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The *Journal of Construction Education* (ISSN 1522 8150) was founded in 1996 by the Associated Schools of Construction, an association of 105 international colleges and universities with construction education programs. The purpose of the *Journal* is to provide an important process necessary for the preservation and dissemination of manuscripts that report, synthesize, review, or analyze scholarly inquiry. The *Journal* is an important way of our focusing international attention on and contributing to the understanding of the issues, problems, and research associated with construction education and training. The recognition of scholarly work within the realms of curriculum information, contemporary educational practices, educational research and instructional application development within construction departments, schools and colleges, and industry are the reasons for the *Journal's* existence. The *Journal's* mission is to provide construction educators and practitioners with access to information, ideas, and materials for improving and updating their understanding of construction education and training. It is also intended to help its constituency become more effective in developing the talents of learners within construction programs. This *Journal* is not only a living textbook of construction education, but also a perpetual and dependable learning source for construction professionals whether they are within academia or within industry. The *Journal* will be published tri-annually (Spring, Summer, and Fall issues). The divisions of the *Journal* include invited and editorially reviewed Book Reviews and Teaching Profiles, and blind peer reviewed Educational Practice and Research Manuscripts.

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Beginning of a Journey: A New Editor's Observations

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Introduction

As the new editor of the *Journal of Construction Education*, my academic publishing journey has just begun. Judging from the last few months' work, this will be a delightful challenge. The manuscripts that have recently been submitted for review will undoubtedly add to the body of knowledge for educators, students and industry professionals alike. My hope is that future articles will build upon the pedagogical foundation currently in place and will continue to add more knowledge for the teaching profession.

At this time, it is appropriate that those of us who have followed the birth and growth of the *Journal of Construction Education* recognize and acknowledge the efforts and time invested by Dr. Ken Williamson of Texas A&M University. Ken is the immediate past editor of the *Journal*; in fact, until my tenure began this summer, Ken has been the only editor of the *Journal*. Without his efforts, and without the support of the board members of the Associated Schools of Construction, it is probable that as educators, we would not have this additional avenue that allows us to meet some of the publishing demands of our respective colleges and universities. Thank you, Ken, for a job well done. In addition, I personally want to thank Ken for the many hours he has spent trying to educate me in the processes required to continue in his footsteps, especially during a very trying time in his life as he continues a valiant fight against cancer.

My thanks also go out to Dr. Thomas Mills of Virginia Tech. As my associate editor, he has given much wise counsel. Having served as an associate editor to Ken Williamson for some time now, Dr. Mills is familiar with the processes necessary to edit and publish the *Journal*. I look forward to working closely with him in the future and value his experience and counsel.

Finally, my thanks also go out to all of those who have submitted manuscripts and to those who have graciously taken their time to review those manuscripts for publication. This is a wonderful service you do for our profession. Without your efforts, the *Journal of Construction Education* would cease to be. For those of you who have not published or who have not volunteered to be reviewers, please consider this an invitation to help make the *Journal* even better.

As I begin this journey, I have no preconceived plan to suggest any major changes to the current editorial or review processes of the *Journal*. The mission of the *Journal of Construction Education* remains the same. We will continue to do our best to encourage well-written research articles that deal with construction education and pedagogy. In addition, we intend to provide an outlet in the near future for articles that deal more specifically with construction practices and methodologies.

By Way of Introduction

Now, let me say just a few words of introduction about your new editor. Like many of you, I was born and reared in a family that relied on the construction industry for its financial survival. Several generations of building contractors and lumbermen precede me in our family lines. A number of them were instrumental in helping tame a small part of wilderness area in Southern Utah. Of necessity I was involved in the building business from a young age, often working in our family's lumber yard after school and on Saturdays, selling and delivering building materials to job sites near my home town in Central California. Some 25 years ago I made a conscious decision to follow in my father's footsteps as a general contractor. For some 15 years I was an owner/partner in construction companies that built and developed residential and light commercial projects in several western states. None of these were huge projects, but the experiences I gained have proven invaluable to me while teaching construction management courses at Brigham Young University during the past 11 years.

