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Abstract

Technological advances in robotics, digital fabrication, and sensor technologies are changing the landscape of innovation, design, and production. However, integration of these technologies in architecture programs is a challenging task. It requires extensive knowledge of the robotic arm operations, complex computer applications, and developing interdisciplinary skills for producing the end of arm tooling, which makes architectural experimentation and production possible. The following paper describes an informal approach to an interdisciplinary collaboration experiment for initiating operations of a new robotics lab. Leveraging the inaugural event of the lab, students and faculty were invited to design, construct, and participate in exhibiting four projects at the event. The paper explains each project, how student and faculty interacted and learned advanced fabrication techniques, and how their experience contributed to the overall establishment of the lab.

Introduction

Technological advances in robotics, digital fabrication, and sensor technologies are changing the landscape of innovation, design, and production. Intelligent machines are not only replicating human's physical capacity but are increasingly enhancing and augmenting humans in a wide range of endeavors and businesses in manufacturing, construction, and engineering among others. These technologies are no longer the province of large corporations and institutions but are becoming prevalent in small businesses and firms (Manyika et al. n.d.). It is expected that they will become ubiquitous - a competitive necessity for large and small organizations across the economy.

These advances are also reshaping the Architecture profession. Automated building design with advanced software, mass customization of building components with robotics, and large-scale 3D printing of buildings are growing at a steady rate (Kolodner n.d.). According to the World Economic Forum (WEF), robotic construction and production will be strong drivers of employment in architecture and construction. They foresee that manufacturing will transform into a highly sophisticated sector where high-skilled people, such as architects, will be in strong demand (WEF, 2016). It is also expected much of the routine activities of architects will be automated in the near future (Davis, 2015). Therefore, advancing technological capability of architects is becoming a critical aspect of the profession, research, and education.

While technical and specialized skills of architects will continue to be important, because of the interdisciplinary nature of advanced technologies, collaborative skills are becoming increasingly critical as well. Building an understanding across different disciplines as well as the ability to work with others creatively will be a key element that will differentiate the new workforce (Partnership for 21ST Century Learning, 2015).

With these technologies and their associated skillsets as the hallmark of future jobs, architecture schools are moving to incorporate robotics technologies into their curriculum and create interdisciplinary educational opportunities for students. Many schools are investing in robotic arms and the required infrastructure (Brell-Çokcan and Braumann 2013). However, other than a handful of universities with extensive resources, integration of robotic arms into architectural curriculum is challenging and faces several challenges which goes beyond securing funds for the purchase of equipment.

The first challenge is getting started which is often a long process. This requires a custom-built environment with adequate physical infrastructure, knowledge of hardware components, understanding the operating system, and calibration of the arm and tools. The second challenge is having the right tools. Robotic arms are extremely versatile and can carry numerous tasks, however a key barrier is in devising the appropriate end of the arm attachment or "end-effector". Producing end-effectors which makes architectural experimentation and production possible entails knowledge of computer applications, mechanical systems, and integration of sensors and in some cases small robotics. Many of the available end-effectors in the market are produced for repeatable industrial applications, have limited use for architectural production, and are cost prohibitive. Therefore, architecture students often need to design and fabricate their own.

Finally, the absence of a support structure for integration of these technologies to the curriculum, and facilitating interdisciplinary collaboration is another barrier. Many architecture students are not aware of the utilities of the robotic arms and lack the required programing skills which makes them disinterested. Because these skills are not often taught in the architecture curriculum, reaching out to other disciplines for collaboration is critical. Providing incentives for collaboration with other disciplines, developing team-based projects, and

opportunities for students to integrate new skills into their coursework are all a part of building students' motivation, capability, and their use of these technologies.

This paper describes an approach to engage students with the newly established Robotics and Digital Manufacturing Lab (RDF) at Florida International University. The approach involved an interdisciplinary experiment for developing several projects for the inauguration ceremony of lab. The authors (faculty and graduate students) of this paper were the inaugural team in reasonable for organizing several student teams who exhibited their projects at the event.

