Collaborative Design Processes: A Class on Concurrent Collaboration in Multidisciplinary Design

Lucio Soibelman, Ph.D.[1], William O'Brien, Ph.D[2], and George Elvin, Ph.D.[3]

[1]-Assistant Professor - University of Illinois at Urbana Champaign – Department of Civil and Environmental Engineering – soibelma@uiuc.edu – (217) 333-4759
[2] – Assistant Professor – University of Florida - M.E. Rinker, Sr. School of Building Construction wjob@dcp.ufl.edu - (352) 273-1168
[3]- Assistant Professor - University of Illinois at Urbana Champaign – School of Architecture - elvin@uiuc.edu - (217) 333-5870

Abstract
The rise of concurrent engineering in construction demands early team formation and constant communication throughout the project life cycle, but educational models in architecture, engineering and construction have been slow to adjust to this shift in project organization. Most students in these fields spend the majority of their college years working on individual projects that do not build teamwork or communication skills. Collaborative Design Processes (CDP) is a capstone design course where students from the University of Illinois at Urbana-Champaign and the University of Florida learn methods of collaborative design enhanced by the use of information technology. Students work in multidisciplinary teams to collaborate from remote locations via the Internet on the design of a facility. An innovation of this course compared to previous efforts is that students also develop process designs for the integration of technology into the work of multidisciplinary design teams. The course thus combines both active and reflective learning about collaborative design and methods. The course is designed to provide students the experience, tools, and methods needed to improve design processes and better integrate the use of technology into AEC industry work practices. This paper describes the goals, outcomes and significance of this new, interdisciplinary course for distributed AEC education. Differences from existing efforts and lessons learned to promote collaborative practices are discussed. Principal conclusions are that the course presents effective pedagogy to promote collaborative design methods, but faces challenges in both technology and in traditional intra-disciplinary training of students.

1. Introduction
Collaboration between geographically distributed, multidisciplinary teams is becoming standard practice in the AEC industry. However, educational models in architecture, engineering and construction have been slow to adjust to this rapid shift in project organization. Most students in these fields spend the majority of their college years working on individual projects that do not build teamwork or communication skills. When these students confront the intensively collaborative reality of today's AEC practice the inadequacies of their education suddenly become clear.

The rise of concurrent engineering in construction demands early team formation and constant communication throughout the project life cycle. But AEC education seldom supports these needs, focusing instead on individual projects with few opportunities to build teamwork and communication skills. Similarly, while most students are exposed to information technologies that are focused on supporting individual disciplines (e.g., CAD for the architect, structural analysis for engineer, project scheduling for the builder), AEC curricula have not focused on introduction of collaborative information tools.

Today, it is possible for design and construction organizations to be supported by virtual studios-networked facilities that provide the geographically distributed participants in a design project with access to the organizations' databases and computational resources, efficient messaging and data exchange, and sophisticated video teleconferencing. Unfortunately, effective integration of these technologies into the work practices of design professionals has been problematic. While AEC project organizations increasingly use information technologies to facilitate practice, beyond isolated examples there is little evidence to suggest that this capability has significantly shortened facility design times or dramatically increased the number or quality of design alternatives.

In response to these limitations, the authors developed the Collaborative Design Processes (CDP) course to provide students the experience, tools, and methods needed to improve design processes and better integrate the use of technology into AEC work practices. CDP is a graduate level, capstone design course where students from the University of Illinois at Urbana-Champaign and the University of Florida learn methods of collaborative design enhanced by the use of information technology. Students work in multidisciplinary teams to collaborate from remote locations via the Internet on the design of a facility. To-date, students have produced designs for a boat house (2001), a fitness center (2002), a worship facility (2003), and an university student center (2004). Team members from structural engineering, architecture and construction management generate designs, schedules and budgets while experimenting with different work practices to take maximum advantage of information technology using commercially available software. Students also produce individual and group critiques of their work processes, providing a reflective assessment of their collaborative skills and a chance to propose new methods based on their experience and learning in the course. The course thus combines both active and reflective learning about collaborative design and methods. The course is designed to provide students the experience, tools, and methods needed to improve design processes and better integrate the use of technology into AEC industry work practices.

