Reaching for Sustainability Using Technology and Teamwork: Testing Integrated Project Delivery in Multi-Disciplinary Studio Teaching

KATHRINA SIMONEN
University of Washington

CARRIE DOSSICK
University of Washington

ROBERT PEÑA
University of Washington

Concurrent with the grand challenges of urbanization, globalization and sustainability, the Architecture, Engineering and Construction (AEC) industry is experiencing a technological revolution. The pressure to create higher quality, lower cost, lower environmental impact buildings in an increasingly competitive market is driving the building industry to explore alternate modes of designing and delivering buildings. Building Information Modeling (BIM), Integrated Project Delivery (IPD) and Design Build are current practice innovations working towards these goals. Practice appears to be leading academia in driving innovation and integration in the AEC industry. Given the changing needs of industry and the pressing economic and environmental challenges a critical re-evaluation of education of building industry professionals and of academic research agendas is essential to advance design and construction process. Taking advantage of the fact that the Departments of Architecture and Construction Management reside within the same college at the University of Washington, a new studio based course, integrating architecture, construction management and engineering students was developed in 2008.

INTRODUCTION

The architectural studio is rarely questioned as the model for delivering the knowledge and skill necessary to integrate the complex aesthetic, technical and social concerns of architecture. Other disciplines are recognizing and modeling studio-based teaching (Kuhn, 2001). Students are expected to demonstrate technical competence within the studio (NAAB, 2009) yet the challenge of integrating disciplines remains a challenge (Boyer and Mitang, 1996). Most architecture programs have adapted studios to satisfy the 'comprehensive design' requirements of accreditation. The authors have found time constraints of schedules and student knowledge to be significant barriers to enable technically rigorous and architecturally sophisticated 'comprehensive' solutions. Building technology subjects such as structures, energy performance and materials and methods of construction are most commonly taught as distinct architectural topics rarely directly linked to the design studio or design process and subjects such as cost estimating and construction scheduling are not typically covered in much detail. While synthesis is expected to happen in the studio (Smith, 2011) the increasing demands for more sophisticated design integration within both practice and academia drives the need to explore alternate methods of delivering architectural education and challenge studio structure, content and methods.

In contrast to the deep synthesis of the design studios, 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. Separating the learner from the relevant context can cause 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).

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. 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 and technical constraints;
- Explore the use of location, form, and materials, to promote an architecture well adapted to the conditions of the environment;
- Investigate building and construction practices that minimize environmental impact and promote and express principles of environmental sustainability and;
- 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 have developed a design studio-based course, the Integrated Design Build Studio, which 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 College, 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 teams ranging in size from 3 to 8 (depending upon the term) and are assigned a "collaboration suite" where they set-up an "office" and can work during and outside of studio hours. The course has been taught three times since 2009, and will be offered for a fourth time in winter 2012.

INTEGRATED DESIGN BUILD STUDIO

Architecture studios are traditionally problem-based classes in which students synthesize, develop and expand upon their newly acquired knowledge from the support curriculum. Here we modify the traditional studio to focus on collaboration across the traditionally silo-ed disciplines of architecture, engineering and construction. The course is structured on a practice model where faculty provide 'principal' level support and identify 'consultants' on an as needed basis. Differing from conventional studios there are not daily 'desk crits' but rather open consultations as needed for both individuals and teams. In this modified form, the pedagogy of this design/build studio rests firmly on a "three-legged stool" of intention, technology and methodology, namely: *sustainability*, *building information modeling*, and *collaboration*.

The concept of this studio is to explore Integrated Project Delivery. Given the authors' academic affiliations, there is an emphasis on the intersection of architectural design and construction in this curriculum; however, students from civil engineering and landscape architecture have also participated in the class and we are exploring how to integrate with other senior 'capstone' projects. All authors have engineering backgrounds and industry guests were architects, engineers and builders, so that attention to all three disciplines—Architecture, Engineering and Construction—are both balanced and integrated. To this end, the studio focuses as much on the collaboration across disciplines as it does on the products produced.

