PEDAGOGY OF ARCHITECTURAL ROBOTICS

An Inconvenient Studio for Unsolicited Innovation

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Abstract. As computation and robotics become more prevalent in all aspects of architecture, their impact on education assumes greater importance. The paper presents the outcomes of a collaborative undergraduate architectural design studio that investigates the realms of architectural robotics and computation by stepping into the fecund intersections between multiple disciplines. The pedagogical prototype, Unsolicited: An Inconvenient Studio, broadly focused on the topics of robotics and responsive architectures. The notion of robotics was interpreted to include a range of robotic technologies and their formal manifestations in the form of biomorphic, mechanomorphic, polymorphic, and amorphic robots, and interactive architecture. Taught using a recently developed framework that focuses on self-organizing systems and the creation of innovative technology-driven design entrepreneurs rather than merely on the creation of designed artefacts, students found themselves not only innovating with new digital technologies but also bridging architecture, urbanism and computer science. The paper describes the pedagogy, processes, and outcomes of the studio.

Keywords. Robotics; interactive architecture; pedagogy; innovation; studio.

1. Introduction

As computation and robotics become more prevalent in all aspects of architecture, their impact on education assumes greater importance (Gramazio and Kohler (2014), Fox and Kemp (2009), Brayer (2013), Braumann and Brell-Cokcan (2012), Silver (2013)). Studio pedagogy that engages computing technologies has a long scholastic history (Akin 1990, McCullough,
Mitchell & Purcell 1990). Every time a new technology was introduced, there has been a spirited discussion of their impact on architectural education (Senagala 1999, Senagala, Vermillion 2009). With the advent of digital fabrication and robotics, there is again a need to examine or reexamine the assumptions and practices of architectural design pedagogy.

The paper presents the outcomes of a collaborative undergraduate architectural design studio that investigates the realms of architectural robotics and computation by stepping into the fecund intersections between multiple disciplines. Taught using a recently developed framework that focuses on self-organizing systems and the creation of innovative technology-driven design entrepreneurs rather than merely on the creation of designed artifacts, students found themselves not only innovating with new digital technologies but also bridging architecture, urbanism and computer science (Senagala, Vermillion 2009).

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Consistent with the pedagogical methodology of previous iterations of the Inconvenient Studio, which has been widely disseminated, faculty allowed the students to explore the topics, create project proposals and form autonomous companies that were ready to be launched. A local innovation incubator, which is a non-profit entity aimed at supporting entrepreneurs, was utilized as a resource to guide the student companies toward a potential
launch while aiding them in the formulation of problems which could be addressed through emerging digital technologies.

Through a system of self-organization, the studio functioned as a unique sub-institution for learning. The instructors served as intellectual venture capitalists available for the companies to collaborate and learn from each other. Students, acting as self-organizing agents were immersed with time-oriented responsibilities developing and meeting project schedules, fundraising and working within budgets, creating press releases and office advertisements and maintaining a public web presence—all in parallel with the overall task of design + research. Students were advised to raise funds through external resources wherever possible to demonstrate their proposals value and relevance to the larger society.

Through self-organizing processes, three distinct entrepreneurial units (companies) were formed with projects ranging from robotic furniture to interactive global urban installations. Each company held a unique set of goals and understanding of the place for robotics and technology within the discipline of architecture. Though the process was trying, each group developed its own unique personality, means of working and a common purpose. Although initially the gaps in knowledge and technology were high, each group found its own specialists to handle specific aspects of design, which would arrive. If a specific skill were still missing, offices would collaborate allowing for a seamless dissemination of information throughout the studio as a whole.

The pedagogical prototype has made it clear that the studio pedagogy must respond to the emerging conditions and technologies of the world, such as robotics, not just through a selection of topics, but also through a fundamental re-examination of the pedagogical model central to architectural education, the studio.

