Formations of Digital Craft Culture

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The architectural discipline has debated the notion of digital craft for more than two decades. The discussion first centered on defining digital craft in relation to traditional hand craft in such works as Malcolm McCullough's seminal Abstracting Craft. More recently, digital craft's status has been confirmed as central to the contemporary practice of architecture through books such as Branko Kolarevic *Material Effects* and Gail Peter Bordon and Michael Meredith's *Matter.* Yet despite the emerging prominence of digital craft, specific knowledge on the production of it remains elusive. That is, we know digital craft when we see it, yet it is not always clear how to engage in a process that produces it, especially for students who are new to the discipline. As new digital modeling, simulation, and fabrication techniques take root within schools and the profession, it has become increasingly apparent that the formation of digital craft culture hinges on much more than just access to specific tools, but also on an intensive and rigorous understanding of the how the tools can be used with expertise to produce results that synthesize geometric logic, parametric thinking, and iterative prototyping. This paper documents these essential topics of digital craft culture within the field of architecture through several academic and professional projects.

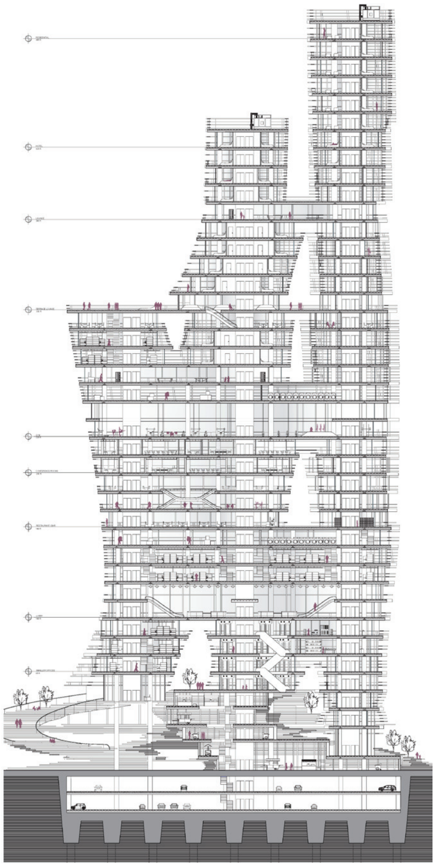
Within the last ten years, schools of architecture and professional practices have had to radically upgrade their software and hardware tool sets. We have now reached a point where access to some of the most innovative tools, from advanced parametric modeling software to robotic fabrication, is in the hands of many designers. Much of this is the result of the rapid democratization of both software and hardware that has occurred in the last ten years. Applications that were previously available only in the automotive and aerospace industries have been made available at lower prices or have been redesigned, in the case of Gehry Technologies' Digital Project, to make them more accessible to the discipline. In addition, many new applications focusing directly on conceptual generative design have been introduced by existing developers such as McNeel's Grasshopper and Autodesk's Vasari. Furthermore, digital fabrication technologies that only a decade ago seemed foreign to most schools and practices, such as laser cutting, CNC milling, and 3D printing, are now not only commonplace but essential modes of production. This rapid acquisition and integration of advanced fabrication tools has been further expanded recently through investigations of robotic fabrication strategies.

Yet in some ways our expanded toolsets have out-paced our intellectual capacities to utilize them with a high level of craft. This is a topic that many academics have struggled with as we see a new generation of students become more digitally adept while simultaneously becoming less aware of traditional craft and, more importantly, less able to keep pace with the methodologies required to master digital craft. For example, it is a paradox of contemporary architectural education that as our tools have greatly increased the speed and complexity of our students' drawings, renderings, and models, the overall craftsmanship of the representations has decreased. We long for the possibility of seeing drawings with depth, renderings that are selected and composed with care, or models without burned edges. A schism has occurred within the education of an architect where she has access to the most advanced tools yet struggles to stay abreast of the skills needed to not only produce work at earlier generations' standards of craft, but to redefine craft for future generations. We need to build new conceptual and pedagogical frameworks that allow young designers to construct a deep awareness, appreciation, and facility with digital craft.

