Exo-Skeleton: A Micro Design-Build

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INTRODUCTION

This project showcases a novel methodology of multiplanar robotic tube bending, exploring further development possibilities and utilization in an undergraduate elective seminar, which arguably served as a micro design-build (Figure 1). As the challenges of contemporary practice grow to include the integration of digital technology and fabrication methods, the ability to synthesize these tools into a productive creative process is a growing pedagogical concern. Tricia Stuth outlines this in her writing on embedded knowledge, *Second Nature:* "Designbuild impels students to synthesize design and technology and begin to embed skills and knowledge that ultimately give rise to intuitive understanding of technical concepts." [1]

BACKGROUND

The installation presented in this project employs workflows developed by two of the authors in previous research that enable multi-planar robotic bending of metal tubes with high accuracy and repeatability.[2] This allows for the rapid full-scale fabrication and assembly of complex spatial tubular configurations comprised of unique modules without the need for elaborate jigs or falsework support. The workflow follows a lineage of research projects exploring the application of robotic bending of linear elements, primarily in solid-core rod form.[3] Solid profiles prove far from ideal in terms of material efficiency when considering structural cross-sections for scaling up to larger structures, therefore leveraging the inherent material and structural efficiency of hollow tube sections was a logical extrapolation of the bending technique. Additionally, the speed of the robotic fabrication method allows for meaningful iteration and tactile physical feedback during the students' design explorations.

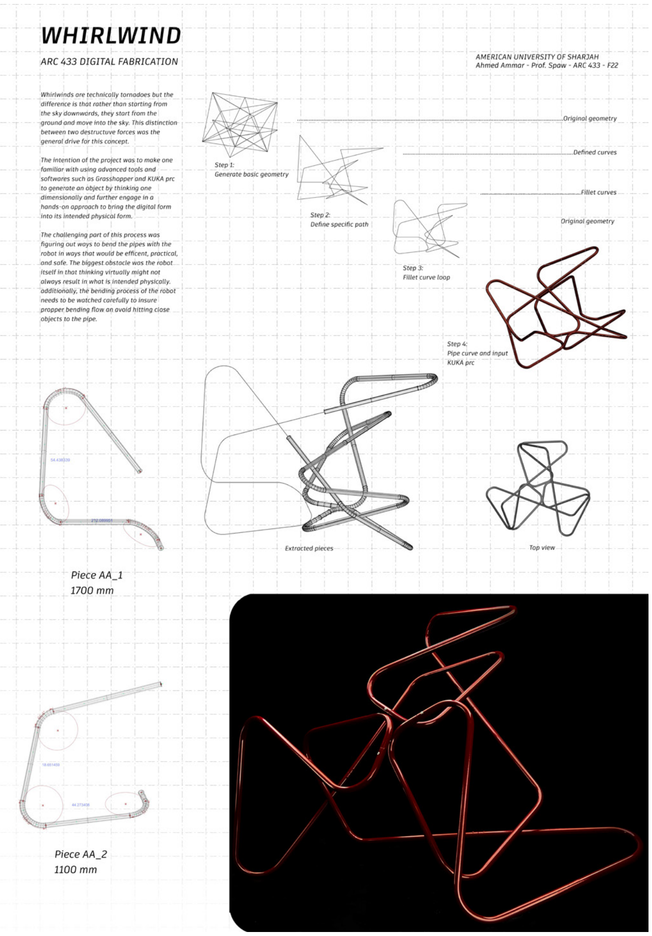
A MICRO DESIGN BUILD

Introduced within the context of a three credit hour Advanced Digital Fabrication elective, the students were tasked with designing and building an installation with the aim of utilizing the previously mentioned workflow and leveraging its unique characteristics. There was an intentional emphasis on smaller, faster builds with the final results being far from preordained, an approach that grew from instructional experience in a previous design-build option studio.[4] Throughout the process, the primary design outcomes were student-driven, with minimal input from the instructor. This was an intentional decision taken to shift the onus of the project's completion and success, and ultimately ownership, to the collective initiative of the student team. The instructor's role here was primarily to facilitate the usage of the tools and workflow, aid with troubleshooting, and coax the collective decision-making process forward with organizational and procedural suggestions.