Building Information Modeling (BIM) and other computational tools are integrated into the studio curriculum. In initial offerings all students received introductory instruction in Revit, Navisworks, and Ecotect. In later offerings we leveraged existing student knowledge and held targeted workshops to strengthen skills based on student needs. Each team develops a design, a conceptual cost estimate and a construction plan and schedule. Depending upon the quarter students additionally performed comprehensive energy analysis, building life cycle assessments and/or developed a target cost model that was tracked throughout the design process. This studio builds upon the technical skills, design awareness, ordering principles, and construction management knowledge developed in previous coursework and/or design studios.

Sustainabilty

The design problems are developed from local projects with ambitious targets for resource efficiency, performance, environmental health and human satisfaction. Students have worked within the framework of the *Living Building Challenge*™ or *The 2030 Challenge* to develop high performance building designs. Students are expected to develop climate responsive design proposals and demonstrate the potential of reducing their energy demands using expertise gained in previous courses. Last year, students were expected to develop a comprehensive life cycle analysis integrating embodied and operational energy impacts (see fig 1). Imposing criteria of a budget, a construction schedule, and high levels of building performance provides a compelling challenge, testing student's design imaginations against the demands of a competitive, risk-averse industry.

Teamwork is designed to be fluid, allowing members to take on various disciplinary roles over the term (e.g. structures, mechanical systems, architectural design). Over the 10-week course team members participate in various workshops to learn both concepts and applications, and work out design problems in technical "huddles," often with an instructor or guest (professional) "consultant." Students who specialized in analysis might attend a workshop while their teammates develop the design and work on other aspects of the project, just as they might in a professional team.

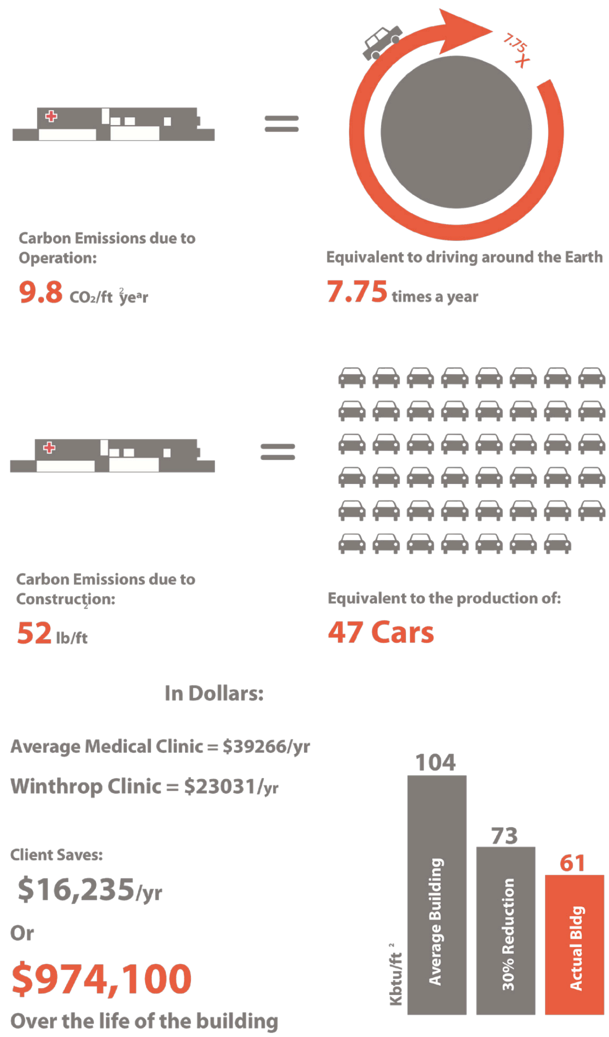


Figure 1. *Life Cycle Assessment Summary 2011 Team: O. Keith, J. Marsan, E. Wang and C. Appling*

Reducing building energy use has been central to these projects. Consequently, analysis methods to predict building performance have been a particular focus. 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 to create energy models of their buildings. 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 day lighting. In the third year students used the Energy Star Target Finder to establish energy performance goals and published prescriptive guidelines to meet energy reduction targets for the building type selected. These different methods have provided framework adequate to integrate energy performance and architectural design into the team discussions and project solutions.

