Digital Fabrication and the Design Build Studio

Historically, there has been a rift between design and construction in architecture, but the growing popularity of design/build in the profession and in the university setting has begun to mend the gap. Currently, for many professional practices the integration of construction with design follows a set strategy; technology is reserved for the design sequence, followed by construction via traditional methods (by hand). But, we are at a point of transition in architecture.

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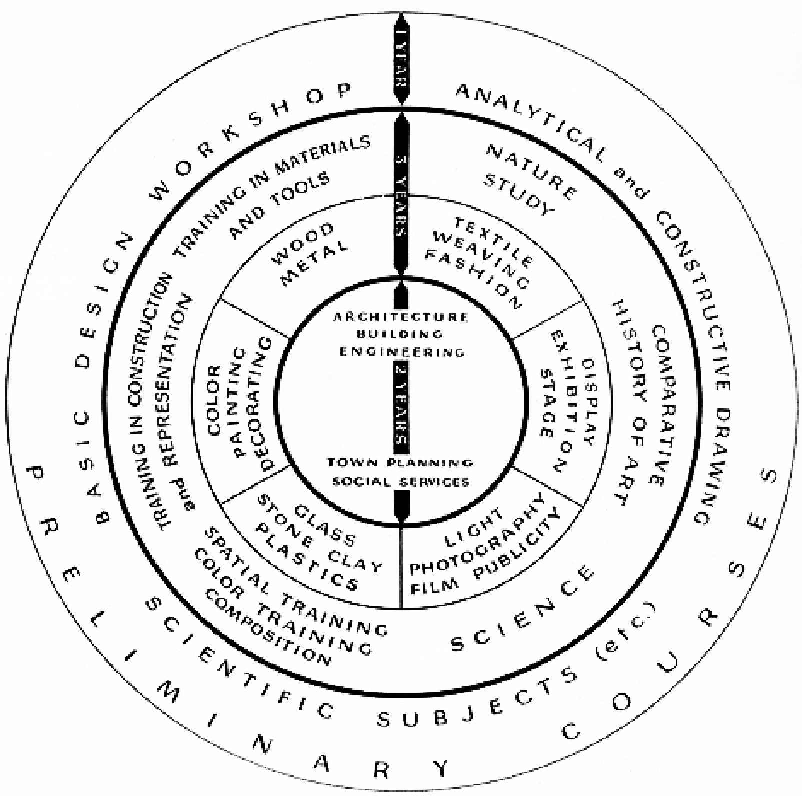
Digital devices are now the norm in the office and the academic studio. Students and professionals design with three-dimensional digital tools, and, through this technology, design and construction are inextricably woven together in a continuous feedback loop. In particular, recent university design/build programs are following more closely the model of the Dessau Bauhaus, by employing the latest technologies to find new ways to create and construct architecture. Because these programs have now propagated more widely, it is prudent to examine the different methods of application in order to understand the potential ramifications of each program type. It appears that most programs can fit into one of two categories: **1) Traditional Full-Scale** or **2) Digitally Crafted Segments**. In the first type, the program adheres to traditional building methods, like the balloon frame. Technological advances are limited to environmental concerns; materials are chosen to increase energy efficiency or reduce the impact the building has on the environment. The construction component of these courses is usually manifested in the erection of entire buildings (small, modest pavilions or homes). The second category of design/build programs is focused on incremental construction. Students use digital tools for design and construction to create a portion of a building demonstrating a process or method of building. The building segment is representative of the whole and indicative an allegiance to parametric design and the pursuit of research as a design tool. Studying the results of these two academic paradigms facilitates the exploration into the best course of action for prospective changes to design/build programs.

In architecture, theory (design) and practice (construction) have not always assumed equal status. For a time, the role of theory eclipsed practice. Although we are working in academia and in practice to bring these two back into balance, currently, a complex and segmented process usually separates the architect from the builder. Building fabrication is compartmentalized, rather than activated as an extension of the design process. Architecture education has mirrored practice in elevating design over construction, but for a number of programs, design/build courses are becoming an integral supplement to curricula. These courses provide a fairly accurate paradigm for architecture practice and the result is that students are better prepared for the complex demands of work in an architectural office. In an article called "Learning from Construction" in *Architecture Magazine* these courses were described by Joseph Bilello as "intended less as surveys of the popular alternative delivery method than as hands-on clinics to teach students about sites, structures, materials and joinery. Academic design/build programs remove design projects from the studio vacuum and push students to reconcile their drawings with the reality of structures they can build, weld wire and plumb. This process encourages students to work as part of collaborative teams, resolving conflicts, managing finances, and communicating with clients."[1]

THE BAUHAUS: THE ORIGINAL DESIGN BUILD STUDIO

To begin to understand the current design/build programs, we need to examine their roots in the Dessau Bauhaus paradigm. As established by Walter Gropius in 1919, the school fostered a cyclical and fluid design process and a forward-thinking pedagogy evolved from industrial design and mass production.[2] Students of the school were encouraged to build in order to further explore design intentions. This model has spawned the design/build strategy as a delivery method in practice and academia to offer faster paced production and more cost-effective buildings than the typical architect/contractor combination.