In order to leverage this digital forming method to its fullest, the students were introduced to the digital and physical fabrication processes associated with robotic tube bending through a preliminary prototyping exercise. For all of the students this was their first experience working with a six-axis industrial robot, with many safety protocols and procedures to learn. The goal of this initial exercise was to familiarize students with the workflow of robotic tube bending while enabling them to better understand the fabrication constraints of the method (Figure 2). This hands-on understanding of the length, weight, and geometry constraints of the material and method would later allow the students to better harness their learned experience in the design, fabrication, and installation of the eventual construct, as separate coordination and tolerance challenges arise when scaling up to a larger assembly.

Next, the students were each charged with pitching viable sites and micro programs that could exploit the particular capacity of the associated robotic fabrication method (Figure 3). After making their presentations, the students collectively decided to reimagine a series of studio pinup boards. Working initially in small teams and then later working as an entire group of fifteen, the students iterated on the installation design within the constraints of a modest budget and the limited time associated with an elective course. Therefore, they had to collectively self-organize their various roles and delegate responsibilities to realize the piece. This included the necessary but mundane realities such as coordinating a production schedule, the creation of systems required for tagging and tracking of parts, and interfacing with a local factory to ensure the accurate powder coating of multiple elements in a variety of colors.

Figure 1. Overview of completed Exo-Skeleton project. Image by authors.



Whirlwinds are technically tornadoes but the difference is that rather than starting from the sky downwards, they start from the ground and move into the sky. This distinction between two destructuve forces was the general drive for this concept.

The intention of the project was to make one familiar with using advanced tools and softwares such as Grasshopper and KUKA prc to generate an object by thinking one dimensionally and further engage in a hands-on approach to bring the digital form into its intended physical form.

The challenging part of this process was figuring out ways to bend the pipes with the robot in ways that would be efficent, practical, and safe. The biggest obstacle was the robot itself in that thinking virtually might not always result in what is intended physically. additionally, the bending process of the robot needs to be watched carefully to insure propper bending flow an avoid hitting close objects to the pipe.

Figure 2. Preliminary prototyping exercise exploring the constraints of the workflow. Image credit Ahmed Ammar.

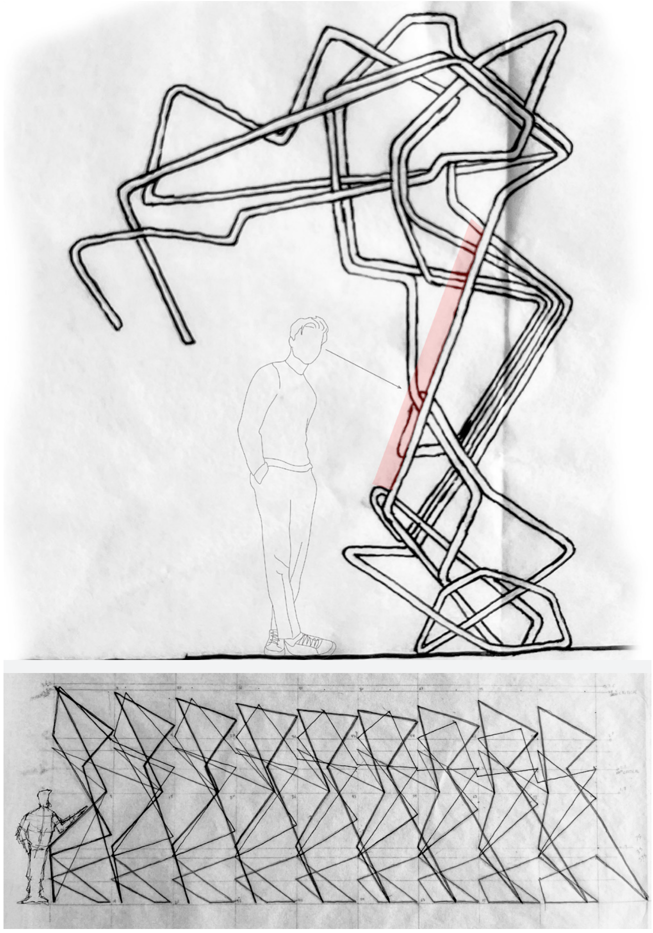


Figure 3. Developmental sketch of project proposals. Image credit Ahmed Ammar.

