

# Infusing Technology Driven Design Thinking in Architectural Education: Two Case Studies

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**ABSTRACT:** This paper narrates two case studies on technology driven design thinking-based education methodologies in an architecture program. The first case study course focuses on a design/build studio course in which the client, the campus performing arts center, incubated the studio in their production facility to mentor the students as they created a new cafe for the facility. Students engaged with the full spectrum of the design-thinking process, interviewing theatre-goers in the *empathize* mode, seeking the right problem in the *define* mode, generating alternative concepts in the *ideate* mode, rapidly *prototyping* with computer-aided design and manufacturing technology, *testing* resulting prototypes on users on site, learning from feedback, and cycling back through the design-thinking process, evolving the prototypes to higher and higher levels of resolution in each iteration. The second case study course integrates BIM (building information technology) into a traditional large technical lecture course, using the technology to overcome challenges caused by the size and mixed levels of students, meanwhile provide hands-on experience which is typically very difficult to implement in a large lecture course. These two pedagogical approaches intended to integrate fast-changing technologies into architectural education while simultaneously creating a novel learning environment for students. The authors reflect upon the results of the two case study courses, proposing recommendations which could be useful for educators and institutions contemplating the potential for technology to change student experience.

**KEYWORDS:** building information modeling, rapid prototyping, architectural education, design thinking

## INTRODUCTION

Educators and practitioners have come to the consensus that technology has radically transformed how the architecture, engineering, and construction (AEC) industry practices and operates. Creativity and innovation has already been critical in educating future designers, architects and engineers. Teaching design thinking has been a key part in architectural curriculum. In the past several years, the emergence of a new wave of technologies such as 3D fabrication, BIM have been observed in industry as well as school. The rapid development and take up of technology, especially among young students has a significant impact on curriculum design, challenging educators and institutions to address the changed learning patterns and needs of the students. Consequently, we have seen a number of new teaching methods and trends have emerged in architectural schools recently, for instance, Design Thinking, Game-based learning, Flipped Classroom, Project-based learning in the school, etc. And a number of new technologies have been introduced to the students as teaching tools. In this paper, we will explore the impact of technology on learning through two case studies examining different pedagogical methods, course types, student audiences, and technologies.

BIM is a set of technologies and processes that can be adapted to different practice models. The learning curve for BIM programs is long and steep and they require a complete change of mindset from educators to set aside their conventional way of teaching and mentoring and relearn an instructional method. For these reasons, the obstacles to adopting the BIM approach are major, and the pedagogical shift has been spotty and unsystematic.

The introduction of prototyping into an architectural design studio in the context of the five-step design thinking process offers students vivid feedback on their response to human needs as well as technical performance and aesthetic aspects of their design proposals. Full-scale prototyping directly addresses learning outcomes of understanding materials, assemblies, and structures. The need for digital fabrication equipment and physical materials pose challenges for schools lacking resources. The time required to complete multiple cycles of prototyping and testing makes it difficult to undertake projects of large scale. And, this student-led learning approach requires a change in mindset on the part of the the instructor, who must shift roles from the critic who explains why the student's approach will or will not work to the guide who takes students on a journey of discovery.

## **1.0 First Case – Design / Build Studio**

### **1.1. Overview of design thinking and rapid prototyping**

The key workflow concept underpinning the five-step design thinking process taught at Stanford University's d.school is that designers begin by discovering user's needs and complete the cycle by testing prototypes with those users in order to validate their design solutions. While it is generally too costly and time-consuming to build a full-scale testable model of a building design, mock-ups of innovative building components are created and tested, but typically for evaluation of technical performance or visual qualities. For example, building facades are typically mocked up and tested in laboratories to test for water penetration and resistance to wind forces. Facade mockups are also frequently assembled on-site to test visual properties of materials. These prototypes are created late in the design process and used to validate fairly thoroughly developed concepts. A key concept in the design thinking process is to begin with low-resolution prototypes in order to quickly gain feedback on early-stage concepts. As early concepts are validated, subsequent prototype iterations can gain higher resolution to elicit more detailed feedback. While prototyping and testing for conformance to user needs is not the norm in architecture, it is more common in interior design, where users interface directly with components of interior spaces, and in product design, where usability and desirability are critical.

