Building a Structural Ethos

> ‘Durable knowledge’ is a clear awareness of facts arrived through an intense observational and constructive effort. Creating a physical structure through the tactility of the hand helps one arrive at a ‘durable knowledge’.
> — Artist Donald Judd

BRUCE WRIGHTSMAN
Kansas State University

ABSTRACT

Artist Donald Judd formulated the term ‘durable knowledge’ which is a clear awareness of facts arrived through an intense observational and constructive effort. Creating a physical structure through the tactility of the hand helps one arrive at a ‘durable knowledge’ of the subject matter. A project, which set out to achieve a ‘durable knowledge’ of structures is a full-scale footbridge developed from 2007-2012. Second-year architecture students as part of their first structures course design, fabricated then tested a full-scale footbridge. The footbridge had to span 10-feet over an existing creek, weigh less than 70# and support a load significantly greater than its own weight with only minimal deflection. Students worked in small groups developed a structural strategy, selected building materials and built their footbridges at full-scale. The project was structured as a science lab; akin to a design studio beginning in a research phase in order to develop a design strategy that would lead to a concept from which to construct prototypes to test before final on-site testing. The iterative methodology of prototype development and testing served as a ‘feedback loop’, which was vital to the learning objectives of the class.

The process of translating design ideas from paper (theoretical) to full-scale (real) covering the spectrum of structural analysis to constructed assembly immersed students into a world where theoretical structural challenges addressed in lectures are tangible matters with real consequences that must be explored and tested. Connecting the physical rigor of the hand (intuitive) with analytical rigor of the mind opened pathways, leading to tactile improvisation and subsequently making the knowledge learned more durable.

This paper will present the unique footbridge project, which broke away from a traditional structures curriculum in lieu of an innovative ‘design/making’ pedagogy for exploring structural design and performance.

RE-THINKING HANDS-ON LEARNING

Within many architectural programs, the engineering department or other professionals with engineering backgrounds have traditionally taught the structures curriculum. This can often result in difficulty communicating to architectural students the applied value and importance of structure as a design discipline. Structural and architectural design is inseparable, and should ideally be taught as such from an architectural perspective. Historically the architect served as the 'master builder,' with structure integral to the hands-on construction of architecture. While the traditional role of the architect is not to build they must understand how the 'performance and craft' of building is obtained and the challenge that lies in successfully achieving these goals. Introducing students to structures as a craft of making through a personal hands-on learning experience places students more in-tune with the physical condition and challenge of building structures more profound in their design thinking.

The material-structure assembly is a fundamental concept in architectural education. It can be easily ascertained through design studio and Design-Build projects. Design / build projects and hands-on learning approaches place a responsibility on students to actively participate as contributors to the learning environment rather than passive recipients. In a normative architectural education, however, only a limited number of students will have the opportunity to engage in a hands-on learning experience. This is due in part to the practical logistics of studio class sizes, with enrollment of only 12-16 students. Moreover, a relative minority of design studios is taught from a Design-Build learning format. In contrast, the Architectural Structures course is often taught in a large lecture format exceeding 90 students. A structures curriculum is ripe for exploration and invention because it covers issues of program, form, and material assembly. Its pedagogy must address both an analytical understanding of structures as well as the tectonic integration of material and form with its structural surrogate. It could greatly benefit from active material investigations.

Following Judd's principle of 'durable knowledge', I developed a full-scale structural footbridge design project, from 2007 to 2012, from which to teach principles of structural design and performance. The project set out to build a 'durable knowledge' by immersing students into an in situ structural design project. Working in groups of four to five students designed, fabricated and structurally tested, a full-scale footbridge following multiple structural performance criteria.

> Kinetics (kə-`ne-tiks): the mechanism by which a physical or chemical change is effected. .

A building structure is a problem of lightness. Elemental building components present themselves as physical loads, transported to site, before becoming conveyers of structural loads.[1] Structural integrity is the ability of a structure to hold together under a load, including its own weight, while resisting bending or breaking. This concept places a high economic and environmental value on the impact weight plays in architectural structures. The weight and efficiency of individual elements and their associated assemblage must be carefully considered as a design problem.