Given the budgetary and time constraints, the propagation of repeating project elements is limited to a manageable number in order to achieve the desired project resolution, while still proving the design's ability to expand and adapt. In spite of these constraints, the students demonstrated the effectiveness of the bending technique. Their final design utilizes repeating skeletal and triangulated reinforcing elements that morph along the length of the installation (Figure 4). This takes advantage of the multi-planar robotic bending workflow's inherent ability for mass-customization, variability, and accuracy with minimal impact to fabrication time. As the project progressed and the first initial elements were tested on site, it became clear that it was necessary to develop a variety of methods to fixture the bent tube sections in place (Figure 5). This also became an opportunity to develop methods to attach and hold the proposed acrylic pinhole pinup board and magnetic pinup board to the bent tube framework (Figure 7). Parallel studies carried out by the authors on a variety of 3D-printed snap joints to work with the specific tube diameter and tolerances were shared with the students, who then worked with the authors to adapted the joint geometry to their specific use case, incorporating zip ties, set screws, and blind pop rivets into the 3D-printed joints where necessary. Additionally, some final tube elements were redesigned and fabricated employing newly-developed Augmented Reality (AR) assisted robotic bending workflows using the Microsoft Hololens 2 and Fologram plugin for Rhino+Grasshopper (Figure 6). This allowed for more predictable outcomes with clear advantages in part sequencing, accuracy checks for complex bends, and in-situ comparative adjustment of the physical installation to the projected digital model overlay.[5]

RESULTS

Named *Exo-Skeleton* by the student cohort, the structural framework is held in compression using 3D-printed connections between an existing suspended tubular frame overhead and the floor slab below (Figure 9). While the majority of the micro design build process was completed during the course duration, a smaller subset of the students served as paid "research assistants" after the semester officially finished to complete a number of outstanding tasks associated with finalizing and attaching the pinup surfaces to the skeletal frame.

In summation, the course structure allowed the students to take initiative in the pursuit of an iterative design approach

