Bringing Together 'A', 'E' and 'C' in a Problem-based Collaborative Studio

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Abstract

This paper resents a pedagogical model, course work and lessons learned from two Integrated Practice/Design Build Studios. The Integrated studio is a project-based senior undergraduate construction management and architecture studio where students from the two disciplines as well as civil engineering and landscape architecture worked in a collaborative environment to deliver a design proposal, conceptual estimate, schedule and construction plan for a building project with challenging sustainable goals such as net-zero energy consumption. The central problem of the studio projects was to demonstrate the possibilities for making market-ready, high-performance, climate-tempered buildings that can achieve net-zero energy use on an annual basis here in Seattle. The pedagogical model is built on the processes of Integrated Project Delivery (IPD), a design approach that integrates people, systems, business structures and practices for harnessing the talents and insights of all participants in order to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication and construction. In this paper we will ~~we~~ report the faculty perspective of the challenge of interdisciplinary education that brings together students from departments that have very different expectations, histories, disciplines and cultures in the context of a sustainable project supported by BIM technologies.

Keywords

Education, Studio, Interdisciplinary, Sustainability, Building Information Modeling, Energy Modeling,

1. INTRODUCTION

Concurrent with the grand challenges of urbanization, globalization and sustainability, the Architecture, Engineering and Construction (AEC) industry is experiencing a technological revolution. To incorporate industry challenges and changes into education, much of the curriculum in the University of Washington's (UW) College of Built Environments leverages experiential learning (such as site visits, hands on labs, internships, computer visualization and service learning). Furthermore, the unique experiential learning environment of the design studio is at the heart of the Architecture, Landscape Architecture and Urban Planning curricula, where students synthesize, develop and expand upon their newly acquired knowledge from the supporting curriculum. Experiential learning activities, such as the problem-based work in design and planning studios, help students retain and apply the fundamentals of their disciplines while engaging in real world problems. Engineering and construction programs can leverage the studio model to develop experiential and contextual learning opportunities to engage with a dynamic and increasingly interdisciplinary industry.

In contrast to the deep synthesis of the design studios and other problem-based curricula, many lecture-based construction and engineering education paradigms foster tenuous decontextualized knowledge. Construction engineering and management students experience fragmented and specialized courses where concepts are presented as independent and unrelated entities divorced from the complexities of real-world situations and problems (Chinowsky and Vanegas, 1996; Fruchter, 1997). McCabe et al. (2000) argue that much of the civil engineering coursework teaches only theories of engineering and construction and that students may encounter difficulties when applying these theoretical constructs to real world situations. Sawhney et al. (2001) maintain that many civil and construction engineering curricula do not allow the inclusion of issues of importance to industry, the participation of practitioners, or hands-on experience. Brown et al. (1989) describe students who recall information on a test as not being able to apply the very same concepts in the problem-based environment even when the situation clearly merits such an action. Another example of this fragility can be observed in school when students neither retain nor are able to utilize knowledge allegedly acquired in previous courses (Bertz and Baker, 1996). Separating the learner from the relevant context can cause the knowledge itself to become ineffectual due to absence of the natural complexity of content; this in turn creates the ancillary effect of stifling creativity and diminishing enthusiasm among students (Barab et al., 2001). Additionally, when experiential learning happens outside the classroom (such as internships), students are often exposed to individualized and unique experiences that are not easily shared with others.