2. Self-Organizing Agents

In response to the need for the rapid acquisition of skills and knowledge necessary throughout the course of the semester, students self-organized and formulated a series of intense weekly skill building “events” as a means of facilitating rapid intellectual growth. Through a series of internal workshops facilitated by both students and outside experts in conjunction with external lectures, students built necessary programming, design and entrepreneurial skills. A series of debates with outside faculty then followed. These debates were utilized as a means to test the think tanks emerging theoretical frameworks and situate them within the current and future discourse of architecture.
2.1. DEUTERO LEARNING

Irrespective of the technological context, one of the aims of higher education is to enable students to learn to learn, which has been called deutero learning in systems theory literature (Bateson 1972). In the typical studio environment, students function as individuals who possess necessary skills to achieve a successful and rigorous project (figure 2a). Gaps in skills and information are then filled by the instructors. Although teaching methodologies may vary greatly within the typical studio environment, these courses can typically be categorized within one of five categories: 1. Master apprentice (figure 2a), 2. Master group (figure 2b), 3. Master group or apprentice + community partners (figure 2c), 4. Master apprentice + external network (figure 2d) and 5. The Immersive studio or “Rural Studio Model” where the community becomes the studio environment (figure 2e). Although these studio models allow for high levels of variation, the one constant is the dissemination of information from the top down.

![Figure 2. Current Architectural Studio models](image)

Rather than working within a traditional master/apprentice studio environment, *Unsolicited: An Inconvenient Studio* allowed students to become peer instructors, where individual skills were shared through in-class work-
shops allowing for the evolution of in-house specialists. As certain skills become necessary throughout the development of office structures, robotics and fabrication, individuals would host open workshops (class and department) allowing for individual think tanks as well as the class as a whole to rapidly move forward.

If desired skills were not possessed within the class, the studio connected with individuals beyond the class in the university or the world at large to gain all necessary skills. While deutero learning is a challenging process—frustrating at times—it equipped the students with lasting learning skills.

![Figure 3. An Inconvenient Studio model](image)

### 2.2. MINI LECTURE SERIES

To more deeply engage the knowledge of architectural robotics within the course, a mini lecture series was self-organized throughout the course of the semester. From Stuttgart to Hong Kong, a group of innovative designers, thinkers and makers were selected, solicited and presented their positions on the role of robotics within the discipline of architecture.

Ensuring a large diversity in viewpoints and research directions was an important goal for the lecture series. Students learned how robotic fabrication could be utilized as a means of translating biological systems into architectural form (*Simon Schleicher, ICD, University of Stuttgart*), to how built environments could act as design agents, interacting and reconfiguring to their surrounding environment and inhabitants (*Simon Kim, UPENN*), or even how imbedded intelligence could be programmed within self-assembling 4d printed systems to create architectural aggregations (*Skylar Tibbits, MIT*).

Sparking continuing debates throughout the semester, students within the course not only gained a deeper understanding of this innovative pedagogi-
cal framework but also expanded an open debate throughout the college as a whole.

2.3. THE DEBATES

Learning involves challenging preconceptions and assumptions that come under scrutiny when new worldviews are introduced. One sign of learning is the presence of certain level of conflict, struggle, and inquiry. Several times throughout the semester, the class hosted debates to further test their ideas. These open debates forced individual think tanks to embrace new approaches to design and new ways of engaging technologies in design. Such active debating enabled the offices to advance their own direction. They were pushed to rethink how they frame architecture, robotics, and their office philosophy. This rigorous back and forth process allowed for the robust definition of offices and projects by the end of the semester.

3. Student Work

We now present selected projects from three companies that went through the entrepreneurial process, traversing a steep learning curve, overcoming personal challenges and self-doubt to emerge as individuals with greater self-awareness and developed an ability to work in collaborative project-driver environments.

3.1. LEGO-BOTS

Over the course of three weeks, LEGO-BOTS introduced students to the fields of robotics, computer programming and reactive design systems while setting the direction for the remainder of the semester. Although the learning curve was high, all three groups pushed forward attempting to both define the pedagogical stance of their offices while integrating robotics into architectural systems. While some groups quickly reached the limitations of the Lego robotics and quickly moved into more robust Arduino based systems, others struggled to grasp the full potential of the robotic systems.

In the end, three distinct offices and three working prototypes were created. Design(function); created a working full-scale Arduino based prototype for a shape shifting desk lamp. Through a series of custom fabricated gears and pulleys, the lamp reconfigured itself to create optimal lighting conditions.