Inaugurating the RDF

Upon agreement on the event, the inaugural team proposed several projects to highlight different technologies and tools that the lab offers. Once the projects were announced to architecture students, they were placed into groups based on their interest in the projects and each graduate student of the inaugural team became responsible for mentoring one of the groups.

To begin, each group conducted a charrette on how to approach the project and understand the required technical expertise to complete the project. Then, the mentors of each team reached out to students and faculty from computer science, art, engineering, and music to join the teams. Brining faculty and students from other disciplines onboard was not a difficult task as they realized the event's high visibility.

Mentors served several roles in the project. They led the project by identifying problems, providing feedback, and facilitating communication among different disciplinary perspectives to resolve issues. They helped students to learn from each other, build their technological skills, and understand how to navigate in interdisciplinary environment. Each project engaged a specific aspect of robotic processes for showcasing the end-effector design and development, convergence of digital and physical

simulations for artifact creation, and incorporation of external data to control a system of actuators. These projects are described by the mentors of each team in the following sections.

Inaugural Scissor

This project commenced the event by a novel approach to cutting the inaugural ribbon with a scissor controlled by a robotic arm which involved close collaboration with sculpture art students. The project was conducted in three stages: 1) design and fabrication of end-effector, 2) integration of end-effector with the robot, and 3) programming of simulation for robotic movement and scissors actuation.

First stage required creating a frame for mounting the scissors to the robot. The team decided to use a steel frame (because of its strength) for attaching the scissor to the robotic arm and mounting a linear actuator onto the frame safely. The next step was to transfer the linear motion of the pneumatic actuator to radial motion for opening and closing the scissor. This was achieved by
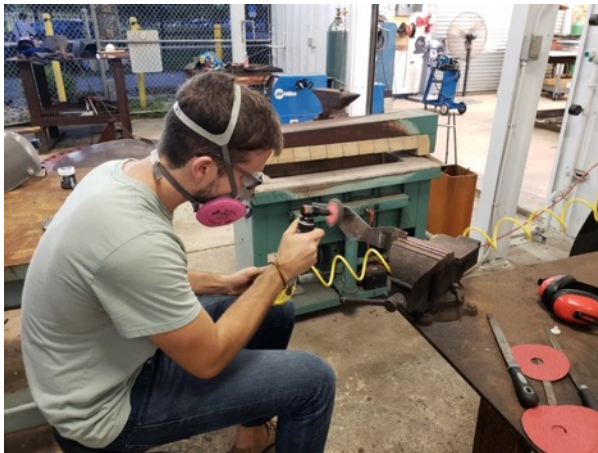
Sculpture department student grinding steel frame

mounting the actuator on separate pivot points and give it enough tolerance to open and close completely. The final step of fabrication was to create a 3D printed attachment for the eyelid of the scissor handle that would be fixed to the linear actuator. The scissor was 3D scanned and the model was imported to Rhino for designing the attachment which was printed from PLA filament.

The second stage involved mounting the end-effector to the robot to check its tolerance for collision. Once the actuator was tested manually it was connected to a two-way pneumatic solenoid controlled by the robot.

The final stage was to program the end-effector for a simulation that demonstrated the range of motion of the robotic arm as the end-effector actuated to open and close the scissor. The simulation moved around the envelope of a geodesic dome (see next section) in a playful manner until it reached the cut point. A final calibration of the simulation was conducted at the day of the event to ensure the end-effector lined correctly with the ribbon for cutting when the President of the University pressed the command to initiate the sequence.

The project was successful and the attendees enjoyed

Scissor end-effector mounted to robot and actuated

the show. However, the most important aspect of the project was the interdisciplinary collaboration and learning teamwork. Working collaboratively students learned about fabrication techniques using steel and understood the mechanical principals needed to properly actuate the end-effector. The development of the end-effector was documented and are currently used to teach workshops for developing them.