The introduction of prototyping into an architectural design studio in the context of the five-step design thinking process offers students vivid feedback on their response to human needs as well as technical performance and aesthetic aspects of their design proposals. Rapid prototyping shortens the time between concept and realization. Krista Ninivaggi of SHoP Architects calls this aspect "direct to fabrication," saying, "we can be in the studio riffing on ideas, and then those same design ideas can go from my desktop right into production with my design files." (Szenasy 2014) It also gives students direct experience of actual materiality, unusual in the studio environment, where design technologies of drawing and digital modeling tend to explore and represent materiality poorly, if at all. Physical modeling typically substitutes materials such as chipboard and basswood for actual building materials. And 3-D printing renders models in a uniform plastic material. As Alvise Simondetti notes, "Computer Aided Design has brought designers away from material properties including surface roughness, strength, thermal properties, elasticity etc. and the physical world characteristics including gravity. The CAD office generally looks more like a managerial suite than a builder's workshop. Rapid Prototyping has the potential to bring the material back into the architect's studio and give the designer that "feel" of the artifact that had disappeared." (Simondetti 1997,7)

### **1.2. Course design**

The course was envisioned as a design-build studio that would serve the campus performing arts center's need to replace their aging on-site cafe. There was great potential for a productive exchange in this project. The performing arts center wanted to gain student buy-in by involving a group of students from another academic unit in their activities. They sought a creative new vision to replace a conventional university food service outlet located in a prominent position in their venue.

This faculty member saw an opportunity to meet the learning objectives of the architectural design studio whose brief was:

Investigations into the relationship between the man-made and the natural world including introductory issues of assembly and material value. Design of the site and the building are combined into an integral process delimiting and probing the boundaries of each and exploring their reciprocal relationship. The architect's obligations to the natural and urban contexts are explored in many dimensions including historical, typological, environmental, and physical (UMD).

A design-build project offered direct opportunities to engage issues of assembly and material value. And we could investigate the reciprocal relationship between an interior space and its context. And, we could explore the architect's obligations to the context of the building interior in many dimensions. During the second half of the semester we would design a cafe for a natural landscape setting, allowing us to engage with the full spectrum of issues detailed in the brief.

Another compelling value to be gained from this relationship with the performing arts center was the opportunity to work in their well-staffed and well-equipped Scene and Prop Shops and to be incubated within the theater's vibrant culture of making. We would gain access to the performing arts center's Computer Numerically Controlled (CNC) machine, lacking in our own School's shop. And, the client would fund all necessary supplies and hire a digital fabrication consultant for our studio.

The design studio was composed of ten graduate students in their second year of a three and a half-year master of architecture degree program. The diverse group included students from a range of undergraduate

majors and prior careers including architecture, art, history, accounting, and the military. The students brought varied levels of experience with digital modeling and woodworking to the studio. None had experience with digital fabrication.

### 1.3. Methodology

We began the studio with case study research focused on two topics, the cafe typology and environments created with Computer Numerically Controlled (CNC) machine technology. The cafe typology studies introduced the student team to the basic elements of design for small restaurant spaces. They also offered understandings of the relationship of built form to context and environmental factors. And, they demonstrated how a wide variety of program and design concepts could animate cafe design. The explorations focused on environments fabricated with CNC machines exposed students to the types of form-making enabled by the unfamiliar technology that they would be implementing later in the course. At this point, we brought in a consultant experienced in design for digital fabrication to begin working with the students to understand the potential, limits, and processes of the CNC fabrication technology.

The team launched into the design thinking process, beginning with *empathy*. In this mode, students engaged in the activities of immersing in the users' context, interacting with users, and interviewing users. We considered the cafe's context both narrowly, as a particular space situated at the head of a grand stair, along a primary building circulation route, and at a key building node - and broadly, as the performing arts center, a venue for a wide variety of performance types. Students interviewed client representatives along with a variety of users at different times and engaging in various activities.

