PAPER

Digital Digital Fabrication Fabrication: Remote Collaborative Teaching and Learning in Advanced Fabrication

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Many schools of architecture are facing a pressing issue: How do we offer access to fabrication in an equitable and inclusive manner? Furthermore, how can we create a sustainable, pedagogical model for our institutions to share knowledge about machinery and fabrication processes that are often inaccessible? Two architecture programs, one a PWI (Predominately White Institution) and one an HBCU (Historically Black College/University), joined forces during the 2020-2021 academic year. Together they explored the teaching of advanced fabrication in a virtual/remote learning space. Advanced fabrication mentors from the PWI provided virtual/remote mentorship for students at the HBCU, to assist in designing for and using the ShopBot CNC router at their school's fabrication space.

The team of fabrication mentors stayed constant over both semesters, in contrast to a changing cohort of students and project objectives. During the fall, HBCU worked with mentors to complete a bigger scale, parametric modeling project. Throughout this semester, both teams realized that existing practices, already developed for use in other remote learning environments, were not fulfilling the pedagogical goals of these advanced fabrication efforts. In the spring semester, the PWI/HBCU teaching team reworked the curriculum, as the student body progressed towards smaller scale making-focused projects. In addition, the implementation of innovative technologies in live-streaming allowed for more responsive and interactive collaboration.

These projects tackled two primary challenges: working through the technical issues of digital and physical fabrication, and establishing a remote, fabrication-oriented mentorship process, which by nature is hands-on and requires in-person work. Coordinated work sessions between the two universities' fabrication spaces were facilitated through a real-time, multi-camera, CNC set-up which utilized open-source broadcasting software to sync multiple audio feeds, screen share (Rhino and CNC programing software), and live video feeds of both CNC router setups. Iterative improvements to the technical set-up were invaluable as consistency and learning from past errors were major keys to success, evidenced by a dramatic improvement in the quality of work and participation from one semester to the next.

To sustain this new pedagogical model of exchange, a legacy of knowledge needs to be built. This starts by ensuring that there are always more experienced students who can guide incoming students (and those who are new to fabrication). All of this will be possible by maintaining the primary goal of increasing accessibility to the technological and machine-based integration that is necessary for architectural education programs to remain relevant in the future. This collaboration demonstrated that remote digital and physical fabrication is possible, and both universities are working to expand this platform to other projects and collaborations. By recognizing and leveraging the expertise that already exists within faculty and staff of each institution, collaboration-come-knowledge exchange is not only possible but fruitful and highly effective. Remaining vigilant in the efforts to increase equity of access should be the charge of all schools of architecture; embracing ever-evolving pedagogy through an understanding that experimentation is necessary will propel this type of learning, allowing for a model that is both transportable and sustainable.

The process of teaching advanced fabrication in many architecture programs is characterized by a dependency on knowledge and accessibility to resources. This creates an imbalance, where privileged institutions can easily adapt to, and stay relevant within the rapidly changing digital fabrication methods that dominate architectural research and education. All the while, less privileged institutions are left to fend for themselves with fewer resources and little to no access to the knowledge required to teach digital fabrication. Is there a replicable and adaptable pedagogical model that can level the playing field? In a world obsessed with copyrighting and the protection of knowledge, we propose the opposite: a democratization of information. Our experience as educators, fabricators, administrators, and students serves as a testament to the benefits of such an attitude towards pedagogy. No one institution or demographic should hold the majority of knowledge and access to digital fabrication techniques.

Figure 1. Example of a scene simultaneously broadcasting multiple workspaces, both digital and physical. Author.

This paper will detail our exploration of advanced fabrication in virtual/remote learning spaces using an interactive, transferable model of real-time knowledge exchange, as well as the lessons learned from a year of collaboration between two institutions: Florida A&M University School of Architecture and Engineering Technology (FAMU), a Historically Black College/University (HBCU) and University of Michigan's Taubman College of Architecture and Urban Planning (UoM), a Predominately White Institution (PWI) . By the end of this paper, we will have given the history of the collaboration between both programs, described the projects tackled, and defined the mentorship model that drove the successful result.