Geodesic Envelope

This project was an open-ended exploration of robotic assembly to demonstrate the KUKA KR10's reachability, flexibility, and accuracy. Our team developed a geodesic steel dome and envelope components to be placed on the structural frame of the dome during the event. We
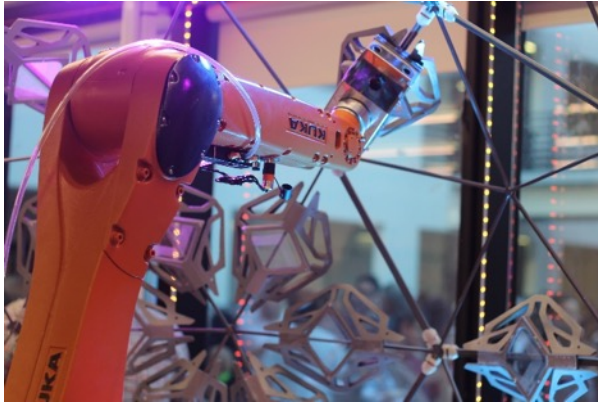
Placement envelope components on Geodesic Dome

designed the project around the vacuum gripper which was one of the lab's first purchased and integrated end-effectors. The project was conducted in three stages: 1) development and testing of a vacuum gripper pick and place script, 2) design of a robotic arm assembly, and 3) design and fabrication of the dome and its envelope components.

To design a sequential motion of the arm we developed a pick and place script using Grasshopper 3D, which is a visual programming software. The team created a 3D model of the physical environment surrounding the robot (work cell) to avoid any possible collisions. Once that was accomplished, the script was tested with the robotic arm controller. In our first test, the gripper was damaged because of minor discrepancies in the heights of the physical environment and the digital model. Small adjustments to the 3D model were then applied to reconcile to the digital and physical environments and the simulation became successful.

The second stage involved developing a form which showcased the robotic arm's capabilities. This was

achieved by mapping the maximum reach of the robotic arm's work envelope. The envelope has a deformed spherical shape that represents the full extent of the arm's movement in all directions. This realization led the

Geodesic Dome with KUKA KR10 in Action

team to design a geodesic dome fabricated from steel. This structure provided the right shape to showcase the accuracy of the pick and place simulation and it could be fabricated easier with modular construction.

The envelope components were milled from wood and used magnets to attach to the steel frame. The physical placement of the components by the arm inside the dome was challenging as the physical locations did not match the virtual environment. In fact, even small movement in the dome caused discrepancies and deflections on the sides of the dome. Our team's deliberation on how to solve the problem led to designing a new end-effector which could calibrate the joints coordinates in the virtual 3D model accurately. Once the coordinates were updated, the simulation succeeded.

This project was a learning experience in how to use a vacuum gripper that required establishing a workflow for using an extremely accurate tool (robotic arm) and reconciling it with analog fabrication. This workflow was documented and is used by other students at the lab.

Arduino Drum Installation

The ribbon cutting ceremony was accompanied by a drum roll that was played by four automated drums. The premise for the project was to play several algorithmic

musical pieces written for percussion instruments at a speed and complexity which humans could not play. To create the system, several activities occurred simultaneously.

One of the activities was the fabrication of the mounting system for the mechanized drum stick connection to the drum set. To save time and effort, our team used an existing system to produce the mount. Another activity required prototyping and programming of the drums which was controlled by an Arduino micro controller. To achieve this, the team had to resolve several issues. First was the actuator movement, as it only moved in one direction and then needed to be reset. The team's solution was to use a computer chip that controlled the power input for the motor to actuate back and forth.