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In a lecture at the ACSA National Meeting in 1959, Gropius explains the goals of the DBS as an educational model. The Bauhaus touted research as the precipitant necessary to further educational aims. A revolutionary concept at the time, the Bauhaus focused on teaching students to put stock in process over given information and to value the experience gained through live projects that are described here by Walter Gropius:

Figure 1: Dessau Bauhaus, *coursework breakdown.*

"In an age of specialization, method is more important than information. Training should be concentric rather than sectional with an emphasis on relations.

Design knowledge only comes by individual experience, where feedback on one's own work is of paramount value. Through the feedback students receive when trying to build their designs, they quickly learn to account for constraints. The aim is to provide a rich and deep learning environment, facilitating a student to design and build ubiquitous computing, not only within human capability constraints, but also for human enjoyment, spirituality, etc.

At the start, basic design and shop practice combined should introduce the students to the elements of design and simultaneously the ideas of construction. In succeeding years, the design and construction studio should be supplemented by field experience. Construction should be taught with design, for they are directly interdependent.

…Students learn to design better when first encouraged to explore, try, reflect upon, and integrate design and construction."[3]

The Bauhaus program aimed to connect the craftsman with the artist and shift construction to the center of the architect's training. Gropius explains this emphasis on hands on teaching: "Starting with the simplest tools and least complicated jobs, [the student] gradually acquires the ability to master more intricate problems and to work with machines, while at the same time, he keeps in touch with the entire process from start to finish."[4]

In the "learning-by-doing" workshops taught by Johannes Itten and Josef Albers, students were allowed to experiment with materials in an open-ended format, emphasizing rigorous process and intuitive design methods. The decision to abandon basic instruction, in which students merely paint and draw, in favor of a systematic study of materials, of their constructional, functional and economic requirements and possibilities, was didactically significant. Albers explained that the objective of his course was "the ability to invent through construction and to discover through observation is developed, at least at first, by undisturbed, uninfluenced and unprejudiced experiment that is a playful tinkering with concrete goals and experimental work."[5] Thus, the opportunity to explore and find new ways to fashion architecture was central to the focus of this school.

Despite the fact that many American schools formulated their programs using the Bauhaus as a model, the practice of building full-scale prototypes or studying details in the tectonic realm did not originally translate. Instead, the focus was on a representation-based pedagogy and the three-dimensional models and drawings in plan, section, elevation are rarely at full-scale. Only recently, has the inclusion of a design/build component in architecture programs moved from the fringe of architectural academia to a compelling didactic tool. The inclusion of these supplemental courses means an interrelation of conceptual ideas with fabrication. Thus, concepts are tested and the best solution can be revealed through the process of making. But, there are multiple academic solutions that have been applied in different universities. Comparing the two main significant approaches, **Traditional Whole** and **Digitally-Crafted Increment** reveals much about the design/build paradigm and the potential futures for architectural academia.

TRADITIONAL FULL-SCALE DESIGN/BUILD

Full-scale traditionally constructed design/build was initiated with the work of **Yale University's Building Project** (established in the 1960s) and **Auburn University's Ru-**

ral Studio (established in the 1990s). The resulting projects retained original building methods, and didn't push the boundaries of architectural research as intended by the ideals of the Bauhaus. These studios and others that tend toward this method emphasize cost savings and efficiency over a rigorous design process, therefore eroding the link between design and construction by reversing their usual roles.