Expertise, plus interest in learning, plus resources, plus an outcome is a typical and well documented model of mentorship. The novel aspect of the mentorship described in this instance is the virtual learning space that leveraged open-source software capable of simultaneously syncing multiple video and audio sources and computer screen sharing with CNC fabrication specific software. [Figure 1] An open-source, remote learning environment makes high-level mentorship possible even when an institution may not have the financial resources to explore more traditional mentorship through in-person learning. This remote learning environment also allows for mentorship to occur no matter where in the world the participating institutions are located, allowing for a sharing of knowledge from any time zone.

Digital fabrication is a method of making that requires the operator to be in the same physical space as the machine being used. Here inlies the difficulty of remote digital fabrication mentorship and a solution we sought to invent: how can a virtual space be created that can mimic and replace the hands-on, tactile experience of digital fabrication?

ALL ABOUT RELATIONSHIPS

Born from existing relationships, the Equity in Architectural Education Consortium (EAEC) was founded in 2018 by architecture schools, departments, and programs at eight different institutions (Florida A&M University, Florida International University, Hampton University, Howard University, Morgan State University, Tuskegee University, the University of Michigan, and the University of Oklahoma). As part of its mission, EAEC seeks to cultivate existing relationships between their member institutions through projects of mutual exchange. Their collaborative mentoring initiatives, known as Stacked Mentorship Programs (SMP), "...builds upon existing apprenticeship and mentorship practices in architectural education and practice." These programs provide the institutions opportunities to share knowledge and resources with each other. In addition, the projects focus on Diversity, Equity, and Inclusion efforts, creating participatory spaces for historically underrepresented communities.

Our SMP model to be discussed in this paper was developed during the 2020-2021 academic year when our two institutions collaborated as part of the *Prototyping and Fabrication Stack (02)*. Students at FAMU were trained to use their school's ShopBot CNC router by advanced fabrication experts from UoM. During the early development stage of the project, a few questions were originally posed: How do you frame an experience of exchange between institutions, where not only the students, but all participants benefit from interacting with each other? How do we create a manageable system that introduces beginners to the advanced fabrication process? How do we tackle the foreseen (and unforeseen) circumstances from teaching/learning remotely? How do we implement emerging technologies in virtual collaboration to improve the experience of digital fabrication mentorship in a virtual learning environment? All of these questions led us to produce an adaptable pedagogy that would allow for the continuous evolution of projects and teaching approaches while further developing the intimate trust between the institutions involved in the Stacked Mentorship Programs.

MENTORSHIP AS PEDAGOGY

Due to the nature of this collaboration between institutions, it was crucial to evaluate pedagogical strategies and propose a method distinguishable from the lecture-based modus operandi common in traditional studio-learning spaces. By recognizing inequitable practices in architectural academia, we wanted to challenge how knowledge was transferred and look into effective practices implemented in other academic scenarios, beyond architecture. Over the years, experts have suggested principles that members from the academic community can implement to improve the quality of education. Some of these guidelines resonated with both the specific objectives of the digital fabrication project, and the overall mission of the EAEC. Our pedagogical goal was to encourage interaction between all participating members, celebrate the diversity of talents and ways of learning, and incorporate active learning techniques[2].

Our method was grounded in mentorship as pedagogy. Discussions around mentorship in academia are not new, and definitions are varied across different disciplines and contextual circumstances. However, we can argue that traditionally, "mentoring has carried a connotation of a mostly unidirectional relationship between a more senior individual using life experience and acquired knowledge to guide the development, growth, or entry of the mentee into future life stages or career paths."[3] We wanted to explore a mentorship model that would benefit all parties in their professional and academic growth, regardless of whether the assumed role was that of a mentor or a mentee. In addition, the nature of the collaboration between our institutions would allow for participants from different backgrounds to work together. This meant that the model must not set fixed mentor/mentee roles, and welcome moments where these relationships may be reversed.