The environmental sensitivity of the actual site did not allow the footbridges to physically anchor into the ground. In the spirit of Australian architect Glenn Murcutt, the footbridges had to "touch this earth lightly". A key design consideration for this lightweight portable approach was in its assembly and fabrication. Each footbridge could not be a single monolithic piece like a beam; it had to have at least one connection along the length of the span. It could operate kinetically (ability to change configuration) or have the ability to be disassembled into smaller components and quickly re-assembled at the site. The kinetic operation of the project placed the emphasis on the detail component, its 'ethos of making' and palpable significance of craft. Each team could employ any material in its construction. The joint/connection became the essence of the project and challenged teams to think about lightness and efficiency beyond the material itself and focus on the material/tectonic condition within the larger whole.

PROTOTYPES AND TESTING

Several teams began with exploring kinetics as operations of transformation. The intent of these studies was learning formal and material relationships of the movement patterns and investigating their potential connection for formal change. Research into the field of kinetics and tools of kinetic operation became testing ground of experimentation and how transformative operations of these assemblies could be repositioned to become linkages for spatial transformation. Folding, hinging, weaving, sliding and telescoping became areas of investigation. Learning from the material and tectonic assemblies that define their kinetic movement. Questions such as "Which members can be implemented purely in tension in order to save weight" or "How can this hinge connection remain flexible, yet keep the connection rigid" became variables that informed the design. They pushed experimentation and gave students a 'tactile and durable knowledge' of how the loads were transferred through their structural assemblage.

The experimentation was conducted at both a small and large scales that would then be presented at a mid-review submittal. This required each team to build a component or the entire footbridge at full-scale using the intended materials. For some, moving from small to large scale would necessitate teams re-designing their experimentation and material selection thus creating a more iterative process where testing and analysis became imbedded into the design process. The design focus on lightweight assemblies fostered experimentation in pursuit of innovative approaches of materiality, connection and technique.

Following the prototype phase the 7 week project culminated with "Footbridge Loading Day" where all the footbridges were deployed over a small creek on the campus near the Architecture building and tested for structural performance. Like an anticipated car show, the event grew during the five-years into a festive atmosphere where students, faculty and general spectators gathered at the site to see the innovative design solutions. Many of the project efficiently and elegantly passed the structural design criteria. While not all the footbridges tested where successful in supporting the load or meeting the deflection requirements, a small group ended in catastrophic failure and the unfortunate thrill of the class.

The testing of the footbridges is integral to the teaching methodology. The acknowledgment of failure is important to integrate into the learning objectives for the course. Failure is not a normally accepted practice in the traditional design process, yet for the footbridge projects they became the condition for how analysis and design intent changed through the iterative flow of design and experimentation. All the projects submitted a final portfolio, documenting the design and prototype process they completed. Finishing with critical reflection and lessons learned from the design process through final testing. The pedagogy behind the footbridge project fostered an environment that allowed students to be designers: intuitive, fearless and inventive. Three footbridges, which successfully encapsulate the goals, challenges and rewards of the footbridge project and the value of the hands-on learning approach will be presented.

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Figure 1: Footbridge 1 open (left) and closed (right)

FOOTBRIDGE 1

Footbridge 1, was completed in 2007. It telescoped open to span the required 10-foot length over the creek. The group researched folding apparatus's such as chairs and accordion partitions to develop their kinetic strategy. Threaded rods connect the three wood sections together and allow the wood segment to fully rotate around the pinned connection and telescope open or fold into a series of flat components easily transportable [Figure 1]. Its structural innovation lies in the integration of the platform, which is comprised of 4 separate panel sections that hook onto lateral rods between hinge points and lock the footbridge in place, creating its stability. The kinetic strategy proved to be lightweight and exceedingly rigid. The footbridge deflected less then 1/16" of an inch.