Consequently, our challenges are both local and global in scale. Individual students need to exercise and develop the skills required to work effectively and productively in a rapidly evolving world of design and project delivery, were owners, designers and builders are pushing for sustainable solutions to the increasing needs of the urban Built Environment. In programs of Architecture, Engineering and Construction, we seek to develop the technical skills, design awareness, ordering principles, and construction management knowledge that will launch our students into successful and fulfilling careers. In curriculum that supports an Integrated Practice, Integrated Project Delivery, or Design Build approach to these challenges, the teaching and learning goals are multifaceted:

- Explore how technology and collaboration support sustainable design and construction;
- Develop strategies and techniques for balancing tradeoffs between design intent, technical constraints, budget constraints and logistical issues;
- Explore the use of location, form, and materials, to promote an architecture well adapted to the conditions of the economic and physical environment;
- Investigate building and construction practices that minimize environmental impact and promote and express principles of environmental sustainability;
- Communicate and collaborate effectively in a multi-disciplinary team-based decision making process;

To address the challenges of fragmented curriculum, as well as the learning goals listed above, faculty in the Departments of Construction Management and Architecture in the College of Built Environments (CBE) have developed a ~~modified~~ design studio-based course, the Integrated Design Build Studio that ~~begins to pull together~~gathers together these elements. This is a course where interdisciplinary student teams exercise these skills through the delivery of design and construction proposals for real and highly relevant local projects. This studio course, designed as the capstone course in the 5th year of the dual Architecture/Construction Management degree program in the CBE, is also offered to other majors in the College as well as students in the College of Engineering. The course meets three afternoons per week for four hours each day. Students are organized in three teams of 5 to 8 students each, and are assigned a "collaboration suite" where they set-up an "office" and can

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work during and outside of studio hours. The course has been taught twice, winter terms 2009 and 2010, and will be offered for a third time in winter 2011.

2. COURSE: INTEGRATED DESIGN BUILD STUDIO

Architecture studios are traditionally problem-based classes in which students synthesize, develop and expand on their newly acquired knowledge from the supporting curriculum. We modify the traditional studio by creating a team based course with a focus on collaboration across the traditionally silo-ed disciplines of architecture, engineering and construction. In this studio the students bring in their new knowledge from their own disciplinary curricula—technical skills, design awareness, ordering principles, and construction management knowledge developed in previous coursework and/or design studios. In this modified form, ~~this~~ the pedagogy of this integrated studio ~~design~~ rests firmly on a "three-legged stool" comprised of intention, technology and methodology; namely: *s*~~:~~ ~~*S*~~*ustainability*, *b*~~*B*~~*uilding* *i*~~*I*~~*nformation* *m*~~*M*~~*odeling*, and *c*~~*C*~~*ollaboration*.

Although this course is ongoing, in this paper, we focus on the concepts and experiences from the past two years. One of the main goals of this studio was to explore Integrated Project Delivery. Given the authors' academic affiliations, there was an emphasis on the intersection of architectural design and construction; however, students from civil engineering and landscape architecture have also participated in the class.~~,~~ ~~both~~ Both authors have engineering backgrounds~~,~~ and industry guests were architects, engineers and builders, so that ~~all three~~attention to all three disciplines—Architecture, Engineering and Construction—~~were~~ were ~~integrated~~both balanced and integrated. To this end, the studio focused as much ~~as~~ on the collaboration across disciplines as it did on the products produced. Students worked through collaboration exercises and ~~maintained~~ maintained a collaboration diary to reflect on group dynamics, teamwork, leadership and the work processes they were exploring in the studio. Building Information Modeling (BIM) and other computational tools are integrated into the studio curriculum to support the analysis, design, project management and communication of design intentions and conversations about means and methods. Students received introductory instruction in Revit, Navisworks, and Ecotect. Each team developed a design, a conceptual cost estimate and a construction plan and schedule. The teams then developed and refined somewhat concurrently as the project moved from the schematic mid-term assignment to the more detailed design development final deliverable.