FUNDAMENTALS OF COMPUTATIONAL DESIGN

One of the primary difficulties faced by young designers in developing a strong practice of digital craft is the lack of core knowledge of computational design principles. Each tool, from a hammer to a 3D modeling application, is embedded with certain constraints imposed by the designer of the tool. These craftsmen and programmers make their tools with specific material and operational processes in mind, however the nature of these processes is not always clear to the user. In the specific case of the design of digital modeling packages, programmers have made decisions about the various types of digital geometry to support. Although to the novice all digital geometry might appear to be the same, to the expert, the different geometry types are like different materials. In the same way that a fabricator would use different tools to cut metal or wood, the digital designer needs to understand the material-like properties imposed by geometry types such as nurbs, meshes, subdivisions, or solids. Furthermore, each of these digital geometry types is formed by a whole host of more fundamental concepts and mathematics. Analogous to the molecular structure of physical materials and the knowledge that a material scientist uses to analyze and construct new materials, contemporary digital craftsmen must understand the essential computational tools and processes that make and transform geometry on the screen.

In the last several years, we have seen a new awareness of the need for deeper computational and mathematical knowledge within the discipline. From the publication of Helmut Pottmann's *Architectural Geometry* to the significance of conferences and workshops such as ACADIA, Smartgeometry, and Advances in Architectural Geometry, the discipline has



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awakened to the importance of the topic to contemporary practice and education. In order to better prepare our own students at the California College for the Arts for even a basic computational design course in the core architectural curriculum, we revamped the required math course for the Bachelor of Architecture to specifically focus on the essential mathematical, geometric, and trigonometric operations used in digital modeling applications and environmental analysis. This new course, Advanced Geometry, forms the basis of our digital media curricular stream that extends across all five years of the degree.

At the advanced level, this material is reviewed and expanded on through one of my annual courses, Generative Design. Although the course primarily covers parametric modeling and digital fabrication, the first two weeks of the class intensively review core concepts on which all subsequent material will build such as vector algebra, trigonometry, and local coordinate systems. The course is structured on the idea that it is more important to learn the fundamentals of computational design than the specifics of any particular application. Software is always in flux but core concepts that allow us to create digital geometry will not significantly change. That is, although specific implementations of the geometry in code is new, most of the concepts driving the code are decades if not centuries or even millennia old. These concepts are as fundamental to the craft of digital architecture as the grain of wood is to a carver or the composition of clay is to a potter. Without understanding what could be called the materiality of digital geometry, there is no possibility of digital craft in architecture, as geometry is the language of the discipline through which all material effects are produced.

DEVELOPMENT OF PARAMETRIC THINKING

The education of architects at all ages is directly informed by their analysis of the work of others. As writers learn and refine their craft by reading the work of their peers, we photograph, draw, diagram, and model other architects' work in order to develop our own craft. This process has been central to the curriculum of all architecture schools and it has primarily focused on the construction of static models, drawings, or writings. However, it is the transformative potential of architectural precedents that guides this interest. We look to the work of others to understand the range of possibilities in design process and hope to find our own path of innovation through and between them. Parametric modeling, or more precisely, parametric thinking, provides a framework that structures the analysis of precedents through the rigors of geometric logic while opening the doors to the generative power of differentiation and repetition.

Within the last eight years teaching computational design, I have attempted teach the specific concepts and tools of parametrics through the analysis of case studies. In studios, seminars, and workshops at the Architectural Association, Yale University, Ohio State University, and the California College of the Arts (CCA), I have concluded that the development of parametric thinking applied to precedents, or the ability to understand the geometric and generative logics of other architects' work leads to a design process that is rigorous yet adaptable to change. The significance of

Figure 01: *Little HK* by BArch student Angie Williams in the author's Ctrl-Alt-Rpt advanced studio at CCA.

Farshid Moussavi's collaborations with her students at Harvard's GSD on the volumes the Function of Ornament and the Function of Form cannot be understated in its documentation and promotion of this concept.

In my Generative Design seminar at CCA, the course is structured around seven modules focusing on core concepts of parametric design such as differentiated fields, conditional procedures, and component logics. Paired with each of these modules is at least one case-study project that the students are tasked to analyze and then build a parametric model using the parametric design software Grasshopper for Rhino. Using the knowledge gained through this intensive parametric analysis of precedents, the course concludes with a final project in which students are asked to research a case study of their choice by first analyzing it through the construction of a new parametric model and then exploring the project's generative potential through modifications to the geometric parameters and logic. Through this process, students develop a population study that diagrams the genetic bonds that tie a larger family of related projects together.

This approach was further explored in an advanced design studio called Ctrl-Alt-Rpt at CCA in 2011. The studio was divided into three phases. In the first phase, titled Control, students were presented with a case-study project and asked to develop an intensive parametric model of it. This model, not the *actual* 3D model, but the generative logic driving it, acted as the source DNA with which students began to explore. This investigation was analogous to the mapping of an organism's genome. No new projects were created, but rather genetic tendencies and predispositions of the original precedent genome were discovered. That is, students parametrically pushed and pulled the model in order to find its potential architectural opportunities or risks.

