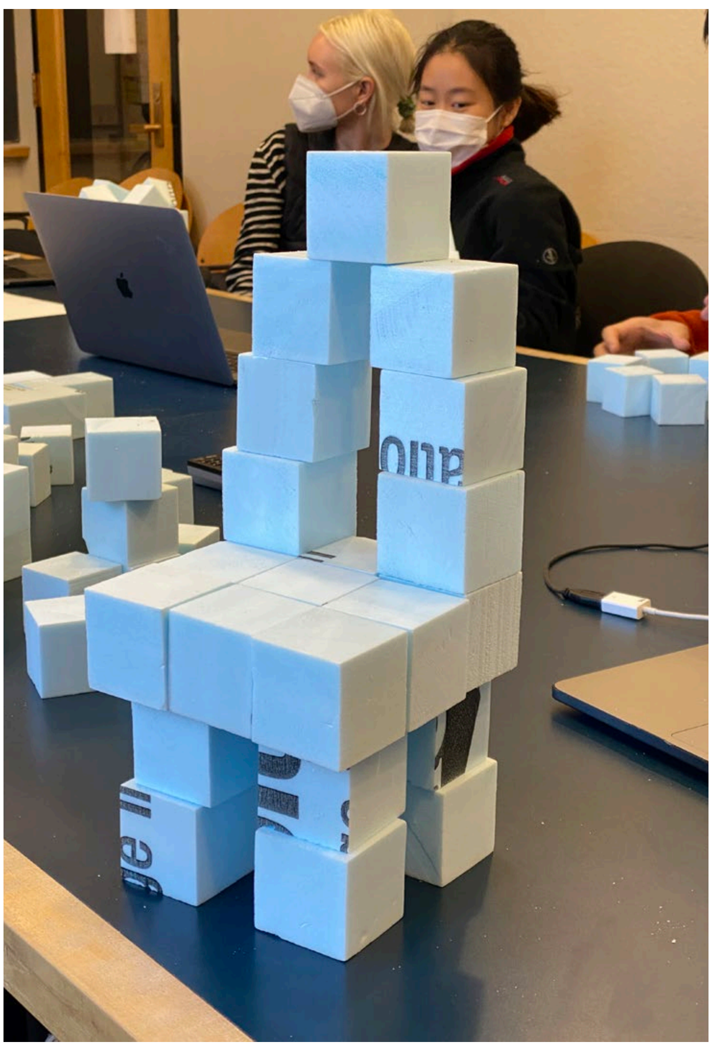
The chair assembly begins by initializing the legs of the chairs by placing the cubes in a square configuration. The robot uses this rule operation again as it stacks and repeats with a shorter spatial relationship to create a visual separation between each block. Next, the robot assembles the seat of the chair. The robot places a cube in the center of all four legs, and from here, the robot places blocks around the center of the first cube with the 3mm tolerance gap.

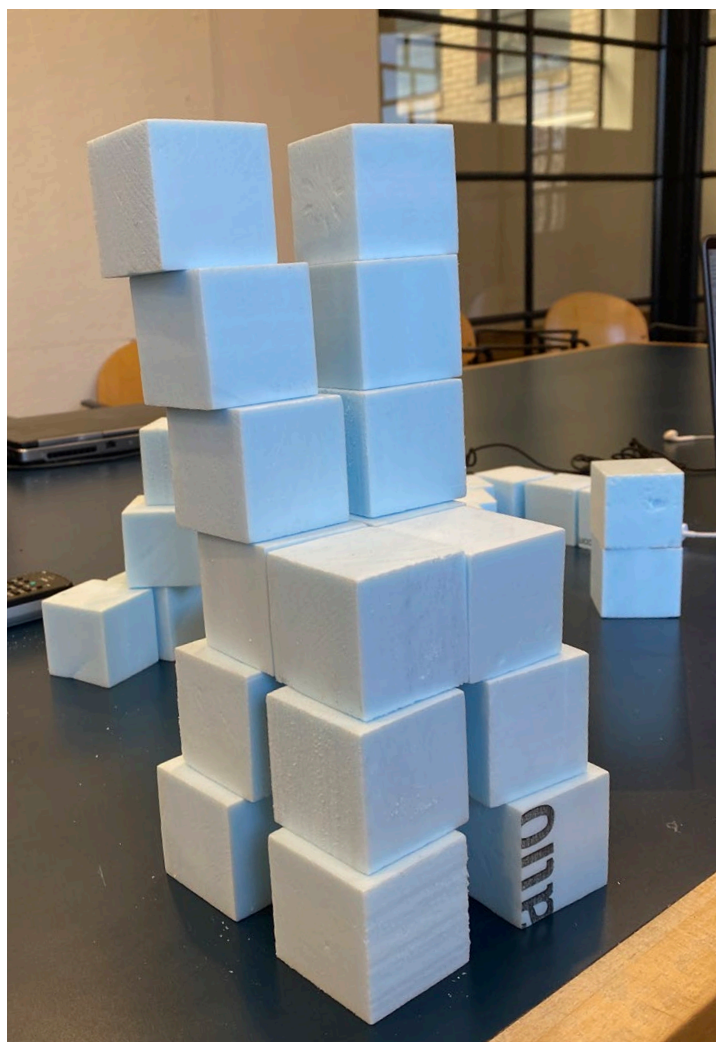
Finally, the robot assembles the chair's back by creating an arch using the same spatial relationships required to construct the legs of the chair and the spatial relationship of the first stack in the chair's seat. By decomposing the spatial relationships used to build the chair, designers can uncover methods to make other architectural objects, such as tables, stools, or vases.