2.1 Sustainability

For the design problems, we introduced actual projects that were currently in early phases of programming and conceptual design from the local community. In both years, these projects had ambitious targets for resource efficiency, performance, environmental health and human satisfaction. Students worked within the framework of the *Living Building Challenge*™ to develop buildings that must produce as much energy on-site as they use on an annual basis, along with other demanding environmental criteria. To achieve this their buildings must to have been particularly climate responsive, reducing their energy demands by optimizing their form, orientation, envelope strategies, and programmatic organization. Next, their mechanical systems must have been seamlessly integrated with the architecture, gaining every two-for-one opportunity possible to meet budgetary expectation. Imposing criteria of a budget, a construction schedule, and high levels of building performance provided a compelling challenge for the team, testing students' design imaginations against the demands of a competitive, risk-averse industry.

We encouraged students to break out of their disciplinary roles and explore the culture, philosophy, practices and training of others on their team through collaborative work. Teamwork was designed to be fluid, allowing members to take on various roles over the term (e.g. structures, mechanical systems, architectural design). Over the 10-week course team members participated in various workshops to learn both concepts and applications, and worked out design problems in technical "huddles," often with an instructor or guest (professional) "consultant." Students who specialized in analysis might attend an energy modeling workshop while their teammates develop the design and work on other aspects of the project, just as they might in the professional workplace.

Tools appropriate to the scale and complexity of the projects are introduced and then applied to the project. In the first year students were coached in Ecotect, and used this digital tool to create energy models of their buildings. In the second year students used analytical methods to predict the energy use intensity (EUI) of their buildings and physical models to explore both solar control and daylighting and the University of Washington's Integrated Design Lab (IDL).

2.2 Building Information Modeling

The second leg of the stool is Building Information Modeling (BIM). The instruction with BIM took two forms: teaching the software functionality, and then working *collaboratively* with the software. Teaching software was relatively straightforward: it was taught in tutorials and then required technical support for detailed questions while the students developed their models. Teaching collaboration was more challenging and was deeply interwoven with other interdisciplinary collaboration issues. We discuss working collaboratively in the next section of the paper.

The inclusion of BIM in this studio was both dynamic and challenging. The students ~~come~~ came to the class ~~in~~ with diverse baseline knowledge of BIM tools. Some students had taken courses where Sketchup, Revit or Navisworks were taught. These students were already proficient with particular BIM tools, while some only had passing familiarity, and still others had never ~~seen~~ been exposed to BIM before. To address this disparity, we offered a 2-day workshop in the first week of class where the basics of Revit were introduced. In the past two years of the studio, most of the students attended these workshops. Some students~~;~~ ~~they~~ might have known a ~~different~~ related program such as AutoCAD, but still wish ~~or wanted~~ to review the basics before diving into a Revit-based project with a collaborative team. Later in the quarter, when the teams were starting to think about consolidated models and construction schedules, we conducted a tutorial for Navisworks tools such as presentation, clash detection and 4-D modeling.

As with the sustainability analysis, students ~~tended~~ tended to specialize in modeling tasks as well. Some students ~~took~~ took on more 3D modeling roles, while others ~~took~~ took on Navisworks roles. Some students, particularly those with no previous experience with 3D or BIM tools, ~~had~~ had limited use of the technology and ~~focused~~ focused on other research and analysis tasks. No matter what their level, students ~~learned~~ learned from each other and soon ~~exceeded~~ exceeded the faculty's knowledge of the programs' functionality. This poses a challenge for those looking to teach with technology—we as university professors are not everyday users of BIM tools and do not have the tips and tricks at our fingertips. To address this issue, we need to tap into knowledgeable students, the user groups, and help desks to link students to technical support that facilitates their technical proficiency. We have found however, that students were very resourceful and in the studio environment, they supported each other's learning and everyone's skills developed organically.

The exciting result of integrating technology in this way ~~was~~ was that the students ~~applied~~ apply their technical skills in the context of the problems they' ~~we~~re working on. They either practiced previously learned skills or immediately applied new skills they acquire in the studio workshops. Students commented at the end of the studio that this was the only way to really learn BIM—to *use* it. When asked what BIM meant to their studio experience, one architectur~~al~~e student said that he couldn't just draw an abstract idea about the design, but that he had to model the "real thing" because these guys, (pointing to the students sitting next to him), need to get accurate material quantity take offs for the estimate. In this way, BIM made the connection between the disciplines explicit for the students. Through the process of creating a BIM together, the students uncovered for themselves the connection between the abstract ideas of the design and the realities of putting the building together.

