Jiaying Wei

Carnegie Mellon University
Ph.D. Candidate in Computational Design
2026

Computational Design | Architectural Robotics | Human-Centered Automation

Research · Teaching · Design

RESEARCH AGENDA

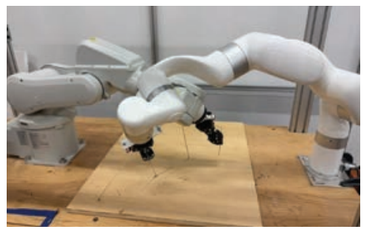
My research develops computational and robotic systems that enable architecture to be built in uncertain, material-rich, and human-centered construction environments.

I position computational design as an operational framework connecting design intent, robotic perception, material behavior, motion planning, and fabrication execution. My work asks how robots can sense, learn from, and adapt to real materials and human practices, rather than simply execute pre-scripted digital toolpaths.

My agenda advances four connected directions:
1. material-aware robotic construction
2. human–robot collaborative fabrication
3. multi-robot assembly and mobile manipulation, and
4. machine learning-based material skill.

Across these areas, I develop workflows that integrate learning-based robotic vision, adaptive planning and task scheduling, physical interface for human-robot collaboration, stability-aware sequencing, and robot learning.

With this agenda, at a long horizon, I aim to move architectural robotics from deterministic automation toward adaptive, perceptive, and collaborative construction systems. My long-term goal is to develop robots as new instruments for architectural making: systems that can read material conditions, negotiate uncertainty, collaborate with people, and expand the ways architecture can be designed and built.

Multi-robot, human-assisted fabrication

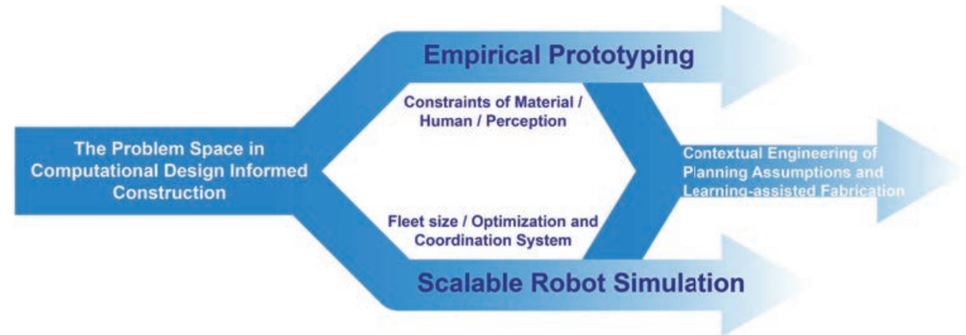


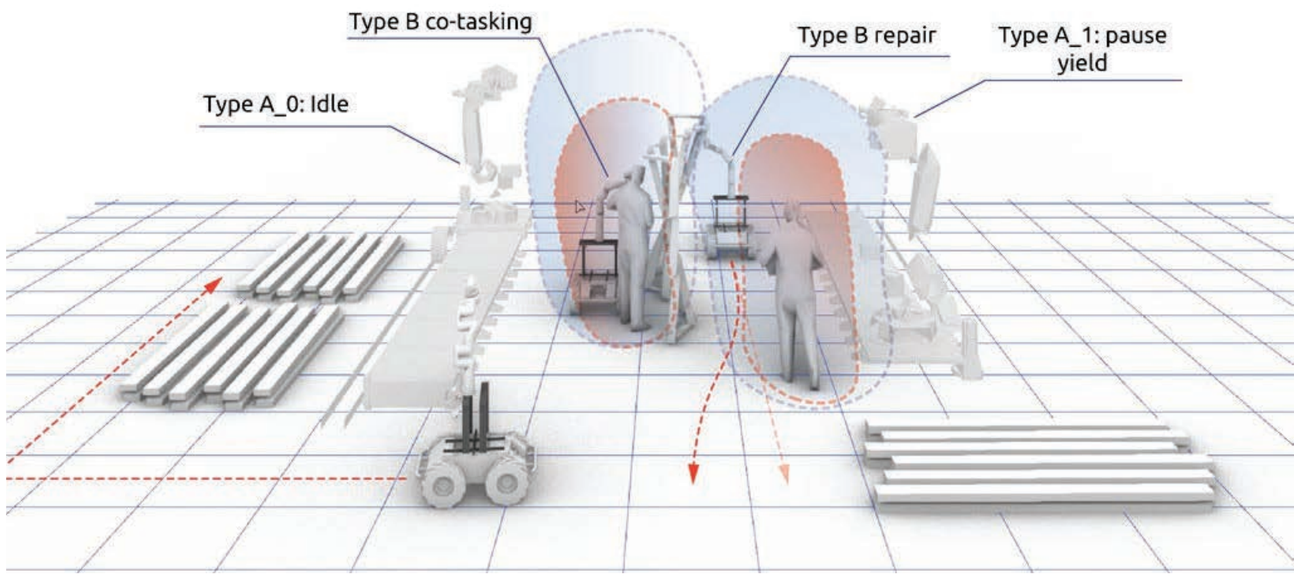

Perception-driven parametric assembly and learning-based material skills

Orchestrating Heterogeneous Multi-Robot Construction: A Human Factored Collaboration Framework

Dissertation Research
(2026 Jan -)

The future of construction robotics will be shaped by coordinated teams of heterogeneous robots that share dense, evolving construction sites while collaborating with and yielding to human workers. This thesis argues that multi-robot architectural construction must treat on-site humans as first-class participants, translating their access, communication, and interventions into explicit spatio-temporal constraints. It introduces a MRS TAMP orchestration framework with a Right-of-Way Policy (RoW): a formal ruleset defining who yields to whom, and under what site conditions. Echoing Asimov's laws as an archetype of human priority, all robot typologies obey the RoW hierarchy—secondary tasks yield to primary structure, and all tasks yield to humans—so safety distances, collision avoidance, task feasibility, and production efficiency remain aligned as geometry and human presence evolve. The thesis contributes physical studies of robot-robot and human-robot collaboration, a hierarchical orchestration system, and a practical model of human-aware autonomy for mass-customized construction.



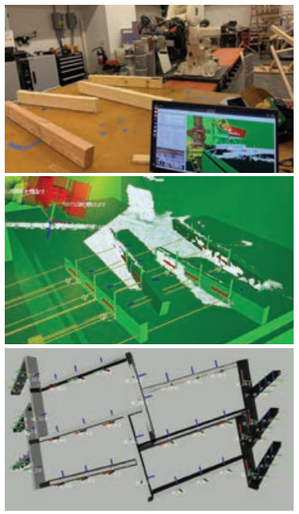


Prototyping Research: cross-reference validation

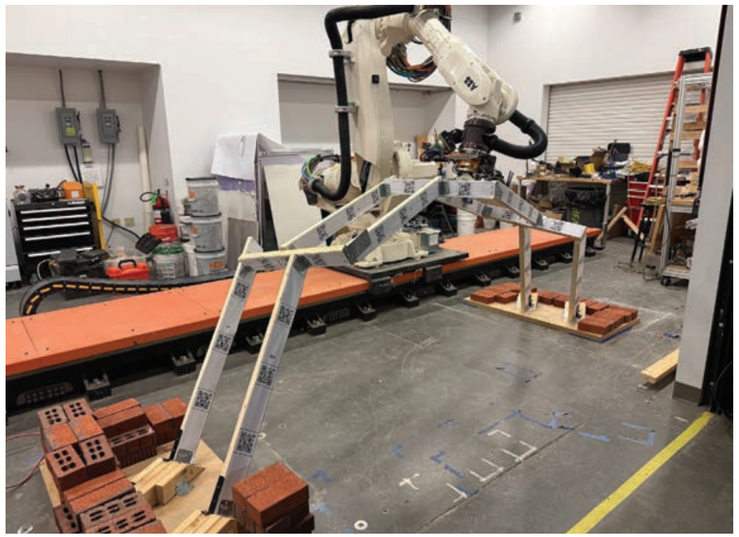
At the unique niche of construction, many of the parameters and constraints are informed by physical prototyping and construction process. These factors contribute to theoretical assumption and results of planning algorithm and simulation to substantially support MRS development in a long run. Therefore my research agenda is backed by and includes strong presence of assembly, 1:1 scale prototypes to argue the usage of constraints in physical settings.



Prototype A: Vision driven Robotic Assembly and disassembly



batch-wise detection



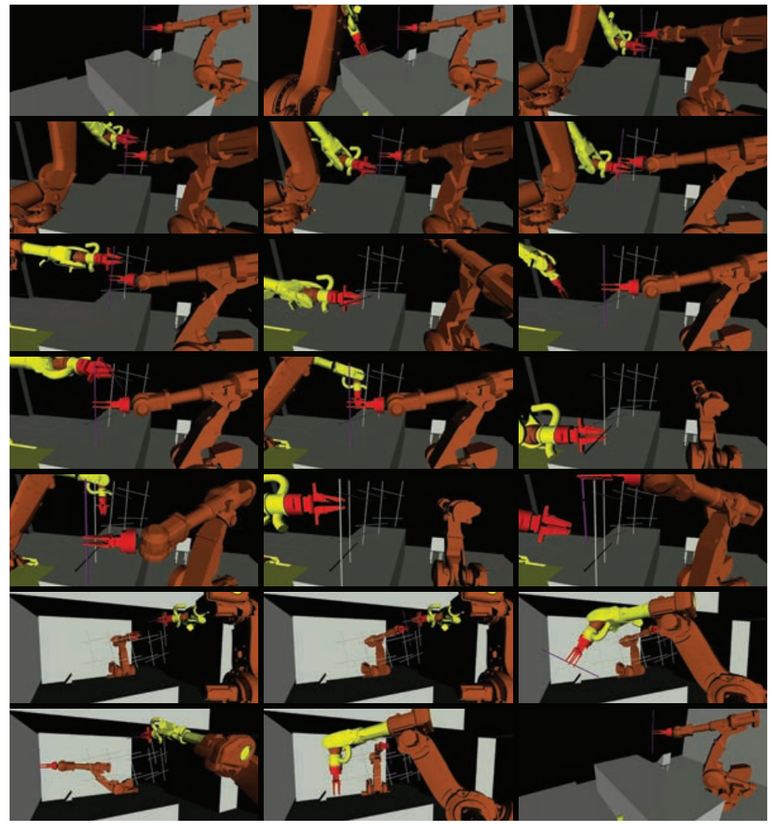
Prototype B: Vision driven Robotic Assembly and disassembly

Industrial multi-robot collaboration in complex geometry

One critical factor that separate robotic application in construction scale vs robots in other applied, human-engaged scenario, is that the environment itself is heavily shaped by the task of the robots - “ live in the world that built itself”. These task carry magnificent scale while also requires precise executing that is challenging for digital twin due to computation power, perception accuracy,etc.



Multi-robot with complex reciprocal form.



Multi-robot collision free planning and simulation

Planning development of in-situ multi-robot system

To coordinate human, heavy payload industrial robots, smaller assistive mobile manipulators in a evolving construction site where all agents schedules and constributes to the environment they build. Planning at larger fleets is a foundational research questions about the challenges in construction site. This dissertation propose a unique Task and Motion Planning (TAMP) skeleton to respect human agents in centralized manner. This planning approaches is founded with the understanding that long-term co-existence of human and robots construction site is critical for future automation.