Another problem was controlling multiple actuators simultaneously because the Arduino is a single task controller. After some research, we were able to use a digital library that allowed the Arduino to multitask. Developing communication between the Arduino and the musical composition program was also a problem. We overcame this by using a digital output from the program
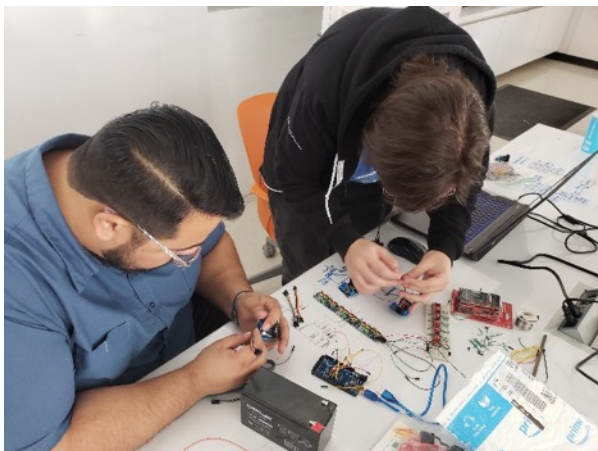
Architecture and Computer Science students working together for actuator prototyping

which was interpreted by the Arduino to control each drumstick independently based on the note it was assigned to play. The drum set was then stress-tested and became ready for playing music pieces that were

composed by the team to highlight the drum set's capability.

As this project involved different skills form each discipline, communication between the team members became the main driver of learning. The lessons learned through our interactions were valuable for the members of the team and will be shared through workshops and future collaborative project.

Inauguration attendee viewing the robotic drum installation

Ceramic Wall

In this project, we investigated and tested clay printing techniques using the robot's manufacturing logic. The result was a wall assembly composed of non-uniform ceramic modules. The project's aim was to explore new possibilities for a traditional material using digital craftsmanship. The design of the modules required the team to understand the material properties of clay and develop an algorithm using Grasshopper 3D software. Clay consistency and plasticity, the speed of the robot, and extrusion rate were the main criteria for designing the algorithm.

The team optimized the printing process by manipulating three variables: different clay mixtures, feedback from the robot's execution of the script, and extrusion rate from the clay extruder mounted on the robotic arm. Once the team found the appropriate balance between these variables, the modules were printed and were ready to be fired at

the Art Department's kiln. This process required guidance by students with expertise in ceramics. The modules were then connected and assembled to a small wall

Digital translation from KUKA-PRC algorithm
system.

The overall process combined traditional and digital fabrication techniques. The ceramic students contributed knowledge of clay properties and firing techniques, while learning about the robotic arm's capabilities. Architecture students became exposed to the ceramic art and many
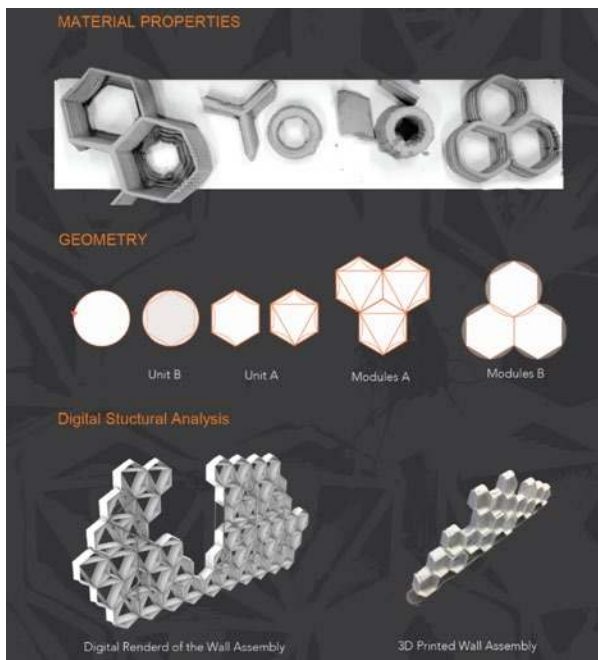
Ceramic modular wall assembly

variables involved in the fabrication of a computational design.

Both disciplines gained crucial problem-solving skills, which took place over the course of the project in continuous conversation about the traditional and digital processes and best strategies to integrate them.