Using this precedent genome mapping, students moved into the second phase called Alt, in which the genome was tasked to adapt to a radically new environment and typology. All of the original projects were relatively low buildings, yet the students were asked to begin modifying the parameters of their models to create a new skyscraper in Hong Kong. Unburdened by the slowness of actual evolutionary processes, students could freely splice, mutate, and crossbreed their precedent genome to produce new performative behaviors that were better adapted to the local ecological and programmatic niches. This evolutionary design process, based on the parametric transformation of precedents, was more successful in comparison to the traditional use of precedents in design studios where students often feel either overly constrained by the precedent or unable to discover an appropriate avenue of generative change. Additionally, by working and reworking the same generative model throughout the term, students became expert parametric craftsmen able to understand the nuances of geometric logic and how it can be informed by environmental and programmatic factors.

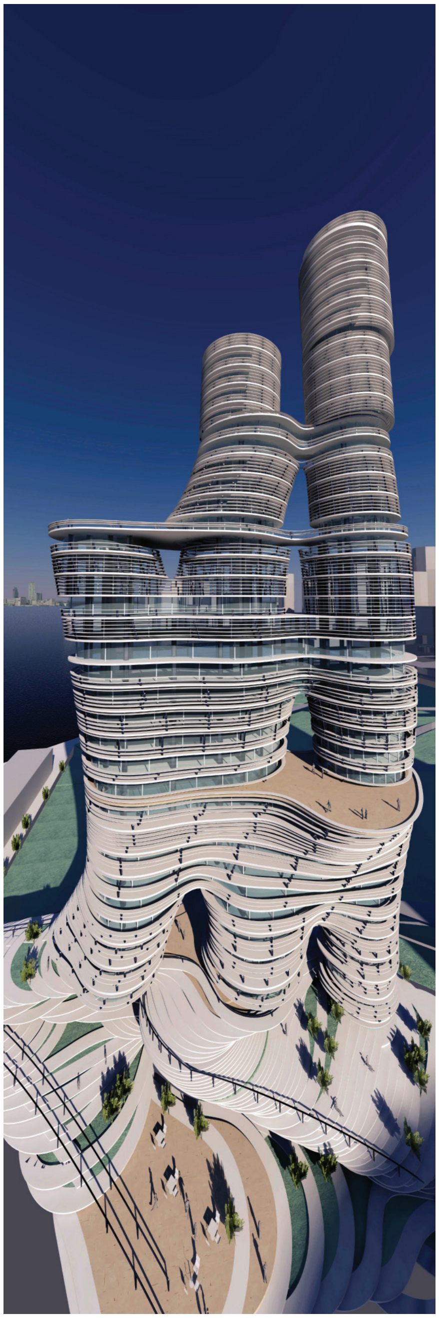

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Figure 02: *Little HK* by BArch student Angie Williams in the author's Ctrl-Alt-Rpt advanced studio at CCA.

INTENSIVE PROTOTYPING

The third and final component of the CCA advanced studio in 2011—Repeat—focused on another aspect of digital craft. The pervasiveness of digital technologies in architectural education and practice has produced a disappointing side effect. The speed at which drawings, renderings, and models can be produced has accelerated at an ever-faster pace while the craft of the representations continues to decline. What once took days or weeks to produce by hand (if even possible), now may take hours or even minutes. Yet with this increased speed of production came a lack of attention to detail. When a hand-drawn two-point perspective took days to produce, a student and instructor would obsess over the view, line weights, and style. Likewise, individual plans and sections were laborious tasks that were conscientiously planned while students now have the ability to quickly cut plans and sections at any position almost immediately from a 3D model. Models, planned and built over weeks of time, yearned for the status of fine furniture yet now models are often produced (if at all) at the last minute using the laser cutter or 3D printer. What has happened to the culture of representational craft in the architectural discipline in the age of digital technology?

We are essentially trapped by the speed of our tools. Knowing that the parametric model can adapt quickly, that drawings can be pulled from the model nearly automatically, that models can be fabricated robotically, we push the process of design up to the last minute and forget about the value of production. Prior to digital technologies in the design process, we had to make decisions early because we knew that production simply took so long and was so difficult. That is not to say that designing stopped with production, but we learned to design through production and to craft our representations with care and foresight. One might find some similarities in this situation with the relationships between the fast food and slow food movements. Although modern transport, agriculture, and logistics have greatly increased the speed while lowering the costs of food, certain essential qualities such as flavor and nutrition have been supplanted and are currently being revived by slow food advocates.