Students began the *define* mode by mining their observations and interviews for insights into client and users' experiences, needs, desires, and aspirations. They arrived at several key insights: 1) the director views food and drink as a type of performance, hence fitting into the mission of the performing arts center, rather than existing merely as a support function, 2) the space comes alive during the NextNow Fest, when scenery, lights, and action spill out of the theaters and invade the lobby, 3) people do not perceive the two disconnected parts of the cafe, food service and seating areas as part of a unified whole, 4) the seating area, located at the building's hub, is an important community meeting space, and 5) students enjoy sitting on the deep window sills that connect the main corridor with the courtyard and verdant landscape beyond. They translated the resulting insights into "how might we?" statements to find a set of actionable challenges that would define the design problem.

Moving into the *ideate* mode, students worked individually, utilizing technologies of hand sketching and physical modeling, to explore potential solutions to these challenges in schematic design proposals. In this iteration, the sketches and models served as both investigative tools and *prototypes* for testing with the *clients*. Based upon client feedback, the team moved into the next iteration of the ideation, prototyping, and testing modes, narrowing the design options from ten to two. Option 1 was named the Garden Cafe, responding to the perceived desire for connection to nature. Option 2 was named Morph, highlighting the concept of a single architectural element that transformed as it undulated through and connected the disparate spaces of the cafe. Once again, sketching and physical modeling served as both ideation and prototyping technologies. In the third iteration, the team realized that the biomorphic form of Morph was an abstract representation of nature. This insight allowed the team to coalesce around a single schematic design proposal.

Subsequent ideation, prototyping, and testing iterations focused on developing this design concept at increasing scale and specificity. The team shifted technologies to work primarily with digital modeling. Our goal was to create construction documents that the Food Services crew would use to build the food service area and to create digital files that we would use to construct the elements of the dining spaces. Students modeled in Revit, then exported their files to Autocad. In Autocad, they separated the layers into individual pieces to be cut on the CNC machine.

Once we had the first iteration of the digital model complete, we started the rapid prototyping process. We began working in a new environment, the performing arts center's Prop Shop and Scene Shop, with their extensive facilities for both manual and digital fabrication, including a three-axis CNC machine with a 4' x 8' bed. We also gained the teaching support provided by the performing arts center's technical and instructional staff, including Director of Production and Instruction, Technical Director and Assistant Technical Director and Scene Shop Coordinator, members of the Set Construction Crew, Properties Shop Master, and Assistant Technology Manager specializing in lighting. These experienced makers and teachers advised us to revise our ultimate goal of constructing the cafe down to a still ambitious, but manageable, goal of producing final prototypes and fabrication files for construction by a commercial

millwork shop. This shift in objectives relieved the pressure and, importantly, switched our focus from design-build to process and pedagogy of rapid prototyping.

#### 1.4. Findings and discussion

Changing the orientation of the studio from design-build to rapid-prototyping transformed our concerns from product to process. Students were able to take the time to learn from testing each iteration of the prototype. The Prop Shop Master taught me to avoid critiquing the students' digital models, but instead to let them build their ideas out of inexpensive material, oriented strand board (OSB), and learn from user feedback and observation. The rapid prototyping process afforded multiple iterations during the limited project duration, giving us the ability to test prototypes multiple times, gaining new knowledge each time and revising based on this direct learning. Our prototyping process was semi-indirect computer-aided design (CAD), direct computer-aided manufacturing (CAM), and manual assembly (Simondetti). Drawing was done remotely, in the architectural design studio. The cutting, assembly, and finishing process, however, was hands-on in the shop, giving students a tactile experience of material and assembly, addressing the studio learning objective in a highly experiential manner.