2. The Collaborative Design Processes Course

The CDP course is a capstone design course where students learn methods of collaborative design in the AEC industry enhanced by the use of Information Technology. Students work in multidisciplinary teams to collaborate from remote locations via the Internet on the design of a facility. Team members from structural engineering, architecture and construction management generate designs while experimenting with different work practices to take maximum advantage of information technology using commercially available software. Students also develop process designs for the integration of technology into the work of multidisciplinary design teams

Facility design is fundamentally a collaborative, interdisciplinary, geographically distributed, multimedia activity. A typical AEC project, for example, might involve architects, a client team, structural engineers, mechanical engineers, electrical engineers, cost consultants, lawyers, interior designers, landscape architects, construction managers, construction contractor, subcontractors, materials suppliers, and various regulatory agencies. The various individuals and firms that are involved constitute a virtual organization that exists throughout the life of the project and is then disbanded so that the components may be recombined for new projects. Coordination of the work of these parties to make a coherent design is a challenging problem. Too often, traditional practice has seen the development of designs that are over-cost, over-schedule, and of poor quality on several metrics (such as constructability, aesthetics, etc.).

Recent years have seen the advance of information technology to alleviate these problems. Today, it is possible for virtual design organizations to be supported by virtual design studios-networked facilities that provide the geographically distributed participants in a design project with access to the organization's databases and computational resources, efficient messaging and data exchange, and sophisticated video teleconferencing. Unfortunately, integration of this technology into the work practices of design professionals has been problematic. There is little evidence to suggest that this capability has significantly shortened facility design times or dramatically increased the number or quality of design alternatives. How to integrate information technology to improve the work practices of multidisciplinary design teams remains a fundamental problem. This course was designed to provide students the experience, tools, and methods needed to improve design processes and better integrate the use of technology into AEC work practices.

The course allows students to experience virtual design teamwork for themselves through hands-on design of a building project. This direct experimentation phase occupies one half of the students' coursework. A series of 12 lectures by faculty and industry experts from Architecture, Structural Engineering and Construction Management provide a framework for understanding concepts, issues and state-of-the art practice in collaborative design processes and technologies. Based on these lectures and discussions, students reflect on their own experience with the design project to produce a revised process to improve future collaborative efforts. There are two main assignments during the semester: the design project and the process critique. During the design project a multidisciplinary groups of students are assembled with members from different schools. Each group has at least one structural engineering student, one project management student, and one architectural student. During the first half of the semester each group works on the defined project with the goal of delivering the complete architectural design CAD files, the estimate, the schedule, and the structural project for the designed facility. To complete the project, a virtual jury is conducted. Finally, during the process critique students present lessons learned during the semester concerning the difficulties of collaborative design and propose process improvements. They critique their design process in the design project, including the difficulties of implementing the available IT tools to support multidisciplinary design. Based on their critique, students present improved work process methods, and make recommendations for the development of improved software tools for the design. The goal of the process critique is to help students understand the interaction between generation of information, modes of exchange, and the impact of new media for communication and accumulation of information mapping information bottlenecks and information overflows during the design process

The course objectives are:

- Understand group dynamics and develop negotiation and decision making skills through direct experience of group design work and through critical reflection, evaluation and analysis of multi-disciplinary, net-based collaborative design process.
- Complete facility designs including plan, schedule, budget and structure using different work processes enabled by the use of information technology.
- Learn how to evaluate and integrate technologies of multidisciplinary remote collaboration that will soon be the medium for design and delivery of AEC projects.
- Design improved work process methods and make recommendations for the development of improved software tools for collaborative, multidisciplinary design.

3. Other University Based Collaborative Design Efforts

A number of other courses have been developed to teach multidisciplinary, geographically distributed teamwork employing information technology solutions. Fruchter (1999) developed a distributed learning environment that included six universities from Europe, Japan, and the United States and a tool kit that was aimed to assist team members and owners to capture and share knowledge and information related to a specific project, to navigate through the archived knowledge and information, and to evaluate and explain the product's performance. Hussein and Peña-Mora (1999) created a framework for the development of distributed learning environments that was applied during a distributed engineering laboratory conducted jointly by MIT and by CICESE in Mexico. These authors studied students' interaction within the distributed classroom and with the gained insights generated guidelines for the development of distributed collaborative learning courses. Devon et al (1998) developed a French-American collaborative design project using many different forms of information technology. Similar to the efforts described above several other universities developed their own collaborative design courses, e.g., the University of Sidney (Simmoff and Maher 1997), Carnegie Mellon University (Fenves 1995), and Georgia Tech (Vanegas and Guzdial 1995).