It was important for us to recognize that putting this model into practice would require a process of trial and error, given the limited amount of time to prepare, and the limited precedents of mentorship models in the setting of architectural education dealing with similar conditions. We define our pedagogical approach as a type of formulaic mentorship. The formula is not explicitly defined in mathematical terms, or expressed in symbols, yet it encompasses more than just a list of ingredients. We use the word formula to mean "a method, statement, or procedure for achieving something (mentorship), especially reconciling different aims or positions."[4] In this way, a formulaic mentorship is one that can be defined, implemented, and evaluated objectively through a given set of parameters.

With our formulaic mentorship, institutions can access more expertise without the economic burden of traditional mentorship, where an expert is hired for one specific task and measurable outcome. While traditional teaching methods have historically offered meaningful knowledge acquisition in a single setting, our mentorship pedagogy has the potential to become a portable, interconnected model for education. This experimental design-research project challenged the traditional way of teaching by creating a decentralized system where multiple entities could gather and share in one virtual space. This entailed fragmenting the curriculum into a range of workshops and virtually-connected physical spaces that were tailored for the transfer of a specific skill. The design of our pedagogical model speculates on how these segmented workshops can create a sequential network of knowledge hubs that perpetually benefits its participants and can be continually referenced. The setup is positioned as an adaptable framework that leverages numerous skills to curate an array of interactions- ranging from intimate reviews to collective seminars.

First we must define the components of the proposed mentorship formula: goals, constants, and variables. For the case studies in this paper, the goals were the democratization of CNC Fabrication knowledge and the spawning of a knowledge legacy that would allow for a more independent, accessible, and perpetual utilization of the new skillset. Those goals were reached through both constant and variable parameters. The first constant parameter was the collaboration of two institutions that had a pre-existing relationship on which to build. Second, and perhaps the more important constant parameter, was active, collaborative learning as opposed to traditional, lecture-based mentorship. Together, these two formed the base of our formulaic mentorship. A collaborative learning space falls into the variable parameter category as this can be either a physical space, or, as shown in our case studies, a virtual space. Whether virtual or physical, this space is the locus for many other variables which include funding, equipment, the student body, and expertise. As our learning space was virtual, it required