Of course, it would be inappropriate to fill in the blanks of my past life at this time, but I must say that I have thoroughly enjoyed the opportunities I have had to teach young men and women who are focusing on a professional life in our industry. Like many of you, I choose to teach, not for the financial returns, but because I feel I have a chance to make a difference in the lives of my students. And that is one of the reasons I am excited about the opportunity to edit this journal. It is now my privilege to read, edit, and make available manuscripts that will hopefully help each one of us as educators to improve our teaching and research.

Conclusion and Challenge

Because our profession of teaching construction management at the college level is relatively young, as compared to many of the social sciences and even to architectural- and engineering-related curricula, there is much work to do in order to strengthen the existing foundation of pedagogical research. As construction-management educators please consider how well you are presenting the theories and practice of our profession to enthusiastic, inquiring young minds. What kind of meaningful experiences can you share with your colleagues to help them improve their teaching?

At this time I would like to issue a personal challenge to each of you to devise well-planned research projects that will allow you to share new knowledge with your colleagues so we can provide richer learning experiences to our students. As we work to improve ourselves as researchers, it is my hope that the manuscripts published in the future will serve to elevate the image of the *Journal of Construction Education*, in addition to providing a source that will allow each one of us to become better educators.

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1522-8150/01/$3.00/Educational Practice Manuscript

Collaborative Design Processes: An Active- and Reflective-Learning Course in Multidisciplinary Collaboration

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Collaborative Design Processes (CDP) is a capstone design course where graduate 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. 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.

Key Words: Collaborative design, multidisciplinary design, concurrent engineering, Internet collaboration

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. For example, 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).

Concurrent with the advent of new methods of project delivery, there have been advances in information technology solutions to support practice. 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. As noted by O'Brien (2000) is his review of implementation issues in project web sites, many professionals have difficulty devising new work procedures or understanding the potential of new technologies to support changes in practice. Thus 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.

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. 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) and a fitness center (2002). 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.

Related Education 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.

Collaborative Design Processes Course Description

Course Overview

The CDP course is a Master's level, 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 improving the work of multidisciplinary design teams. These process designs are extended to include novel incorporations and extensions to information technologies.

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 a facility design 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.

Lectures

The goal of lectures is to introduce concepts of collaboration and collaborative practice to students, providing the necessary tools for them to effectively accomplish course requirements. Lectures are grouped under four main concepts that the instructors believe are central to the collaborative process: One, negotiation. Two, collaborative design practice methods and concepts. Three, examples of collaborative practice and supporting technologies. Four, tools for mapping processes and human-computer interactions.

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 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 with faculty and students.

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 process critique has two components: an individual critique and a group critique. The individual critique is an informal document where students record their own experiences and ideas for improvement. These individual critiques are shared among group members to facilitate development of the group critique. The group critique is a formal document that requires students to first analyze their work methods and suggest process improvements. Second, students are asked to critique their use of existing information technologies and suggest improvements in technologies that would support their revised work methods. To provide students structured approaches for process and technology analysis, the instructors introduce the design process mapping tools used by Baldwin, et al (1999) and the use case approach for detailing human-computer interactions (Kulak and Guiney, 2000).

Course To-Date: Execution in Years 1 & 2

The CDP has been offered for two years, in Spring 2001 and Spring 2002. 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.

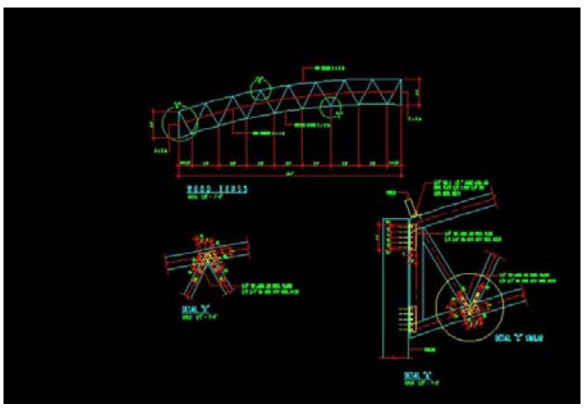

Figure 1a: Boathouse truss and truss connections detail.

Figure 1b: Boathouse 3D model.

Spring 2001

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.