**Figure 1:** Prototyping: Direct CAM with student operating CNC machine. Source: (Author 2016)



**Figure 2:** Prototyping: manual assembly. Source: (Author 2016)



**Figure 3:** Testing chair and table prototypes. Source: (Author 2016)

Lessons we learned from the prototypes that we would not have learned from creating scale models: 1) ergonomics lessons in human dimensions, comfort, and function, 2) physical properties of designed products, such as weight, texture, strength and appearance of joints, 3) lessons in user response to designs, 4) differences between different materials in terms of strength, durability, and appearance, 5) the relationship between design decisions and construction processes, 6) relationship between the drawing and the full-scale realization, 6) how the element fit into the context, 7) how the designed product would function under simulated use conditions. Reflecting upon the studio experience, one student observed, “We’re so used to building things that are scaled to fit in our hands. I was actually able to sit in something I designed instead of just photoshopping people into it. The best part was seeing our designs come to life and being able to interact with it as it was meant to be used.” (Haley 2018)

## **2.0. SECOND CASE STUDY – BIM INTEGRATION IN LECTURE SETTING**

### **2.1. The role of and challenge for BIM education in architectural curriculum**

Educators and practitioners have already built a consensus regarding how BIM has radically transformed the way the AEC industry practices and operates. The activity of parametric modeling is fundamentally different from drawing and drafting because the product is a database of information and relationships instead of a set of 2D or 3D representations to be interpreted by different team members. Therefore, the move from traditional CAD to BIM constitutes a new methodology rather than the simple introduction of a new tool (Denzer et al., 2008). BIM has already disrupted the traditional building industry practice methods and threatens to disrupt the methodology in and pedagogy of AEC education, but this has only showed in isolated courses, programs, and schools. In comparison to the industry transformation, the incursion of BIM seems to have encountered more obstacles. BIM is “parameter-defined” and “inherently answer-driven,” while traditional design thinking is “question-driven” (Denzer et al., 2008). The new BIM approach could be seen by traditional studio teachers as a threat to critical (design thinking). The promotion of the BIM pedagogical shift needs to respect traditional design thinking to be successful. Based on previous study and program experiments, the obstacles to using BIM as a pedagogical tool include the following: 1) a higher requirement for students’ knowledge base and skill sets, 2) the disconnection and discontinuity among different courses, and 3) the fast pace of program/software development. The biggest challenge is to understand the opportunities presented when digitally driven learning and process technologies are envisaged more comprehensively and profoundly than as mere tools. Considering BIM only as a set of tools could undermine the additive value of skills and intentions working together to improve learning outcomes. BIM is not a tool, but a way of learning and thinking (Ambrose 2012).

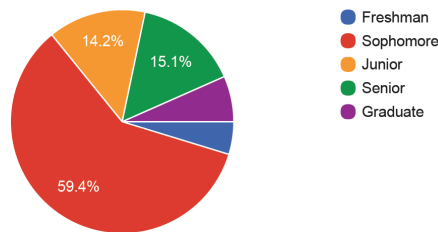
Livingston thinks the placement of BIM-based investigation in technical courses addresses larger issues of architectural representation (Livingston 2008). The course taught at Montana State University was a 400-level construction documentation course. Students are required to create a schematic design information model and then develop details illustrating materials and connections based on the initial model. The way in which BIM played an important role is through the formulation and construction of details that integrate into the larger information model, forming a critical relationship between the role of 2D and 3D information.

### **2.2. Course Design**

The course developed by author is derived from a traditional “Building Materials and Construction Methods” (BMCM) lecture course that is a required course for the Bachelor of Art in Architecture, Bachelor of Science in Architecture, and Master of Architecture degrees. It is offered as a mixed graduate/undergraduate technical prerequisite course in an Architecture curriculum (refer to Figure 4). The course is designed for a large student body, around 108 to 120, with a clear goal of not only teaching students fundamental knowledge about building materials and methods but also exposing students to BIM technologies and using BIM as a teaching tool to enhance and deepen their understanding. One important outcome for the students completing the course is to be able to understand the complicated and multi-disciplinary construction activity and the integrated process in the building industry. This outcome requires students not only to understand

materials properties and construction methods, but also to establish a framework to understand the different players in the building industry. This has been a challenge for a large lecture course taught in a single-discipline school in a traditional education curriculum. In this course BIM is used as simulator to aid students' active learning and design thinking. The ability to simulate building construction and assembly methods is a great way for students to bring design thinking (define, ideate and prototype) into a traditional lecture class.