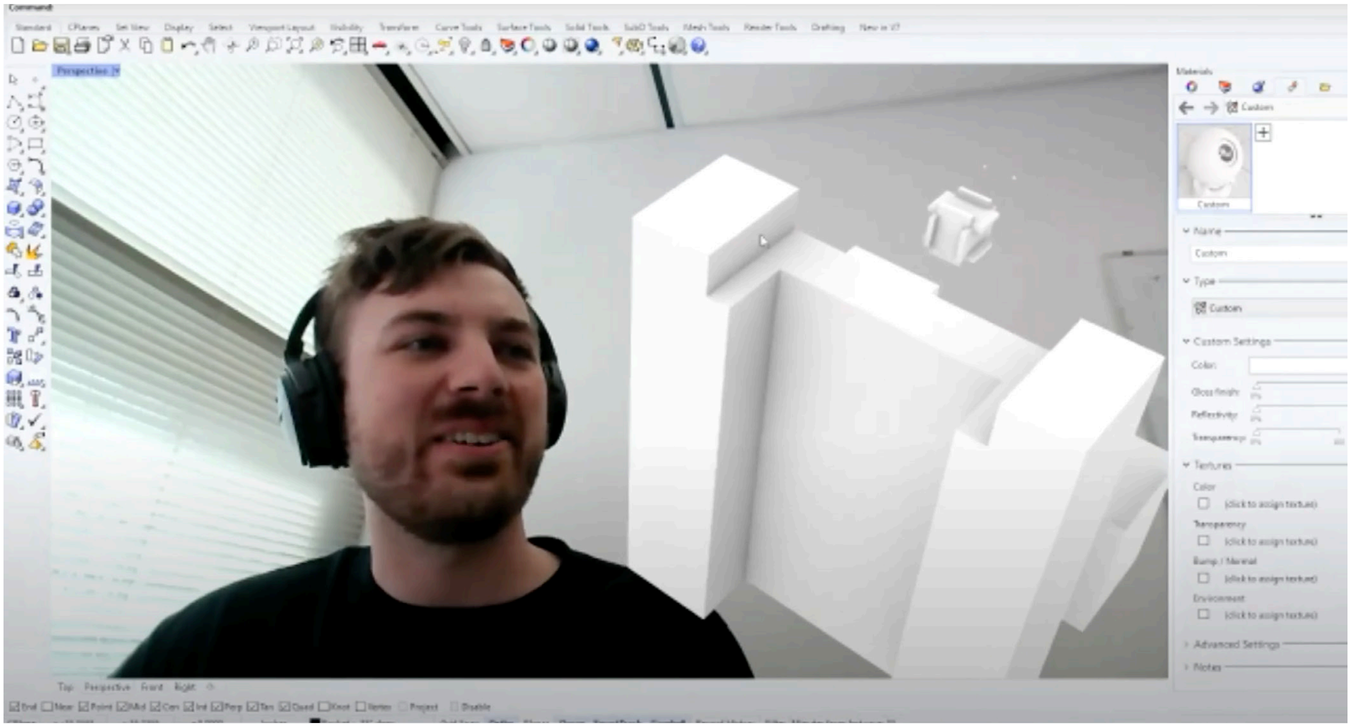

Figure 2. Video feed superimposed beneath Rhino workspace. Author.

another variable: the use of emerging technology that allowed for a richer, more engaging virtual space than simply a multi-person video call.

The recent surge in video conferencing software, spurred by a global COVID-19 pandemic, had a profound impact on teaching and the academic environment in general. Microsoft Teams, Google Classrooms, and Zoom have since become commonplace in spaces of learning[5], and allow multiple people to converse in a virtual space, share screens, and digitally message. These basic functions have an implicit bias towards a lecture-style teaching environment, and the efficacy of these softwares is challenged when placed within a fabrication environment that requires a high level of engagement.

Designing a course around the use of a CNC router presented several challenges in a virtual learning space. Complex tools and machinery require careful and continuous observation from multiple camera angles simultaneously. Users must visualize and test their projects using a combination of software interfaces, physical materials, measurements, and tooling. The environment in a fabrication space can switch from conversation to the overwhelmingly loud drone of motors in an instant rendering spoken conversation nearly impossible. Zoom's out-of-the-box functionality was not able to adapt to these conditions, necessitating a new and novel approach to virtual learning tailored to digital fabrication.

The resulting virtual learning environment was a network of video capturing devices, microphones, computers, and broadcasting software, which increased functionality and expanded the capabilities of Zoom and other existing video-conferencing platforms. This network was built around two open-source softwares - OBS Studio[6] and VDO.Ninja[7]. It is important to note that these open-source softwares were selected over alternative options because they are accessible to all, with no fees for downloading and using the softwares which reduces the barrier for entry to this novel form of virtual learning.

OBS Studio is a broadcasting utility software for composing and live streaming video feeds. In particular, we utilized OBS Studio to generate composite "scenes" which consisted of multiple video and media streams, including webcam videos, screen captures, digital messaging, and audio streams . Additionally, the software's greenscreen capabilities allowed us to superimpose users into their Rhino3D[8] digital modeling space, allowing for real-time interactions with virtual models [FIGURE 2].

VDO.Ninja is a peer-to-peer forwarding service capable of streaming real-time remote videos feeds into OBS Studio from anywhere in the world. This tool was critical in bringing together the live feeds from both FAMU and UoM into one simultaneous live feed.

The network of devices, as illustrated in the network diagram [FIGURE 3], included six different video feeds, two audio sources, and multiple screen shares from two locations 1,000 miles