Currently, most design/build programs follow this long-established format. A few notable examples are **University of Virginia's Community Design + Research Program**, **University of Arkansas Design/Build** and **Auburn University's DESIGNhabitat**. These programs focus on hands on experience through the act of construction and community outreach, attempting to create buildings that fit into their cultural and climatic settings. This is evident in the words chosen to describe their programs. UVA summarizes their collaborative Community Design and Research Center (CDRC) with the intention that "through design and public service, [students] are able to apply their skills to compelling social issues, gaining real–life experience in the process and broadening their conceptions of what professional practice can be."[5] The Fay Jones School of Architecture at the University of Arkansas fixates on building by hand for the community. In fact, according to them, students have "sketched, sweated and hammered through some 16 design/build projects."[6]

Auburn retains a similar concentration, but a recent AIA paper by Justin Miller and David Henson reveals DESIGNhabitat's expanding aspirations to target design-based research objectives. The ambition of DESIGNhabitat projects is to fulfill one of two goals, (1) to test hypotheses or (2) to demonstrate the effects of integrated design strategies.[7] Simulation becomes a crucial apparatus in scrutinizing a design from component to full working prototype, as students probe the limits of digital tools and technologies.[8] They evaluate the performance of preliminary designs to analyze the potentials before any actual building phase. But, still, the program has its limitations: the evolution of programmatic phases over the past eight years centers on climatic concerns, energy conservation strategies and construction by hand.

TECHNOLOGY AND ARCHITECTURAL ACADEMIA

Design/build programs of this first type have often been critiqued because the architects (or students) restrict themselves to technologies that are, for the most part, outdated. An alternative is found in the incorporation of leading digital practice-based techniques in design and fabrication. The introduction of innovative materials, CATIA modeling, digital fabrication and automated construction invigorates the architectural process from concept to production. By informing learning objectives with cutting edge ideas, the efforts of design/build programs are expanded to more varied results and these studios supplement and advance educational outcomes.

Fittingly, the word technology is rooted in the Greek word techne, which refers to both "art" and "skill."[9] Thus, it follows that the utility of digital tools can redefine their relationship, strengthening their bond and reaffirming the base meaning of the term technology. Through the use of these technologies, students design in three-dimensions from the beginning, incorporating considerations of how best to fabricate. This can only be approximated in chipboard and graphite on trace paper. The late Marco Frascari comes closest to describing the potentials for the bond between construction and thinking in "The Tell-Tale Detail." He describes learning as "an exchange between the construing and the construction and a balance between the thinking about and the making of an artifact."[10] The use of technology in the creative revealing of ideas through construction facilitates this "exchange" and strikes a harmony between design and construction.

There are many possibilities for the future pf architectural education, but digital software and fabrication appear to be critical to the development of architectural academia. Several programs take advantage of digital tools culminating in projects documented with incremental full-scale models that are either sectional (Georgia Institute of Technology) or component-based (ETH Zurich and Berkeley University), or complex smaller constructions (Carnegie Mellon University).

INCREMENTAL FULL-SCALE DESIGN/BUILD: SECTIONAL

Incremental full-scale models give students the opportunity to design complex buildings via elaborate means. The sectional prototype analyzes the potential of the building strategy chosen by the students. Research is fully engaged as students use technology to examine new methods of design and fabrication. This kind of design/build programs is reminiscent of Jean Nouvel's process of designing the metal sun-screen units with active diaphragms for L'Institut du Monde Arabe. Because these increments can be duplicated infinitely in a field condition, utilizing this unit-based approach allows students to focus on a particular aspect of their design or method of construction which means that complex designs can be achieved.

Georgia Tech is one school that employs digital tools and technologies to build sectional models that demonstrate construction techniques. Since joining the faculty as Thomas W Ventulett III Distinguished Chair in Architectural Design in the School of Architecture in 2012, Marc Simmons has pushed his students to explore the cutting-edge. In his Design & Research Studio of Fall 2012, groups of students worked on the design of three separate site-specific buildings for the DUMBO area of Brooklyn, New York. The strategy of this studio follows that of leading practices. The objectives of the studio are described as: "An analytical and interpretive process may yield a critical design for the building envelope, understood in the broadest terms, and provides ballast for the continued evolution of a set of envelope ideas that quickly emerges into full physical and empirical assessment and development. This question of origination - yielding a set of ideas and positions framing specific envelope designs is profoundly important enabling the realization of technical designs and solutions that not only perform, but engage broader aspects of human experience."[11] The emphasis for this course was on the development of the building shell through an iterative analysis of context, materiality, systems and performance. The projects were tested through physical models, samples, mock-ups and full-scale prototypes. In the end, the students made extensive use of Georgia Tech's Digital Fabrication Laboratory to create full -scale prototypes of each specific façade system proposals.

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Figure 2: Mixed-use development section model, *students put final touches on their full scale mock-up.*

One of the groups that was tasked with the design of a mixed-use development created a complex parametric building envelope. The students built numerous digital models, chipboard models and full-scale styrofoam section models to test their design before fabricating the final full-scale segment, a portion of the folding facade. Because the students chose the material of concrete, they built a formwork from pieces cut using a CNC router, placed rebar and then completed the wall with multiple pours. In the process, they began to understand the complexities of this type of construction.