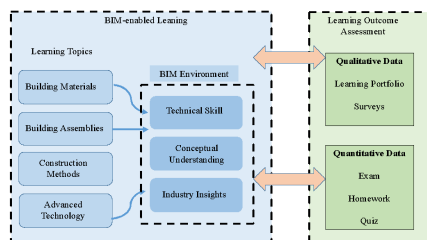
A total of 118 students in Fall 2016 and 106 students in Fall 2017 enrolled in the class, including 4.6% freshmen, 59.4% sophomores, 14.2% juniors, 15.1% seniors, and 6.4% graduates. Of these, 51.9% were female students and 48.1% male students. Of these, 58.5% knew nothing about BIM at the beginning of the class, 16% had never used a 3D program, and 33% had learned Revit to certain degree as a drafting tool in community college or high school but never realized that Revit is one type of BIM software.



**Figure 4:** Level of students in Fall 2017. Source: (Author 2017)

The course contents are divided into three integrated categories: 1) three major building materials: wood, concrete, and steel; 2) major building assemblies: wall, roof, and other enclosure systems; and 3) integrated construction methods and modern technology. BIM is used as a platform to help students understand and interweave the three categories. Gaining an understanding of the relationship between design, construction, and energy consumption is especially important if students are to think critically about how a building's design and construction impacts the building's sustainability (Shen et. al 2012) (refer to Figure 5).

BIM-enabled Pedagogy for "Building Materials and Methods Course"



**Figure 5:** BIM-enabled pedagogy for BMCM course. Source: (Author)

### 2.3. BIM contents

The BIM content was divided into three major parts: 1) what BIM is and what BIM can do in design and construction; 2) what building component/assembly is and how to use the "Revit family" to represent and simulate the materials and constructions; and 3) how to represent/build the different wall assemblies, particularly brick and stone (refer to Figure 5). The technical details of how to use the software were taught using in-class tutorials, exercises, assignments, and multiple outside-class workshops conducted by the instructor and three teaching assistants. Altogether, 24 hours (roughly 16 hours of course time) of workshop and in-class hours are offered to teach software. Beyond the workshops, students are required to enroll in the online comprehensive Revit tutorial offered by Linda.com in the first week of the semester. Altogether, 72 hours of online training are available to students on Linda at any time without charge.

### 2.4. Methodology and Sample Assignments

Assignments, graded homework, and exams were used to provide frequent assessments of students' learning outcomes. To answer the question of whether BIM is an effective teaching method/tool in a topic-based lecture course, the author designed an assessment framework to measure the learning results and students' progress through the entire semester. Since this is large class with 108 students, the conclusion of this paper could provide a meaningful and helpful reference. The data generated by this research was a mix of qualitative and quantitative information. Quantitative data were from four surveys conducted after each major exam to collect students' self-assessments and feedback on the effectiveness of the BIM teaching method.

The following shows two homework assignments. The second and third homework assignments have portions about modeling/prototyping concrete floor systems and masonry walls. As shown in figures 6 and 7, almost half of the students felt strongly about the knowledge gained in learning brick walls.

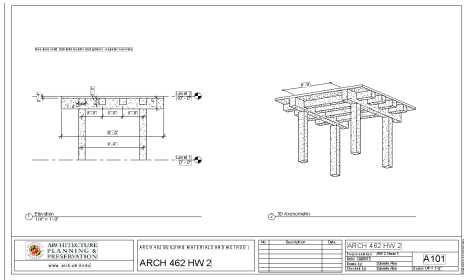


Figure 6: Homework two student's submission – concrete system. Source: (Author)