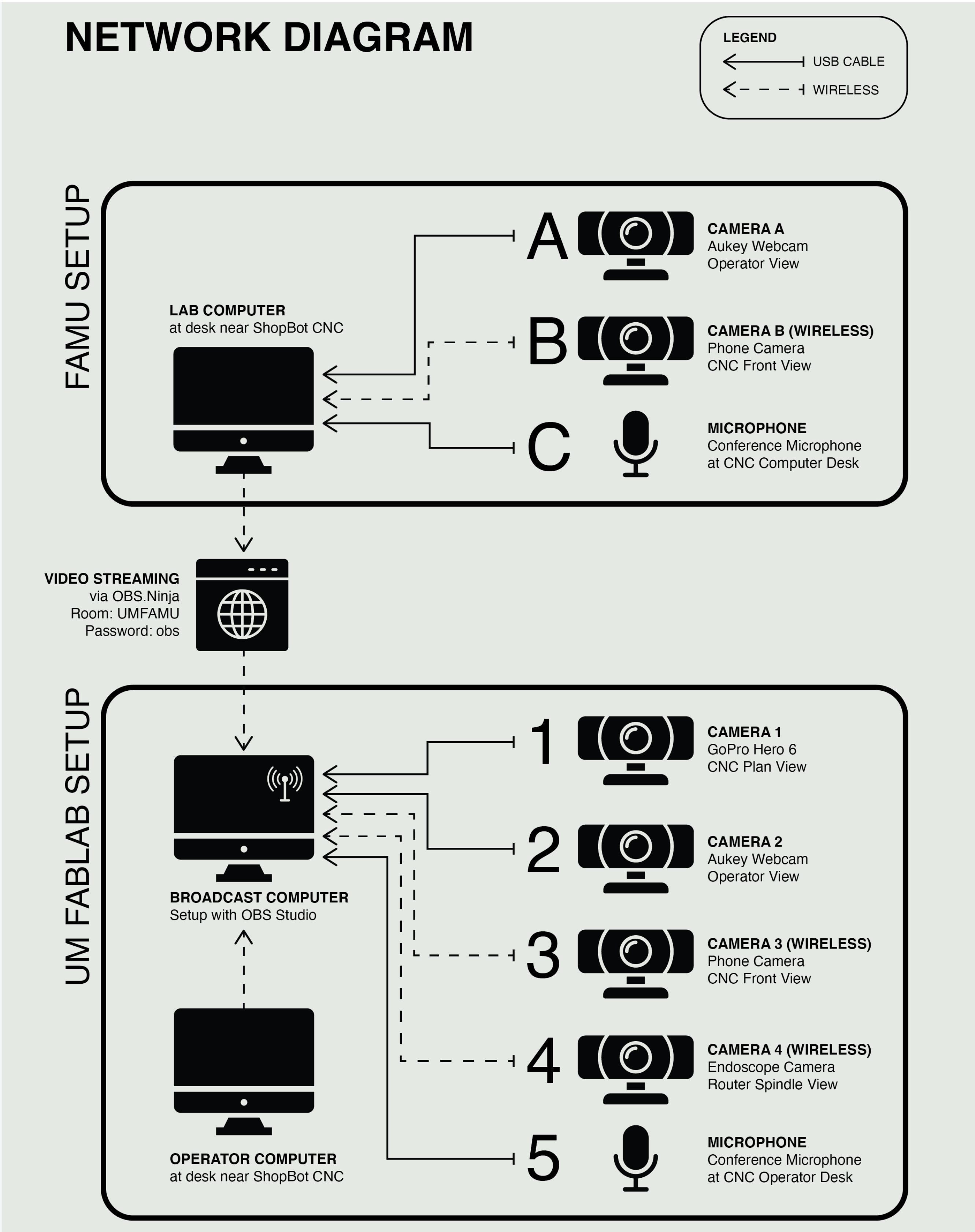

Figure 3. Network Diagram. Author.

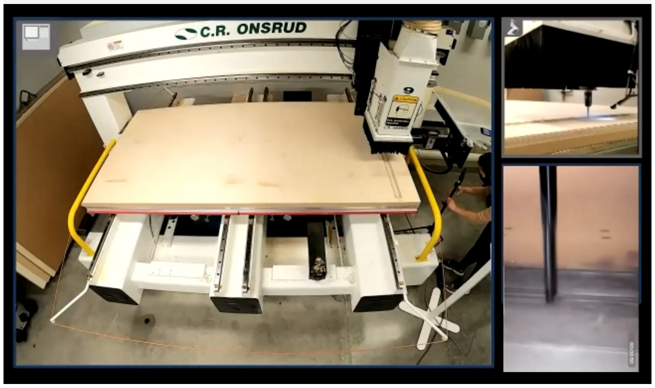

Figure 4. Multiple cameras capturing CNC router operation. Author.

apart. A mixture of wired and wireless connections were utilized depending on the position and purpose of each video feed. Cameras were positioned strategically to capture the simultaneous operation of the CNC routers in both locations. For example, a wireless endoscope camera was attached to the spindle to better document the cutting action of the tools [FIGURE 4].