Several of the courses reviewed above have been observed first-hand by the authors as graduate student participants and/or as faculty judges. These collaborative courses are product centric, with the main output of the course a final group design project for a facility. These existing courses are excellent additions to the AEC curricula and provide students active learning experience in multidisciplinary design. However, it is the authors' opinion that there is room for innovation to better accommodate a process focus and to provide students time to reflect on and integrate their experiences. Thus the University of Illinois/University of Florida CDP course was designed to provide the student with the tools to analyze and improve not just the designed facility but also the design process. Reflection on the design process is a key aspect of the course and students' deliverables include both a facility design and a process critique. A further difference between the CDP course and other courses is an emphasis on the use of off-the-shelf software tools. Many of the other efforts have employed experimental software that supports specific aspects of the collaborative design process. However, the use of such software provides the students with limited opportunities to directly apply their learning in practice. Thus while there are limitations to commercial products, a decision was made to give students exposure to leading commercial tools rather than experimental ones.

4. Outcomes and Lessons learned during CDP 1st, 2nd, 3rd, and 4th Years

The CDP has been offered for four years, in spring 2001, spring 2002, spring 2003, and spring 2004. Enrollment has been offered on a limited basis; students are Master's students near graduation or Ph.D. students. In all cases, students entering the class were expected to have significant academic training in their respective discipline. Most students also had some professional work experience. Teams were formed by the instructors to provide a balance of work experience and technological skills. Teams were also formed to provide a mix of students between the University of Illinois and the University of Florida, requiring students to collaborate across a geographical distance. No physical meetings were held between Illinois and Florida students; all lectures and group meetings were held virtually through the Internet.

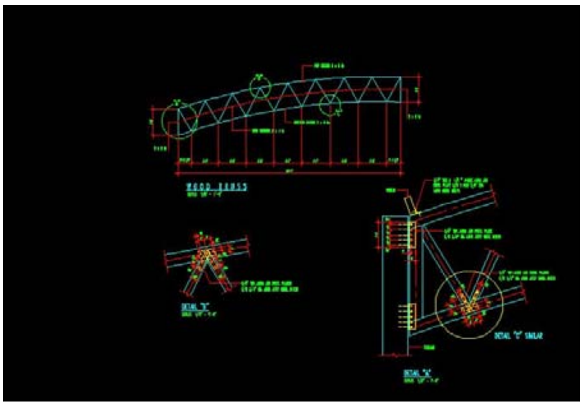

Figure 1a: Boathouse truss and truss connections detail.

Figure 1b: Boathouse 3D model.

For spring 2001, the instructors choose as a design project a boathouse. Students were grouped in five teams of five: two architects, a structural engineer, and two project managers. There were typically two students based at the University of Florida and three at the University of Illinois. Each team was required to use specific software for collaboration: Microsoft NetMeeting™, and Bricsnet's Project Center™. Other resources provided by the instructors limited software to AutoCAD™ and standard scheduling and estimating packages, although students were not excluded from using other software they had access to.

Student teams began design of the project early in the semester with one formal design review with the instructors approximately halfway through the design project. A virtual jury was conducted at the close of the project with students, instructors, and guests judging the designs on aesthetics, conformance to functional requirements, technical accuracy, and projected cost/schedule performance. Figures 1a and 1b are examples of student work for the boathouse design.

Demeanor varied widely across the groups during the design project. Some groups worked together with a high degree of cooperation whereas others where confrontational (we discuss aspects of collaboration below). To a limited extent, group and personal demeanor carried through to the development of the process critiques. However, groups were generally able to develop effective critiques of the design process and technologies independent of their demeanor.