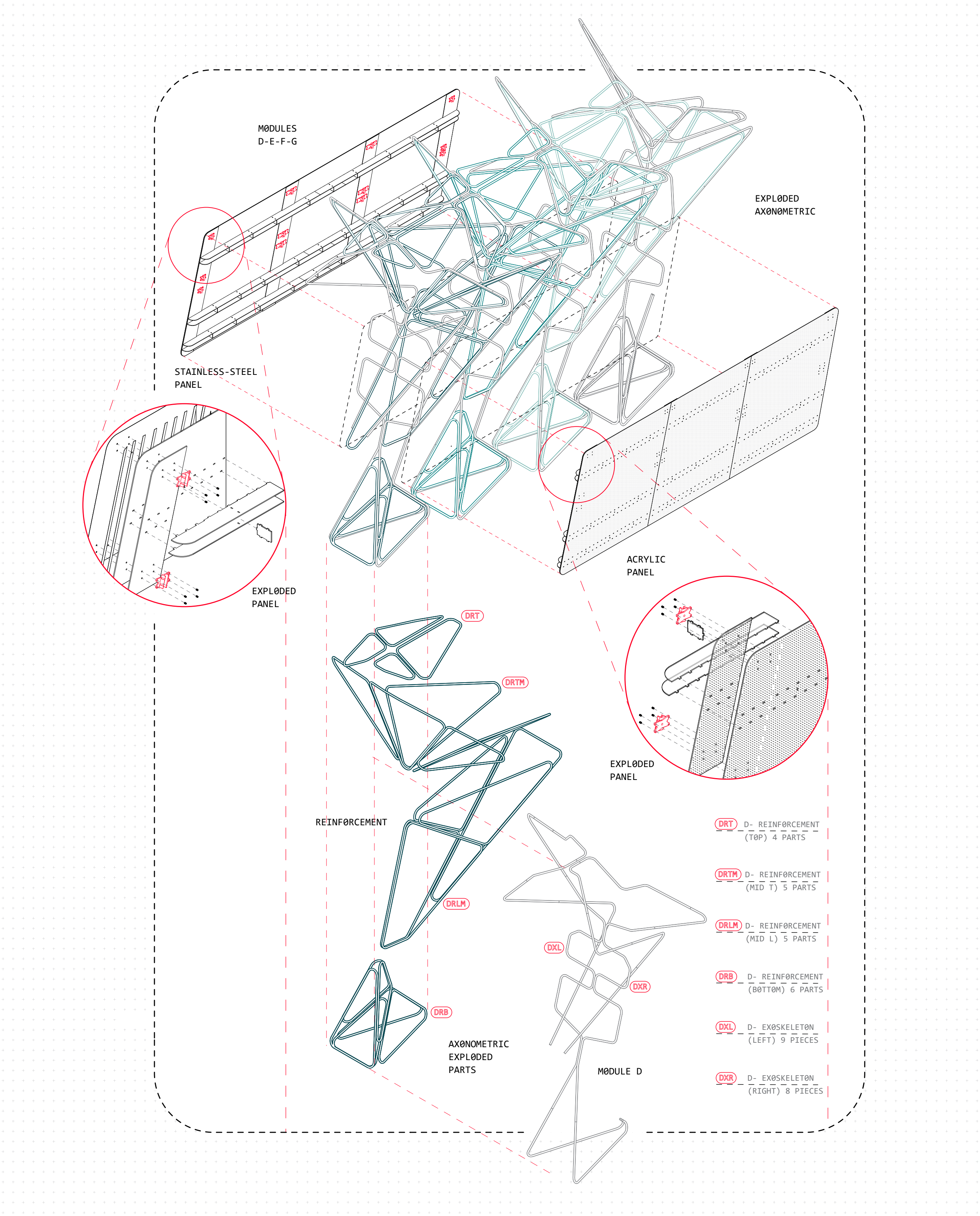


Figure 4. Exploded axonometric detail. Image credit Ahmed Ammar.

Figure 5. Test installation of initial elements on site. Image by authors.

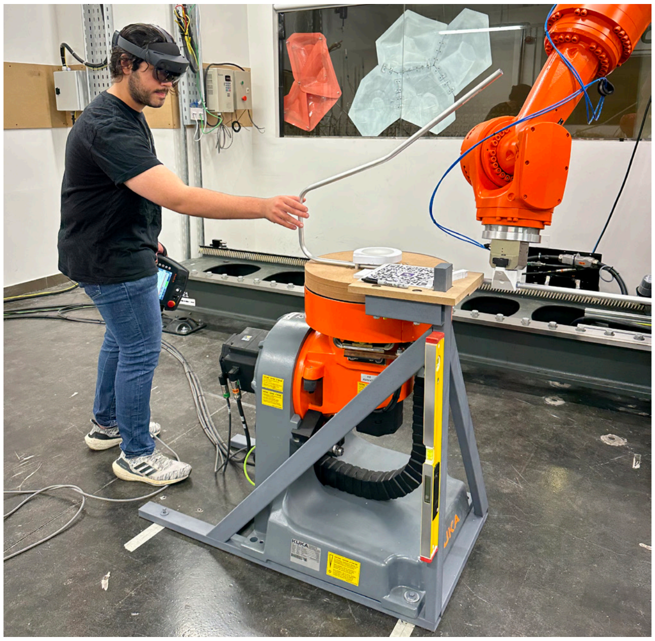


Figure 6. Augmented reality assisted robotic tube bending. Image by authors.