Lastly, the process of setting up and operating the collaborative network was documented into a manual, with the intent of maintaining an open-source workflow that can be shared and developed with other institutions looking to utilize the technology in their own fabrication spaces. This network model continues to evolve as a tool for high-level mentorship and collaborations within the context of digital fabrication and advanced manufacturing.

CASE STUDY 01: FALL (SEASON 1)

During the Fall of 2020, administrators, faculty and fabrication experts from both institutions met to discuss the possibility of collaboration and began planning the mentorship program. The main goal of the Fall (Season 1) was to implement the collaboration as soon as possible and to introduce the students to CNC fabrication concepts and processes. The COVID-19 pandemic played a major role in facilitating this new model of mentorship as it eliminated the possibility of traditional mentorship models which require traveling. This presented us with a unique opportunity to erase geographical boundaries and still offer a transfer of knowledge.

A group of graduate students at FAMU was identified and invited to participate in a series of CNC routing mentoring sessions as part of their graduate assistantship. UoM was tasked with providing the knowledge to FAMU on how to use their CNC router and the technicalities of digital fabrication. At the same time, UoM benefited from this collaboration by reactivating their fabrication spaces that were otherwise momentarily underutilized due to the realities of the pandemic. Through these sessions our goal was to begin to empower the students to feel comfortable with fabrication, and to spawn an internal legacy of knowledge at FAMU that would allow them to take advantage of their fabrication space. Students were asked to create post-natural disaster shelter designs which could be constructed quickly with minimal access to technology and building materials, and that could be put together with minimal understanding of construction techniques. The assignment emphasized the importance of modular design and connections that can be created through the use of a CNC router.

Season 1 succeeded insofar as the students learned basic CNC operation and produced simple prototypes of their work, however, it also had many drawbacks. Season one's curriculum was added to the graduate students' responsibilities after the semester had started. The students felt pressured and did not engage in the program as much we had hoped. The remote workflow and the interface of the remote digital fabrication learning was not yet fully established and the technical side of the mentoring program was in the trial and error phase. In the beginning of Season 1, expensive software, hardware, and tools were not available to FAMU; Zoom was the only virtual tool available for communication between the schools and it caused a loss of detail over the video and audio feeds, focused on people talking rather than machine operation, and only had one video feed per user. These technical issues, common in virtual learning space scenarios combined with the traditional teaching method did not produce the results we had hoped for. Students were disengaged, uninterested, and did not get much out of the experience. Moving into Season 2 it quickly became clear that we needed to make changes that would address these issues. We observed that our mentorship model was ineffective for collaborative learning and the need for emerging technology in virtual collaboration was imperative to keep all participants engaged and invested.

CASE STUDY 02: SPRING (SEASON 2)

In Season 2, the technical issues from Season 1 of remote collaboration were adjusted to improve the teaching and learning experience. Multi-camera and microphone set-up improved the quality of mentoring sessions. Curated views from multiple cameras captured the fabrication process at the macro and micro scale, and the open source software for transmitting and broadcasting simultaneous video feeds allowed for increased access to the fabrication process for both the UoM mentors and the FAMU students. This allowed for a much more comprehensive understanding of the making process and machine operation. Each member of the new student cohort was paid a stipend to participate in this mentorship course and all chose to participate as an elective. Part of the students' charge was to prepare to continue the mentorship program for younger divisions in the coming semesters. Students were far more excited to participate in the newly designed, highly interactive learning setup and enjoyed participating in the newly minted remote space set up. Side-by-side compositions of the two fabrication spaces at FAMU and UoM allowed for more immediate feedback which more closely mimicked in-person learning and seemed to dissolve the virtual space.

Figure 5. Mentee's constructed wooden puzzle. Author.