BIM

The second leg of the stool is Building Information Modeling (BIM). The instruction with BIM takes two forms: the software, and working *collaboratively* with the software. Teaching software is relatively straightforward: it is taught in tutorials and it requires technical support for detailed questions. Teaching collaboration is more challenging and is 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 is both dynamic and challenging. The students arrive with diverse baseline knowledge of BIM tools. Some students have taken courses where Sketchup, Revit or Navisworks were used while others have never been exposed to them before. To address this disparity, for the first two years we offered a 2-day Revit workshop. In the third year we eliminated the introductory workshops. Later in the quarter, when the teams are starting to think about consolidated models and construction schedules, we review Navisworks tools for presentation, clash detection and 4-D modelling.

Some students take on more 3D modelling roles, while others take on Navisworks roles. Some students focus on other research, design and analysis tasks. No matter what their level, students learn from each other and soon exceed 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 diverse resources to link students to technical support that facilitates their technical proficiency. We have found however, that students in the studio environment support each other's learning. Eliminating the introductory workshop did not significantly change student outcomes and appears to have empowered students to learn independently.

The exciting result of integrating technology in this way is that the students apply their skills in the context of the problems they are working on. Students commented at the end of the studio that this was the only way to really learn BIM—to *use* it. Furthermore, when asked what BIM meant to their studio experience, one architecture 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. 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.

Collaboration

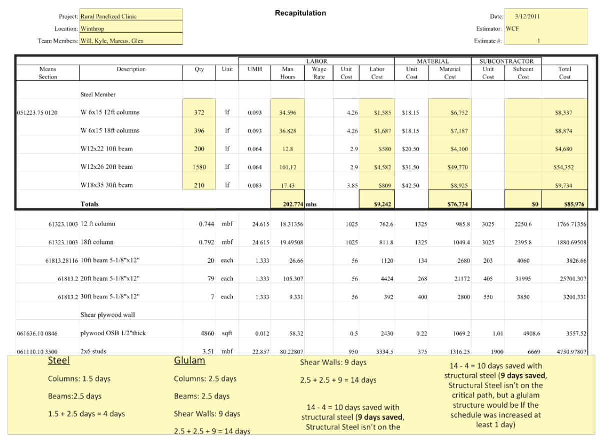
Many have found that technical proficiency needs to be coupled with collaboration strategies to fulfil the promise of BIM technologies (Eastman, Teicholz, Sacks, & Liston, 2008; Smith & Tardif, 2009. When asked about a recent IPD/BIM project, an owner representative said in an interview that, "we chose the people who we knew we could work with." In the educational context, interdisciplinary collaboration not only challenges students to think outside of their newly acquired domain lens, but also gives them contextual exposure to develop the professional collaboration skills. In this studio, we seek to create teams where students synthesize their disciplinary learning by challenging them to work with colleagues from other disciplines. In the context of the "team" they understand very vividly their role as the designer, engineer or builder and what each discipline contributes 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. We 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, this does not 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.

Within the design process, the sharing of responsibility depended most upon team dynamics and the temperament of individuals. Engineering and construction management students need effective coaching by their architect peers to gain comfort with the open ended and iterative process of design. Disciplinary confidence, comfort with uncertainty and willingness to trust others were key traits that successful teams demonstrated.