The immediate digital and physical production of models and mock-ups was a critical tenet of the studio employed to interrogate design issues. Each artifact created brings up more questions, begetting the fabrication of the subsequent model to further understand the reality of the projects and aid in decision-making. According to Simmons, the design process is iterative and interwoven: "In a perfect world, it is a continuous, virtuous, spiral-formed cycle of design incorporating and assimilating new information, parameters and understanding."[12]

INCREMENTAL FULL-SCALE DESIGN/BUILD: COMPONENT

Despite this successful example, component fabrication is more proliferate in design schools than the sectional builds. In this approach, students research and design methods of building rather than a particular structure. Two schools that subscribe to this modus operandi are ETH Zurich and Berkeley University.

The Programmed Wall was a student project that was part of a course at the Swiss Federal Institute of Technology, Zurich (ETH Zurich) in 2006. This project, a four-week workshop in which students design brick walls to be constructed by an industrial robot, is an example of ingenuity in the digitization of assembly. This project shows the potentials for translating parametric design to automated construction. Students mastered a method of design by manipulating the positioning of an object in a field, thus allowing for computer-aided assembly and formation of tessellated walls.[13]

The course is described as a step toward future building practices. "If the basic manufacturing conditions of architecture shift from manual work to digital fabrication, what design potential is there for one of the oldest and most widespread architectural elements -- the brick?"[14] The students explored a process that could become the future of masonry construction. Unlike a brick mason, the robot can position each brick precisely, without reference or measurement, and therefore, can work quickly and efficiently. Students exploited this ability by "developing algorithmic design tools

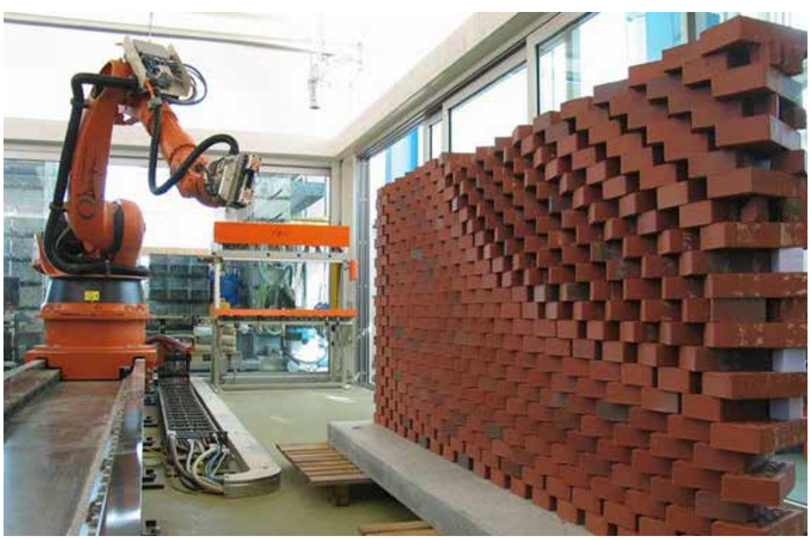

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Figure 3: Programmed Wall, *5-axis robot building one of the wall scripts.*

that informed the bricks of their spatial disposition according to procedural logics."[15] Designing parametrically with software in this fashion links a part with the whole through a set of defined geometric relationships. This process fosters the potential for the design of a module that acquires multiple variations as it is instantiated across a field. "Even as the design of the field and the module differ, together they invariably form a tessellated pattern."[16] So, instead of designing the geometry of the wall, the students were able to design the constructive logic that can have many formal architectural applications.

The project Digital Weave, built and designed by graduate students in Lisa Iwamoto's studio at Berkley University, reveals another version of digital design-build. This five-week workshop resulted in an installation at the San Francisco Museum of Modern Art Contemporary Extension. Students were asked to create a thirty-two-by-eighteen-by-eleven-foot environment for the exhibition that had to be quickly assembled and disassembled in the museum in a matter of hours.[17] This led them to focus on compressibility in order to facilitate mobility and quick construction on site. The use of digital tools was sensible, since this way the model pieces could be sequentially fabricated by computer-controlled machines and be put together like a puzzle. Students created this project by applying a "sectional methodology to a pliable material," a thin plastic.[18] Thus, Digital Weave was designed as a kit of parts by way of CAD/CAM technologies used for conceptual and constructional methods. The form is merely a simple Rhino model that was sectioned radially into a set of unique vertical ribs. The floor itself was pieced to function like a puzzle and notched for rib placement. The rib geometries were refined in AutoCAD and both these and the plywood floor sections were cut with a CNC water jet cutter.[19]

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The format of the project allowed students the freedom to work through their designs in feedback loop between design and fabrication. Students were able to test their design and determine potential issues with constructability and structural stability by building full-scale mock-ups before the form of the final prototype was set. The precision of the technology allowed for easy construction without the need for mechanical fasteners between the floor and ribs, but only in the connection of two ribs.[20] The outcome was an intricate design composed of a multitude of individual parts that reveals the opportunity of mass customization in the digital design-build format.