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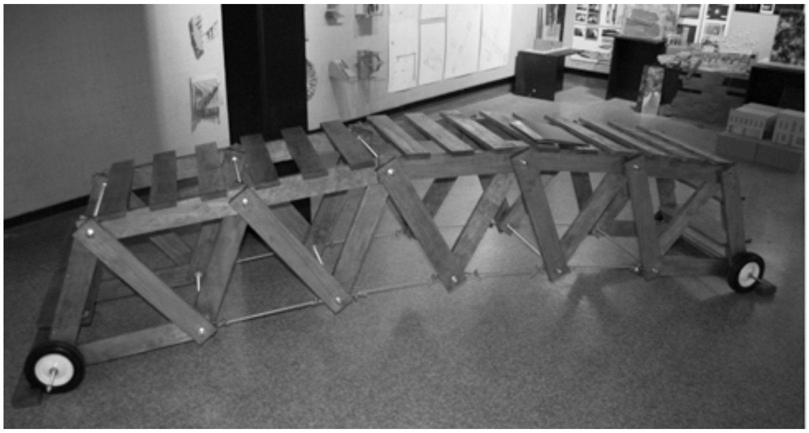
Figure 2: Heatherwick Rolling Bridge – precedent study

FOOTBRIDGE 2

Footbridge 2 was competed in 2009. The group began by researching the rolling bridge by Heatherwick Studio in London, [Figure 2], and became inspiration for their design. The Heatherwick Bridge example unrolls outward from a hexagonal shape to a simple beam span. The design team explored the kinetic operation and chose to re-design the unrolling operation for their footbridge. Instead of using an aluminum frame and folding hinges, their footbridge used wood members, threaded rod and cables to tie the wood segments together. Their re-design of the of the unrolling process was to mounted wheels on the two ends of the bridge and have rolls outward on the bottom side of the bridge to form a shallow arch which would allow the top side of the to serve as the walking platform for the footbridge, [Figure 3].

FOOTBRIDGE 3

A success of the footbridge project is how it illustrates the significance of craft to structural design. The most successful project were those that critically focused on



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craft and detail. Footbridge 3, completed in 2012 was comprised of two segments locking together at a high-point with wood pins, [Figure 4]. The design team was interested in creating a design that did not really on mechanical fasteners. They researched Japanese wood joinery and created an exquisitely detailed footbridge relying on the friction and strength of interlocking wood pieces. The only mechanical fastener they used was an eyebolt to install a cable need to resist the horizontal thrust [Figure 5]. The exquisite execution of the details by the design team resulted in a strong structural performance and its nomination as best design by the class.

CONCLUSION

The Footbridge Project broke away from a traditional structures curriculum strategy. They provided a new practice for exploring structural behavior. The introduction of kinetics (operation) as a design concept was intended to break the traditional typological design structure and challenge students' conceptual thinking. The project was structured more as science laboratory, where an ethos of structure, material and tectonic can emerge through experimentation and testing as well as through successes and failures.

The complexities of the projects required students to work together with a shared interest to achieve the end goal. These types of collaborative opportunities are uncommon in an architectural education, yet for architecture students they prove enormously instrumental to their maturation, both as design students and later as design professionals. Innovative strategies like these prepare them for an architectural industry that is technically rigorous and strategically dependent upon strong collaboration for success.

I have tried to foster a culture of making through traditionally large lecture classes such as structures by incorporating full-scale constructed architectonic projects.

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Figure 3 Footbridge 2 open (left) and closed (right)

Figure 4: Dry fit wood joint detail at loading

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By translating design ideas from paper (theoretical) to full-scale (real) covering the spectrum of analysis (conceptual) to material (real), students are directly connected with structural strategies and the realities of gravity, resistance and tolerance. A structural ethos emerges from the depth of exploration the footbridge project provides. I believe this ethos will expand an architectural student's design decisions and provide avenues for exploration that will only augment their architectural education and future positions as practicing architects.

ENDNOTE

1. Buekers, Adriaan & van Hinte, Ed. Lightness, 010 Publishers, Rotterdam, 2001, pg. 12

Figure 5: Base step and cable detail