Figure 2. *Target Cost Data: Integrating cost from week 1. 2011 Team: M. Kim, Y. Kit, A. Mosen.*

Sharing of responsibilities and integrating construction elements within the design process appears to have had more to do with the course structure and teaching effort. In the first two years 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 often retreat to their disciplines and roles to complete the assignment. In the third year we developed curriculum to enable students to build 'target cost' models (see fig. 2) at the early phases of design and required students to explore alternative proposals weighting design, cost, environment and time (see fig. 3 & fig 4.). These two exercises were effective in encouraging iteration and integration of architectural and engineering concerns.



Recapitulation

Project: Rural Panelized Clinic
Location: Winthrop
Team Members: Will, Kyle, Marcus, Glen

Date: 3/12/2011
Estimator: WCF
Estimate #: 1

				LABOR					MATERIAL		SUBCONTRACTOR		
Means Section	Description	Qty	Unit	UMH	Man Hours	Wage Rate	Unit Cost	Labor Cost	Unit Cost	Material Cost	Unit Cost	Subcont Cost	Total Cost
	Steel Member												
051223.75 0120	W 6x15 12ft columns	372	lf	0.093	34.596		4.26	$1,585	$18.15	$6,752			$8,337
	W 6x15 18ft columns	396	lf	0.093	36.828		4.26	$1,687	$18.15	$7,187			$8,874
	W12x22 10ft beam	200	lf	0.064	12.8		2.9	$580	$20.50	$4,100			$4,680
	W12x26 20ft beam	1580	lf	0.064	101.12		2.9	$4,582	$31.50	$49,770			$54,352
	W18x35 30ft beam	210	lf	0.083	17.43		3.85	$809	$42.50	$8,925			$9,734
	Totals				**202.774**	**mhs**		**$9,242**		**$76,734**		**$0**	**$85,976**
61323.1003	12 ft column	0.744	mbf	24.615	18.31356		1025	762.6	1325	985.8	3025	2250.6	1766.71356
61323.1003	18ft column	0.792	mbf	24.615	19.49508		1025	811.8	1325	1049.4	3025	2395.8	1880.69508
61813.28116	10ft beam 5-1/8"x12"	20	each	1.333	26.66		56	1120	134	2680	203	4060	3826.66
61813.2	20ft beam 5-1/8"x12"	79	each	1.333	105.307		56	4424	268	21172	405	31995	25701.307
61813.2	30ft beam 5-1/8"x12"	7	each	1.333	9.331		56	392	400	2800	550	3850	3201.331
	Shear plywood wall												
061636.10 0846	plywood OSB 1/2"thick	4860	sqft	0.012	58.32		0.5	2430	0.22	1069.2	1.01	4908.6	3557.52
061110.10 3500	2x6 studs	3.51	mbf	22.857	80.22807		950	3334.5	375	1316.25	1900	6669	4730.97807

Steel
Columns: 1.5 days
Beams:2.5 days
1.5 + 2.5 days = 4 days

Glulam
Columns: 2.5 days
Beams: 2.5 days
Shear Walls: 9 days
2.5 + 2.5 + 9 = 14 days

Shear Walls: 9 days
2.5 + 2.5 + 9 = 14 days
14 - 4 = 10 days saved with structural steel (**9 days saved**, Structural Steel isn't on the

14 - 4 = 10 days saved with structural steel (**9 days saved**, Structural Steel isn't on the critical path, but a glulam structure would be If the schedule was increased at least 1 day)

Figure 3. *Alternative Cost Models: 2011 Team W. Fort, M. Crider, K. Smith, G. Stellmacher.*