Take a Seat

Tim Cousin





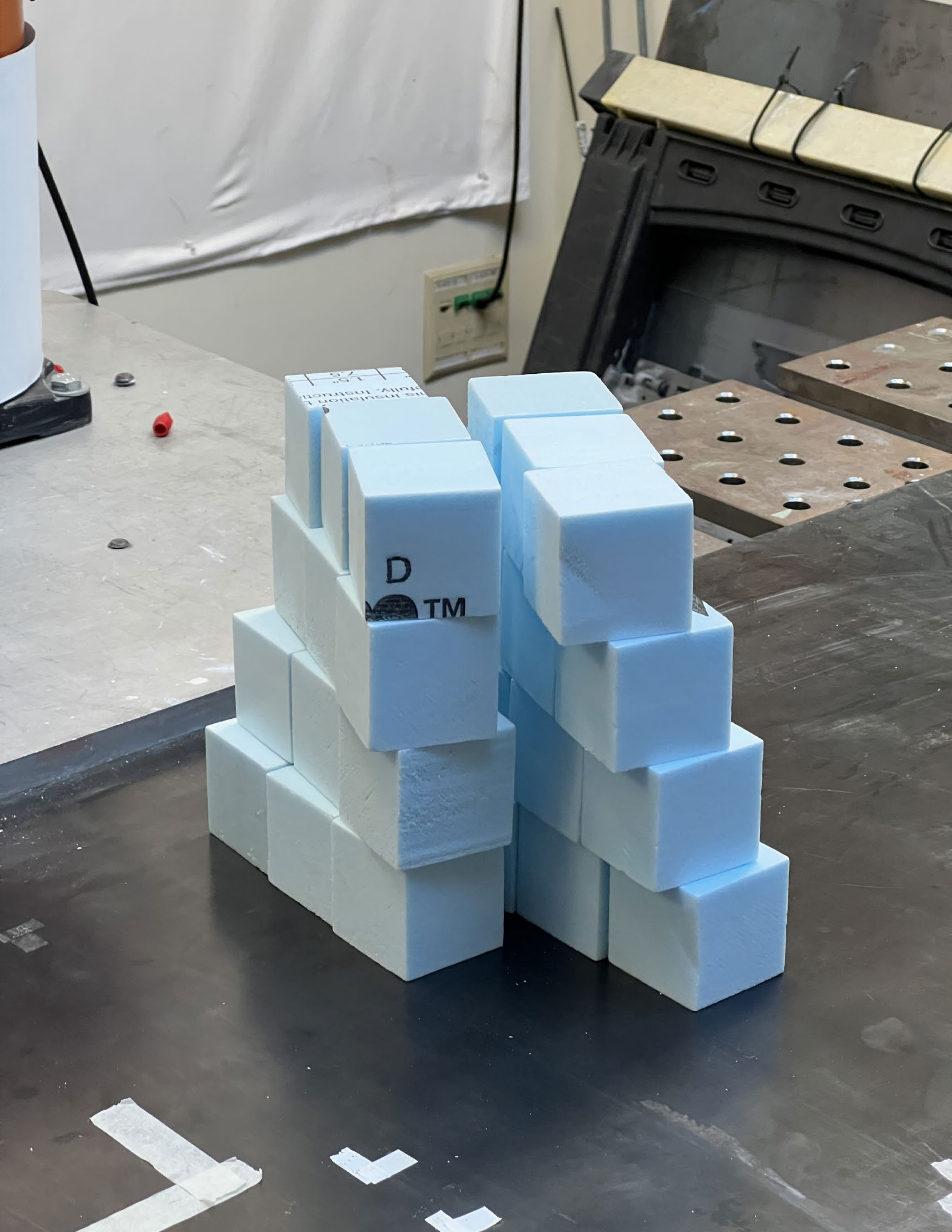


11

Passageway

The Passageway reveals how design rules create spatial relationships that evoke compelling architectural experiences. The design comprises two simple rules. The first rule places a cube parallel to another cube, while the second rule stacks a cube on top of another cube at an acute angle. When the rules combine in sequence (111211211211), where 1 denotes the application of rule one, and 2 denotes the application of rule two, it creates a cantilevered wall that radially curves. When a designer places two of these walls next to each other, an architectural space appears. The designer uses a 2mm gap between each cube to work around the tolerances in robotic assembly.