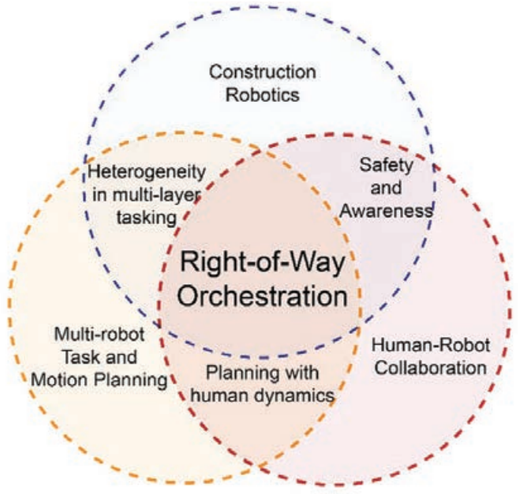


Figure 1. Human centered heterogenous MRS conception

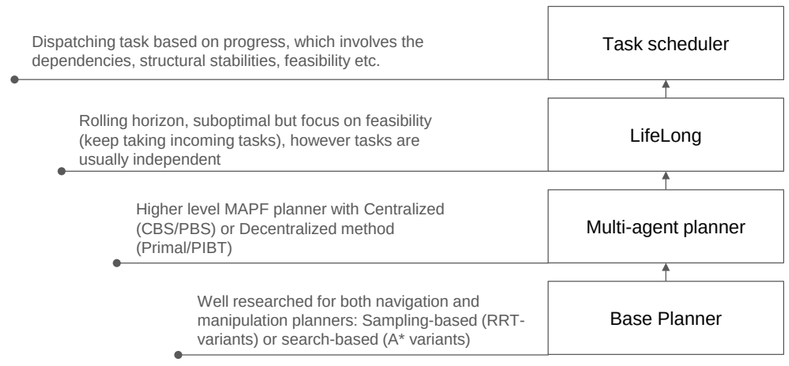


Figure 2. TAMP planning structure

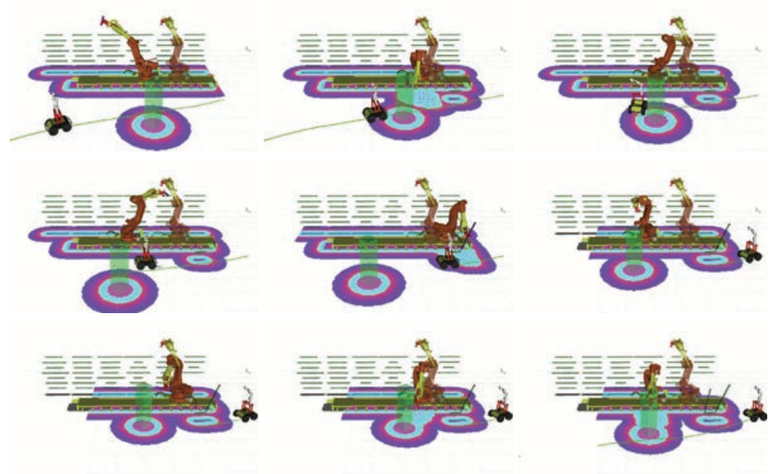


Humans	Global access	Can intervene any time	Highest priority in shared space	Decentralized, Not planned, Upon Request
Type-A robots	Heavy industrial arms on rails /mobile track	Responsible for primary structural tasks	Large safety zones	Slow to reroute
Type-B robots	Mobile cobots	Smaller payloads, resilient recovery	For panels, finishing, inspection, assisting humans	Higher flexibility, replans/ yields first

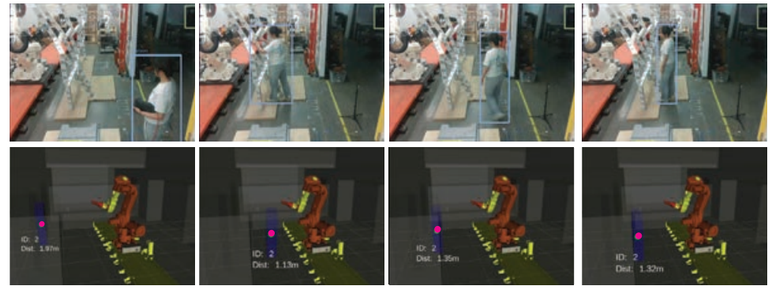
Figure 3. Agent Typologies and definition

Machine Learning and AI assistance in Human Robot Collaboration

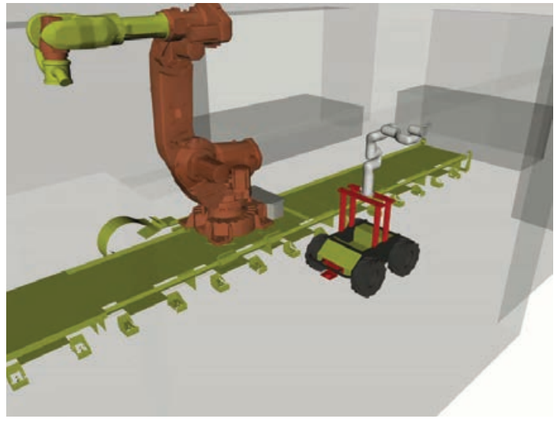
This work deploys light-weight, on-device perception for construction robots. Small vision models process stream images with pointcloud validation to detect human position in congested space, track moving workers, and update ROS planning constraints. The system prioritizes low-latency safety response, material localization, and verified perception before robot motion is executed in shared assembly tasks.



Robust Planning encountering spontaneous moving human in both UGV navigation and motion planning



In-lab validation of real-time human figure 3D tracking using YOLO machine learning model





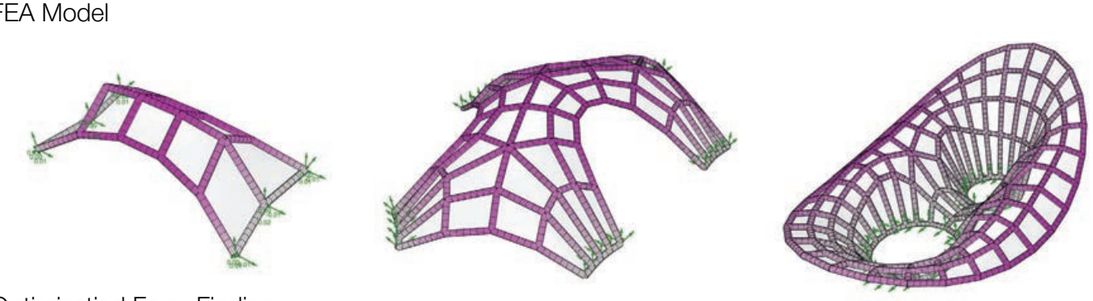
Digital twin of physical robotic construction setup.

Finite Element Structural Analysis in Multi-Robot Assembly

Wei, J., Lee, J., & Bard, J. (2025, October). Sequencing optimization of stability-aware robotic assembly for discrete frame structures. In Proceedings of IASS Annual Symposia (Vol. 2025, No. 3, pp. 1-10). International Association for Shell and Spatial Structures (IASS).

This research investigates a stability-aware robotic assembly process for discrete frame structures. The approach generates sequencing for robot target assignment that provides temporal support for stabilizing the structure during construction, thereby enabling scaffold-free assembly. We integrated iterative finite element analysis to greedy search for optimal assembly sequences by: 1) assuming a temporary rigid support by robot at its current assembly location; 2) finding the next component that results in the minimal average displacements across members of the in-progress structure through greedy search; and 3) introducing penalties to re-rank low average displacement options that contain significant displacement outliers. This digitally simulated sequence-finding pipeline minimizes displacement throughout the assembly process of long-span, free-form, linear element structures joined by rigid connections. The result establishes a high-level foundation for target-sequential assignment in robotic assembly. The proposed method is generalizable to discrete frame structures, as demonstrated in this paper through case studies of funicular shell structures with a multi-robot step-up.