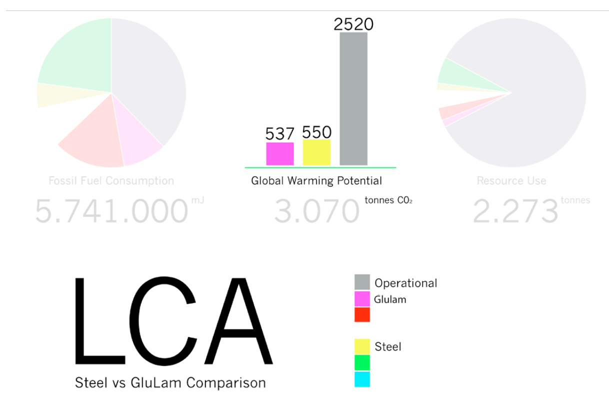


Figure 4. *Life Cycle Assessment of Alternatives: 2011 Team W. Fort, M. Crider, K. Smith, G. Stellmacher*

Although there was a tendency to focus on the project development 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. In the third year we developed an online 'survey' to help prompt students to evaluate particular issues and still provide a forum for direct feedback to faculty. The faculty found that this individualized feedback was particularly critical as the studio structure provides significantly less one-to-one consultation than typical and students needed additional avenues to give and receive feedback.

STUDENT WORK

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 less 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. Closer to what is typical in professional practice; concept formation occupies a relatively small portion of the overall design effort.

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.

For the first studio, the program for the design explorations was a mixed-use building of approximately 45,000 s.f. This was an actual project in the early stages of pre-design for a local non-profit organization whose mission is to safeguard the natural environment by promoting responsible human activities and sustainable communities. The Foundation intends this mixed-use building to meet

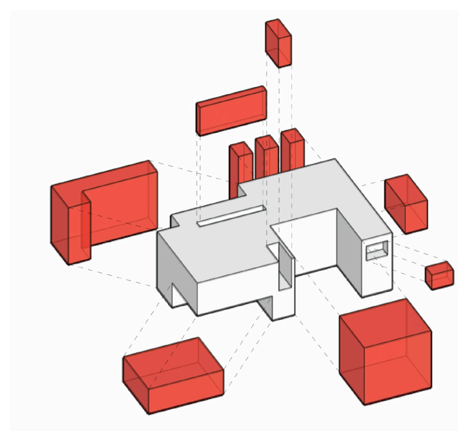


Figure 5. *Studio Design Proposals: Strong concepts helped teams develop more successful design resolution.*

the International Living Building Institute's Living Building Challenge.

The second studio was part of a partially funded research project to design, build and monitor a net-zero energy, high performance re-locatable classroom. 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 a local park, a project under consideration by the local utility. Design proposals were required to include landscape design and infrastructure, renovation and re-purposing of existing structures, new outdoor structures, and a high performance modular classroom.

The third studio was integrated into a larger college sponsored research effort exploring opportunities to link improved access to rural health care and urban disaster resilience. Students designed a stand-alone medical clinic integrated with a mobile emergency room. Student teams were asked to explore different construction delivery methods (including site built, modular and panellized systems) in order to look for opportunities to reduce construction time and cost and critically evaluate the impact of system selection on design resolution.

Visiting professional engineers, estimators and contractors who provided real work feedback to their designs, cost estimates and construction schedules, supported the students' work. 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.

LESSONS LEARNED: AN EVOLVING CURRICULUM

The challenges of this studio are 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 is a daunting task. The collaboration process is the "vessel" into which we throw everything else: technology tools vs. skills; professional/cultural differences; work processes (design vs. analysis; team vs. individual). The friction that inevitably comes from throwing all of these factors into this vessel is where a lot of the learning takes place. In our experience, the technical challenges are relatively more straightforward than those characterized by the interdisciplinary collaboration and teamwork of the course. While the objectives of leading to sustainability through collaboration and technical integration remain unchanged, the structure and character of the curriculum continues to evolve.

Effective Collaboration Requires a Focus on Team Dynamics

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

We've found that the dynamics of each team develops in its own unique and organic way, perhaps as a function of both the personalities of the players and 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 they integrate 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.

Collaboration was most effective when the teams had at least two students with the confidence and maturity to be effective leaders and inspire the rest of the team through their dynamic interactions. Establishing effective teams was most effective when faculty had previous knowledge of the majority of students enrolling in the course.