The chief challenge in the robotic execution of the design was designing the proper rotation angle employed in rule two. The student found a relationship between the length of the wall and the rotational angle in rule two: for the design of a wall, a smaller angle creates a wall that spans longer without failing structurally; a larger angle creates a shorter structure with more rotation and a dynamic overhang. Iterating through the physical-to-digital-to-robotic process, the student found the proper rotation angle for their design while negotiating volatile forces caused by the design's cantilever. Overcoming the issues in cantilever design, spatial relationship tolerances, and material inaccuracies, the student produces a beautiful architectural space.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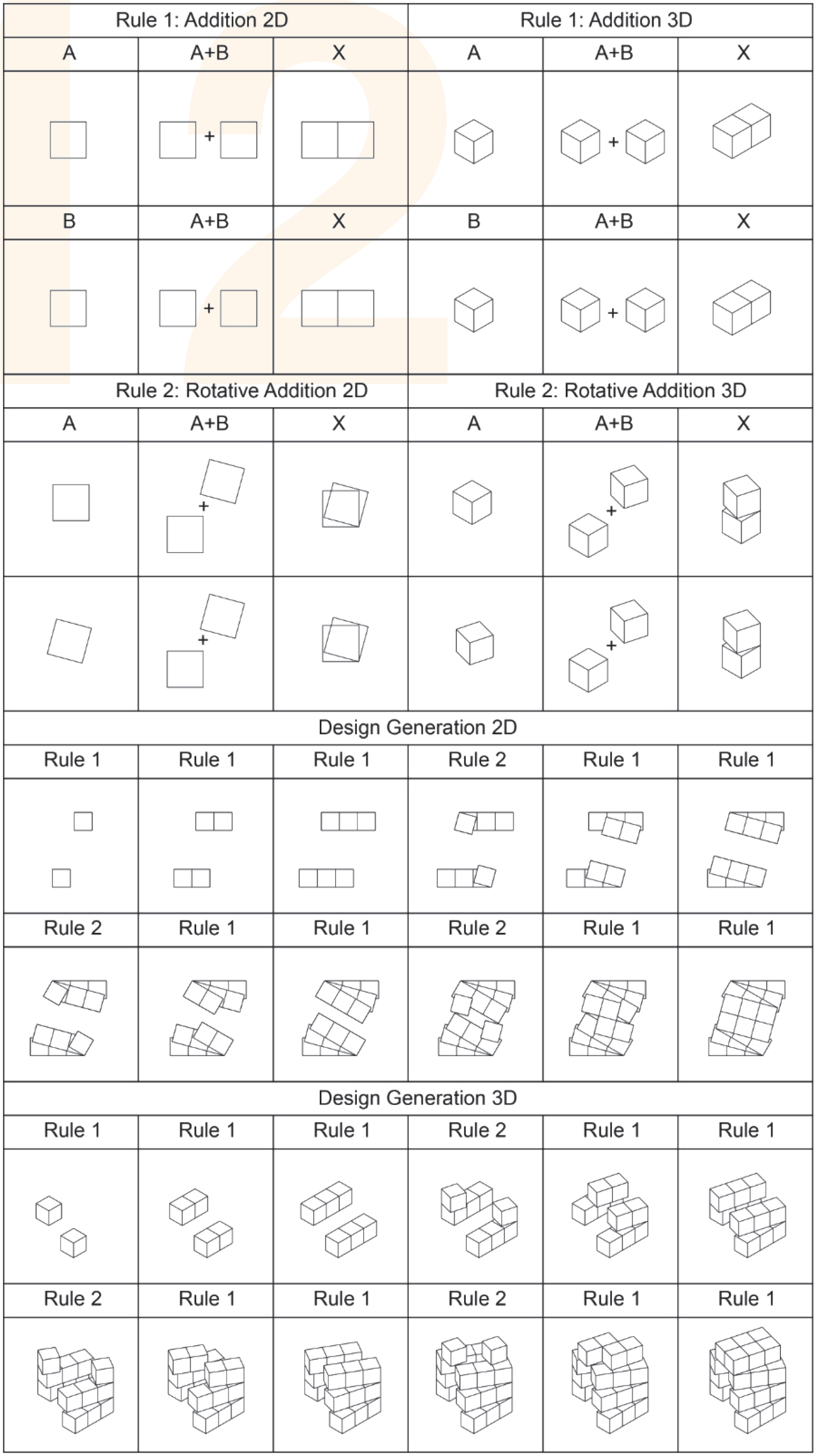
Rule 1: Addition 2D
Rule 1: Addition 3D
A
A+B
X
A
A+B
X
B
A+B
X
B
A+B
X
Rule 2: Rotative Addition 2D
Rule 2: Rotative Addition 3D
A
A+B
X
A
A+B
X
Design Generation 2D
Rule 1
Rule 1
Rule 1
Rule 2
Rule 1
Rule 1
Rule 2
Rule 1
Rule 1
Rule 2
Rule 1
Rule 1
Design Generation 3D
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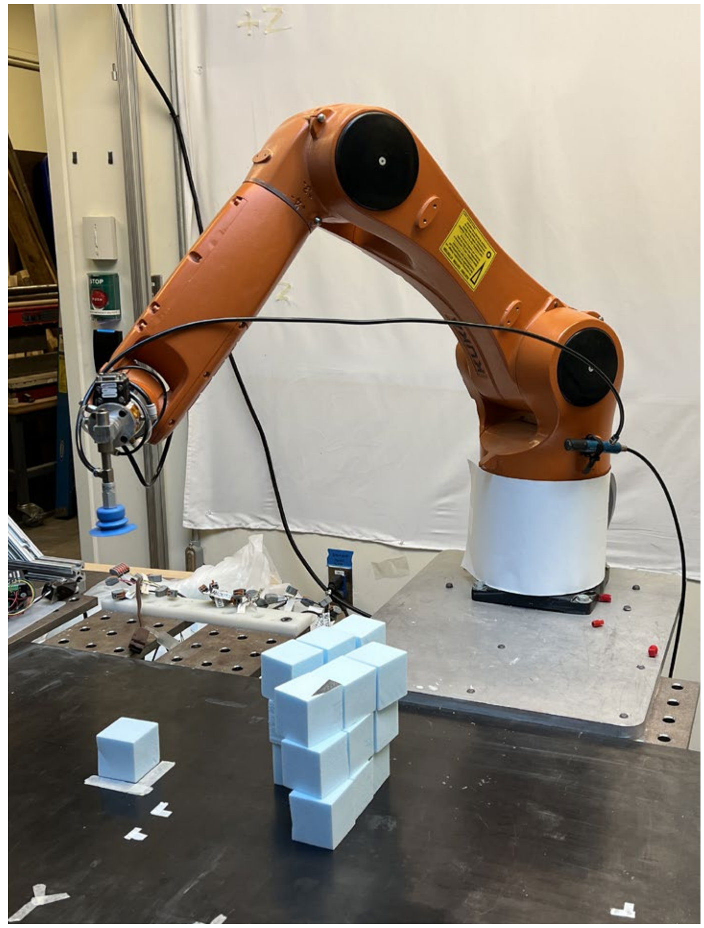
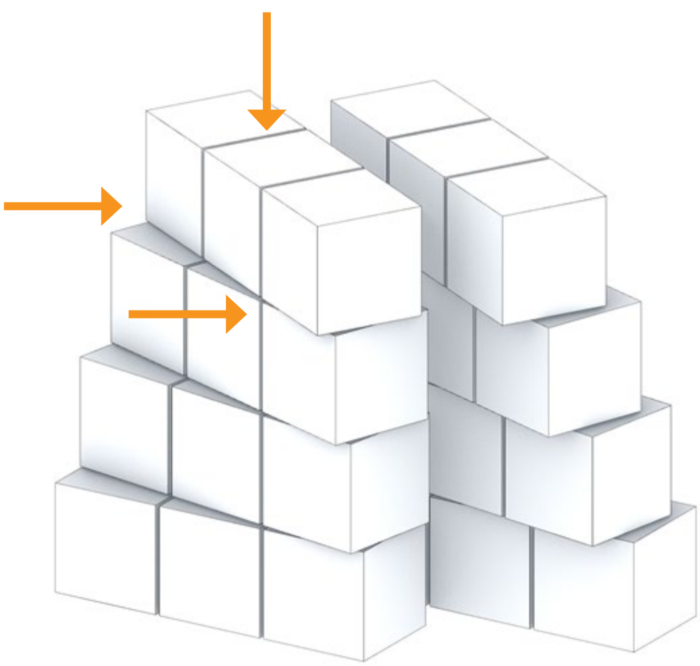
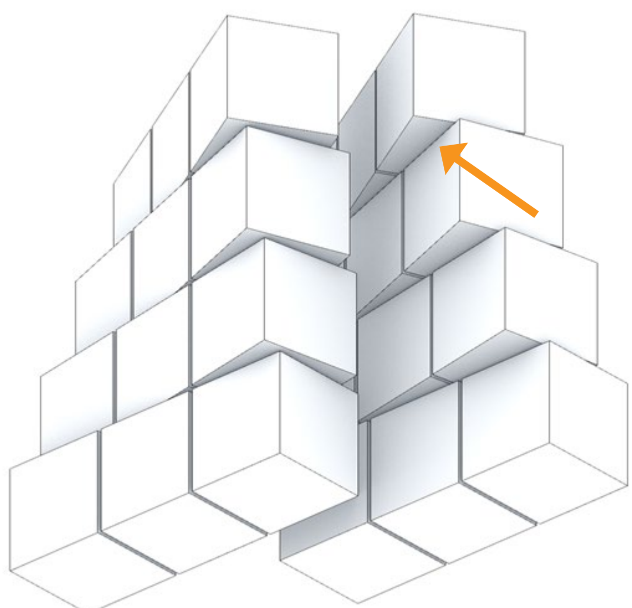
Passageway

