Elements | robotic interventions II

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Reviewing the current research trends in robotic fabrication around the world, the trajectory promises new opportunities for innovation in Architecture and the possible redefinition of the role of the Architect in the industry itself. New entrepreneurial, innovative start-ups are popping up everywhere challenging the traditional model of the architect. However, it also poses new questions and challenges in the education of the architect today. What are the appropriate pedagogical methods to instill enthusiasm for new technologies, materials, and craft? How do we avoid the pure application of pre-set tools, such as the use of the laser cutter has become, which in many schools around the world has caused problems rather than solving problems? How do we teach students to invent their tools especially in a society that doesn’t have a strong background in the making? The primary focus of this paper is on how architectural CAAD/ CAM education through the use of robotic fabrication can enhance student's understanding, passion and knowledge of materiality, technology, and craftsmanship. The paper is based on the pedagogical set-up and method of an M. Arch I studio that was taught by the author in fall 2016 with the focus on robotic fabrication, materiality, traditional timber construction systems, tool design and digital and physical craftsmanship.

Keywords: CAAD Education, Digital Technology, Craftsmanship, Material Studies, Tool Design, Parametric Modeling, Robotic Fabrication

INTRODUCTION
Ludwig Mies van der Rohe coined the sentence “Architecture starts when you carefully put two bricks together. There it begins.” (Mies van der Rohe) If we take him seriously, Architecture is, in essence, a material practice based on technology and craftsmanship. Mies didn’t receive any formal education as an architect, in fact before he learned how to draw in some of the most prestigious offices of that time, he started as a craftsman, learning the trade of stone carving from his father. One could argue that this education and knowledge of materiality, craft and technology set him apart from his peers. For Mies, the material was always the beginning, and his buildings that influenced a whole generation of architects persuaded through their painstaking craftsmanship and attention to detail (Whitman 1969). In parallel, the Bauhaus, where Mies was the third and last director also had a pedagogical system that believed heavily in experimental material studies and the study of
different crafts. Today the Education of an Architect in many Universities around the world is very different. While students nowadays know how to map, model and mediate all kinds of big data, social aspects, and geometry, how to argue through critical thinking for or against a project intelligently, students seldom start from a material experimentation or craft to inform their design. In a profession that is heavily ruled by economic constraints and the concepts of mass production, the architect is very dependent on existing technologies and material systems, making it at times difficult to innovate. However, since approximately two decades we are witnessing a shift in architecture and its education that has the capacity to bring the profession again closer to materiality, craft, and technology. Computation, new software packages, and new CAAD/CAM construction methods have paved the way for architects, designers, educators and students alike to engage again much more in the innovation of building processes and the making of a building. With the advent of robotic fabrication in Architecture, we are now witnessing the next step in this evolution. Robots are now connecting technology and knowhow, as well as imagination and materialization, like never before, and have the potential to reveal a radically new way of thinking about materialising architecture (Gramazio & Kohler, 2014). While previously CAM systems were limited to a particular function, the robot starts to give the opportunity to open up an entirely new paradigm. Since the robotic arm in essence just represents precise numerically controlled movement in space, the architect him or herself can now invent and define the technology, craft and material system from scratch. Industrial robots are distinguished by their versatility. Like computers, they are suitable for a wide variety of tasks because they are “generic” and therefore not tailored to any particular application (Gramazio & Kohler, 2014). This offers not only ground-breaking trajectories for the education of Architecture students but also for the profession, challenging the predominant job description of specifying pre-existing building systems.