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2.3 Collaboration

Many have found that technical proficiency needs to be coupled with collaboration strate~~i~~gies to fulfil the promise of BIM technologies (Eastman, Teicholz, Sacks, & Liston, 2008; Smith & Tardif, 2009). In the author's own research, when asked about a recent IPD/BIM project, an owner representative said in an interview that, "we chose the people who we knew we could work with." In the educational context, interdisciplinary collaboration not only challenged students to think outside of their newly acquired domain lens, but also gave them contextual exposure to develop the professional collaboration skills. IPD and other forms of AEC collaboration require a cultural shift from more adversarial delivery methods. Those who have worked in IPD discuss the creation and reinforcement of "teams." In this studio, we sought to do just that—create teams where students synthesized their disciplinary learning by challenging them to work with colleagues from other disciplines. Team members did research, did analysis, made design decisions, and built models to realize and communicate the results. In the context of the "team" they understood very vividly their role as the designer, engineer or builder and what each discipline contributed to the "team's" development of the final project.

To accomplish the task of designing and virtually building a project, the individuals on the teams took on- a variety of roles, some related directly to their disciplines such as conceptual and technical design and analysis, and other roles relating more to the process, organization and management of the project. ~~a variety of roles. Some of these roles were managerial, while others were analytical.~~ We recommended that each team member adopt specific roles as part of setting up how the team divided the responsibilities and scope of work, but encouraged the team members to be open to the evolution of these roles as the team's work progressed. We sought to avoid the "divide and concur" mentality and reinforced the idea that although they may have taken a lead in particular areas, ~~did not~~this doesn't mean that they did all of the work related to that role; we encouraged everyone to participate in all aspects of the project and work together to discover and explore the research, design and construction activities. Interestingly enough, this was easier to do within the architectural design process, but much more difficult with construction elements. One reason for this might be the fact that construction costs and schedules were often developed towards the end of the conceptual design process and the students were busy preparing for the deliverable and did not have time to discuss and share information. When it came down to the wire, they did retreat to their disciplines and roles to complete the assignment for the mid-term and final deliverables.

Although there was a tendency to focus on the technical aspects of the project, we did routinely make collaboration the topic of conversation and a theme throughout. We launched the studio with a collaboration workshop where the team reviewed collaboration strategies and developed an initial collaboration agreement. As the work progressed and the teams formed,

we discussed plans and the strategies in a group every two weeks and students wrote in an individual collaboration diary (separate from the design sketchbook for confidentiality). Students were able to reflect upon the collaboration experiences and these reflections also help the faculty understand how the teamwork was progressing.

3. STUDENT WORK: DESIGN, ANALYSIS AND PLANNING

For their mid-term and final deliverables, the student teams developed design models, engineering analysis, construction cost estimates and construction schedules. In contrast to a traditional architectural design studio where *individuals* spend most of the term exploring formal and conceptual issues, these design *teams* had little time to linger in the concept and form-making phase but had to complete conceptual design quickly so that they could develop the structural, mechanical and envelope design, cost estimates and construction schedules. However, the iterative nature of IPD emerged when the students after the mid-term deliverables went back to the form-making discussions and revisited and revised their building forms based on systems, constructability and architectural issues. In this way, the architectural discipline was interwoven into the design of the systems and construction. The depth of design inquiry required the students to make decisions about the construction and materiality of their buildings that is uncommon in architectural design studios. It compelled a design process much closer to that in professional practice, where concept formation occupies a relatively small portion of the overall design effort compared to an academic design studio where the majority of the effort is given over to conceptual design followed by production of presentation drawings and models.