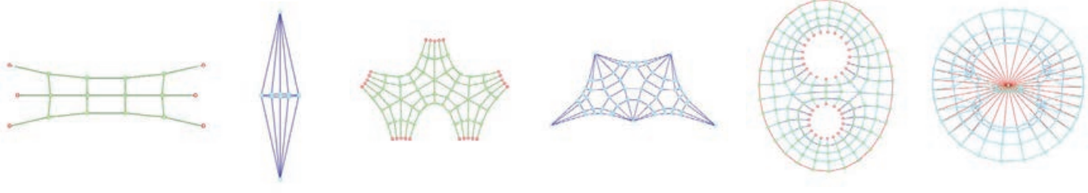
FEA Model



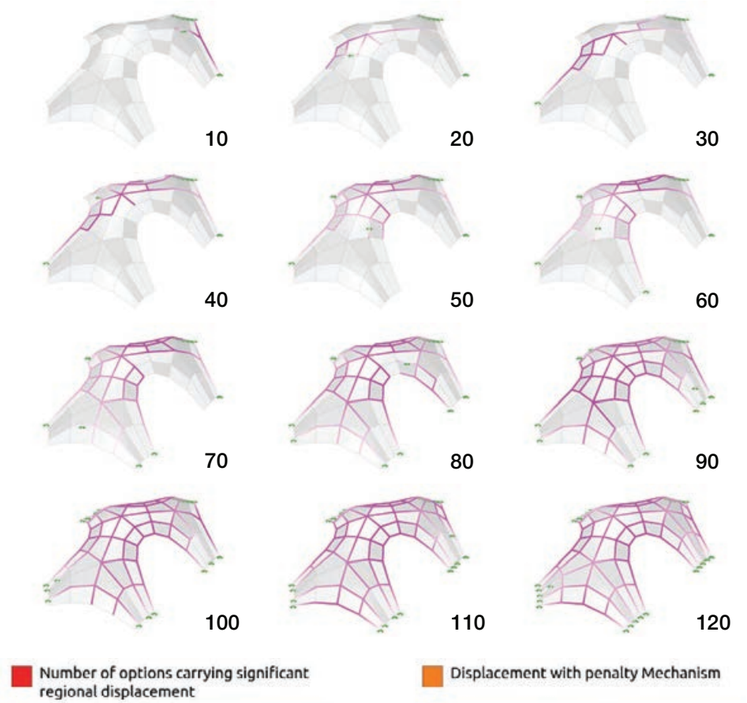
Optimizatied Form Finding

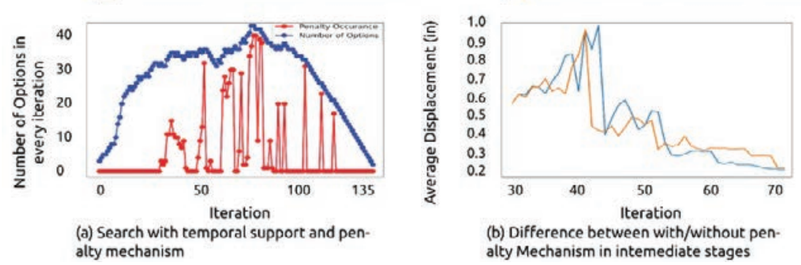


Force Graph



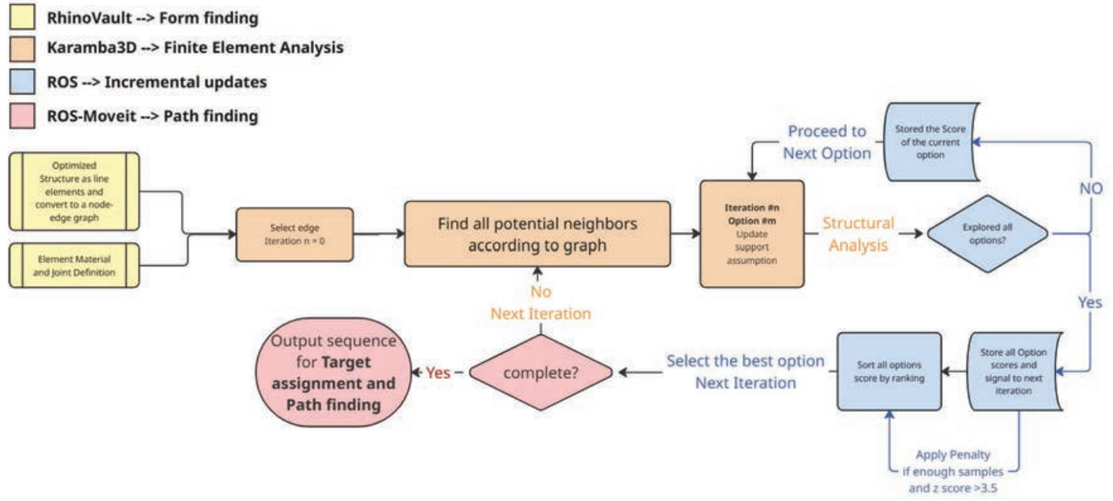
Stability in robotic assembly is not only a final-state structural problem, but a construction-sequence problem. This research asks how robotic mobility and temporary support can reduce reliance on conventional formwork while maintaining stability throughout assembly. Iterative FEA is used to evaluate candidate sequences and select robot assignments that minimize displacement during construction.





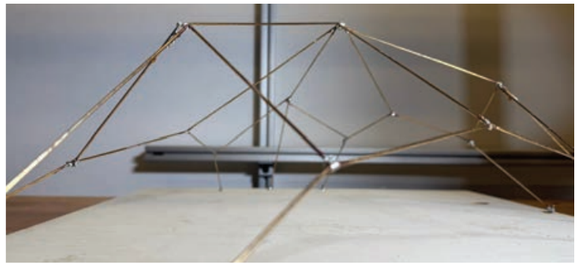
(a) Search with temporal support and penalty mechanism

(b) Difference between with/without penalty Mechanism in intemediate stages



Multi-Robot physical validation for stable assembly sequencing

Thin copper rods assembly sequence optimization based on Finite Element Analysis using dual-manipulator. Connections are soldered manually.





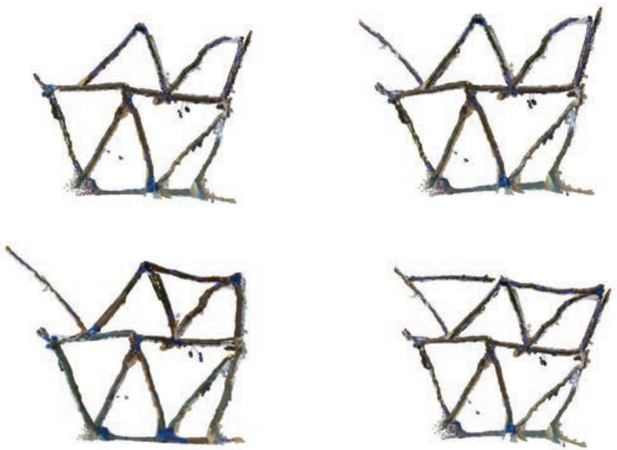
Responsive Robotic Assembly with Heterogeneous Materials

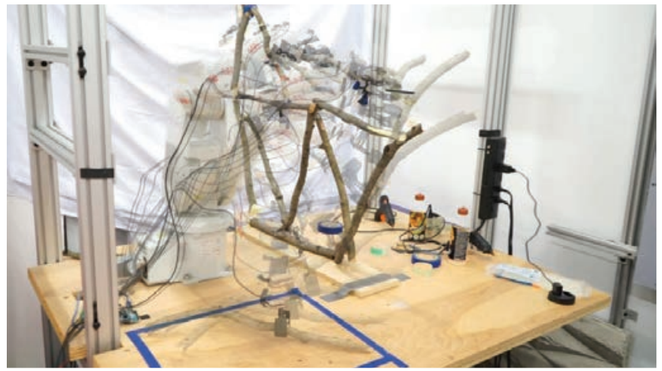
Jiaying Wei, Daniel Cardoso Llach, and Joshua Bard. “Responsive Robotic Assembly System With Heterogeneous Materials: A Case Study with Unprocessed Wood.” ACADIA 2023: Habits of the Anthropocene: Scarcity and Abundance in a Post-Material Economy, vol. 2, pp. 352–360, 2023.

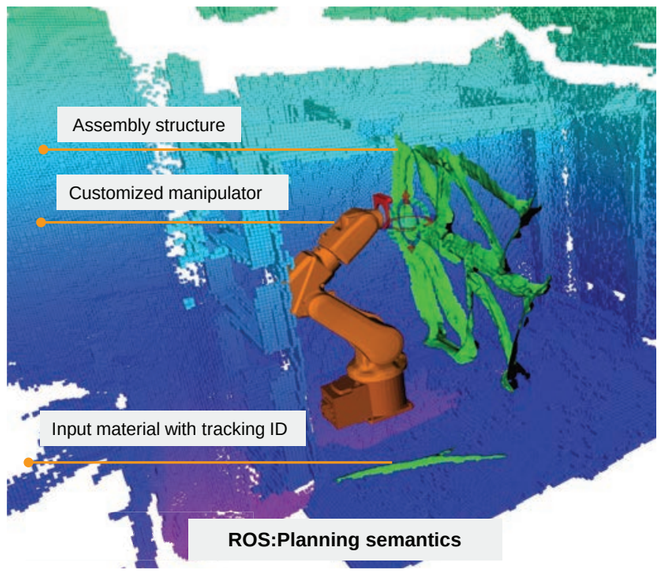
This paper develops a ROS–Grasshopper framework for responsive robotic assembly with non-standardized tree branches. Combining adaptive path planning, material analysis, sensor-based calibration, and parametric design, the system links robot trajectory planning with real-time design decision-making. Through iterative prototypes using branches collected from local parks and forests, the research addresses the geometric and tectonic challenges of irregular biological materials while bypassing industrial standardization. The framework enables adaptive, mass-customized fabrication with heterogeneous natural resources, using 3D mapping, empirical design solving, and efficient data organization. By employing raw and scavenged wood, it proposes a more ecological, resourceful model of architectural robotics.





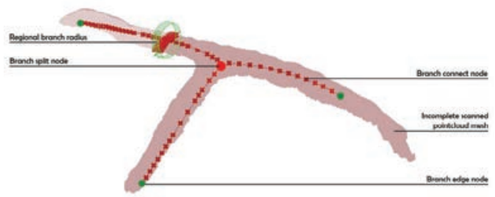


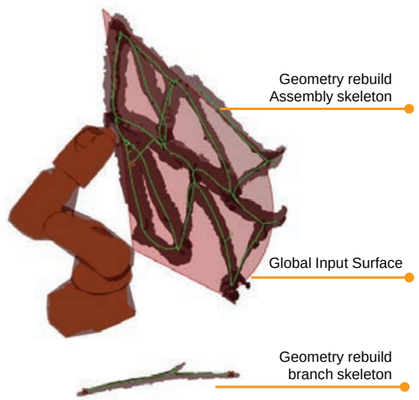




ROS:Planning semantics

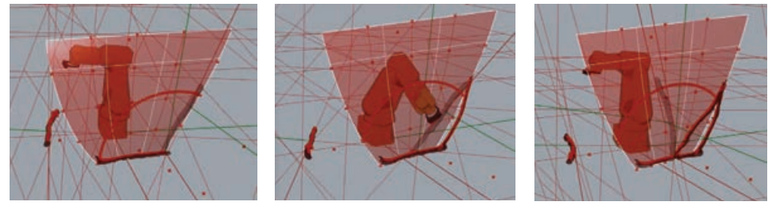
Each branch is scanned as a physical input rather than assumed as a standardized part. RTAB-Map and Octomap reconstructs the work scene, while bounding-box filtering, clustering, and skeleton contraction extract branch geometry, nodes, and connection logic. ROS maintains collision-aware planning and object attachment states. Grasshopper receives simplified branch and assembly data, applies UV-guided placement rules, and returns pick-place goals for iterative human-supported assembly.





GH:Design semantics

A 2 m × 5 m arch structure assembled from six modular branch structures demonstrates how distributed robotic operations can scale toward an architectural design product.









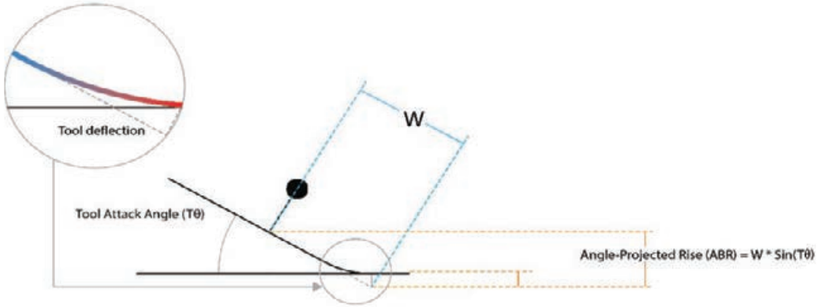




Diffusion Policy in AEC Finishes Automation

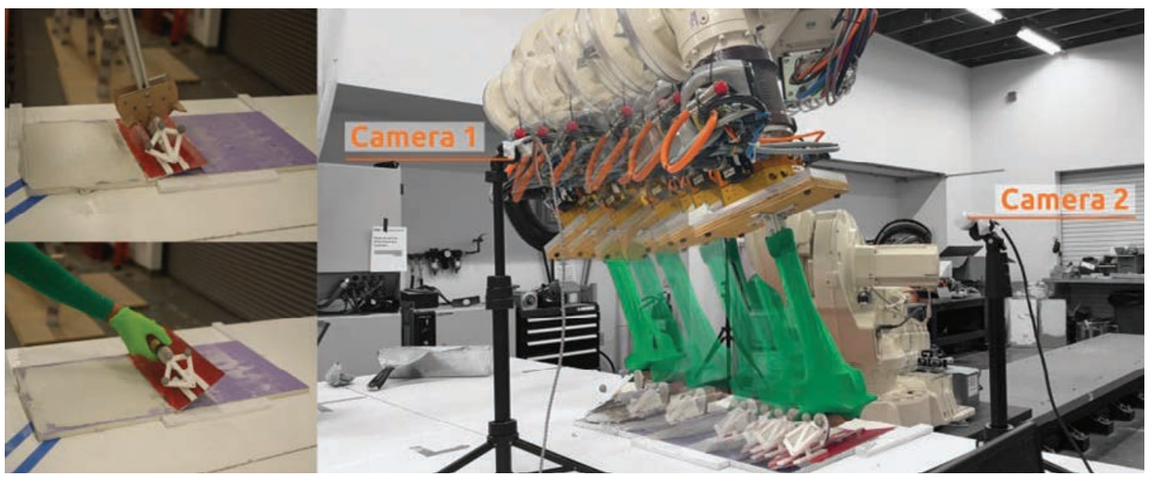
PI: Prof. Joshua Bard
ACADIA 2026
Accepted

This Project introduces a framework for freeform robotic shaping of hard-set materials with three main components: stroke sequencing, stroke mechanics, and coverage supervision. We explored the test case of plaster rendering applying a layer(s) of plaster over a wall or ceiling surface - to gain new insight into the nuanced stroke mechanics required to smooth hard-set materials. Our team developed a human demonstration capture pipeline using MOCAP and depth cameras to analyze and model key attributes of troweling across a trajectory, including tool velocity, attack angle, and inferred tool deflection (a proxy for tool pressure). We applied the demonstration data to a diffusion policy-based approach, which we compared to the human demonstrations it trained from and a statistically inferred offline planning approach from the same dataset. Our findings demonstrate a reliable data capture and training pipeline that supports robotic systems capable of covering target areas with moderate overall finish quality and achieving autonomous general task initiation and completion. These results point towards a promising domain of skill transfer for complicated, multi-modal, long-time-horizon tasks in robotic construction.