The second company, Trans4m utilized Lego Robotics to create a full-scale prototype for a bending active louver system to be integrated into existing building facades. Adapting to light, the prototype twists to create optimal shading conditions.
The third company, *stimuLATE* created small-scale prototypes for adaptive urban rain screens that transform from street lamps to large-scale umbrellas based on weather conditions.

We provide here examples from two of the student-formed companies.

![Figure 4. Process from LEGO-BOTS](image)

### 3.2. DESIGN (FUNCTION);

With previous knowledge in programming, *design*(FUNCTION); lead the way in both the teaching and integration of robotics into the studio. Focusing on enhanced spatial experiences through the interaction between humans and emerging robotic technologies, *design*(FUNCTION); strived to re-invent how architects design, define and use global urban public space in the immediate future. Through the connection to, and the expansion of the Internet of Things into urban spaces, their office attempts to collapse global space into a series of interconnected nodes.

Through their project (*urbanNETWORK*);, the students proposed creating a new typology of public space through the redefining of currently underused monumental urban spaces. Rather than relying on the creation of singular fixed artefacts for human interaction, (*urbanNETWORK*); utilizes interactive and intelligent architectures that begin to dissolve and distribute themselves among global urban environments. The breaking down of current monumental space promotes the continuous reconfiguration and interaction between agents and artefacts within these urban spaces.

By means of the global distribution of, and digital interconnection through these “interactive pods”, urban interaction is fostered beyond our...
current boundaries of site or city allowing for the blurring between local and global, as well as digital and physical.

Global interaction manifests itself through both physical and digital means. Users can either interact with these “pods” by removing, reorganizing and dispersing the modular seating elements, or can interact digitally through touch, proximity, speech or smart phones. Each interaction creates unique outcomes that can be combined by multiple agents on either the local or global scale. The manipulation of an individual pod in a single location creates similar affects on corresponding pods connected within the local and global network. This interactive play allows for the formation of a singular, interactive and continuous global urban space.

3.3. TRANS4M

Whereas design('FUNCTIONS)’s effort were focused on computer programming and digital interaction, TRANS4M’s efforts were focused on the intelligence of the artefact’s material systems, folding patterns, fabrication methodologies as well as the mechanisms which allowed for uninhibited motion.

Materials testing in relation to available digital fabrication tools played an important role in the final material selection. Initially, more robust additive materials such as carbon fibre, fibreglass and 3d printed resin were tested as a means of creating a lightweight framework. As a means of maximizing the integration of their skills in relationship to cost feasibility, the office switched from high tech materials to precisely optimized and fabricated low tech systems.
Utilizing CNC milling and 3d-printed resin, students began optimizing both surfaces and gears for weight and precision. Surfaces were created through the aggregation of birch plywood members and pivoting within a series of complex servo driven gears. Each axis of motion required a single servomotor.

Through a series of tests on strength to weight ratio, the group developed a subtractive CNC methodology for the minimizing of material throughout individual members as well as in the system as a whole. From the testing, it was determined that the optimal strength to weight ratio would allow for an overall weight of 8lbs, with a maximum loading of 250lbs per axis. Different gear ratios, sizes and configurations were laser cut or printed then tested for strength. An optimum configuration was created and then tested through a series of three scaled prototypes.

4. Conclusions

As computation and robotics become more prevalent within all aspects of the architectural discourse, it is imperative that the architectural learning environment adapts to fully utilize these new methodologies of thinking.

Over the course of a semester, Unsolicited: An Inconvenient Studio introduced a group of students to these new tools and methods. Utilizing the recently develop framework that focused on self-organizing systems and the creation of innovative technology-driven design entrepreneurs rather than merely on the creation of designed artefacts, students found themselves not
only innovating with new digital technologies but also bridging architecture, urbanism and computer science.

Although learning curves throughout the semester were high, we witnessed the formation of three unique and robust offices that were by the end, deeply engrained within the pedagogical framework or architectural robotics. Through constant struggling and reinvention, innovative processes and products were created which pushed forward the current discourse of architecture.

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