To enforce a certain conscientiousness and stimulate an attention to craft during the third phase of the studio, students were asked to stop all major design work six weeks prior to the end of the term and to focus on the production of only three representations. Rather than the papering of boards with dozens of renderings and every floorplan and section and, almost inevitably, a rather undercooked physical model, I asked for one rendering, one section, and one model, each six feet high. The students could show diagrams that they had already completed in phases one and two, but no other media could be shown at the final other than the three large items.

This focus on slowness and quality over quantity was revelatory for both the students and instructor. Freed from the seemingly endless process of design revisions, restarts, and breakdowns, students rethought their designs through the mediums of representation. It was no longer only about the design *process*, but the design *product* and this product was going to be crafted like nothing they had ever done before. Each day for six weeks students and instructor were able to critique various stages of the same drawing, rendering, and model, and through this we all learned a great deal about the how craft is a form of design. When every line, pixel, and piece of chipboard becomes a conscious decision, it forces one to reflect on the design and to make choices that further the design's goals in highly refined and subtle ways.

In addition to explicitly making time in a studio's schedule for a final focus on craft, there are many other strategies for integrating digital craft into a design studio. In an advanced studio in 2010 at CCA, rather than focus on the relationship between craft and digital fabrication at the end of the term, it was explored continuously throughout the entire studio. For this studio I partnered with Kreysler and Associates with the intention of finding innovative design and fabrication strategies for composite materials in architecture. From the first to the last day of the studio, students investigated the cross links between form, fabrication, and materiality. Students began the studio working on three parallel tracks that, over the term, began to integrate into one. The first track focused on the development of parametric modeling skills, the second track on training using the CNC mill and prototyping quick samples, and the third track on hands-on tutorials with the production of composite materials at Kreysler's fabrication shop. As students gained knowledge in these three areas they began to see opportunities that would not have existed if the topics had been introduced sequentially rather than in parallel. The final project consisted of full-scale prototypes of composite façade panels and required students to work directly with the expert composite fabricators as what might be called apprentice composite craftsmen. The simultaneous focus on form, fabrication and materiality established in this studio produced synthetic results where it was impossible in any of the projects to only discuss one topic without mentioning its relationship on the others.

SYNTHETIC PROCESSES

Digital craft is inherently synthetic. Through its basis in computational design, we combine abstract mathematical constructs with the creation of digital geometry. Through our parametric analysis and transformation of precedents, we blend ideas together and discover new architectural possibilities. Through an intensive focus on the iterative prototyping of drawings, models, and images, we assemble a new whole from disparate parts. Out of this milieu a new design methodology has formed that combines materiality, geometry, and performance into one synthetic process. Using examples from three short workshops or professional projects, I would like to demonstrate how this synthetic process works in practice.

In the winter of 2012 I collaborated with Professor Marc Swackhamer at the University of Minnesota as well as 20 graduate students in the design, fabrication, and assembly of the Catalyst Hexshell project. This four-day workshop explored the use of parametric modeling and structural simulation to design thin-shell, thrust-surface structures. Based on the pioneering work of architects such as Frei Otto, Heinz Isler, and Felix Candela, thin-shell thrust surfaces attempt to align the surface of a spanning structure with the direction of the structural forces. Through this alignment of material, form, and force, the structures could become very thin and lightweight, as there are no out-of-plane forces for which to compensate. Using

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Figure 03: *Catalyst Hexshell* by the author, Marc Swackhamer, and workshop students at the University of Minnesota.

Figure 04: SG2012 *Gridshell* by the author, fellow collaborators Mark Cabrinha and David Shook, and workshop attendees at Smartgeometry 2012.

a parametric model made in Grasshopper and a physics engine called Kangaroo, we were able to create an endless number of different shell variations sited in the building. After an introductory day focusing on the core concepts of parametric design and digital/physical form-finding techniques, student teams competed in a one-day design charrette, the winner of which would have their design further refined, fabricated, and assembled by the entire group in days three and four of the workshop. The automatic unfolding, labeling, and nesting of all parts in the parametric model facilitated the fabrication of the shell components.