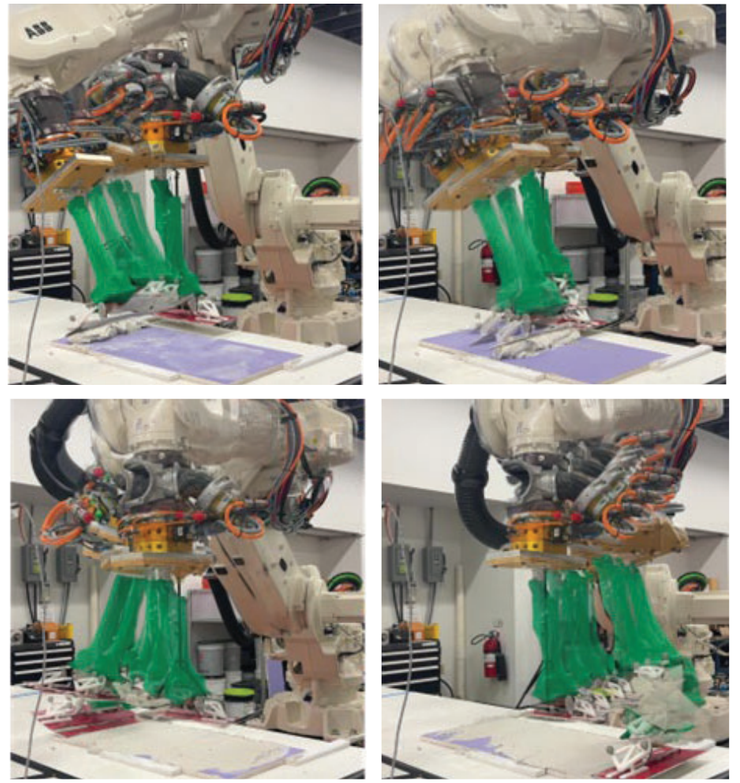


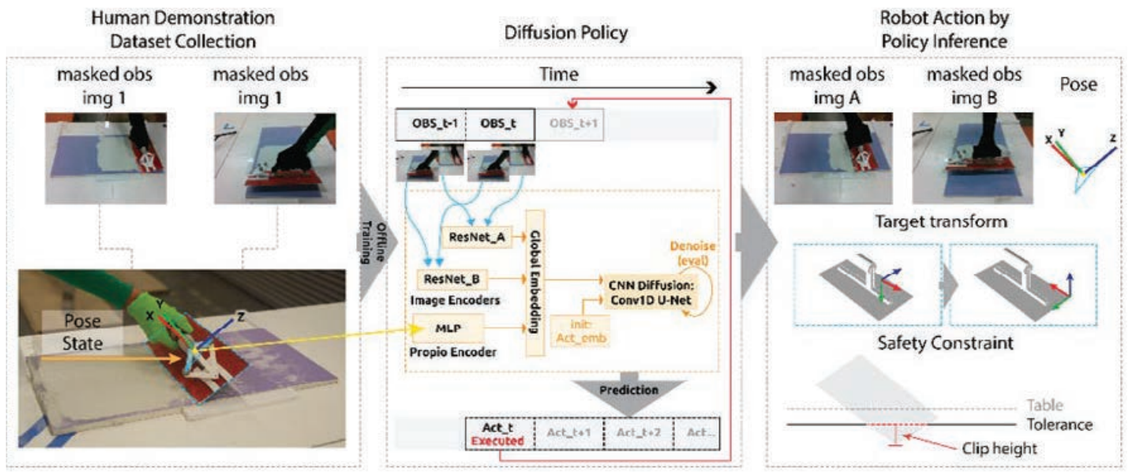
Deflection Ratio (IDR)
$DR = \max(0, TH)/ABR$

Inferred Deflection Percentage(IDP) in a dataset
$ID\% = DR_x/\max(DRi)$
$D=\{DR_i \mid i=1,\ldots,N\}$

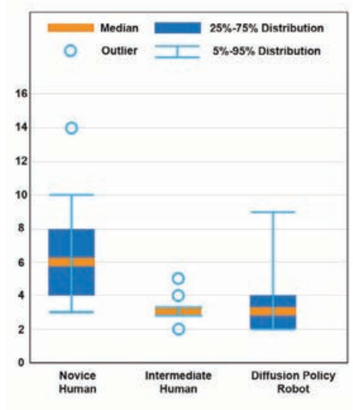


Human troweling demonstrations are converted into synchronized visual observations and 6-DoF tool poses, then trained as a diffusion-policy controller. During deployment, paired camera views and current pose condition the model to predict the next trowel motion. Predicted actions pass through target transforms, and clipping-plane safety limits, allowing supervised autonomous plaster spreading on an ABB industrial arm.

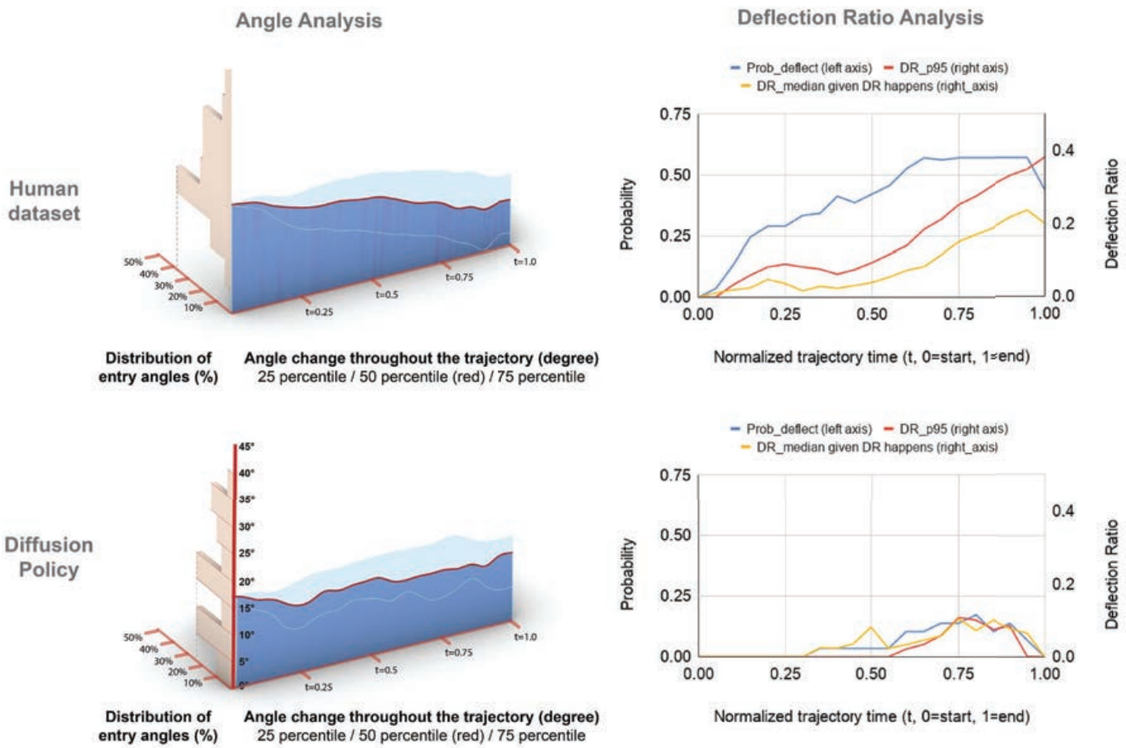




Training and Inference Procedure



Performance of efficiency in novice human plasterer vs. Intermediate human plasterer vs diffusion policy trained from Intermediate human plasterer dataset



The analysis compares human demonstrations with policy-generated troweling. Stroke counts show the robot approaching intermediate human efficiency, while angle plots reveal that the policy learns the human trend of progressive blade lowering. Deflection-ratio curves show a more conservative robotic behavior: lower pressure proxy, delayed deflection, and fewer extreme contact cases, explaining its thicker but controlled finish quality.

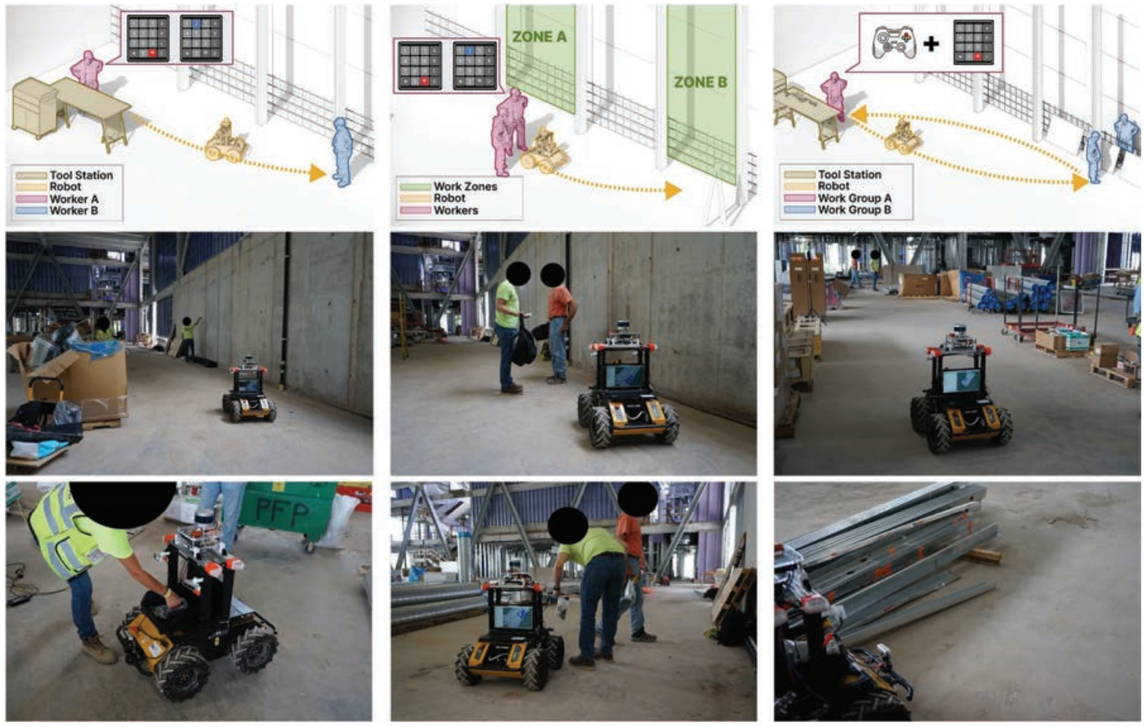
Rethinking Automation in Construction

Project timeline: 2022 - 2024

PI: Dr. Daniel Cardoso Llach
co-PI: Dr. Jean Oh

Yuning Wu, Emek Erdolu, Jiaying Wei, Jean Oh, and Daniel Cardoso Llach. “Robot in the Loop: A Human-Centered Approach to Contextualizing AI and Robotics in Construction.” Construction Robotics, vol. 9, no. 1, p. 1, Springer International Publishing, 2025.