Within this modified and accelerated studio model, the students' design and construction proposals achieved a high degree of resolution including the development of major assemblies, selection of materials, development of the building envelope, integration of structural and environmental systems, preliminary cost estimates, construction schedules, 3D and 4D models. The studio assignments challenged the teams to explore all of these interrelated dimensions.

For the first studio, the vehicle for the design explorations was a mixed-use building of approximately 45,000 s.f. located in the Capitol Hill district of Seattle. This was an actual project in the early stages of pre-design for the Bullitt Foundation, a non-profit organization whose mission is to safeguard the natural environment by promoting responsible human activities and sustainable communities in the Pacific Northwest. The Foundation ~~intended~~ intended this mixed-use building to be at the leading edge of urban sustainability, and to ~~have mee~~meet the International Living Building Institute's Living Building Challenge. The Foundation ~~aspired~~ planned to create a building that generates all of its energy with on-site renewable resources, captures and treats all of its water on site (with the exception of potable water) and is an inspiration to others for its beauty and performance.

The second studio vehicle was part of a partially funded research project to design, build and monitor a net-zero energy, high performance re-locatable classroom called HiPerMod (high performance modular). ~~built upon the investigations and research of two previous courses investigating high performance classrooms to develop highly resolved design proposals for a high performance modular classroom.~~ The goal here was to produce one or more designs from which to develop a prototype re-locatable classroom to be built (summer 2011) and that CEB students would then operate, monitor and evaluate over the following year. In addition to the detailed design of this classroom, teams were to design and locate this classroom as part of a Renewable Energy Learning Center for Magnuson Park, a project that was concurrent with the studio under discussion by Seattle City Light and the Seattle Parks and Recrea-

tion Department.~~.~~ As described by the owner constituents, this new public amenity would celebrate and demonstrate renewable energy and ecological design, and support classes, meetings and public events in a fully integrated indoor/outdoor learning environment using both new and existing structures. Studio design proposals were to include landscape design and infrastructure, renovation and re-purposing of existing structures, and new structures including a picnic shelter, outdoor gathering spaces, and a high performance modular classroom developed to a high level of resolution.

Reducing building energy use was been central to these projects. Consequently, analysis methods to predict building performance were a particular focus of these two studios. Methods to analyze solar heat gain, solar control, daylighting, and envelope heat transfer were introduced in regular workshop sessions and applied directly to the project. Analysis methods included calculations, digital analysis and physical models. Students taking on the roles of structural and mechanical engineers were assisted in their design and analysis work by visiting professional consultants who join the studio on a regular basis.

As described above, the studio started from a program and the teams had to do conceptual design and analysis tasks before they could begin addressing construction. Although constructability issues were part of the conversation throughout the studio, construction cost estimating and construction scheduling was often compressed into the last week or two before the mid-term and final deliverables. When the students were focused on production, it was difficult to share this disciplinary work across the team, and design and engineering students often were focused on their own work product when the construction related analysis was conducted. Consequently, the construction management students enjoyed exposure to the conceptual design in the early weeks of the studio, but the architecture and engineering students did not as deeply experience estimating and scheduling. Similar to the engineering analysis, the students' work was supported by visiting professional estimators and contractors who provided real work feedback to their designs, cost estimates and construction schedules.

Throughout, industry professionals met with the students to support the multiple design and analytical dimensions of the problem. The integrated teams were able to anticipate reviewers comments and criticism based on these consultations. In their mid-term and final presentations, they presented the basis for their design and construction decisions, which were often multifaceted and incorporated architectural design, engineering analysis and construction planning elements.