COMPLEX SMALLER CONSTRUCTIONS

The second variety of digital design and fabrication is manifest in complex smaller structures. Students at Carnegie Mellon can create one of these by participating in one of the adaptive reuse projects in the Urban Design Build Studio (UDBS). In Fall 2010, a graduate studio led by John Folan formulated a proposal to reuse the

Figure 4: Digital Weave, *Students text the compressability of a section of ribs.*

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Figure 5: PURIFLUME, *Students finalize the construction of the filtration system.*

decommissioned Leslie Park Pool in Lawrenceville.[21] This project titled PURIFLUME Splash Pad Play Space, nicknamed the EcoBeastie, is a mobile, proof-of-concept, closed loop water filtration system that features elements commonly found in a municipal spray park.

Over the past decade, half the pools in Pittsburgh have closed due to budget cuts and some have been replaced with spray parks that subsequently put a heavy load on the combined sewer system.[22] Since this design is a closed loop filtration system it eliminates that problem and eventually reduces the cost to the city because it reuses the same 110 gallons of water continuously.[23] In addition to this eco-technology, The PURIFLUME utilizes eco-technology with a UV water sterilizer powered by a photovoltaic array and exemplifies the application of the digital craft in a design-build academic studio.[24] The students used digital design tools and a CNC machine to build this mobile spray park.[25] By incorporating complex design and fabrication strategies to a project that address environmental and social concerns of the community, this project provides a plausible paradigm for student design and production of a functioning design-build prototype.

CONCLUSIONS

As established by these four case studies, research and technology-based approaches act as lynchpins in the design/build process. The very purpose of the programs is to explore the extents of architecture, teaching students the procedure of design as well as a way of thinking. Bernard Tschumi, former Dean at Columbia University School of Architecture, sums up the aspiration of architectural education established through digital design/build studios by suggesting “you want to teach people how to think rather than just to learn the code.”[26] Current design/build programs align closely to their Bauhaus lineage by centering on live projects: elastic format designs that encourage research through trial and error. The working process in design/build is animated, changing according to dynamic external forces. Lisa Iwamoto explains how this functions in academic design/build programs: “relationships among the design, material, fabrication, and assembly are intentionally kept flexible through the final building stage. The design-build process fosters experimentation, where fortuitous "accidents" may lead to new insights and unintended design consequences."[27] The use of full-scale models via digital craftsmanship in the design studio allows for students to work directly with the intended assemblies and gain real world results when testing ideas. Design/build studios attempt to connect students with the design process that a practicing architect experiences, as well as a contractor's procedure of building construction. As the studio emulates the flux of real-life experiences, it simultaneously presents a compelling array of concurrent scales and enhanced decision-based thinking.[28]

Architecture is a rapidly changing field. Computer modeling techniques can now be combined with fabrication software, connecting the architect directly to the fabricator. It is likely that the architect's precise computer model could soon become the shop drawing, and construction will be executed directly from it. These advances in technology have also impacted architectural education. Students use the computer to build models and create walk-throughs that simulate assembling and the experience of a space. However, many design/build programs are a step behind the rest of architectural education. In fact, they often use technologies that are fifty to a hundred years old, but to effectively prepare students to function within the practice, digital design and fabrication should be engaged. It is essential that these studios continuously evolve in response to technological innovation in which technology transfer, virtual reality, and sustainability set new criteria for performance demands. With this approach, design/build programs will act, as originally intended, as hotbeds for research where students pursue advances in technologies and gain knowledge to forward the progress of the field of architecture.

Teaching students to negotiate between digital craft in the generation of design and building assemblies is an integral objective for architecture academia. In digital design/build studios, students learn to work through problems with three-dimensional representation tools and production software and better their design process, strengthen the most immediate benefit of design/build projects for architectural students, the direct connection to practice. Positioning digital tools within a design/build sequence encourages design innovation and pushes the boundaries of architectural education and practice as the courses in the Bauhaus did. This use of technology re-ties design and craftsmanship and secures the continual evolution of the field of architecture with universities leading as innovative and boundary pushing epicenters of research and design.

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