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Abstract
The practice of designing high-performing, technically proficient buildings in an integrated manner has increased in importance (and frequency) in step with elevated expectations for measurable building performance standards. However, traditional pedagogical models for building technology education have done little to adjust in response relying instead upon outdated modes for the classroom structure, content, and teaching methods.

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Brick by Brick:  
Improved Outcomes through Linked Learning Objectives in Beginning Technology Labs

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Intentional integration

We must work to connect the sometimes absurd effects of multiple design responsibilities...by (the) integration of all different elements.

The practice of designing high-performing, technically proficient buildings in an integrated manner has increased in importance (and frequency) in step with elevated expectations for measurable building performance standards. However, traditional pedagogical models for building technology education have done little to adjust in response relying instead upon outdated modes for the classroom structure, content, and teaching methods.

Unique to an architectural education, building technology courses need to impart a more specific, and often divergent set of technical acumen that students need to understand in order to critically incorporate it into their overall design work. Unfortunately these technology courses are rarely taught in an integrated manner so students are left to their own devices to find, and make, critical associations between the different topics being taught. If this information is conveyed ineffectively, a critical opportunity is missed to help students develop an intuitive understanding about the relationship between building technology and potentially responsive architectural forms.

These deficiencies hit beginning design students particularly hard because when initial classes aren't effective, it adversely impacts enthusiasm for learning for the remainder of their education and their retention of information. This problem is more profound in a multi-semester sequence of courses with graduating levels of difficulty, in which there is a necessary expectation of accumulated knowledge and skills from previous courses.

In order to better prepare architecture students for evolving challenges of a highly integrated contemporary practice environment in which building technologies are expected to be understood and integrated into high-performance, sustainable building designs, the traditional means of educating architectural students about these building technologies must also evolve.

This paper will present a case-study lab that is assigned during the first semester of undergraduate architectural study at Iowa State University as a representative example of the unique pedagogy offered in the newly re-formatted and integrated building technology course. For this assignment, students are required to engage a simple design problem using a common load bearing masonry wall from two distinct, yet interconnected perspectives of design education—specifically the materials/assembly and structural design modules. This lab challenges the traditional presentation of course content and learning environment standards based on the hypothesis that experiential exercises, haptic learning methodologies and project-based design exercises in a laboratory setting can provide a more effective way forward in educating architects about integrating building technologies. The results of multiple student submissions will be presented, analyzed, and assessed in comparison to the different learning specific learning objectives and the larger macro educational goals.

Reformed sequence

Today's buildings are not good enough...(because) professionals are operating within a fatally flawed system.
-Patrick MacLeamy, CEO, HOK Architects, "BIM, BAM, BOOM! How to Build Greener, High-Performance Buildings," 2008.

Helping students learn to navigate through the staggeringly complex array of aesthetic and
technical choices in building design is a primary educational responsibility. Because it is so complex, a large portion of architectural design education in studio deals with teaching strategies and priorities for creative problem solving and evaluation. In technology classes, this is frequently different. Although the importance of collaborative design efforts and critical cross-disciplinary integration of building technologies into the design process are frequent topics of discussion, these courses are rarely taught in a manner that supports these lessons. The means and methods by which this information is presented to students should aspire to model the desired priorities and processes taught.

Unfortunately are three common shortcomings in traditional building technology education that exacerbate these problems: First, the three distinct areas of emphasis (materials/assembly, structural design, and environmental forces/systems) aren’t taught in an integrated manner—the courses are split apart from each other (and from design studio) throughout the curriculum and they develop different (often divergent) learning objectives based on their various content. Second, because of the technical nature of the information presented, many courses use an engineering-based pedagogy in which “design” is confined to the analysis and sizing of elements/systems, and the corresponding assessment is based primarily on the accuracy of calculations and not other qualitative standards. Finally, by presenting information primarily in passive learning environments, like lectures, the lessons are disassociated from the active-learning environments found in design studio and practice. The consequences are profound—a combination of these factors can adversely affect the effectiveness of the learning.

In order to address these deficiencies, major revisions were made to the building technology courses offered to undergraduate architectural students at Iowa State University. All three building technology topics were combined together into one larger/longer course sequence. These classes begin during their first semester within the professional program and end during their comprehensive design studio, five semesters later. Each semester includes three different “modules” of information focused on the different technology topics, while still giving opportunities to present integrated exercises between the modules. A large portion of the work takes place in an active-learning lab environment, more akin to a design studio, in which students are taught to develop different strategies for creating assessing their work—including many haptic learning opportunities.

