

Of Hands and Robots: Creativity and Learning in Architectural Robotics

Daniel Cardoso Llach
Carnegie Mellon University
201 College of Fine Arts
+1 857 272 6181
dcardoso@cmu.edu

Ardavan Bidgoli
Carnegie Mellon University
403 Margaret Morrison Building
+1 814-777-8873
abidgoli@andrew.cmu.edu

Shokofeh Darbari
The Pennsylvania State University
147 Stuckeman Family Building
+1 814-865-6112
sud213@psu.edu

ABSTRACT

This paper explores ways to incorporate robots into design education, especially in architecture, in ways that privilege students' visual, tactile and spatial engagement with design problems. The paper is informed by constructionist theories of learning and studies of science and technology (STS) re-thinking agency as relational and distributed. We use these lenses to document two introductory learning experiences in architectural robotics, conducted as part of an architecture graduate course. The exercises combine robotics, scripting, model-making and sketching in ways that emphasize, and take advantage of, designers' visual, spatial, and material sensibilities, as well as the contingent nature of human-robot encounters.

CCS Concepts

• Applied computing → Architecture (buildings)

Keywords

Robot-Human Collaboration; Material Agency; Architectural Robotics; STS; Design Education.

1. Introduction

Interactions with robots are mediated by software interfaces, programming languages and technical protocols that introduce challenges to open-ended design exploration, particularly for learners without a strong computational background. A constructionist learning tradition developing over the last century emphasizes student-centered [1], project-based [2] and material-informed [3] approaches to design education. Can these notions be incorporated into architectural robotics pedagogy? Recent examples of robotics in architecture have started to explore this question, highlighting model-making and programming literacies [4], acknowledging that technological systems engender the need for new skills as well as opportunities for creative human-machine exploration [5, p.173]; the importance of computational literacies in design [6]; and ways in which inquiry-based learning might offer advantages over goal-specific instruction methods [7].

From another disciplinary perspective, recent work within Science and Technology Studies (STS) has offered useful tools to re-think agency as relational and distributed across social, technical and material actors [8-10], which have been usefully deployed to

interpret design and construction processes in architecture [11-13]. In a design learning context, combining insights from constructionism with a relational notion of agency opens a novel space of inquiry that this paper starts to outline.

The paper documents two learning experiences, developed during a graduate course in architecture taught by the first author with the assistance of the second and third authors. The exercises were designed to combine different types of analog design media with the interfaces and languages of the robot. Our observations suggest open-ended exercises in architectural robotics are not only possible but also encourage a constructionist engagement with technologies, materials and visual information, which can be rewarding and pedagogically productive. Further they suggest that designers' own bodies act as modelling environments for robotic operation design, and that human-assistance in architectural robotics can offer opportunities for creative design exploration.

2. The body as a design space

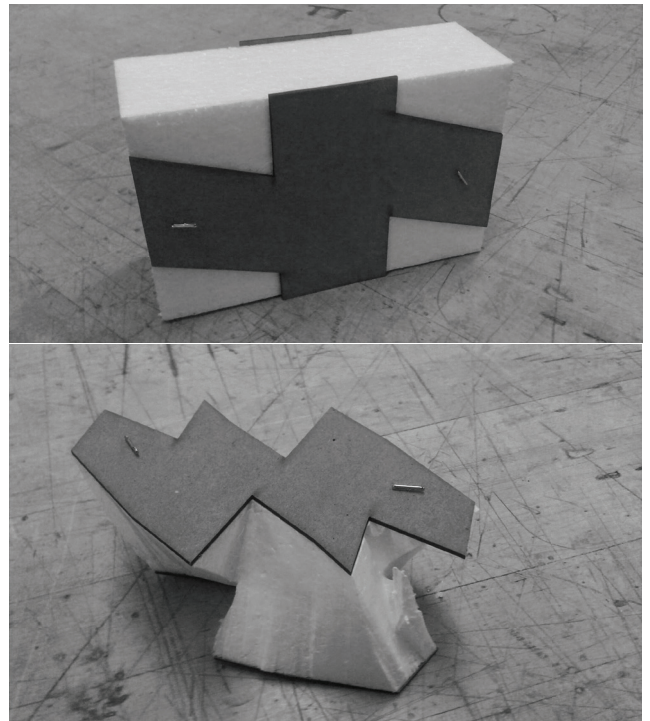


Figure 1. The process of manually producing a module using a hot-wire cutter was aided by templates made out of chipboard.