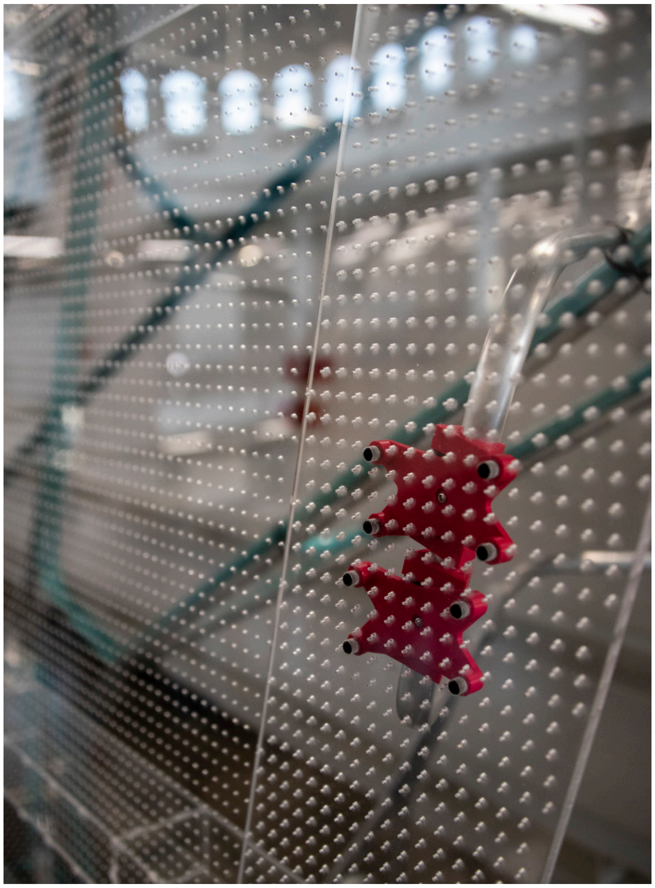


Figure 7. Detail of 3D-printed connection to acrylic pinup board. Image by authors.

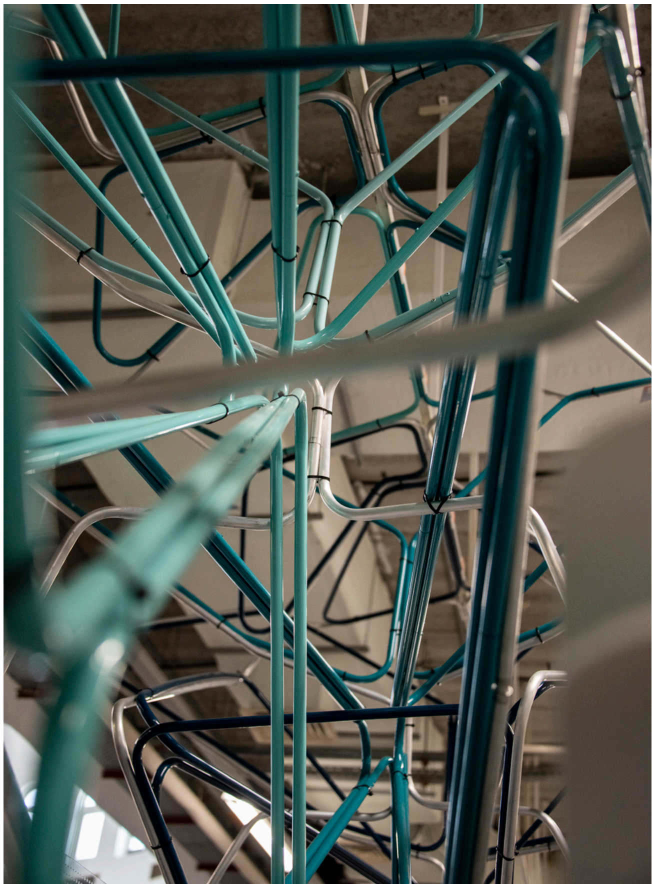


Figure 8. Zoomed in detail of powder-coated bent tube assembly. Image by authors.

while gaining insight into an unique, ongoing digital fabrication research trajectory in a focused, micro design-build experience, and integrate that knowledge into their own collective creative construct.

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Figure 9. Reverse side of installed project showing magnetic pinup board. Image by authors.

ENDNOTES

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