Jin Gao



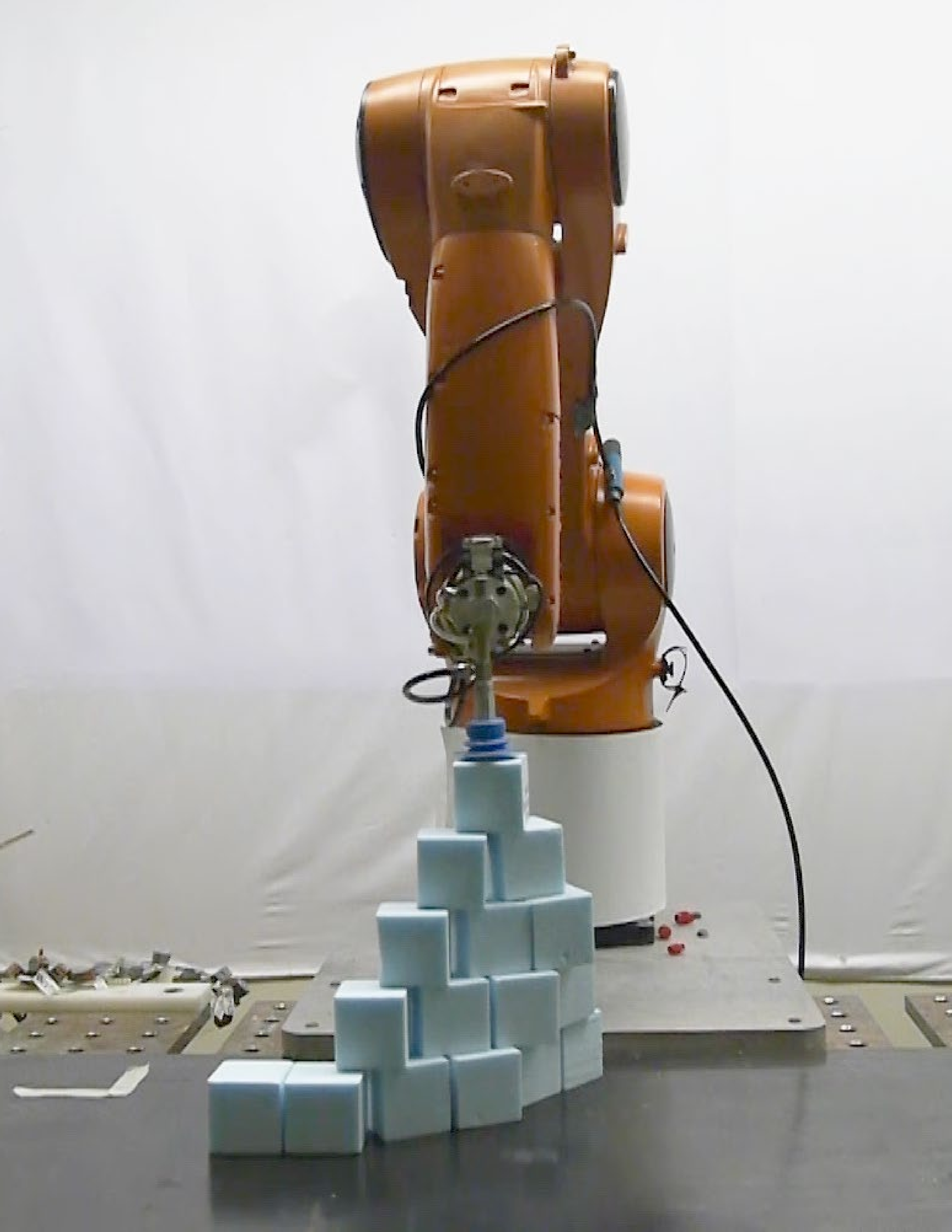


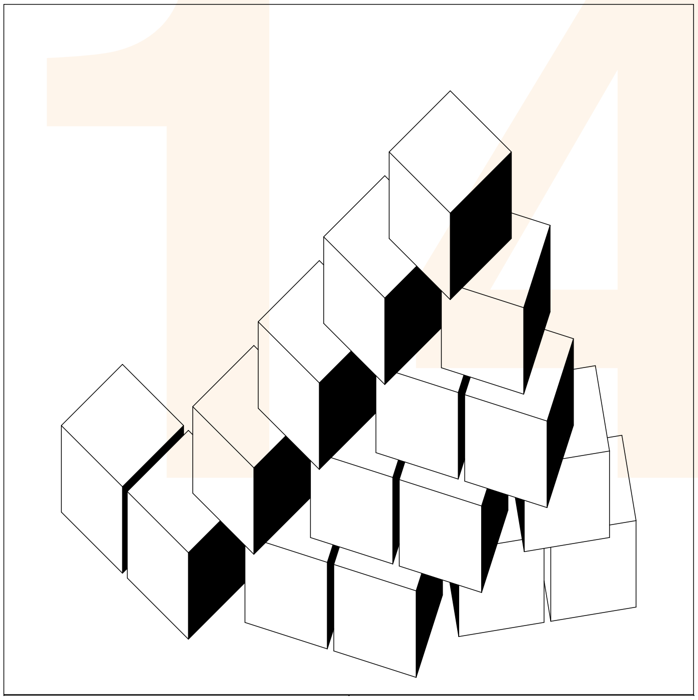


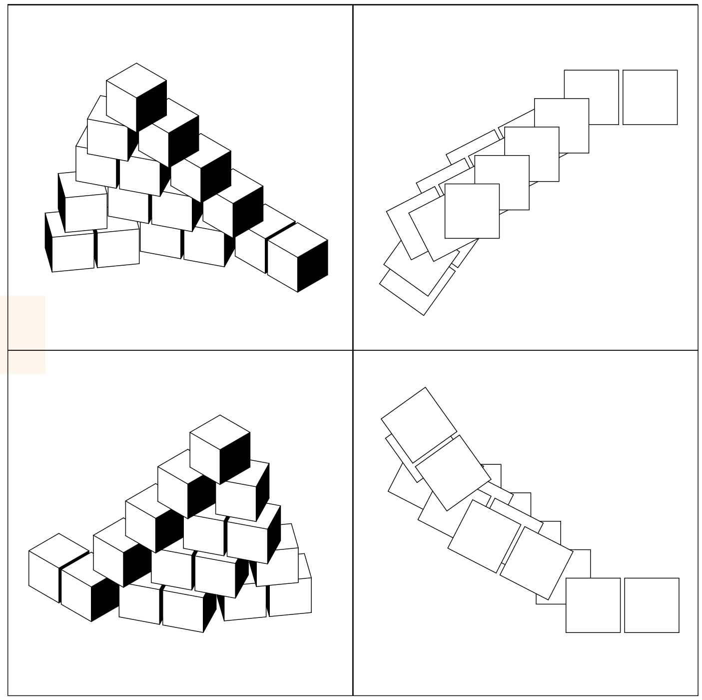
13

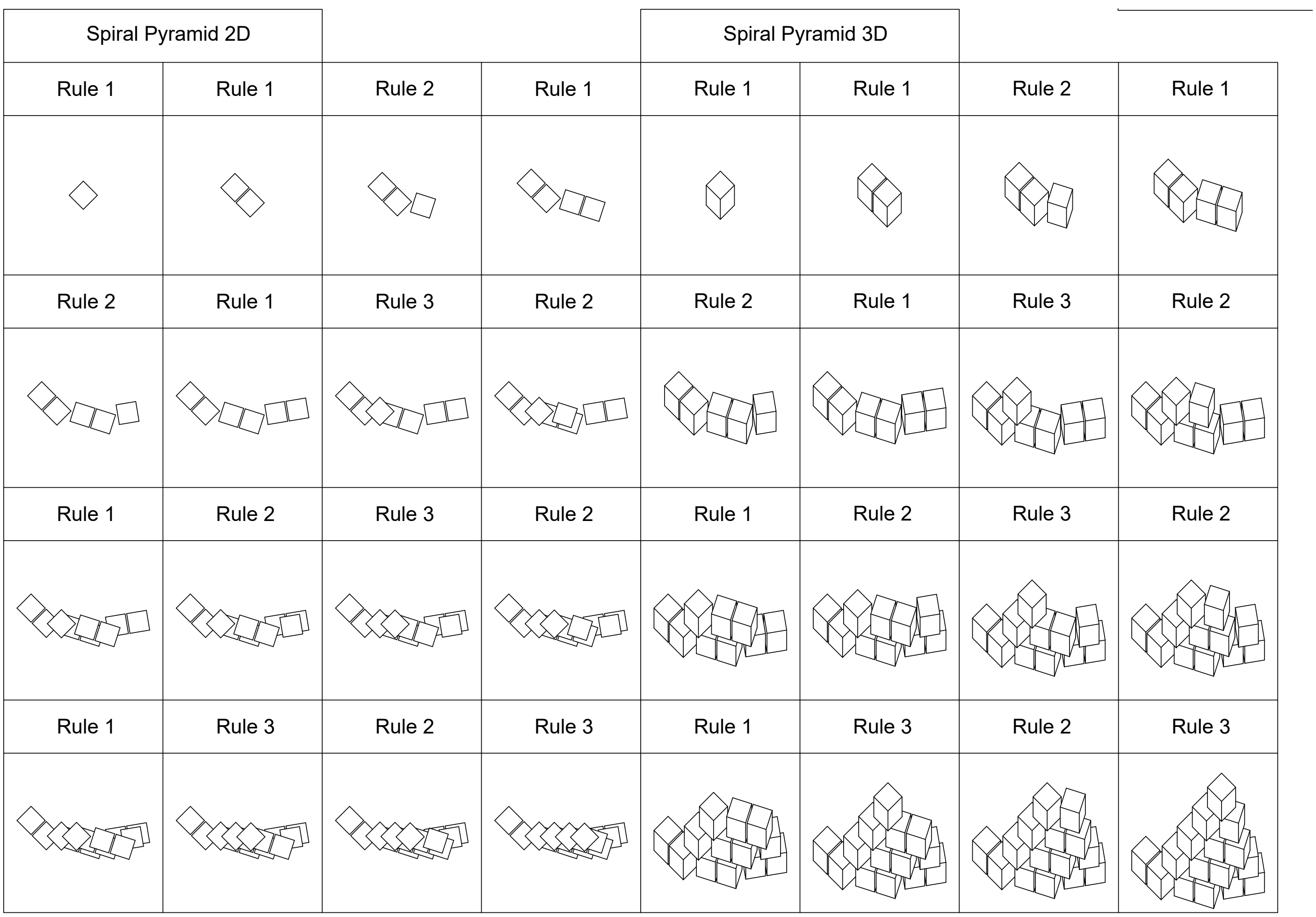
Tower Chord

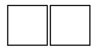
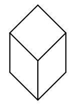
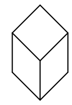
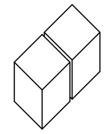
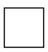
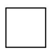
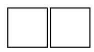
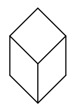
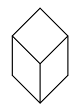
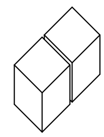
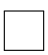
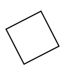
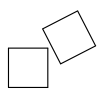
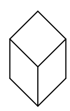
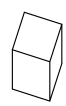
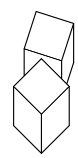
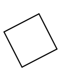
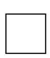