These labs occur during nearly every class period, most frequently following immediately after a lecture. In labs, students are frequently assigned a simple design task that requires demonstrated knowledge of the technology topic. Through rapid iterations and development, students consider order of operations during construction and opportunities for integration. Frequently students build and test mock-ups in order to evaluate performance (Figure 1).

Lab work is performed in a public forum, and students are encouraged to view, share and discuss results of their experiments. Since nearly every assignment is based on individual design work, results and processes can be openly shared without the typical concern of “shared work.”

Although the means and scope vary by module topic, students are consistently required to document their work through lab reports. These reports describe their design decisions alongside technical diagrams and calculations (when required) and require self-assessment and evaluation of their work. Writing lab reports helps broaden the options for learning styles and promotes multimodal means of representations—both demonstrated strategies for increasing the learning capacity, retention and enthusiasm.

Studio work is occasionally directly tied into the lab’s coursework, but most of the time, the different module instructors purposefully craft particular exercises in order to directly illustrate ways to
applying these through design. Primarily these labs remain somewhat isolated within their own module’s topic/perspective, which is beneficial at times to help focus the learning objectives, but it shouldn’t serve as the rule. Lab lessons presented and addressed in isolation from other considerations can yield simplistic results.

The faculty decided that further integration between the modules could yield appropriately complex problems that would more closely mimic real world design problems without placing unrealistic expectations on the design studio sequence. Correspondingly, a series of cross-module integrated lab projects were created and introduced into the sequence.

**Building lessons**

We purposely tried to push the limits of what could be built with bricks.

For their first integrated lab, students were asked to design, construct, and analyze a load-bearing masonry wall. Intentionally this exercise is introduced immediately in their technology course sequence. This first lab has certain technological information it needs to convey, but it supports larger pedagogical priorities as well. By design, the lab format emphasizes the importance of making connections between the different technology topics in order to develop more integrated conceptual design thinking skills.

To help them achieve this, we introduce a range of various problem-solving techniques for students to try, including full scale construction. In other words we try to instill a sustained enthusiasm for the topic by presenting the relevance of the information taught in an engaging classroom setting.

Throughout the entire undergraduate technology sequence, the use of haptic learning techniques is a matter of central pedagogical importance in both theory and practice. Across all three building technology modules, students have built and tested their work in an attempt to better understand the inherent physical behaviors of how their designs work.

This two-part lab was designed to explicitly promote convergent technological and design considerations for masonry structures between the materials/assemblies and structural design modules. The first portion of the lab was based on a long-standing relationship with the Masonry Institute of Iowa.

For nearly thirty years, students in the materials/assemblies course have visited a local brick manufacturing plant for a tour and to construct a basic loadbearing masonry structure with the assistance of local masons. This year, for the first time, the structural design module was included in the development of the lab, albeit in a manner unbeknownst to the students at the time. From the perspective of the students, the lab breadth is ostensibly limited to exploring issues related to the materials/assembly particularities of load-bearing masonry construction (a rich experience in and of itself). However, the specific performance criteria for the wall were all intentionally selected in conjunction with the structural design learning objectives for the upcoming module—at this point they hadn’t had any structural design coursework.

Students were introduced to the principles of loadbearing masonry in a materials/assembly lecture, which covered basic terminology, limitations, and established techniques in brick. Brick courses, bonds, wythes and geometric strategies to increase wall strength were briefly covered, in addition to several examples of traditional arches and contemporary folded or sculpturally morphed brick construction. Teams of students are given a relatively simple problem for an ensuing lab: design and construct a partially perforated, full-scale masonry wall using only 300 bricks. This methodology is based on the idea that students
will learn more through extensive hands-on experience, than with lectures or textbooks alone.\textsuperscript{5}

In spite of the openings in the wall required for perforation, each wall needed to be stable enough to provide an element of repose upon the wall (sitting or leaning) and students were required to accurately build the structure in under two hours. The students are asked to investigate a minimum of ten concepts that meet the requirements in sketch form, before selecting one concept to develop into their design proposal.

As in previous years, local masons donate their time to assist the students. Each five or six student group is assisted by one mason, and the students must use a small design document set, consisting of at least one plan drawing and one section drawing scaled to $\frac{1}{2}'' = 1\text{-}'0''$, and at least one axonometric rendering to communicate their design intent to the mason. The masons are generally fully or partially retired, with many years of experience, and many have volunteered numerous times. The masons demonstrate basic bricklaying techniques, including breaking bricks in half with a trowel, applying mortar to the bed and head joints of the brick and basic wall layout. Mortar is pre-mixed and brought to each worksite, where 300 bricks are pre-stacked. The bricks are all modular-sized, three-hole bricks, and this parameter was communicated to students during the design phase of the project. Several groups elect to use the brick holes to satisfy the perforation requirement.