OVERVIEW
However, every time a new technology was introduced there has also been a spirited discussion of their impact on architectural education (Senagala1999, Senagala, Vermillion 2009). Therefore this paper outlines a pedagogical strategy and method to install new ways of thinking about architecture through the implementation of robotic fabrication into the academic education. The M.Arch I studio that was taught in Fall 2016 at the University of Hong Kong was, in essence, starting from first principles and searching for original methods that had the capacity to create architecture, space, and structure. It had two main objectives. On the one hand, it was a hands-on investigation on how to generate new technologies, material systems and craftsmanship with the aid of the robot, on the other hand, the studio looked in what way these new systems could be applied to develop full-scale performative architectural prototypes. As a point of departure, the studio looked into traditional architectural elements, such as the column, the wall, and the roof. Rem Koolhaas stated in his 2014 Venice Biennale intro; Architecture is a strange mixture of persistence and flux, an amalgamation of elements - some that have been around for over 5,000 years and others that were (re)invented yesterday (Koolhaas 2014). The research studio as well aimed towards the understanding in how we as designers can (re)invent the elements of architecture today through novel technologies at our hand.

STUDIO | STRUCTURE, METHOD AND CONTEXT
The studio was structured into three segments, comprising of a research and exploration section on traditional Asian timber construction techniques, a module on tool design and fabrication, and a final segment that synthesized the two to design, fabricate and build an original 1:1 scale structure. The studio was divided into three groups of four students each and was supported throughout the semester by several workshops that introduced students to
computational thinking, parametric modeling with Grasshopper, robotic programming through HAL, and the secure and safe handling of the robots. The first exercise started with an investigation of architectural elements based on timber construction systems within the Chinese context. In many cases today designers in the arena of digital architecture take the approach to look for systems or recognizable patterns in nature or the sciences, thus following concepts of bio-mimicry or mathematics. While this approach can produce fascinating results, over the years, I have witnessed that students have at times a problem with this methodology, since it lacks the direct link towards architectural applications, and thus students have difficulties to generate reasoning and establish ownership over their design. To avoid this phenomenon, this studio looked into existing architectural material systems that have been tested for various architectural elements throughout history. These elements were then meant as a basis to explore potential reinterpretations for contemporary solutions. Throughout most of China’s architectural history, timber can be seen as the dominant construction material. The country is home to a diverse set of vernacular wooden architecture, highly specific to its context and rich in architectural expression. However, due to the standardized building industry of today that is mostly based on concrete, the construction of timber buildings in China has virtually ceased, hence in contemporary architecture, these traditional elements don’t play a role anymore. One could argue that the extinction of the specific knowledge of craftsmanship involved is only a matter of time. Given this background, the studio sought to revitalize those through the aid of robotic fabrication. Through their research, the students eventually distilled three different systems that built the basis for their investigations. The first being the “Dou Gong” bracketing system, which usually is the structural network that joins columns to the frame of the roof. The second being the reciprocal frame structures that can be found in the timber woven-arch bridges in the Fujian and Zhejiang provinces. And the third being the “Luban Lock” or the so-called “Chidori system” a design concept derived from old Japanese and Chinese toys, and that elegantly produces a six-legged hidden joint (Fig.1). Based on unique structural principles and jointing techniques all three have in common that they follow very strict rules of construction, making them prone for computational explorations.

**COMPUTATIONAL SYSTEMS**

One of the ultimate goals of the studio was to engage students in new ways of thinking about design processes and solutions.

While architecture is in most cases static, the process to arrive at an architectural solution is not. Com-
putation allows the designer to produce many different versions of the same input system. With this approach, architecture can be thought as an adaptable system (Lange CJ, Rocker I 2013). Hence this method provides a framework for the designers to make viable decisions based on different parameters that can adapt to different needs and situations. A computational way of thinking is based on processes that start with elemental properties and generative rules to end with information, which derives form as a dynamic system (Menges and Ahlquist, 2011). Students, therefore, were asked to analyze the underlying principles behind each material system and to investigate their capacity to be codified and translated into possible algorithms. Utilizing Grasshopper for Rhino students explored the various possibilities embedded within their systems (Fig.2) with the focus to generate meaningful architectural elements. Part of the intention of this exercise was to make students understand that parametric thinking has nothing to do with a particular style, but rather with an approach to architectural design, hence any architectural system that follows certain rules could be parameterized.