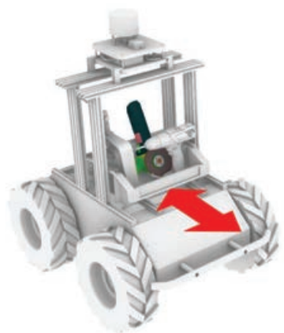
This research investigated the multidisciplinary design and evaluation of a robot to assist carpentry workers on a building site in the United States. We draw from an extended ethnographic engagement with construction workers to inform the design of a prototype rover able to accompany and deliver tools to carpentry workers installing formwork panels. Following a review of the state of the art in construction robotics and ethnography in technology design, we show how insights drawn from our ethnographic study informed the robot’s design as well as its innovative deep reinforcement learning (DRL) architecture for social navigation. Evaluating the robot in simulations, lab settings, and on a construction floor we document its benefits, including apt social navigation and user comfort in construction floors, and reflect on its limitations. Proposing “robot in the loop” as a design pattern combining ethnographic and technical design research, the article shows how the world of construction might be brought closer to the world of technology design, centering workers’ contexts and experiences in the design of new technologies aimed at supporting them.



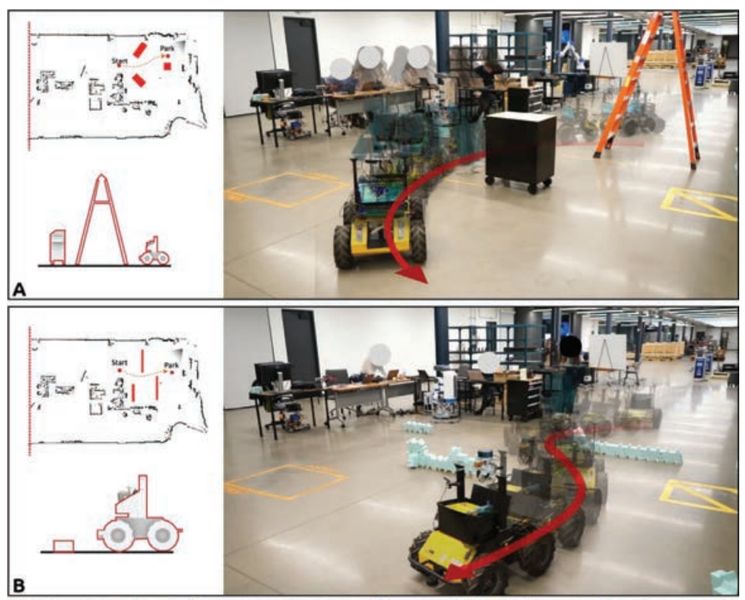
Research Role - Research Assistant:

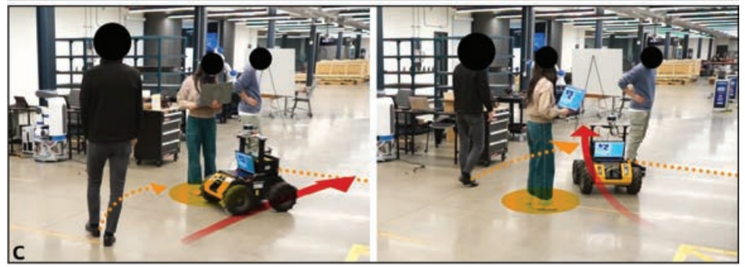
- Robot hardware building
- SLAM Planning stack software infrastructure
- Sensor integration
- On-site demonstration
- Bluetooth remote control
- Figure drafting

This prototype reframes construction robotics as worker support rather than task replacement. Built on a Clearpath Husky, the mobile aide carries carpentry tools and hardware while navigating cluttered construction conditions. The platform integrates 3D/2D LiDAR, RGB-D sensing, onboard computing, Bluetooth control, and a custom tray. Lab tests validate movement among tall obstacles, low debris, and dense human activity.

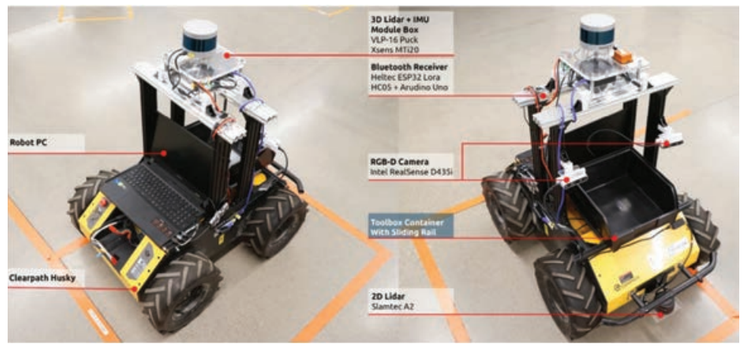


Testing of navigation among complex obstacles and dynamic human obstacle in the lab

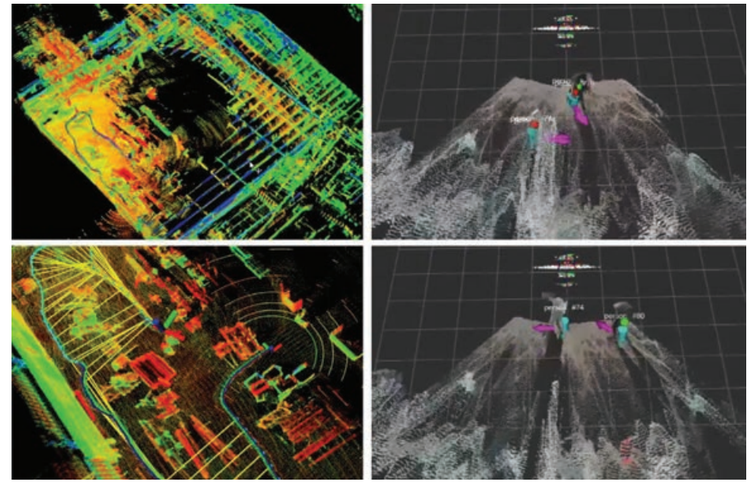




Customized UGV Robot for construction site navigation based on Clearpath Husky platform

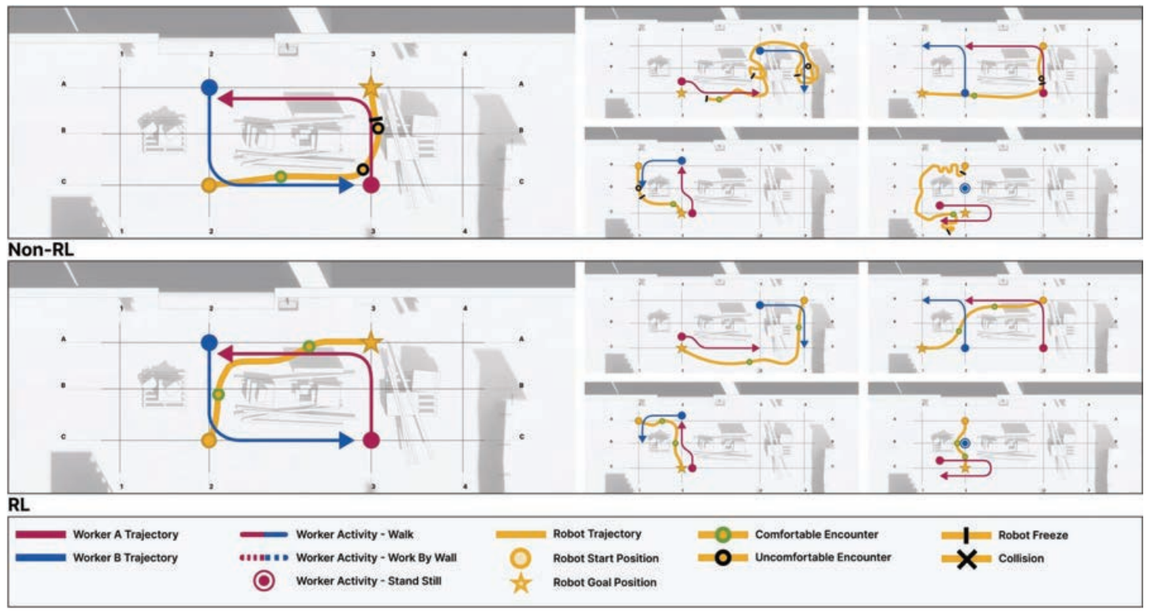


The navigation system combines LOAM-based 3D reconstruction, worker detection, trajectory tracking, and reinforcement-learning-assisted rerouting. Point-cloud maps capture evolving site geometry, while human tracking estimates worker position and movement. A hierarchical planner uses RL to select socially comfortable paths, reducing freezing and improving delivery behavior when the robot encounters multiple workers in narrow construction corridors.



(left) 3D reconstruction of the physical construction environment in the final demo; (right) human tracking and prediction or orientation with reinforcement learning

Validation of robot rerouting robustness in encountering multiple human agents in narrow corridor conditions.



PEDAGOGY

Teaching Philosophy

Vertical Integration of Interdisciplinary Design | Physical Automation

From Computation to Situated Design and Robotic Construction

Architecture is being reshaped by computation, robotics, perception, and learning-based technologies, not as neutral tools, but as forces that transform how design is conceived, tested, materialized, and evaluated. My teaching responds to this shift through a pedagogy that is technologically ambitious yet grounded in physical consequence: tolerance, calibration, material behavior, human judgment, and the uncertainty of construction environments.

Within a five-year architectural curriculum, my teaching can support multiple levels: early computational thinking and representation; intermediate courses in parametric design, simulation, and digital fabrication; advanced studios and seminars that connect robotics, perception, material systems, and construction logics. Across this trajectory, students learn that computation is not only a tool for generating form, but a way to reason through tolerance, sequence, labor, assembly, site conditions, and feedback.

My courses in generative modeling, computational design, architectural robotics, and perception-based fabrication form a coherent pedagogical path, but they are also designed to integrate with studio, technology, and research teaching. I aim to help students become architects who can critically use emerging technologies, translate design intention into material action, and contribute to new forms of architectural practice grounded in both provisioned automation and construction.