**Concept, Craft and Construction**

We would change the design by figuring out our foundation better and...we would spend more time on the process before we go out and lay bricks.

- Student Lab Report

A majority of the student groups quickly discovered the difference between the rough, conceptual planning performed in design studio, and the exacting, descriptive planning required for design-build (Figure 3). The improvements suggested by students ranged from construction methods to detailing to the ambition and scope of the actual designs. The students' tendency to view material as wallpaper or pattern, as opposed to an assemblage of many small, discrete pieces created many of the onsite challenges. The groups that were able to incorporate assemblage into their planning process were able to work more efficiently onsite to realize their designs.

If we were to change anything, we would have started with an assembly line type of system.

- Student Lab Report

![Figure 3: Example of planning with actual brick modules and the resulting project](image_url)

We should have planned out exactly how many bricks were necessary for each component of our design in order to work more efficiently and effectively on the build site.

- Student Lab Report

The real-world scenario and challenge of many hands working together to craft a single object confounded many groups. On the other hand, many concepts from the lecture were adapted successfully; as an example many students utilized simple folds or serpentine plan geometry to create strong, single wythe walls, allowing the 300 brick allowance to create much larger forms (Figure 4). Several groups used small shoring elements, often in the form of temporary brick placement, to create the perforations in the final structures.

![Figure 4: Examples of Folded and Curved Single Wythe Masonry Walls](image_url)
Varied coursing and the use of gradual or punctuated protrusions were utilized to create dynamic forms and dramatic highlight and shadow, (Figure 5). Many groups found frustration as their lack of skill, specifically with mortar placement, affected the craft and overall appearance of the structures. The ability to consistently break bricks to create half bricks with clean edges delayed many groups. These comments were echoed in numerous lab reports.

Another surprising comment noted in the lab reports dealt with the perception that the groups felt they had potentially under-realized potential of masonry in most designs; many groups reflected on their design and concluded that additional courses or more complex pattern would have strengthened their concept and created greater visual interest in the finished project.

Figure 5: Examples of Folded and Curved Single Wythe Masonry Walls

Students completed a full lab report outlining their design and construction efforts, including a justification for their final formal arrangement of the wall and a self-assessment of the entire process. The lab reports were required to include careful documentation of all relevant pieces of information, including accurate heights/courses, radii and lengths. Much of this work was preparatory work performed before construction so these documents either assisted or hindered the groups in direct relationship to their pre-build preparation. Some groups miscalculated the number of bricks required for their design, or selected a complicated and time-consuming custom bond which reduced the number of bricks that could be laid within the time limit. Despite an allowance for jigs or other forms to help with difficult or repetitive placements, most groups elected to rely on simple, repetitive measurements performed onsite.

Stacking and spanning

This lab really had us think about the structure of our wall. We had to consider different ways to alter the design without changing the curve in the wall.

-Student Lab report

Two weeks later, after the transition between modules has occurred, these same students revisit these masonry constructs as part of their structural module in the same course. After an introductory lecture on the structural concepts of strength, stability, shape and force transfer, they are asked to assess their wall design and construction from a structural perspective. They are given an opportunity to modify the walls accordingly in order to incorporate them into a design of a bus stop shelter—an exercise that asks them to incorporate structural elements as either "bricks, sticks, & planes." The walls weren’t required to serve any specific structural purpose within the shelter—a decision that was intentionally left to the students.

The first important lesson the students learned was that there was a clear connection between challenges they faced in assembly (e.g., achieving lateral stability, creating perforations and grounding the element of repose) and the structural lessons of force transfer and equilibrium. In other words, the design challenges need to be considered from multiple perspectives (Figure 6).

The second lesson, that processing abstract information while physically manipulating objects is a proven method for enhancing comprehension, may not be as explicitly evident to the students at the time, but it provides long-term benefits to structural knowledge. Specifically, when the means of presenting and processing information is too abstract, as it often is in traditional structural design courses, students are unable to visualize the concepts being presented and the relevance of what is being taught becomes unintentionally obscured. Although it is a relatively simple structural assembly, trying to understand the behavior of physical phenomena, like a load-bearing masonry wall, without offering students a chance to physically experience it reduces the efficacy of student learning opportunities by forgoing opportunities to enhance their visualization skills of abstract behaviors.
Figure 6: Although structurally conservative, the masonry wall was designed to provide support and shelter.