Situated Learning

Reflecting back on how the team of students came together, interacted and worked at the lab, what worked and what failed, can be explained through the lens of situated learning theory. This theory which was first introduced by Lave and Wenger, views that learning occurs when people are placed into authentic real-world context and interact with others (Lave and Wenger, 1991). Situated learning theory emphasizes the role of social learning and how specific patterns of experience are tied to specific contexts and places. In situated learning, cognition is through the "dialectic between persons acting and the settings in which their activity is constituted" (Korthagen, 2010, p.102 and Lave & Kvale, 1995, p. 219).

McLellan introduces a model of situated learning built on several components. She considers that stories, reflection, cognitive apprenticeship, coaching, collaboration, articulation of learning, and technology are key elements in making meaning and constructing an understanding of our experiences (McLellan,1996, p.7). Using McLellan's model, we can reflect on our experience of the inaugural event as embracement of all of these components.

The celebration of the lab through exhibition of student work was the "story" that created a meaningful structure for remembering what was learned; "reflection" happened in social interaction and conversations among the team leading to problem solving; "cognitive apprenticeship" and "coaching" were a part of the support scaffolding created by the mentors as they participated and provided

guidance on the side; "collaboration" which led to sharing knowledge across disciplines; "articulation of learning" occurred in confronting ineffective strategies and team's arguments on the best way to move forward and; "technology" which was at the core of experimentation.

Project Schedule

The following table shows the progress of the projects over the course of the month prior to the inaugural event**.**

TASK NAME	DISCIPLINES	WK 1	WK 2	WK 3	WK 4	WK 5
Inauguration Scissors						
Schematic Design	Arc	■				
Template Fabrication	Arc	■	■			Event
Mechanical System Design	Arc + Arts		■	■		Event
Mount Fabrication	Arc + Arts			■		Event
Testing of System	Arc + Arts			■	■	Event
Programming of End	Arc				■	
KR10 Envelope						
Gripper Pick and Place Script	Arc	■				
Design of Geodesic Dome	Arc		■			
Fabrication of Steel Dome	Arc		■			Event
Envelope Components Fab.	Arc + Arts			■		Event
Design End Effector	Arc					
New Pick and Place Script	Arc				■	
Drum Bot						
Planning of System	Arc + CS	■				
Fabrication of Parts	Arc		■	■		
Prototyping Logic +	CS + Music		■	■		Event
Programming	Arc + CS		■	■		Event
Musical Composition	Music		■			Event
Testing	Arc + CS +			■	■	
Assembly + Final Calibration	Arc + CS			■	■	
3D Printing Ceramic						
Design Development	Arc	■				
Material Testing	Arc	■				
Programming Script	Arc	■	■			Event
Execution	Arc		■	■	■	Event
Material Enhancement	Arc + Arts			■	■	
Fabrication	Arc				■	

Key Arc: Architecture   CS: Computer Science   M: Music

Conclusion

Using the event as a catalyst, we were able to address some of the challenges for establishing the knowledge base required to operate the lab. Each project showcased at the event was designed to engage a specific aspect of the robotic processes for developing end-effectors, convergence of digital and physical simulations, and incorporation of external data to control a system of actuators.

By leveraging the physical space of the lab, creating a mentoring structure, and facilitating interdisciplinary collaboration we were able to provide an informal setting for situated learning. Participating students in the Inaugural Scissor project learned how to develop end-effectors, the Geodesic Envelope team learned how to use the arm for pick and place assembly, the Arduino Drum Installation team learned about sensor actuation using microcontrollers, and the Ceramic Extrusion students learned about the 3D printing capability of the arm. Mentors of each team became a knowledge source for students by offering multiple workshops in the following months and participating students in these projects became vested in the success of the lab.

With advanced fabrication technologies moving at a fast speed it is critical to equip our students with the ability and competence to use and implement these technologies successfully. Training students with advanced technological skills and ability to work across disciplines will provide them with a competitive advantage and flexibility in the future job markets.

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