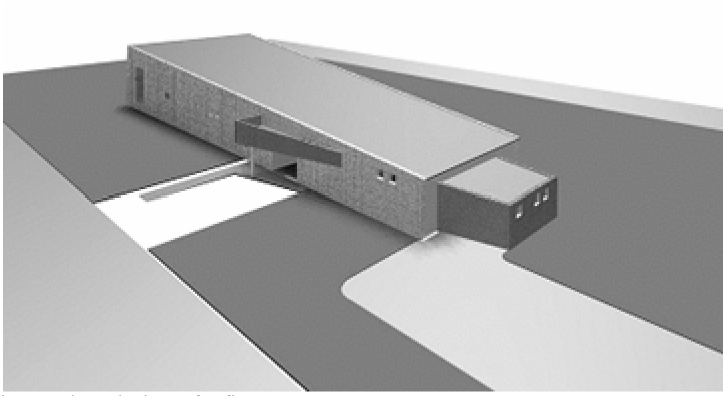

Figure 2: Collaborative student design of a fitness center

The project for spring 2002 was a fitness center (see figure 2). Based on experience in the previous year, the instructors also made several adjustments to the course: First, more choice was given to students regarding their suite of technologies, although all technologies remained off-the-shelf products. Student teams could elect to make use of whatever mixes of technologies they wished to use. Second, the introduction of the design project was delayed and the groups performed value engineering and negotiation exercises as an icebreaker. Third, smaller teams were assigned: one architect, one engineer, and one construction manager. The goal of these changes for 2002 was to develop more focused teams that would better be able integrate collaborative techniques into their work practices and process critiques. Students had more time to develop team skills, and, by reducing team size, each member had a larger role in the project.

These changes were partially successful. Conflict was reduced and students appreciated the negotiation and teamwork exercises although there was a consensus that even more teambuilding would be useful. However, students were less successful generating effective process critiques in year 2 than in year 1. It is the opinion of one instructor that this was partially due to the budget: An extremely tight budget for the boathouse may have forced more collaborative discussions and learning than did the moderate budget for the fitness center. Another possibility is that, due to smaller teams, increasing the scope of the design responsibilities per individual reduces ability to reflect about their tasks while accomplishing them.

The project for spring 2003 was a non-denominational place of worship (see figure 3). The most significant change compared with year 2 is that this time faculty allowed a much tighter construction schedule and budget with the goal of creating more design pressure increasing the need for negotiation among group members. These changes generated a higher level of conflict but the classes on negotiation theory allowed them to better manage the conflict. This time the students were able to develop better process critiques if compared with the previous year.

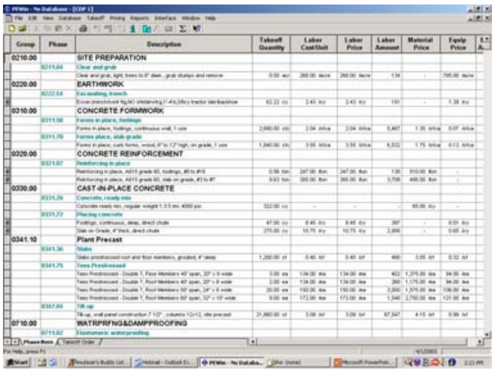

Figure 3a: Non-denominational place of worship estimate

Figure 3b: Non-denominational place of worship 3D model.

The project for spring 2004 was a student center (see figure 4). This semester was a very different than previous ones because the class had a much larger number of students. A new software called Sketch Up 3D was made available for students in Florida and Illinois to support rapid prototype at the conceptual deign phase. Sketch Up provided a powerful tool-set with an intelligent guidance system that streamlined the 3D drawing process with an interface that supported a dynamic, creative exploration of 3D form, material and light without requiring large investments in training and support. The class was divided in 7 large groups and the faculty decided to add more design responsibilities like a constructability manager, an interior designer and a mechanical systems designer to make sure that all group members had at least one area of responsibility. The problems faced this semester were almost the same ones faced during the first year that the course was offered but this time the conflict level was smaller probably because of the collaboration and negotiation tools that were introduced to the students in the beginning of the semester.

