ENCOURAGING CONCURRENT COLLABORATION IN MULTIDISCIPLINARY DESIGN PROJECTS: A CLASSROOM BASED STUDY

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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. When we began the course, we expected that students would develop their group design 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. This paper describes the goals, outcomes and significance of this new, interdisciplinary course for distributed AEC education. It presents its differences compared to other collaborative design courses and shares lessons learned and contributions. It specifically addresses methods for encouraging collaboration in a multidisciplinary design project.

KEYWORDS

Collaborative design, multidisciplinary design, concurrent engineering

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INTRODUCTION

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 in the architectural, engineering and construction (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, schedules and budgets 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. 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 work practices. To-date, students have produced designs for a boathouse (2001) and a fitness center (2002) (Figure 1).

Figure 1: Collaborative student design of a fitness center

The course has several distinct features that set it apart from other collaborative courses. First, we use only information technologies that are readily available to most AEC firms, including Net Meeting, AutoCAD, Revit, and Bricsnet. The use of off-the-shelf software helps assure that the students will be able to apply their learning when they enter practice. Esoteric one-of-a-kind or extremely expensive programs may be of great experimental value in AEC education, but they leave the student without the possibility of actually using these tools in the average professional office. Second, over one-third of the course time is devoted to an intensive review and self-evaluation of the collaborative process employed by each team. After completing the facility design project, the students spend the final eight weeks of the course developing a detailed process critique in which they reflect on, evaluate, and suggest improvements to both the strategies and technological tools of their collaborative design process. These valuable lessons learned can then be shared and taken away by each student, improving future practice.

This paper describes the goals, outcomes and significance of this new, interdisciplinary course for distributed AEC education. It presents its differences compared to other
collaborative design courses and shares lessons learned and contributions. It specifically addresses methods for encouraging collaboration in a multidisciplinary design project.

BACKGROUND

Collaboration between geographically distributed parties is becoming standard practice in the AEC industry. The rise of design-build and fast track methods of project delivery 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 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. In fact, only 46% of all architecture alumni responding to a recent survey felt their school did a good job fostering their ability to work cooperatively in interdisciplinary teams (Boyer and Mitgang 1996).

The shift in project organization toward collaboration has been accompanied by dramatic changes in the media and methods of communication within the AEC industry. The intensive and rapid exchange of information engendered by design-build, fast track and other collaborative methods cannot be achieved using paper documents alone. Students in distributed, collaborative AEC courses today have the opportunity to experience a wide range of information technology tools capable of enhancing communication and collaboration, and graduates of these courses enter the industry prepared to not only participate in the teams that will shape tomorrow’s buildings, but to lead them.

UNIVERSITY OF ILLINOIS AT URBANA CHAMPAIGN AND UNIVERSITY OF FLORIDA CDP COURSE

COURSE OVERVIEW

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

COURSE MOTIVATION

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.

**COURSE OBJECTIVES**

1. 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.

2. Complete facility designs including plan, schedule, budget, and structure using different work processes enabled by the use of information technology.

3. Learn how to evaluate and integrate technologies of multidisciplinary remote collaboration that will soon be the medium for design and delivery of AEC projects.

4. Design improved work process methods and make recommendations for the development of improved software tools for collaborative, multidisciplinary design.

**COURSE CONTENTS**

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:

DESIGN PROJECT: 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
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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.

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.

CDP and Other University Based Collaborative Design Efforts

A number of other courses were developed to teach multidisciplinary, geographically distributed teamwork. 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 Sydney (Simoff and Maher 1997), Carnegie Mellon University (Fenves 1995), and Georgia Tech (Vanegas and Guzdial 1995), among others. These efforts were product centric with groups of students collaborating on a design project. The main objective of these classes was to support the students in improving the product being designed. The University of Illinois/University of Florida CDP course, in the other hand, was process centric providing the student with the tools to analyze and improve not just the designed facility but the design process.

During the CDP course after creating a design, schedule, budget and structural plan for a facility, students were asked to reflect on the group dynamics and technologies of collaboration they experienced. They were asked to propose improvements that may help future collaborators improve their design processes. They were expected to write a report with their perceptions of the team performance/dynamics and to develop process maps describing in a graphical language the flow of work in their team’s design process. In their report they were expected to specifically address the technological improvements which could facilitate collaborative design in the future.
RESULTS: 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 2). 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.*

![Diagram of Serial, Concurrent, and Integrative Approaches](image)

Figure 2: 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.

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.

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.

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