2023 - 2024

Teaching Assistantship

B.Arch Core Course

- Generative Modeling
- Fundamental in Computational Design

2024 - 2025

Senior Teaching Assistantship

- Intro to Architecture Robotics
- Fundamental in Computational Design

2025-2026

Sole Instructor

- Architectural Robotics with Perception
- Intro to Architecture Robotics (STA)

2026 ->

Sole Instructor with curiculum development

- Architectural Robotics with Perception
- (TBA) Studio Teaching engagement

Architectural Robotics with Perception

Spring 2026

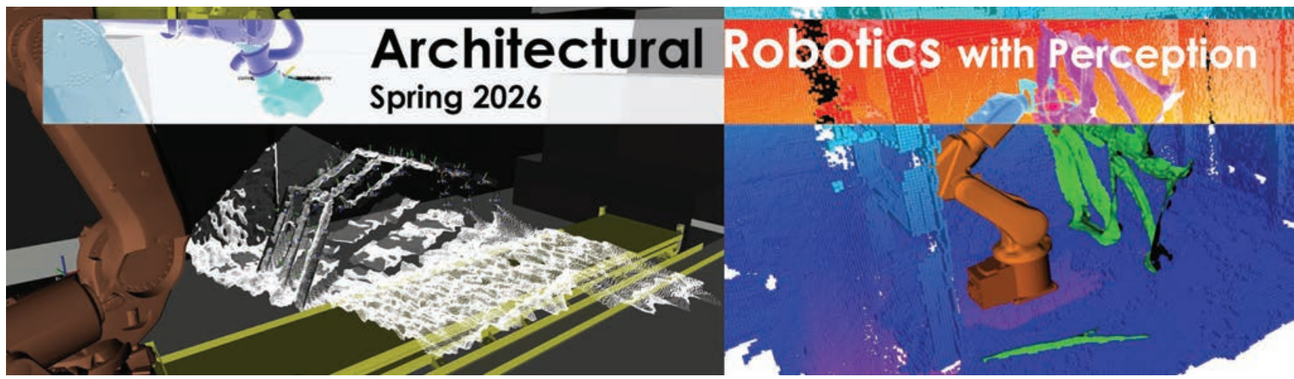
Sole Instructor

Enrollment: 12
Credits: 6

Faculty Course Evaluation Result: 4.71/5.0

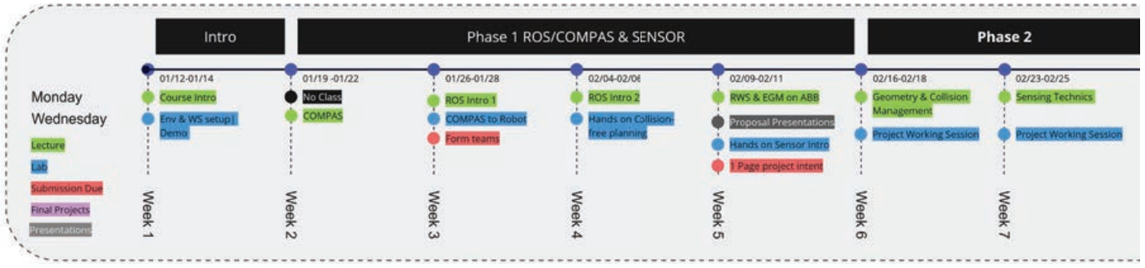
This course is an advanced architectural robotics seminar follows “48-555/48-755: Introduction to Architectural Robotics.” The course teaches how robots sense, interpret, and act in the built environment, connecting design intent to fabrication. Students learn the fundamentals of camera and depth, real-time sensor-based system workflow, and the deployment of useful techniques. Perception streams are integrated into ROS and MoveIt to build planning scenes, manage frames, and execute perception-guided motion. The labs prioritize reproducible workflows and clear documentation, enabling methods that can be transferred to studio, research, and thesis work. The final project invites students to apply a sensing-to-action pipeline to a problem in architectural robotics, such as timber assembly, fixtureless positioning, additive manufacturing, or quality assessment, using their own data and constraints.

Responding to interdisciplinary nature and AI development
The majority of the registered students are not expected to have profound CS/Robotics knowledge, provided that this is an architecture-department course for interdisciplinary studies. One of the greatest challenges is to consolidate the necessary skill set and have student comprehend how to quickly hands-on and perform real-time, perception based robotic motion with a robust infrastructure. So that they can start to explore the relationship between perception and materials that correlates to space, computational design (connection to Rhino and grasshopper). As a course developed during the rapid progress of Machine Learning and Large language model, this course encourages vertical integration of AI-assisted package building and off the shelf utilities to boost learning curves and to overcome the challenge of knowledge barriers, while retaining prudent responsibility of AI-generated content by following strict regulation of ‘Perception/Simulation First, deployment after confirmation’. to let student understand the limitation and their responsibility to deploy AI for complex, physical robotic system.



48-757 Architectural Robotics with Perception (ARwP)

Course Schedule Spring 2026 (subject to change)



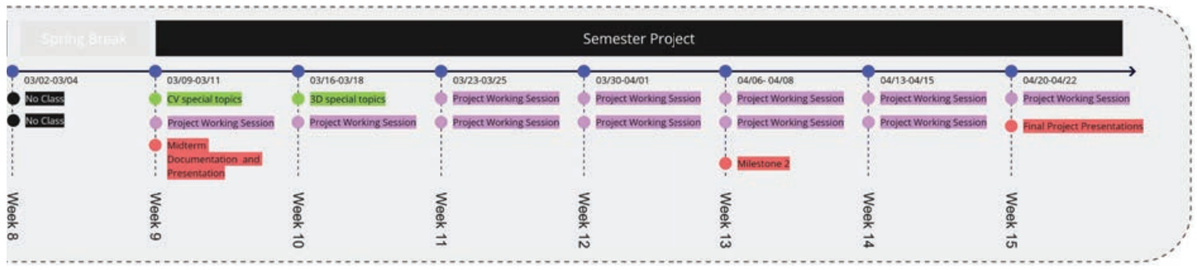
Semester 1/2 - Knowledge Acquirement

Lecture/workshop

- Facilitates class size connection to linux remote system for simulation
- explain basic principles through step by step procedures
- showcase standalone sensor usage

Lab demo by instructor

- Connect simulation practice in workshop to show actual robot deployment
- Provide vision techniques for students to customize later



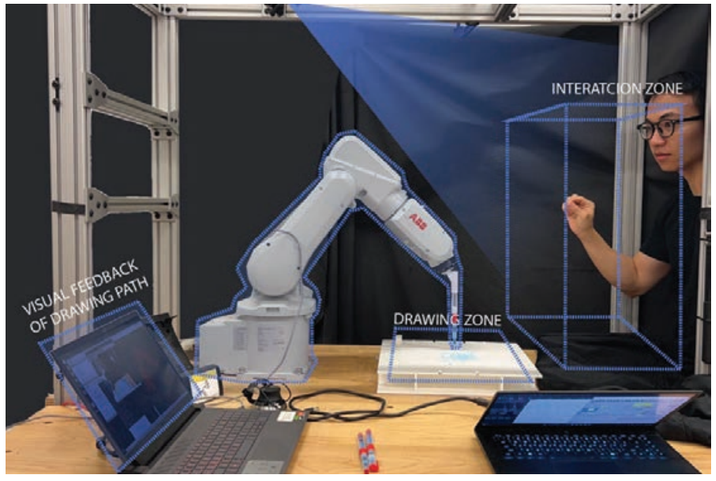
Semester 2/2 - Project Development

Project work session

- Desk Crit
- Debugging session
- Baseline test (minimum viable project)
- Iterative improvement with documentation

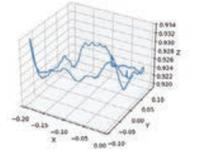
Selected Student Projects

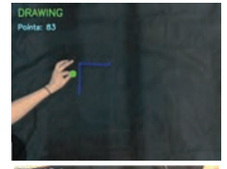
See live demos and extra details at https://www.jiaying-wei.com/arwp-2026

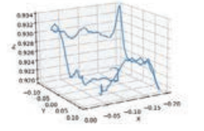


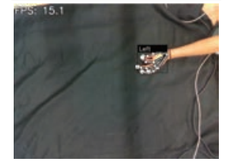




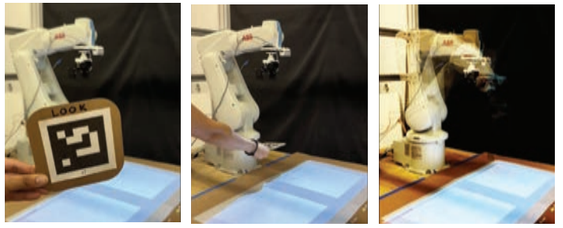


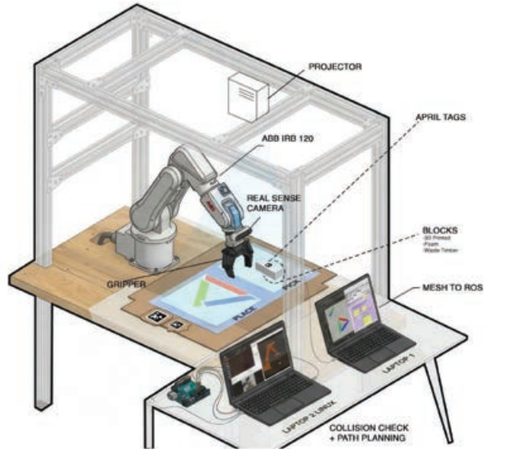


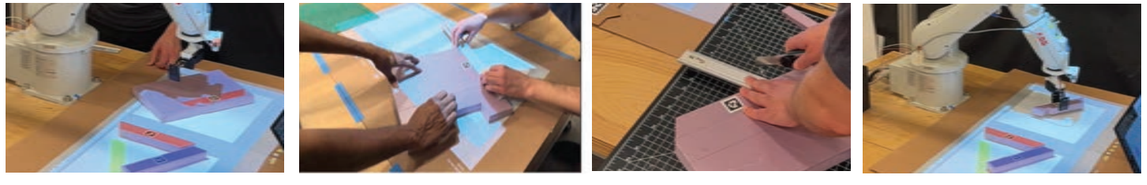




Students use pre-trained ML model ‘Media pipe’ and LLM ‘Claude’ integration into Grasshopper to perform collaborative gestural-indicated drawing on a rolling canvas.







Students use fiducial marker eye-in-hand detection, in combination with 1:1 projection to obtain contour and location of design piece on waste materials. Human performs processing, and robot performs live assembly to construct basic truss elements with interlocking features.