Beyond the changes to the virtual space, the syllabus was adjusted and the student body changed as well; younger, more excited students came on board. Season 2 included one student mentor from Season 1, and their help was instrumental in forging the connection between the students and provided a necessary mentorship link. A more focused and cohesive curriculum was suggested and the schedule was broken down into incremental learning modules with plenty of one on one sessions with the faculty from both FAMU and UoM. The result was a success. Students were able to produce 3-dimensional wooden puzzles [Figure 5], learned and understood the CNC routing process, and most importantly, felt as though they were a part of a larger team. Ultimately, the students enjoyed being mentored and looked forward to becoming mentors for their peers in future sessions.

Season 2 proved to be far more productive with the introduction of OBS Studio and VDO.Ninja which allowed us to recreate the atmosphere of a physical learning space virtually. Beyond the addition of the software, the knowledge legacy had begun. One student in Season 2 was also a part of Season 1 and was the boots-on-the-ground peer mentor for the new student cohort participating in Season 2 [Figure 6]. This proved to be crucial in the effectiveness of the knowledge transfer and the enjoyment of the mentoring process from both the students' and instructors' perspective. Horizontal mentorship provided a greater comfort level with the participating students as they could freely and frequently reach out to the student mentor with questions and concerns rather than approaching faculty.

Throughout Season 1 and 2, numerous limitations and potentials were identified in the pedagogy of these sessions. Leaning on the successes and failures from Season 1, Season 2 was able to actively cultivate mentoring in both a horizontal and vertical organization. Horizontal mentorship helped knowledge transfer between students participating in the mentoring sessions while the vertical mentorship facilitated knowledge sharing between FAMU and UoM.Ultimately, This mentorship program proved to be beneficial on many levels: students were able to expand their knowledge of fabrication which dominates contemporary architectural education, both institutions were able to activate their fabrication spaces, students were able to participate without forgoing needed income, and a new model of teaching was generated which can be applied to almost any institution's needs.

CONCLUSION

What does all of this mean for the future of architectural education and the democratization of knowledge? This means that the physical space often needed for learning, especially through making, can be successfully digitized and can be as effective as traditional mentorship. This means that institutions who have the equipment but not the know-how can access spaces and expertise that can bolster their educational output from anywhere in the world. Ultimately, this means that our new form of mentorship is portable and begins to tear down the inequitable and, often, skewed knowledge base that exists within academia. No one institution or demographic should own and/or hoard the expertise to technology and techniques that drive contemporary academic and professional innovation.

Developing a formulaic model centered primarily around mentorship was paramount. And as educators we were challenged to not only serve the needs of both institutions involved, but also recognize and respond to the circumstances of the student cohort. However, this is only scratching the surface of possibilities moving forward. Through this model there is room to not only look into mentoring initiatives related to digital fabrication, but also other specialties and disciplines. In addition, the demographics of mentors and mentees, the access to tools, the scale of the projects, and many other variables may shift or be prioritized in a future iteration. However, we found that success occurs when uncertainties are embraced and when we have the ability to be receptive to the context of the project rather than attempting to apply a standard, one-size-fits-all model. This was not only evidenced through the readjustment of projects from Season 1 to Season 2, but also in the specificity of workshops, syllabus, and technical setups for the task at hand.

Adaptability is the name of the game. Through our formulaic mentorship pedagogy, knowledge and expertise becomes a horizontal, accessible network rather than a hierarchy. None of the faculty mentors are with the original institutions where this mentorship program was developed. This means that the network of knowledge from this mentorship program now extends beyond academia and into the professional world. Let this be the example for the future of this program. Academic and professional innovation requires the knowledge of all practitioners, faculty members, mentors, mentees, and anyone who participated in the program no matter where they end up. Moving forward, the sharing of knowledge can expand beyond the academic world.

When we frame pedagogy through mentorship, relationships in our academic and professional communities are built and cultivated. Knowledge, machinery, software, and expertise are all resources and our formulaic mentorship model can ensure that these resources are shared in a cyclical manner, are never centralized, and remain accessible to all.

Figure 6. Peer mentor and participating mentee. Author.

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