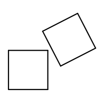
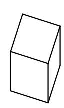
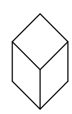
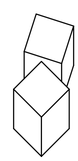
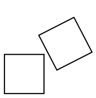
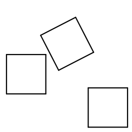
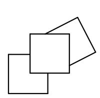
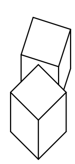
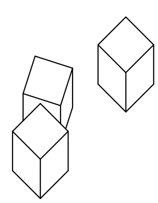
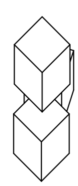
Tower Chord examines rules as the foundation for structural exploration in architecture design. The rules used are similar to the rules in The Passageway. Rule one sets up the initial spatial relationship between two cubes, rule two places a cube with a rotation angle to an adjacent cube, and rule three stacks a cube on top of two cubes at an angle parallel to the block on the left-hand side. When the rules combine in series, an elegant tower appears. Using the rules in the design's system, the designer creates a cantilever that depends on the initial use of rule two, the chief rotational rule. The main challenge is finding the rotation when the robot applies rule two. If the object rotates too much, cantilever distances increase, causing structural instability as the object stacks. Iterating over the correct rotation angle while finding a proper tolerance gap between cubes, the tower achieves elegant structural stability as it climbs, shifts, and rotates. All in all, the design confirms the generative power of rules while leveraging the powerful intuition of the designer.







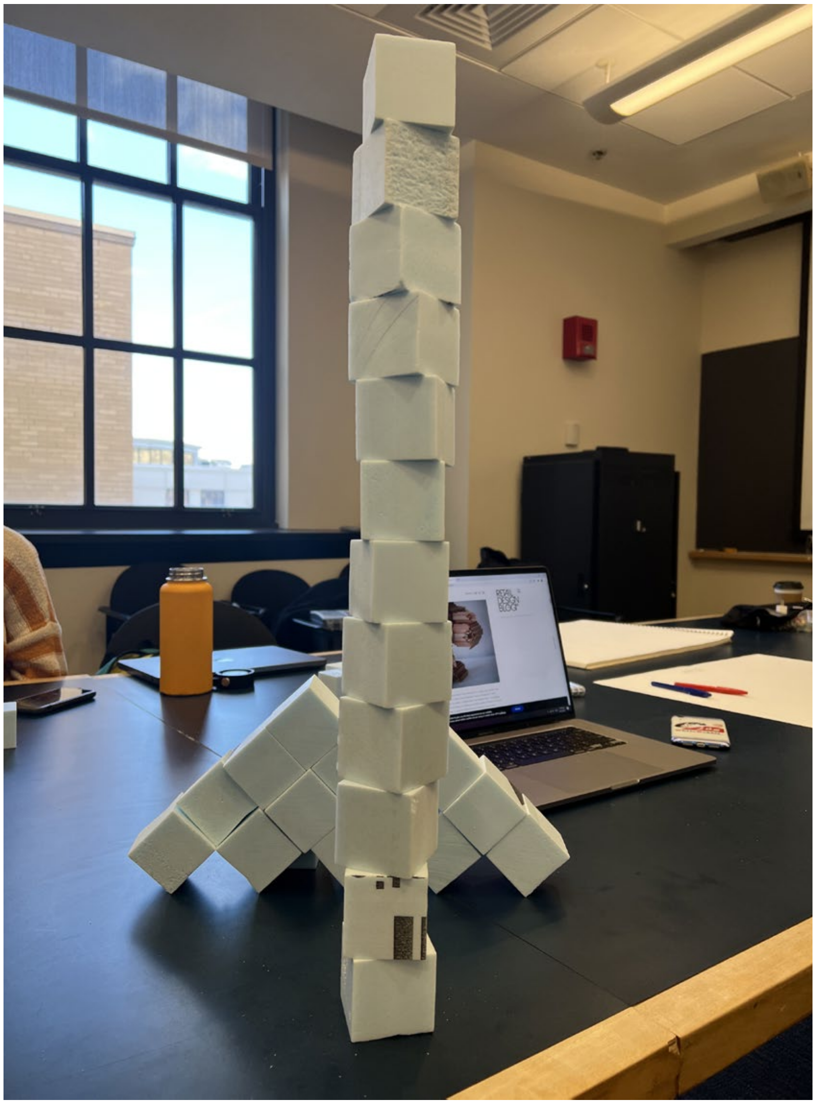

Spiral Pyramid 2D
Spiral Pyramid 3D
Rule 1 Rule 1 Rule 2 Rule 1 Rule 1 Rule 1 Rule 2 Rule 1
Rule 2 Rule 1 Rule 3 Rule 2 Rule 2 Rule 1 Rule 3 Rule 2
Rule 1 Rule 2 Rule 3 Rule 2 Rule 1 Rule 2 Rule 3 Rule 2
Rule 1 Rule 3 Rule 2 Rule 3 Rule 1 Rule 3 Rule 2 Rule 3