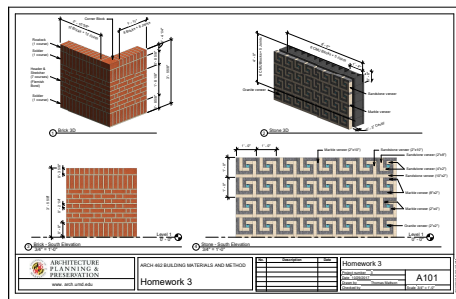
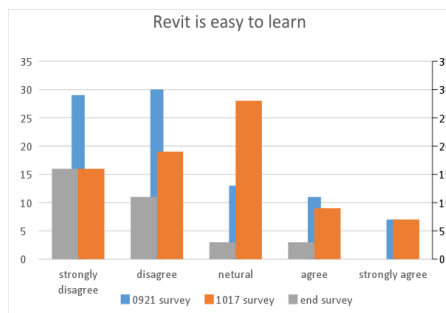


Figure 7: Homework three student's submission – masonry wall. Source: (Author)

## 2.4. Findings and discussion

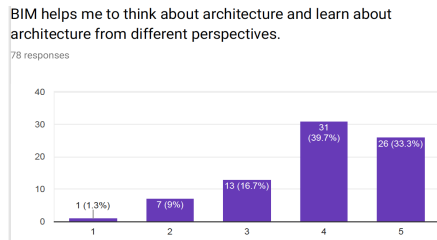
At the conceptual level, BIM is not an easy concept to grasp. It's been proven that grasping the BIM concept demands a more in-depth understanding of the building industry than typically provided in overall curriculums. The lack of preparedness of students was compensated for by self-guided research into this topic. Through several research assignments, a much larger portion of students started to grasp the BIM concept. Establishing the understanding of BIM in a qualitative way is the foundation of the BIM pedagogy.

As for BIM technical skills, Revit is difficult program for beginners. Through the entire semester, students' perceptions about the difficulty of Revit did show meaningful change. From the survey taken at the beginning of the semester, the majority students had a neutral position before learning Revit. Two months into the semester, after several Revit assignments and exercises (10/17), 42% of students thought Revit was difficult and 35% of students were neutral regarding the difficulty of learning Revit. At the end of the semester, 87.9% of students agreed that "learning Revit is the most challenging part in this course" (refer to Figure 8). However, the complexity and challenge of learning this data-rich program forced students to spend time practicing and learning on their own. The additional effort was proportionally directly related to the deeper understanding of the lecture contents. Also, because of the hands-on exercise, which is very similar to their design/studio work process, students had a much easier time translating the knowledge into design. Providing a challenging environment and encouraging students' active learning is the first effective impact of using BIM in a traditional large lecture course.



**Figure 8:** Difficulty of learning Revit. Source: (Author)

Regardless of the steep learning curve for Revit, students understood the importance of BIM integration in this course and agreed that learning Revit was helpful and that “BIM helps me to think about architecture and learn about architecture from different perspectives.” To the latter statement, 39.7% of student agreed and 33.3% strongly agreed (refer to Figure 9). The ability to understand a building assemblage from a structural, environmental and system perspective simultaneously in all courses is so profoundly important and is the way BIM could facilitate design thinking in a lecture course.



**Figure 9:** Students' attitude towards BIM's effectiveness. Source: (Author)

## CONCLUSION

In the past decade, different experimental digital technology (DT) pedagogies have been implemented in AEC programs. Some programs developed new standalone digital fabrication courses to cover the techniques of variety programs. Some programs modified existing core courses to integrate particular digital contents. A third approach is to allow students to produce a digital technology-enabled capstone or thesis project. Previous studies suggest that offering standalone DT courses without any follow-ups in other courses does not support student long-term learning because students rarely find an opportunity to re-use DT skills in different courses. Updating existing course modules has had limited effect since DT was used as a secondary technical tool, and the combination of the steep learning curve and limited course time hinders the effectiveness of the DT pedagogy. The preliminary results from two courses indicated that DT, when integrated as an instruction tool, provided a novel pedagogical and technical platform for teaching critical thinking and design thinking.

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