Introduction to Architectural Robotics

2025

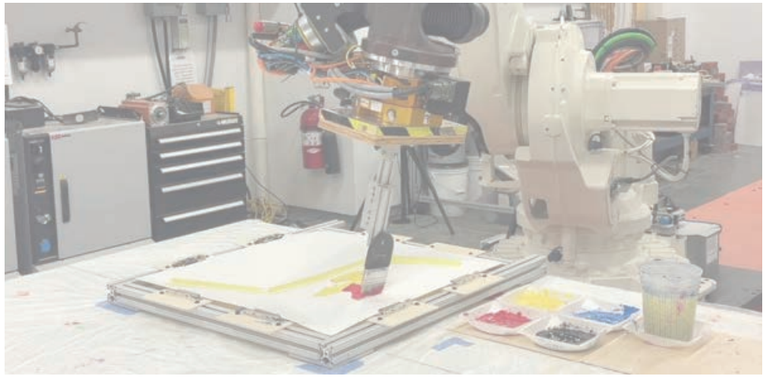
Senior Teaching Assistant
Instructor: Joshua Bard

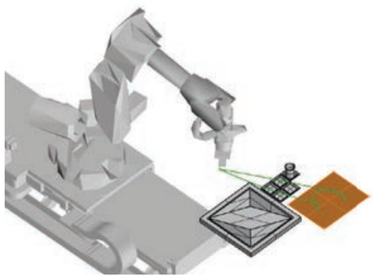
Enrollment: 16
Credits: 9

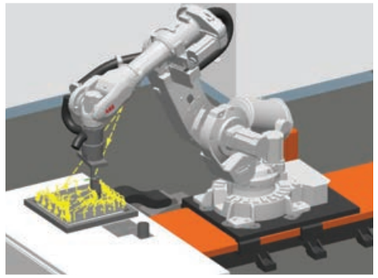
Course development:
ITAR Assignment 2

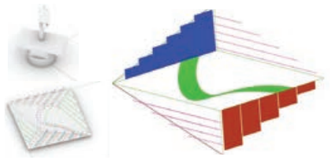
Learning Goal:

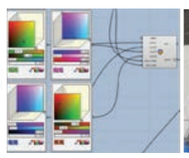
- Familiarity of Rapid code
- Usage of Grasshopper robot-component ->RobotStudio ->execution
- Proper usage of Cartesian motion and non-cartesian motion in robotic execution
- Inverse Kinematics and Joint limits

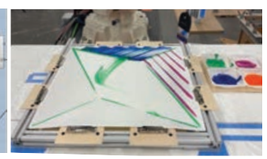


















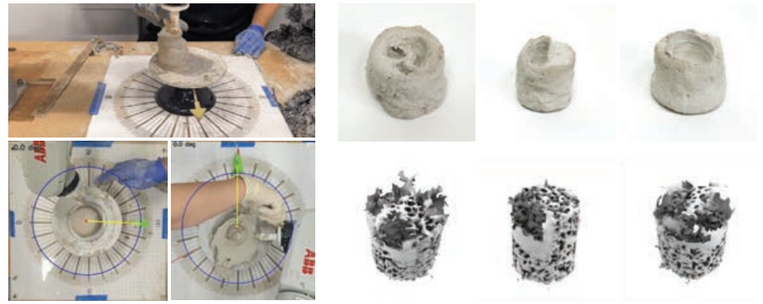


Selected student outputs >>

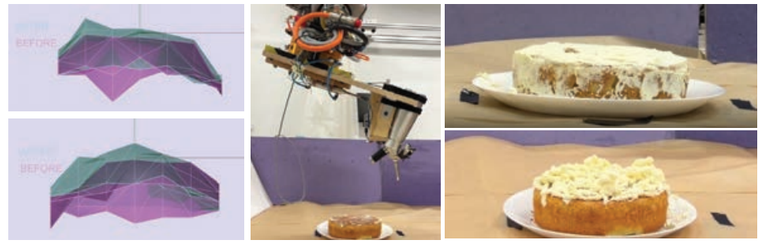
ITAR Final Project

ITAR 2025 promotes the engagement of observations and sensors inside robot/human-in- the loop, Student Projects involves periodic vision-based and infrared IOT devices that combines with
robot trajectories.

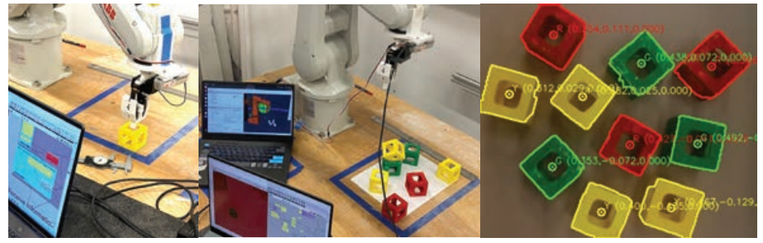
These sensing engagement are not yet fully real-time, but lays a foundation for student to proceed to advanced robotic fabrication and provides early experimentation for various typologies of robotic fabrication



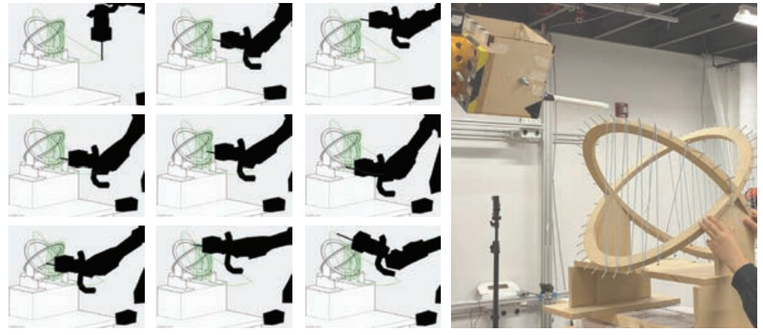
Clay Molding



Robotic Spraying and Layering detection



Visual Language Model with Cubes



Robotic Weaving

See extra details at
https://www.jiaying-wei.com/itar-2025

Introduction to Architectural Robotics

2024

Senior Teaching Assistant

Instructor: Joshua Bard

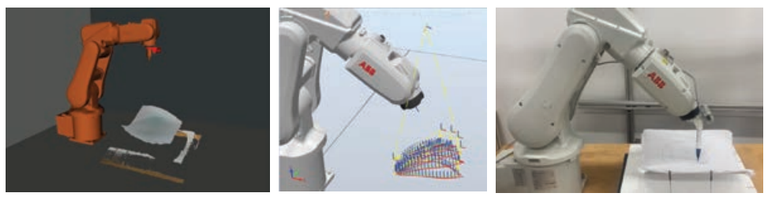
Enrollment: 20
credits: 9

Course development:
ITAR Assignment 2

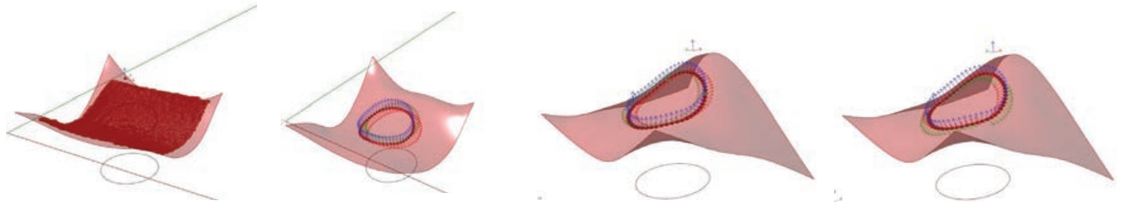
Assignment 2 is the first hands-on project for students to practice Grasshopper->Rapid programming in 3D space, for the first time this assignment introduced the usage of camera perception to obtain 3D mesh or regular surface setup by student, with repeatable calibration method. Student excerise Cartesian movement and physical controller to get familiar with the robot, as well as get aquainted with importance of physical tolerance and compliance.



Selected student outputs

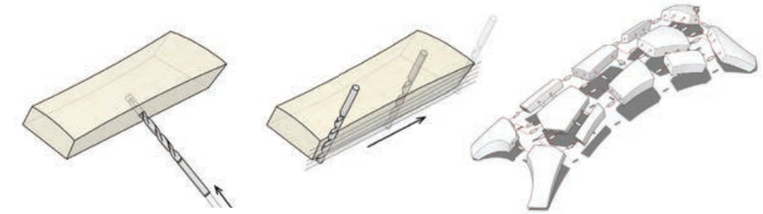


Assignment Template and demo

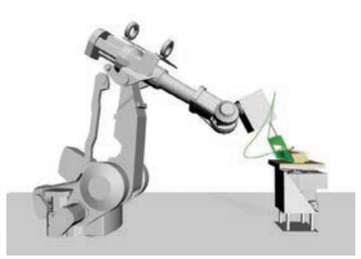


ITAR Final Project

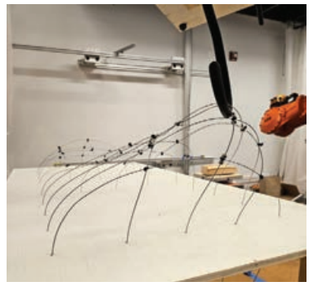
Final team projects are an opportunity for students to explore the world of architectural robotics through design, testing, and physical prototyping. It is also a chance to apply the concepts and workflows learned in the first half of the semester. Each team of 3-4 students will work on a project that explores a novel robotic process. Entry points into the projects can include material exploration, tool development, advanced programming, and sensing. Each team has the option to develop an independent topic, in conversation with the instructional team, or to extend the shared project from HW-2.



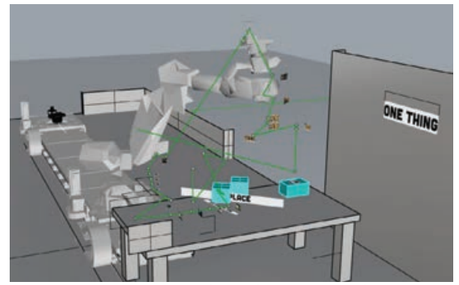




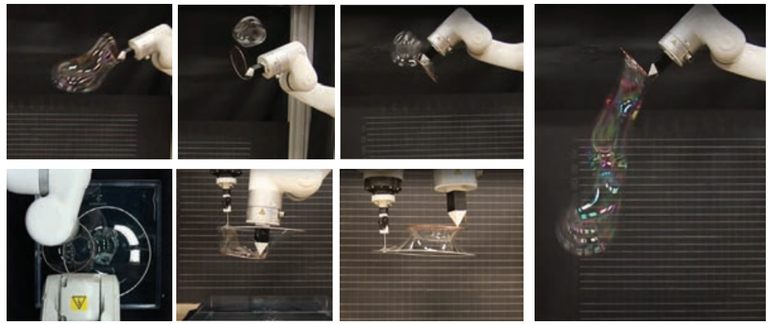
Compression only bench



Wire Bending



Robotic cinematography



Robot bubbling - tension structure



Robot clay 3D printing with topography perception

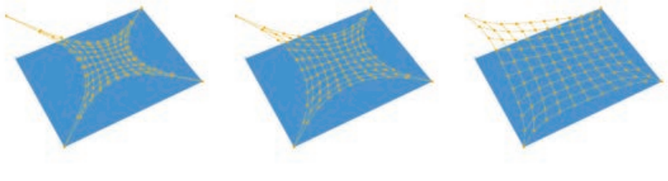
See extra details at
https://www.jiaying-wei.com/itar-2024