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The first exercise invited two students to design a modular architectural component that could be produced using a robot-mounted hot-wire cutting tool. The modular component was developed through sketches, digital 3-D models and hand-cut polystyrene models (Figure 1), which allowed them to visualize the range as well as the sequential nature of the robot's movements. Crucially, not only visualizing through diagrams (Figure 2), but *embodying* the robot's motion, enacting it with their own bodies when hand-cutting the prototypes, was crucial for the designers prior to encoding these procedures in code form. The physical and digital media became a hybrid modeling space key to the definition of the robotic procedures necessary for producing the block.

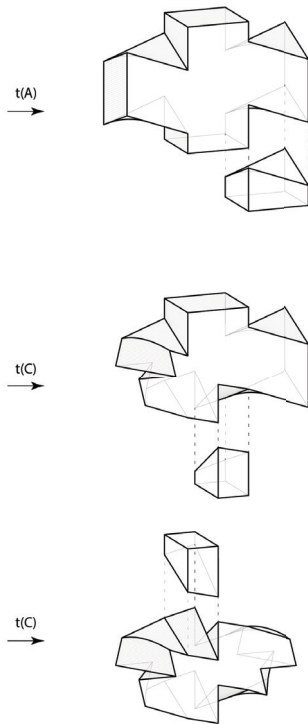


Figure 2. Diagram describing examples of the cutting rules used to produce one module of high-density polystyrene foam.

The encoding of these steps in the robot's language (RAPID) and its operation shed light on another important aspect of designing for robotic fabrication: the inconsistencies that arise between simulations and material effects. Although the operation was carefully specified in the simulation, the first runs burned the polystyrene along several cut lines as a result of differences in the heat applied to the material at turning points, where the hot wire is delayed because of the robot's rotation (Figure 3). While simulations were useful to correct certain errors, the burning of the material was beyond its scope, and was only visible in tests.

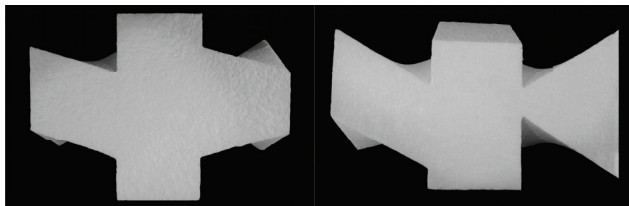


Figure 3. Fine-tuning temperature and speed resulted in more accurate modules.

This exercise shows one way in which analog and digital media may be used in learning to design for robotic fabrication. This combination fosters a tactile and visual engagement with the design problem and, as shown, prompts learners to use their own bodies as a design space for simulation and creative exploration.



Figure 4. A wall configuration created using the robotically fabricated modules.

3. Assisted automation

The second exercise invited teams of three students to ideate and implement a custom “design/make” tool for the robot. In preparation for this task, each student learned to use the robot as a drawing tool —using a mounted LED and long-exposure photographs (Figure 5). This warm-up gave students confidence to start designing more complex robotic tools and behaviours. Teams started sketching and hand-prototyping their tools using a wide range of materials such as chipboard, plywood and recycled metal parts. Three projects took shape through these multi-media explorations: a marker to apply patterns on 3D objects, a clay-carving tool, and a yarn-weaving tool (Figure 6).