Soon after this project I had the opportunity to collaborate with Mark Cabrinha from Cal Poly San Luis Obispo and David Shook from SOM San Francisco on a Smartgeometry 2012 workshop cluster. Working with twelve workshop attendees over four days, our group focused on the design, fabrication, and assembly of a wooden gridshell. Similar to the thin-shell at the University of Minnesota, this project attempted to build on the legacy of Frei Otto and others who contributed greatly to the understanding of gridshells. Gridshell structures are composed of straight timber members that when arranged in specific ways have the ability to produce extremely complex surfaces. Unlike the majority of built complex surfaces, gridshells use a minimum of material and produce very little waste. The challenge we set for ourselves in the workshop was to build a digital parametric model of a timber gridshell that was iteratively informed and verified by structural analysis software. In addition, the model could be used to quickly calculate all material quantities and node locations. Similar to the Catalyst Hexshell project, the SG2012 project was investigated on day one, designed on day two, fabricated on day three, and assembled on day four. The project was produced using only straight wooden lathe so no digital fabrication was needed, and it created nearly no waste.

The last project I will discuss that exemplifies an approach to digital craft that produces a synthesis between form, material, and performance is Chrysalis (III), produced by my professional practice Matsys for the Centre Pompidou in Paris. The project is a small design prototype exploring cellular aggregation on a surface. Made from wood micro-veneer, the prototype hangs like a barnacle-covered cocoon in the gallery. The Centre commissioned the prototype and I was asked to produce a proto-architectural object that explored the future of materiality, fabrication, and technique. The project belongs to a long series of projects by my research practice exploring the generation, fabrication, and performance of cellular morphologies. Using a combination of tools such as parametric modeling in Grasshopper, physics simulation in Kangaroo, and scripting in Python, the cells were relaxed in a spring network to allow the geometry to find a stable state. As the cell positions relaxed, acute angles were minimized making the fabrication and assembly easier. Each cell is composed of two parts: an exterior cone-like folded surface and an interior warped plate that stiffens the outside cells and helps to build a taut inner surface. Using an optimization algorithm, these warped plates could be fabricated from flat sheet materials without any seams or folds. Although small, the project

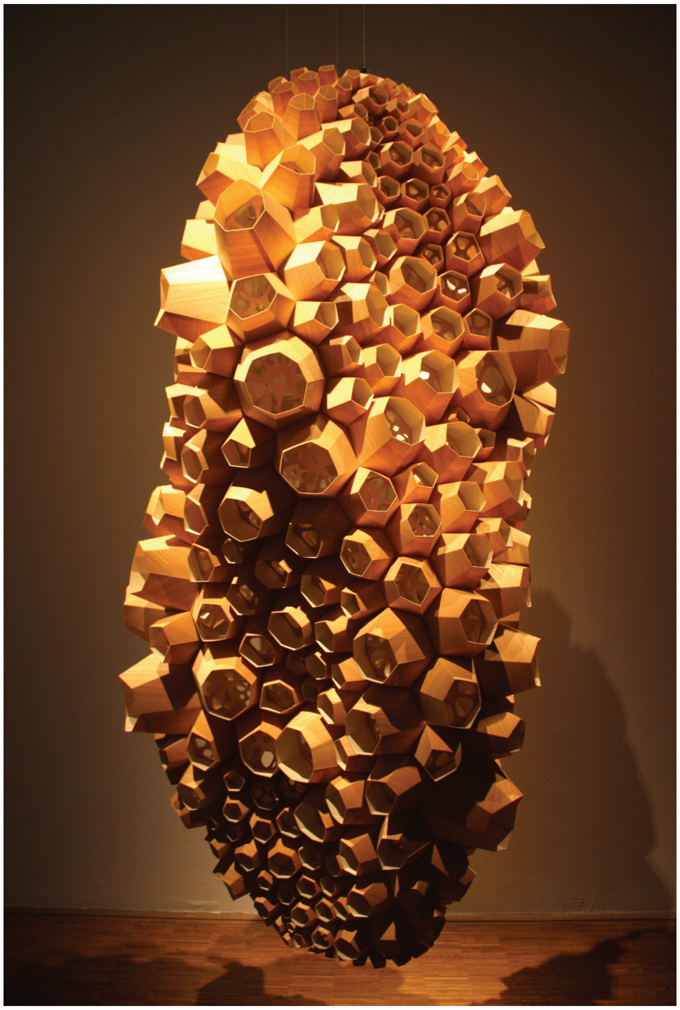

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Figure 05: *Chrysalis (III)* by the author.

demonstrates the how integrative techniques can be used to produce works of digital craft.

CRAFTING THE FUTURE

The discipline of architecture is experiencing a radical shift in the development of digital craft culture. Our tools are robust, yet our conceptual frameworks have lagged behind and are in need of being refreshed. Through the rigorous understanding of computational design principles, the reengagement of precedent through parametric thinking and modeling, the intensive prototyping of architectural representations, and the enabling of new synthetic processes that integrate form, material, and performance, we can produce a new culture of digital craft. ◆

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