Selected Student Projects ->

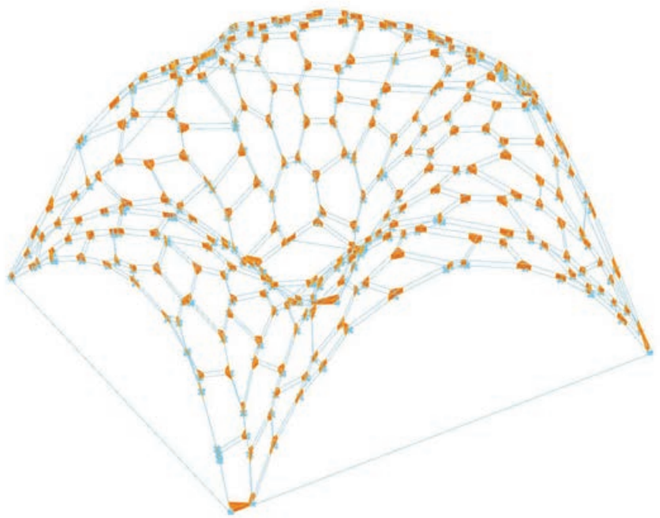
Fundamentals in Computational Design

2024 Teaching Assistant
Kangaroo Workshop

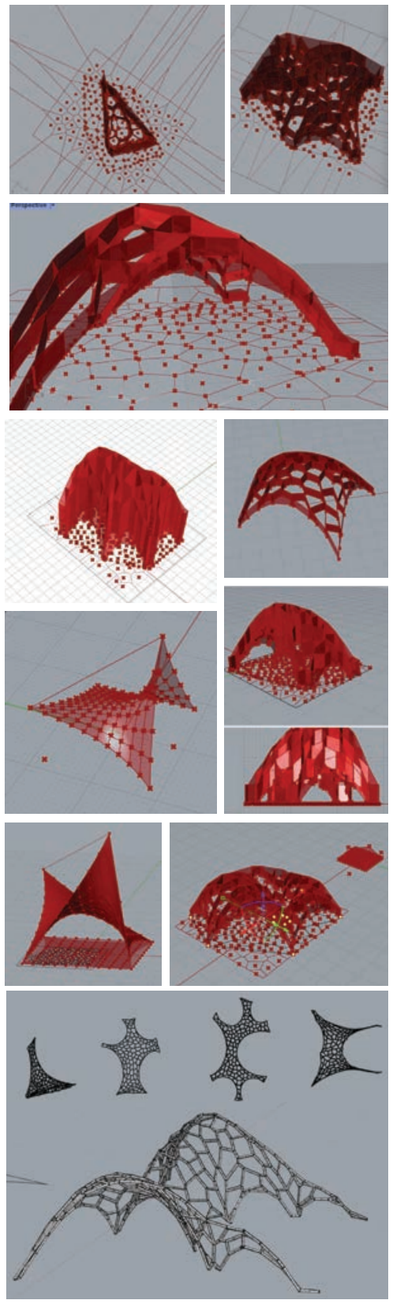
This Kangaroo workshop was prepared for Fundamentals of Computational Design, a required B.Arch course. Students used Grasshopper templates to explore tensile structures, voxel grids, parametric generation, and digital-fabrication decomposition. The workshop connected simulation-based form finding with fabrication-aware organization, and several teams extended the template into their final projects.







student workshop results

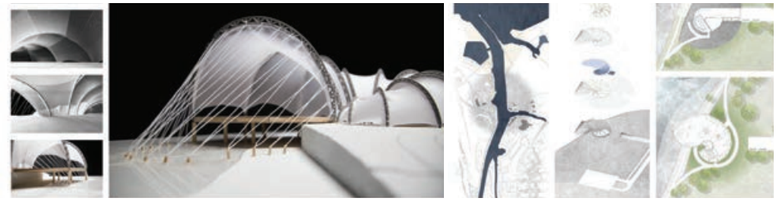


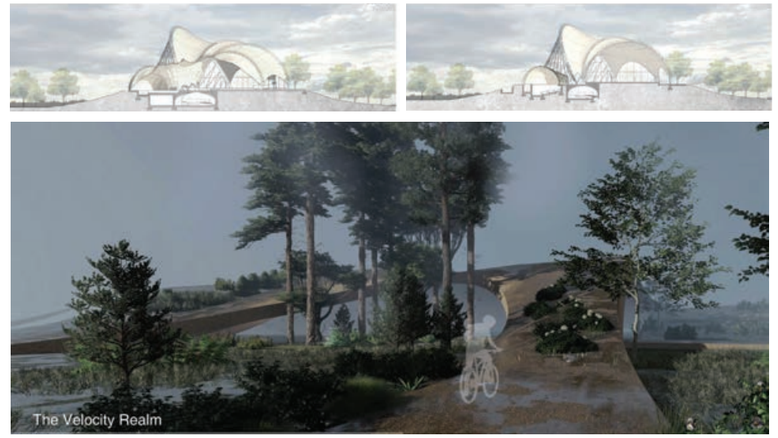
Design Projects

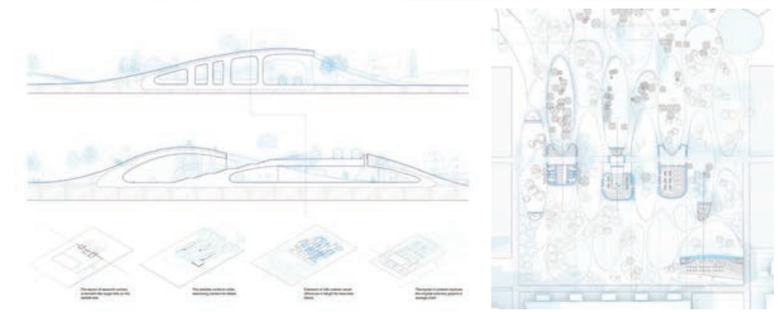
Prior to attending MSCD and PhD CD in CMU, Jiaying Wei completed Bachelor of Architecture in Cornell University. The following presents selected design projects during the studies, followed by professional contribution in the architecture design firm.

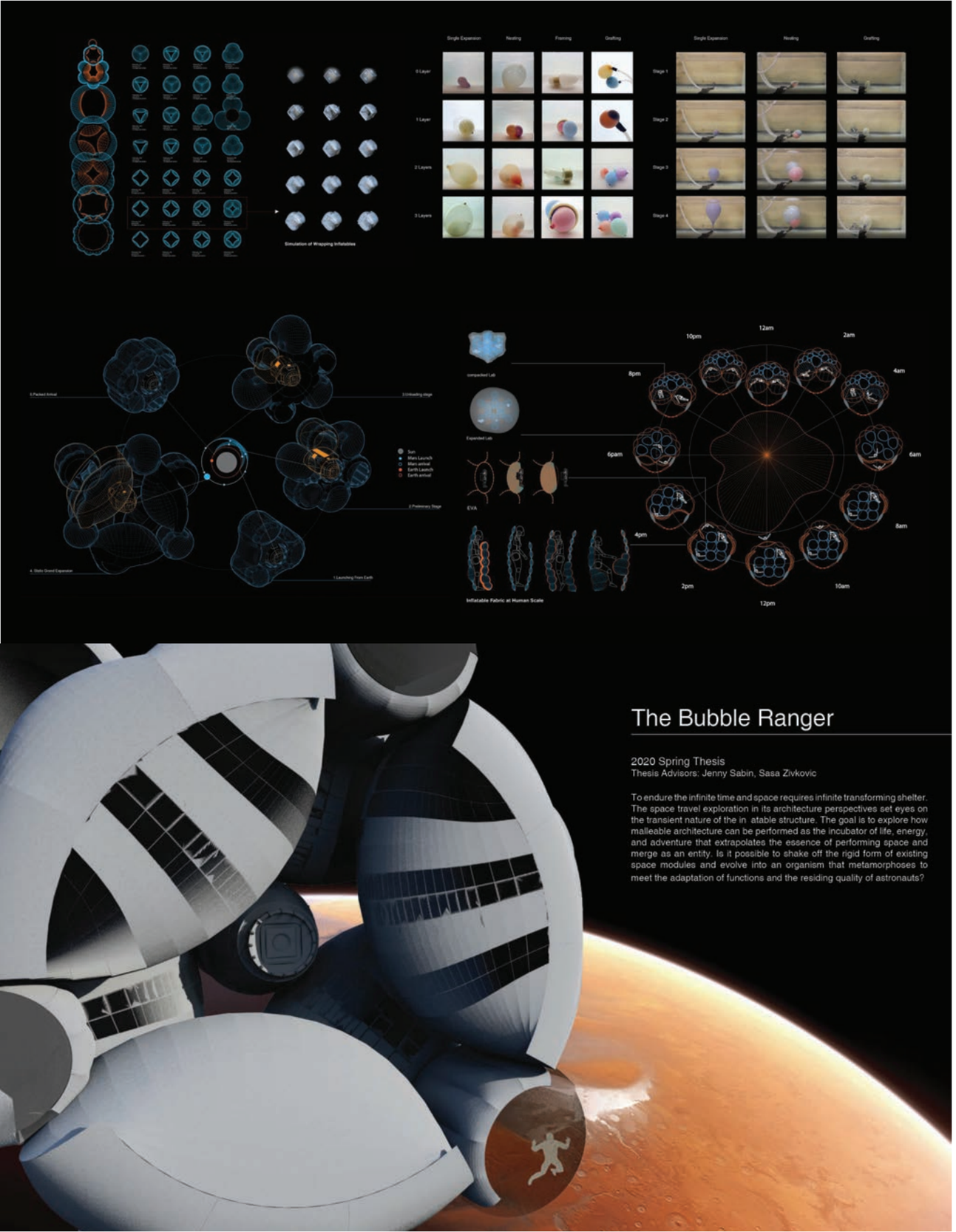
These academic design projects demonstrate an architectural foundation in spatial composition, environmental analysis, tensile simulation, digital fabrication, and computational form-making prior to my graduate research in architectural robotics.











Professional Practice Contributions

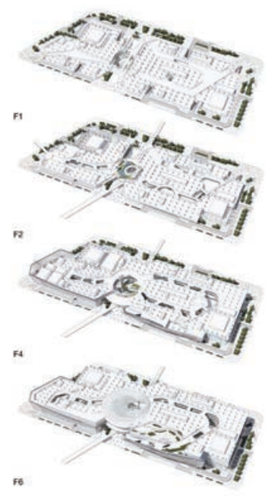
Selected collaborative architectural work, AECOM China Commercial Sector, 2020–2021

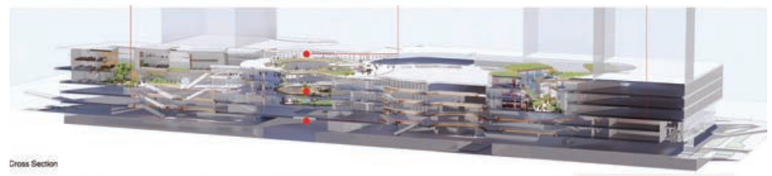
Director: Paul Lee

Competition Entry, China

Role: junior architectural designer; substantial contributor to 3D modeling, drawing post-production, diagram development, and competition presentation drawings under senior project leadership.





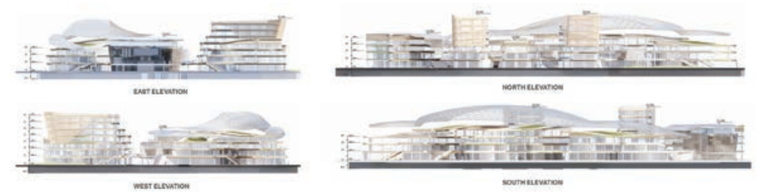


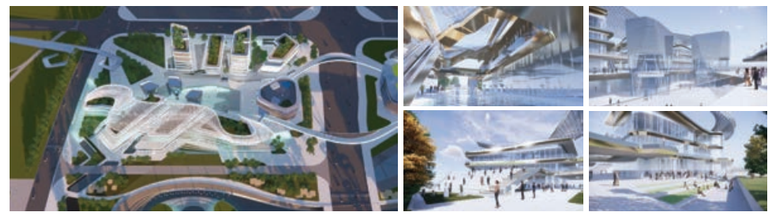


Built Commercial Complex, China

Role: junior architectural designer; substantial contributor to selected drawings, modeling, rendering and design-development materials under senior project leadership.







Selected materials are included solely for private academic review. Projects were completed as part of collaborative professional teams; authorship and ownership belong to the respective firm, project team, and/or client. Identifying information is limited due to collaborative authorship and project-disclosure considerations.

Computational Design | Architectural Robotics | Human-Centered Automation

Research · Teaching · Design