Collaboration Can Be Difficult to Evaluate

This is an advanced project-based class where the students are expected to bring their own expertise and experience to engage in the ways that they find interesting, challenging and meaningful. The learning value comes from being intentional about reflecting and processing the lessons of the collaboration, trying to figure out what works best, 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 the interaction with their peers. For future courses we intend to offer additional coaching to develop skills in communicating technical content, balancing leadership, production and team communication and explaining the importance of process.

Integration Requires Careful Pedagogical Development

Students bring widely varying skills and baseline knowledge to the course. Finding ways for each team member to contribute to the enterprise is critical. A particular challenge has been finding ways for the non-architecture students to contribute during the early stage of concept design. Once 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.

Faculty continue to evaluate what tools and techniques are best for integrating rigorous yet manageable energy analysis into this fast paced project. The integration of environmental life cycle assessment provided a good platform to understand trade offs between construction and operation impacts and could be expanded to integrate with life cycle cost analysis to provide additional overlap between cost and environmental impact.

CONCLUSIONS

The development of the studio is integrated with the research agendas of the lead faculty and is seen as a research project in its own right. We are searching for answers to questions such as: How should we be teaching the next generation of professionals; what opportunities do advanced technologies bring; does the configuration of workspaces and visualization tools impact results; and how best to integrate environmental performance modelling within early design? We are challenged, 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. We continue working to identify the best methods, tools and processes by which to prepare students to lead future practice towards a more sustainable, more efficient and more inspirational built environment.

ACKNOWLEDGEMENTS

We would like to acknowledge the students who worked so hard in these studios and to the building industry professionals who have generously shared their knowledge and insights with the students.

REFERENCES

Barab, S. A., Hay, K. E., Barnett, M., and Squire, K. (2001). Constructing Virtual Worlds: Tracing the Historical Development of Learner Practices. Cognition and Instruction, 19(1): 47–94.

Bertz, M., and Baker, N. C. (1996). CELL — A Vertically Integrated Learning Resource. Proceedings of the 3rd Congress on Computing in Civil Engineering, ASCE, Reston, Va., 348–354.

Brown, J. S., Collins, A., and Duguid, P. (1989). Situated Cognition and the Culture of Learning. *Educational Researcher*, 18 (1): 32–42.

Chinowsky, P., and Vanegas, J. (1996). Combining Practice and Theory in Construction Education Curricula. Proceedings of the 1996 ASEE Annual Conference, Washington, D.C., American Society for Engineering Education. Washington, D.C.

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2008). BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors. Hoboken, New Jersey: John Wiley & Sons, Inc.

Fruchter, R. (1997). The A/E/C Virtual Atelier: Experience and Future Directions. Proceedings of the 4th Congress of Computing in Civil Engineering, ASCE, Reston, VA., 395-402.

Kuhn, S. (2001). Learning from the Architecture Studio: Implications for Project Based Pedagogy. International Journal of Engineering Education. 17(3&4), 349-352.

National Architecture Accrediting Board (NAAB). (2009). 2009 Conditions for Accreditation. www.naab.org, 23-24.

McCabe, B;, Ching, K. S., and Savio, R. (2000) Strategy: A Construction Simulation Environment. Proceedings of the 6th Construction Congress, Orlando, FL. ASCE, Reston, VA,. 115-120.

Sawhney, A., Mund, A., and Koczenzsz, J. (2001). Internet-based Interactive Construction Management Learning System. Journal of Construction Education, 6(3): 124-138.

Smith, D. K., & Tardif, M. (2009). Building Information Modeling: A Strategic Implementation Guide for Architects, Engineers, Constructors, and Real Estate Asset Managers. Hoboken, New Jersey: John Wiledy & Sons, Inc.

Smith, R. (2011). Systemic Shifts in Architectural Technology Education. Proceedings of the 2011 BTES Conference, Building Technology Educators Society, Toronto, ON, 121-129.