**FABRICATION & PROTOTYPING**

The second segment directed the focus onto the making and craftsmanship and the translation of digital information into physical manifestation using the facilities in our lab. In our case the robotics lab is equipped with two industrial robots, a smaller one with no end-effectors to introduce students to the related concepts of robotic fabrication and a larger one that is equipped with a spindle. Since the lab has its limitations in woodworking, students were instructed to research the respective methods of traditional fabrication related to their material systems and to translate it into a set-up utilizing a router or spindle. When it comes to robotics in architecture students are confronted with a multifaceted array of problems ranging from code generation, tool design, fabrication techniques to procedures of assembly. In the past two decades, students in most architectural institutions had only the opportunity to use CNC fabrication tools such as the laser cutter or the milling machine. While those tools helped in the production of physical models, especially the laser cutter had an adverse impact on the student’s understanding of tectonics and craft in architecture. Guided by the constraints of the machine, students avoided confronting themselves with the limitation of the pre-existing set-ups. Other than common CNC fabrication tools, the robot isn’t limited to one fabrication method. Robots are therefore not used as a pure fabrication device, but rather as an open interface for architectural education (Brell-Çokcan, Braumann 2013). To avoid the mentality of becoming just a user of pre-existing set-ups of a specific tool, and to make the prototyping an integrated part of the design process the segment started with a challenge. Rather than using the robot with the mounted milling head for the testing of the fabrication process, students were confronted with the set-up that consisted of the smaller robot with no end-effector attached, and only a spindle with a 10mm cutter mounted on a table. This arrangement was not only challenging regarding tool design but also concerning programming the robot. The robotic arm is in many ways similar to the human arm and hand. To program a tool-path for a drawing executed on a sheet of paper mounted on a table with a pen that is attached to a robot via a penholder is relatively simple with recent software packages such as HAL. So to make students understand the complexities but also the opportuni-
ties within the various processes of robotic fabrication the set-up given to students was constructed the opposite way. In other words rather than working with a pen to canvas configuration, students had to deal with a canvas to pen arrangement, which makes the path design far more complex, but also more engaging into the creative process.

As the constructive capabilities of the robotic fabrication process clearly define the design space and thus productively inform the computational design strategy. Its development can also be recognized as a creative act of design on its own (Budig, Lim, Petrovic, 2014).

TOOL DESIGN

Usually, tool design is not part of the architect’s education. In most cases, we rely on existing tools to produce a creative artifact. Here manifests the enormous potential and promise within the trajectory of robotic fabrication and assemblies. Craft as a form of mastery comes from the constant development and refinement of a set of skills to achieve an aesthetic result. Tools within this process are an important factor. The more sophisticated they become, the more precise a result can be. Tools can also shape an entire craft; therefore it is essential within the discourse of robotic fabrication to embed it into the pedagogical agenda. However, it is not just about the tool or the immediate outcome of the tool, but it is also about a learning process that prepares students for an architectural profession that continually relies on these tools and processes to evolve the field (Sweet 2015).

Though the actual task of the tool was only to be a mounting device for timber stock attached to the robotic arm, it was quite fascinating to see the different approaches of the various student groups when it came to its design (Fig.3). While some fabricated already working prototypes at the start utilizing of the shelf clamps combined with laser-cut parts others produced clear failures that had no consideration for structural stability, precision or work efficiency. However, through the iterative learning process with trial and error, each group succeeded eventually to design and construct a device with unique properties performing to the needs of the individual design of their material system. Many of the traditional timber material systems were based on the use of multiple tools, such as chisel or saw. While those can be much more efficient to do the job, the idea in this segment was to focus only on one cutting device in order to understand the limitations and challenges. For example, due to costs students used mostly soft wood for their projects. The disadvantage of this type of
material is that it easily disintegrates the moment the router hits the surface, leaving undesirable marks on the edge. To achieve clean cuts students, therefore, needed to think creatively how to overcome those through a smart generation of cutting paths.