In general, the similarities between student work in years 1, 2, 3, and 4 of the CDP course are greater than the differences. Students were able to take a design concept and develop a coordinated set of design, engineering, and construction plans in a just over half a semester's time. They accomplished this using off-the-shelf technologies and despite the limitations of distance. Students were also able to demonstrate basic abilities to critique their work processes and technologies and make recommendations for improvement. Unfortunately in all 4 years that the course was offered no group demonstrate abilities to work in a truly collaborative manner.

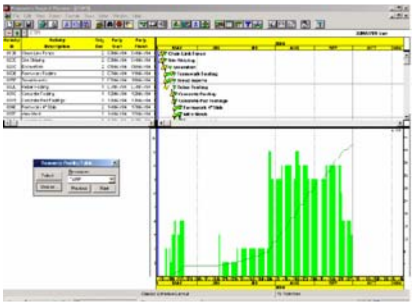

Figure 4a: Student center schedule and resource leveling

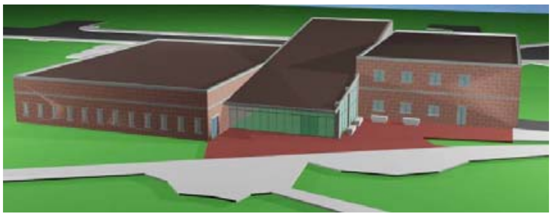

Figure 4b: Student Center 3D Modeling

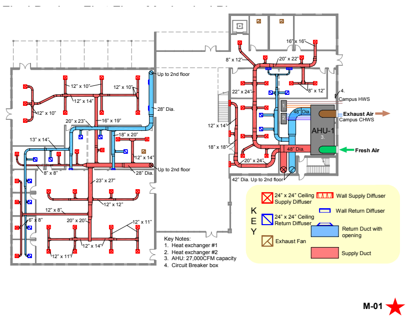

Figure 4c: Student center mechanical plan

Figure 4d: Student Center interior design

5. Persistence of "over-the-wall" Methods

There are three primary work strategies available to a team with distributed members, each strategy reflecting a different relationship between tasks (Figure 5). First, teams may take a serial approach (top) in which each team member performs all of his or her tasks and then hands the results off to the next team member, the project being passed along from team member to team member until completed. This is the strategy we know as the "over-the-wall" method. Alternatively, they may perform their tasks concurrently, or in parallel (middle), each working on a separate task at the same time as the others, but without a frequent exchange of information. And finally, they may adopt an integrative or iterative approach (bottom), frequently exchanging information among team members performing separate tasks of short duration. When we began the course, we expected that students would develop their group projects by working together in an iterative manner, frequently exchanging information and ideas. In most cases, however, *design iterations and information exchanges were much less frequent than we expected.*