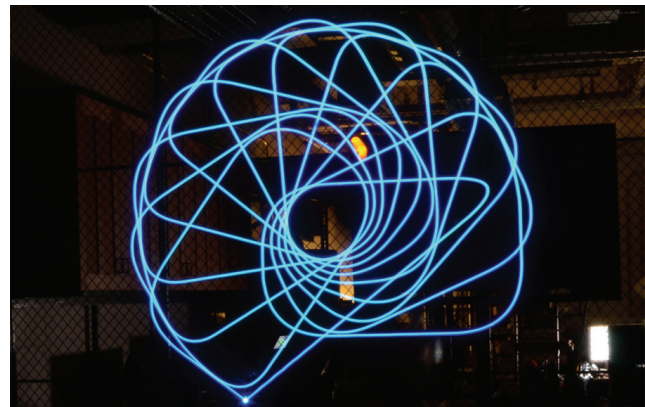


Figure 5. ‘Light drawing’ made by long-exposure photographs of an LED-equipped robotic arm.

An aspect of the yarn-weaving's project illuminated an important aspect of learning to design for robotic fabrication: how contingent is robotic fabrication upon human assistance. Imperfections in the tool forced the team to manually feed the robot during operation, and to correct errors in the robot's disposition of the thread (see Figure 8). Video recordings of this operation suggest a graceful human-machine performance —a dance— rather than a fully automated routine. The result was a geometrically intricate and colorful woven sculpture, but also an example of radical interdependence between humans, software and mechanical systems.



Figure 6. Top: yarn-weaving sculpture by students Vernelle Noel and Xiao Han; Bottom: Robotically carved clay by Mina Rahimian and Rohan Mohana.

4. Conclusion

This paper has documented and reflected upon two introductory design exercises in the emerging field of architectural robotics, conducted within a graduate architecture course taught by the first author with the assistance of the two other authors. The two exercises, which combined digital and analog design media, offer insights into ways to incorporate visual and tactile forms of design exploration into architectural robotics learning. Two unexpected results were observed.

First, we observed how in the definition of a modular architectural component for robotic fabrication designers used their own bodies as simulation tools. This “enactment,” materialized in hand-cut prototypes, was an important vehicle of design exploration. Second, we observed how manual intervention during runtime was used to correct imperfections in the computational specification of a robotic tool, highlighting the profoundly relational and interdependent nature of human-robot design transactions. The embodied enactment of robotic motions, and the improvisational assistance to the robot by humans suggest two new types of human-robot interaction, which might prove generative when considered in relation to questions about architectural robotics pedagogy, and deserve further study.

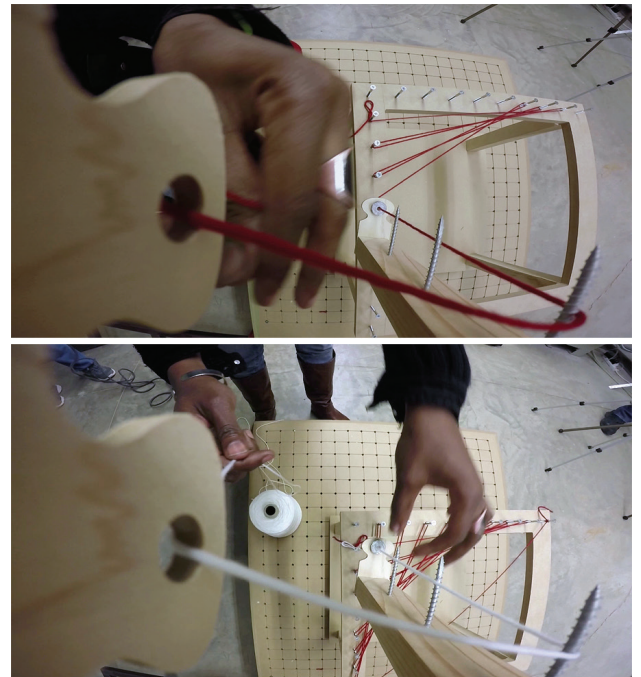


Figure 7. The joint operation of hands and robot here suggest ‘assisted automation’ as a type of human-robot interaction.

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