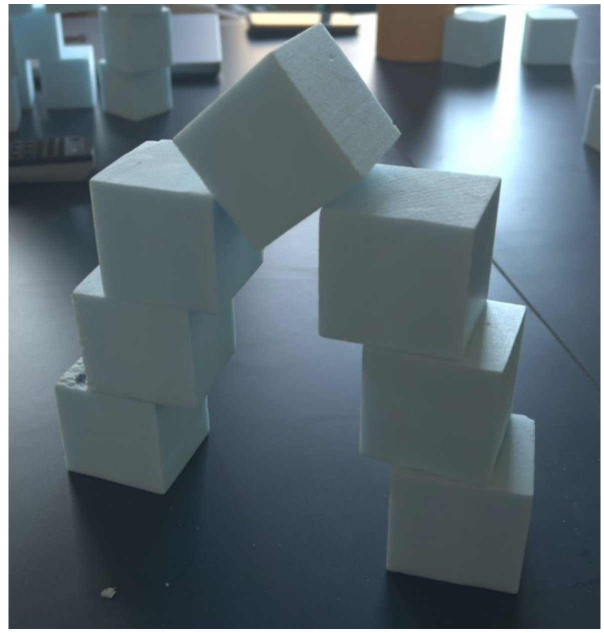
Rule 1: Addition A 2D			Rule 1: Addition A 3D		
A	A + B	X	A	A + B	X
					
B	B + A	X	B	B + A	X
					
Rule 2: Addition B 2D			Rule 2: Addition B 3D		
A	A + C	Y	A	A + C	Y
					
C	C + A	Y	C	C + A	Y
					
Rule 3: Addition C 2D			Rule 3: Addition C 3D		
Y	Y + D	Z	Y	Y + D	Z
					

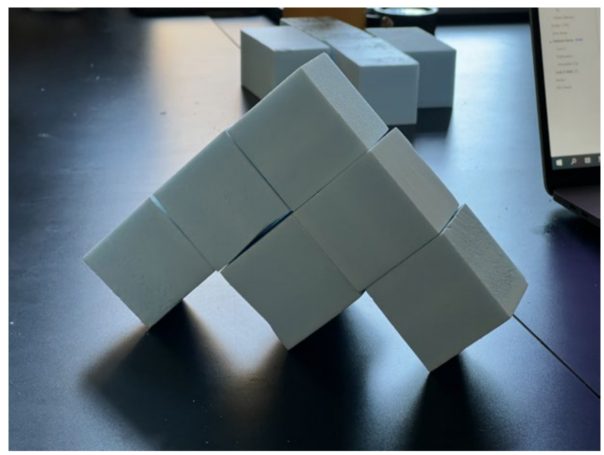
15

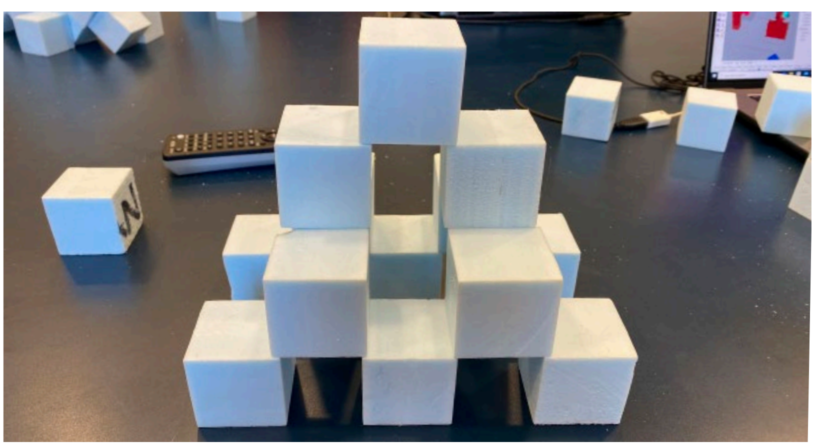
The Next Phase

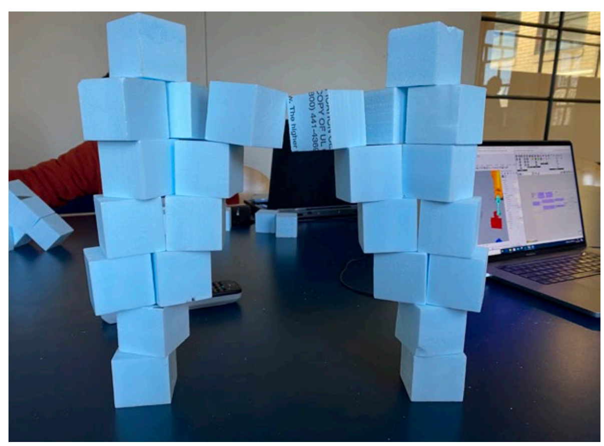
Retrospectively, the workshop provided remarkable results for the implementation of rule-based design in Robotic Assembly. Over the course of two weeks, students designed, iterated, and assembled their architectural creations on a robotic arm. In short, students learned that robots are inherently tasked for repetitive position-based tasks, and they need computational enhancements to become autonomous and adapt to their physical environment. The next steps in the research will look at the architectural robotic assembly using discrete objects with attachment features, and designing objects using different material compositions. With these two goals in mind, the target for the further research in design directed architectural robotics to scale structures to the pavilion level. We imagine structures that humans can interact with, built with very little human intervention, and that chiefly rely on autonomous robots for the assembly and construction process.











16

Myles Sampson

Myles Sampson received his professional degree in architecture at Tuskegee University with a minor in Computer Science in 2019. He is currently a 2nd Year SMArchS Design and Computation student at MIT. He has professional experience in architectural practice working at HOK and GMC. And he worked as a student researcher at the MIT Rapid Prototyping Lab and at the MIT Self-Assembly Lab.

Acknowledgments

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