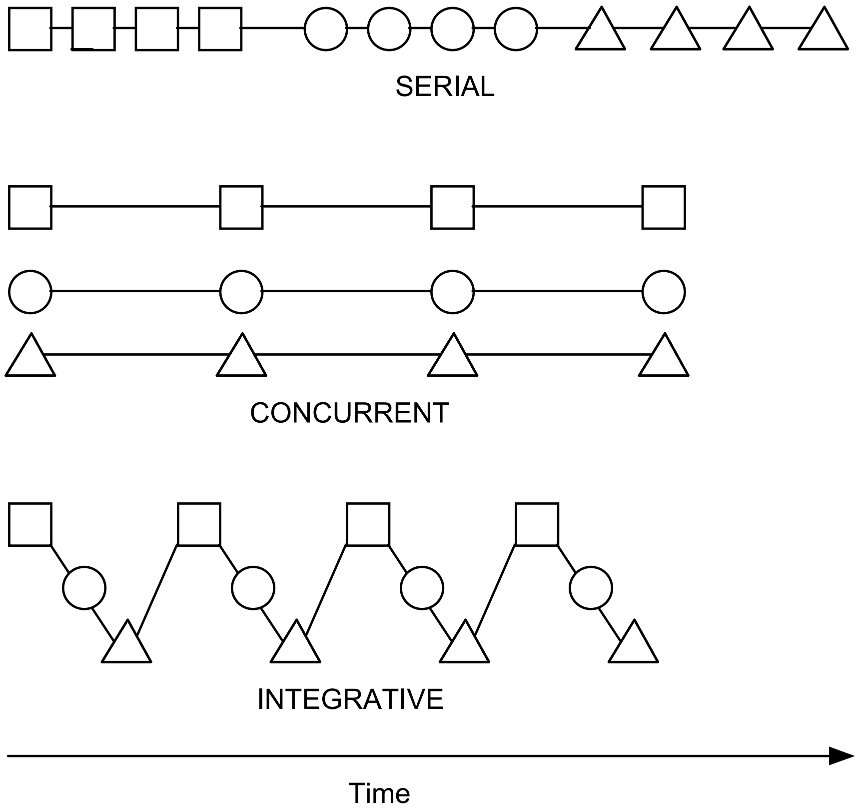

Figure 5: Alternative approaches to collaborative work

The advantages of integrative work methods have been confirmed in practice. They include improved process efficiency, accuracy, innovation and quality (Fergusson 1993). While the tools and training provided to students in Collaborative Design Processes give them the opportunity to rapidly exchange project information and iterate between tasks, most persist in taking an “over-the-wall” approach to developing their projects. Why?

First, design must be somewhat complete in order for the team to develop a schedule, budget and structural plan. Teams are made up of one designer, one cost estimator and one scheduler. In order to perform the tasks of cost estimating and scheduling, the team members responsible for those tasks must have a design on which to base their estimates. In all cases, the cost estimator and scheduler began the project by waiting for the architecture student to produce a design. The level of development of the design prior to input from other team members varied among teams, but in general, teams held off on exchanging information and ideas about conceptual designs longer than we expected. Second, while the information technologies available to the students made remote collaboration possible, available off-the-shelf technologies were not yet sophisticated enough to allow smooth synchronous collaboration such as marking up a design drawing simultaneously from remote locations. It is still much easier to work on one’s own tasks in isolation and then exchange “complete” information than to engage in the technologically and sociologically messy business of synchronous work or rapid exchange of “provisional” or incomplete work.

In addition, there is the matter of control. Students working alone on a task feel a high degree of control over task process and task results. But, when they release the results to others in an iterative exchange of information, the students no longer feel they are in control of their work. Students frequently expressed frustration when waiting for information from teammates, information that was needed in order for them to proceed with their own tasks. This frustration is felt in practice as well, as contractors cite waiting for design information as the most common cause of delay in building projects (Kumaraswamy and Chan 1998). Finally, the educational background of the students, whether in engineering or architecture, was not one that encouraged collaboration or built experience and skill in this method. Students tended to work alone in their university studies, and the few weeks of training in communication and collaboration that preceded the start of the design project in Collaborative Design Processes were not enough to overcome the mindset and habits of students accustomed to working on their own.

According to students, the most difficult problems that they faced were not caused by available technology or by distance but due to diverse backgrounds and expectations. On reflection, the most common feedback given by students is that they spent too much time creating the design and not enough time planning the design process. Observations by the instructors and students suggest three main barriers to adoption of more integrative design methods.

Lack of knowledge about the information needs of others - Students are trained in their discipline with only limited knowledge of how others perform their work or what information others need to accomplish their work tasks. Even students with work experience generally did not demonstrate much knowledge of coordination needs with other disciplines. Students frequently cited their frustrations waiting for information. Further, even when information was shared (e.g., posting a drawing for review by other teammates), the information was not in a desired form or was difficult to extract (e.g., the posted drawing lacked key dimensions or material descriptions). Students also had difficultly sharing key assumptions. Occasionally, lack of knowledge about the work or others would lead to conflicts and suppositions that teammates were not working. For example, a project management student expressed frustration that the only shared products of his work were a schedule and estimate. Whereas the production of design drawings is evidence of work, changing a few figures in an estimate does not demonstrate the amount of work behind those changes. The authors note that these issues in information sharing are common in practice; for example, contractors cite waiting for design information as the most common cause of delay in building projects (Kumaraswamy and Chan 1998).