4. LESSON LEARNED: MANAGING EXPECTATIONS

Just as the problem given to the teams, the challenges of teaching this studio were also multidimensional. Synthesizing three disciplines of knowledge – Architecture, Engineering and Construction – while challenging the students with solving a complex real-world design problem using state of the art tools and exploring emerging work processes was and is a daunting task. The collaboration process was the "vessel" into which we threw everything else and tensions appeared along these dimensions: technology tools vs. skills; professional and cultural differences; work processes (design vs. analysis; team vs. individual). The friction that inevitably comes from throwing all of these factors into this vessel was where a lot of the learning took place. In our experience, the technical challenges were relatively more straightforward than those characterized by the interdisciplinary collaboration and teamwork of the course. Namely, there were fundamental differences in culture and expectation of students from the different disciplines as well as different types and levels of knowledge across the teams, and differences in awareness, facilitation, and willingness to engage with technology.

Comment [t1]: Rob, I can think of many dimensions in which we could reflect on this studio experience. We could talk about teaching with BIM technologies, we could talk about synthesizing sustainability design and construction, we could talk about the challenge of building integrated student teams and then coaching these teams through the studio experience.

Where do you think this paper should head? I feel like perhaps we need to select a focus on build the discussion around that. As is the nature of the studio – we could go in 50 different directions.

Thoughts?

Furthermore, the group dynamic was very different for both the students as well as the instructors who are accustom to solo student work and evaluation.

We've found that the dynamics of each team developed in its own unique and organic way, perhaps as a function of both the personalities of the players and the constellation of their disciplinary skills. For example, in the first year one of the teams' work was characterized as intensely collaborative, they would discuss most of the decisions as a team; they often seemed to be talked animatedly and laughing together. Individuals or pairs would work on a problem and present the alternative solutions to the group who then would discuss the pros and cons of each and how these new alternatives integrated with the other aspects of the project. Meanwhile, a second team was more individualized. They often worked quietly during studio, with solo work being integrated electronically. They did not seem to have as much discussion and collective decision-making or support. Both teams developed thoughtful and coordinated designs, plans and construction schedules, but their teamwork was starkly different in character.

This was an advanced upper-division project-based undergraduate class where the students were expected to bring their own expertise and experience to engage in the ways that they personally found interesting, challenging and meaningful. The learning value came from being intentional about reflecting and processing the lessons of the collaboration, trying to figure out what worked best for this team and these problems, what strategies to employ, and how to resolve conflict and navigate the messiness of integrated teamwork. This particular aspect of the studio posed a challenge both in terms of individual feedback as well as evaluation. Most of the evaluation in traditional engineering and construction management departments is based on the student's work product; consequently, some of the students did not put an emphasis on their reflections or teamwork. For example, some of the students, who are otherwise very good performers, either didn't turn in a collaboration diary at all, or their dairy had scribbled one-l-liners such as "day went ok", "we worked hard today". From the experience over the past two years, we have found that the reflection upon their collaborative process is central to the course and this centrality has to be reinforced early and often throughout the term. In future classes, we are considering making collaboration reflections a weekly graded assignment that faculty can then engage with an individual dialog as well as one with the team.

Another challenge of this course design, was that students brought widely varying skills and baseline knowledge to the course. Finding ways for each team member to contribute to the enterprise was critical. A particular challenge had been finding ways for the non-architecture students to contribute during the early stage of concept design, since these students did not have any experience with this type of work, but yet, were expected to perform at a sophisticated level in an advanced course. Once a concept had been developed, there was a project to take-apart, analyze and develop, most students found something to work on, but before the design took form the process of concept formation and development was opaque for some. However, in challenging the non-architecture students to participate in conceptual design activities opened their experience to this way of thinking and students reported that this understanding was one of the major benefits of the class. One of the more valuable revelations comes from students observing the different skills and work process from the different disciplines. Furthermore, in the end, the students learn through experience that when working collaboratively, each team member had ownership in the design that made the detailed analysis and downstream decision-making more aligned with the concept. In future studios, we are challenged then, in the messiness of the collaboration, to keep a focus on what students are learning from interdisciplinary work as well as what they learn by applying their own disciplinary skills to the problem at hand.

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