Bricks, Sticks, and Planes

Generally the structural content in the work was at a level to be expected of beginning design students—overly simplified remedial force diagrams and misrepresentations of structural behavior, but there was a more widespread level of elevated competency demonstrated between the masonry material and beneficial structural forms, which was quite interesting.

Transitioning from one module topic that they understood somewhat well, to another topic for which they had received little formal instruction produced three general responses in the design work for the bus shelter.

First, some teams left the wall as previously designed and built, relieving it from any additional structural or functional constraints—these students generally received the least benefit from the lab integration. It was suggested to these groups to apply more proactive experimentation to their lab work in an effort to expand their knowledge. Thankfully, this approach was used in the fewest number of labs.

Second, certain teams altered their wall design to make it much more formally conservative than what they had built—mostly as a result of the wall now being used as a load-bearing element for the bus shelter roof. This was the most predominant approach to the lab. This is understandable to a certain extent as many beginning students lack confidence in their structural work and are concerned about “failing” if the structure wasn’t appropriately designed. Through feedback, these student groups were encouraged to continue to experiment and expand upon their previous knowledge as a foundation for developing structural aptitude (Figure 7).

Figure 7: The curved sloping wall that was built was reduced to a very conservative flat surface.

The third type of proposal generally involved an elevated level of formal and structural experimentation, frequently using the curved wall planes they had built as the basis for the shelter’s enclosure and support. Many correctly noted that the wall’s curvature helped provide a certain degree of lateral stability for the structure as well as a sense of spatial enclosure—this is a fundamental learning outcome for the beginning module that they had already intuitively learned! One group extended their curved wall upward to form a thin shell, while another group used the idea of a twisting plane as inspiration for their roof structure and wall (Figure 8). Both groups rightly understood that the twisting nature of the plane would stabilize the structure and demonstrated a critical advanced structural design consideration.

Because of the diversity of submissions, it was somewhat unclear what role the wall construction played in enhancing their direct understanding of structural behavior, but it clearly affected their responses. One hypothesis for the more conservative responses is that the students understood first-hand that more complicated geometries and structural expectations for the wall would require more advanced technical revisions to the design and/or more complicated construction difficulties—a scenario they would be more inclined to empathize with as a result of the lab.
Integrated Assessment

As a result of this combined assignment the students (and teachers) learn that they don’t need to have explicit instructions or knowledge about other building technology topics before engaging these considerations into their designs. Additionally, because the assignment doesn’t explicitly spell out the integrated nature of the exercise from the start, it suggests to students that integrative opportunities between design and technology topics may instead be implicit and simply awaiting their capacity to make the connection between topics (a good match for the intuitive/global learners).

The combination of drawings, diagrams, and constructed assemblies were effective in the transfer of knowledge from the abstract into more tangible realm of intuitive knowledge and design expression. The methodology provided a cognitive grounding in basic structural and material behavior and provided a methodology for self-taught examination and analysis for more advance topics covered in subsequent labs and semesters. These activities immediately improve student motivation, not only by the interactive nature of the classroom environment, but because an advanced capacity for visualization allows for a more diverse means for representing the lessons—models, images, sketches, and written descriptions of experienced physical phenomena.

Importantly, the primary student outcome desired by the assignment isn’t the comprehension of difficult technical information (as these are basic topics), instead it is intended to introduce and develop a new way of working—an integrated design process through which collaborative teams integrate technological constraints with a larger set of design ideas. These lessons are repeatedly reinforced throughout the remainder of the five-course sequence with an escalating progression of difficulty.

Now that two full sequences have been completed, there are positive long-term effects as well that are noticeable. Labs completed in subsequent semesters of the structural sequence showed an advanced level of comprehension of basic structure concepts and behaviors—albeit not directly translated to load-bearing masonry walls. The lab reports have helped the students develop more advanced abilities to create multimodal representations of these assemblies and behaviors which is a skill set that is applied to their larger professional development. Further, in recent years, the comprehensive design studios frequently now feature more highly integrated technological ideas within their designs—to a degree that wasn’t as pervasive before the changes in the technology sequence.

Ultimately, through the research, design, and evaluation stages of the process, students realize that relative success of their design interventions are inextricably linked with their realistic engagement with a broad range of technical encumbrances not normally required of them in design studio.
Notes