Lack of integrative knowledge and abilities within and across disciplines - Concomitant with a lack of knowledge about the information needs of others is a lack of integrative abilities on the part of the project team. This lack is particularly evident around conceptual estimating and scheduling tasks to provide early feedback to the design process. Students had tremendous difficulty in estimating major cost or schedule drivers on designs in an early stage of development. This limited effective feedback and reinforced tendencies to work in a serial manner. In general, engineers and project managers were most comfortable making definite estimates of cost, schedule, and structural design details only after the architects had developed the design to a high level of detail. As an example, on an interim design review, the instructors noted that the proposed design had a very low cost. When quizzed about this, the project management student responded that the estimate was incomplete because the architect had not yet provided a detailed design for key elements.

Cultural expectations vary with individual and discipline - The example above of the student waiting for a complete design before being able to produce an estimate is an example of cultural differences: Despite having work experience, in his home country, work is performed in a serial or "over-the-wall" manner. Thus he was not proactive in providing information or guidance to the architect. In contrast, a Thai project management student on another project provided the architect with an itemized list of costs for substitute materials per unit, providing the architect the knowledge to guide his design choices. There were similar experiences within disciplines. For example, some architecture students were protective of their design role and saw the other team members as their consultants. In a design review, one architect repeatedly used the phrases "my engineer" and "my contractor." Understandably, the project management student did not view his team as a particularly collaborative one. Yet this attitude did not pervade all teams. Some architects were more proactive in soliciting design input. Notably, one group collectively worked to understand the programmatic needs of the interior design and furnishings for the fitness center. This team provided a design that had the most functional interior of all groups, demonstrating the potentials of team collaboration.

6. Recommendations

We believe collaboration with strong iteration and information exchange is desirable, given its favorable results in practice. What, then, are some of the incentives that could be introduced to encourage collaboration and iteration? One possible incentive is to introduce more milestones with specific deliverables along the way to the finished project. Desiring to keep the process as open as possible, we held just one interim meeting with each student team in which we played the role of the client, offering a "go" or "no go" on the conceptual design halfway through the project timeline. More reviews with specific deliverables aimed at encouraging or measuring collaboration could be employed. Another incentive would be to spend more time training the students in collaborative methods before they begin working together, and students frequently expressed their desire for more up-front training. However, we prefer to let the students learn about collaboration by doing it, rather than by listening to someone tell them about it. Their immersion in the collaborative design project is then followed by an intensive and critical self-analysis, the process critique, in which they learn from what they and their fellow students have done.

Another incentive to collaboration would be improved technological tools to facilitate synchronous group work and information exchange. The kit of tools currently available off-the-shelf make remote collaboration possible, but do not yet encourage synchronous collaboration. Two strategies are possible with respect to software for collaborative design – off-the-shelf or custom-built – and we chose to use off-the-shelf software. Given the intensive research and development on collaborative software taking place in private industry, these tools are rapidly improving and each new semester brings significant advances in collaborative software.

Students specifically cite waiting for information from their teammates as one of the primary frustrations of collaborative design. This leads to an additional incentive; information elicitation mechanisms could be introduced to encourage rapid response to requests for information. In the AEC industry, mechanisms aimed at enforcing rapid response in information exchange and decision making often involve economic incentives. In the classroom, we prefer to let the students define their own roles and responsibilities as they begin their collaborative project by drafting a team partnership agreement.

One incentive to collaboration spans beyond the scope of the individual course. That is to gradually reshape the curricula of architecture and engineering schools to encourage collaboration and exchange of ideas among students. If universities and schools can create an overall academic setting where collaborative, multidisciplinary work is considered commonplace, students could bring learned skills and experiences in collaboration to bear on a group design project, rather than learning these skills almost from scratch as they tackle the complexities of a large-scale design project.

In Collaborative Design Processes, our aim is to facilitate rather than impose frequent exchange of information and ideas. The partnership agreement drawn up by each team before they begin their collaborative project helps define some of the expectations and assumptions held by each team member. Project work then forces the students to confront the challenges of collaborative design directly. And the reflective process culminating in the group process critique gives the students the opportunity to analyze "what worked and what didn't" in their work as a team.

These three course components, together with some additional training in the tools and methods of group work up front, provide a setting that encourages students to learn about collaborative design and think critically about its challenges and opportunities.