**ROBOTIC PROGRAMMING**

Students tacking the class didn’t have any previous knowledge in programming or operating a robot. Therefore it is very important to introduce students to a system that was easy to learn and allowed for accurate simulation of the robotic movement. For the robotic programming, the studio utilized HAL, a plug-in for Rhino Grasshopper. As many plug-ins for grasshopper Hal offers the advantage of a brilliant documentation, that offers the opportunity for self-learning and puts students at ease with coding. Though most Master students nowadays have had previous interaction with parametric software packages, there is still a lot of respect and fear in the student body when it comes to special software and advanced technologies. Therefore the software became a key pedagogical tool and allowed students the precise simulation of the fabrication process.

**SYNTHESIS**

To bring the knowledge forward accumulated over the first two modules and further advance the expertise within robotic fabrication and craftsmanship students switched in the final segment of the studio to the large robotic arm in the lab that is equipped with a large spindle. Students, therefore, had to develop new tools to fix the timber sections and a new system to generate tool paths for their final design. While the second module focused primarily on the replication of the existing precedent material system, the final design was meant to deviate from the original system and to push the capacities of 6-axis movement in space. Since the original systems were based on repetitive jointing mechanisms, any deviation from this would result in the dependency of many individual jigs if one would have to fabricate and construct it manually. The challenge for the students was, therefore, to depart from repetitive joints by introducing small changes that made the robot indispensable given the three-week timeframe allocated for the fabrication and construction of the final prototype (Fig.4).

**CRAFTSMANSHIP**

Other than in the European or North American context where the majority of kids grow up in an environment where either their parents have a workshop in the garage, or they are exposed to artisanry through high school education, Hong Kong children rarely have the chance to work with tools or materials before they might enter a formal education of architecture or another design discipline. One reason is the pure absence of space within the city to allow for such culture; the other is the local educational system that is largely focused on mathematics and sciences. Liberal arts education in this setting is merely an extracurricular activity. While the students that were enrolled in the studio had already a previous degree in architecture, most of them were still new to large-scale prototyping. Exposing them to robotic fabrication in an iterative process, they learned through trial and error the craft involved to master their projects. Many mistakes had to be made to reach awareness for clearance dimension, surface finishes, edge conditions and precision. There is a tendency in students today to believe only because a machine has done something it is automatically good and doesn’t need any further treatment. It takes this iterative process to stimulate the conscious and create a sensibility for the craft. Learning involves challenging preconceptions and assumptions that come under scrutiny when new worldviews are introduced. (Daas, Wit 2015)

**CONCLUSION**

The outcome of the studio outlined above was successful regarding the architectural exploration, the design process but also in the overall debate with the students throughout the semester. However several aspects come to my mind that could deepen the
Figure 4
Large scale Prototypes – three explorations
pedagogical set-up on the one hand but also the student’s learning experience on the other hand. Due to the lack of resources and expertise at the time of the academic year, the studio didn’t allow for the development of tools that were electronically driven and controllable through I/O programming. Though I don’t think that it is from a pedagogical point of view necessarily important for Architecture students to work on such devices, it is anticipated to integrate a module of such content into the course, since it offers a multitude of opportunities. On the one hand, it would allow for the collaboration between architecture and engineering students and therefore generate an opportunity to develop a cross-disciplinary platform for the robotics lab in both faculties. On the other hand, new software packages developed by people with an architectural background such as Firefly and HAL in conjunction with Arduino hardware would allow for new fields or trajectories within the architectural profession. Similar to the development of special modeling groups in the past two decades in large architecture firms such as SOM or Foster and Partners, the education of architects with robots and programming will allow future architects to diversify their knowledge and become innovators within the field. Hence it offers new opportunities to specialize as an architect after their formal education. An important aspect of the studio was to reflect on which role the robot will play in the future of the profession and how the role of the designer might change through this technology. Gramazio & Kohler’s early Gantenbein vineyard façade is in this respect seminal, simultaneously exploring the approach of automated bricklaying and its architectural potential. It is precisely this simultaneity of craft, economics, and design that is so striking (Feringa 2014). Indeed this project gives an outlook in how the profession can emancipate itself from the constraints of the industry and change back to a more holistic approach in the future that might remind us of the profession of the Baumeister (Master builder).

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