7. Concluding Remarks

Overall reaction to the course by the students is very positive. For many of them, this is the first experience they have working in interdisciplinary teams. Other students with professional experience felt that the course was beneficial as they played different roles than they had in the past and that the chance to use new technologies was useful. Feedback at the conclusion of the class noted that the students enjoyed the hands-on aspects of the course and felt better prepared for practice after collaborating with people with different perspectives. Students also felt that they built some useful skills in both applying computer skills and in teamwork. Feedback from graduates of the class and now in practice generally supports these views. Some course graduates express frustration that they are unable to deploy in practice the tools they used in class (generally due to a lack of time and professional collaborators familiar with the tools).

The course also demonstrates that the existing state of computer tools enables effective work. In a short period of weeks, students go from a program assignment to generating a coordinated set of plans, schedules, and budgets. The students from Illinois and Florida do not meet face-to-face and do not have previous working relationships. We do not believe such rapid design development would be possible without the use of computer tools to mediate communication.

However, observation and feedback also indicates that the tools do not enable true collaboration. They are still most suited to over-the-wall type development. Tools do not provide effective capabilities to collaboratively explore in real time the different design alternatives along various axes related to the design, construction and engineering disciplines. That said, the use of Netmeeting and similar tools that allow desktop sharing and synchronous voice/video do provide a platform for real-time discussions. Most of the student comments about improving the tools related to enriching the Netmeeting whiteboard functions and/or better integrating this type of functionality with more sophisticated tools such as CAD.

The combination of instruction (lectures and discussions), action (collaborative design project), and reflection (group process critique), has proven an effective model for collaborative design education. It serves to introduce the students to many of the social, professional and technological challenges of remote collaboration currently facing the AEC industry. It highlights the importance of variations in experience, outlook and expectations among students from different disciplines, and the need to address these differences if a successful process and product are to be achieved. In this capacity, the course offers an important addition to traditional, discipline-specific curricula.

In the future, we will seek out new tools for collaborative design that allow for greater co-labor – simultaneous manipulation of design documents by team members at remote locations, for example. Currently, too many off-the-shelf applications for internet-based collaboration simply reinforce the accepted over-the-wall method of sequential, rather than synchronous, labor. The internet has the potential to change the nature of how we work together, and while specific tools and technologies seem to change almost overnight, we believe we have succeeded in creating at least the beginnings of a model that inspires students to ask “what if?” with regard to technology, collaboration, and the design process itself.

8. Acknowledgments

The writers would like to acknowledge the support given by Bricsnet, REVIT and SketchUp for providing the software support for the class. We also thank the NSF SUCCEEED coalition who helped fund course development at the University of Florida. The Departments of Civil Engineering at the University of Illinois and University of Florida and the Department of Architecture at the University of Illinois also provided equipment funding and laboratory space for this class.

9. References

Devon, R., Saintive, D., Hager, W., Nowé, M., & Sathianathan, D. (1998). Alliance by design: an international student collaboration. *Proc. ASEE Annual Conference*, Seattle, WA.

Fenves, S (1995) “An Interdisciplinary Course in Engineering Synthesis” Proceeding of the 2nd ASCE Congress of Computing in Civil Engineering, ASCE, New York, NY.

Fergusson, K.J. (1993) “Impact of Integration on Industrial Facility Quality”, 84, Center for Integrated Facility Engineering, Stanford University, palo Alto, CA.

Fruchter, R. (1999) “AEC Teamwork: A Collaborative Design and Learning Space”, Journal of Computing in Civil Engineering, Oct, 1999, ASCE.

Hussein, K. and Peña-Mora, F. (1999) “Frameworks for Interaction Support in Distributed Learning Environments”, Journal of Computing in Civil Engineering, Oct, 1999, ASCE.

Kumaraswamy, M.M., & Chan, D.W. (1998) Contributors to construction delays. *Construction Management and Economics, (16),* 17-29.

Vanegas, J. & Guzdial, M. (1995) Engineering education in sustainable development and technology. *Proc. 2nd Congress on Computing in Civil Engineering*, ASCE, New York, NY, 425-432.