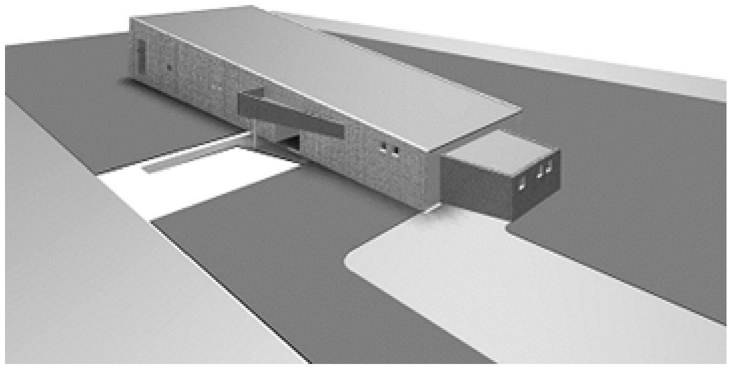

Figure 2: Collaborative student design of a fitness center

Spring 2002

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.

In general, the similarities between student work in years 1 and 2 of the CDP course are greater than the differences. In both years, 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. While the larger groups in year 1 made somewhat better critiques than the students in year 2, in neither year did a group demonstrate abilities to work in a truly collaborative manner.

Persistence of "Over-The-Wall" Design Methods

As described by Elvin (1998), there are three primary work strategies available to a team with distributed members, each strategy reflecting a different relationship between tasks (see figure 3). 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.

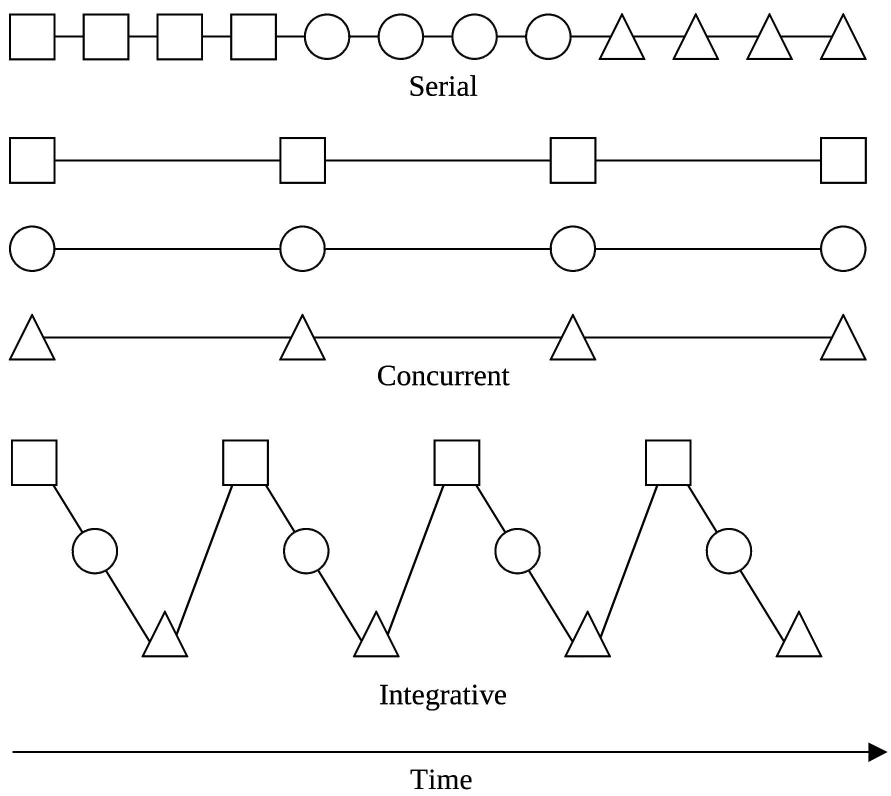

Figure 3: Alternative approaches to collaborative work.

Figure 4 is a student team's diagram of their work process, and is illustrative of the typical design process utilized by all the student teams. The red lines indicate circumstances in which collaborative communication occurred. The green rectangles reflect project milestones, whether group objectives in terms of design development or course deliverables. The red circles labeled "discussion" indicate occasions in which students conducted group chats and videoconferences. As can be seen, students mostly worked in a truncated serial or "over-the-wall" type approach where designs where generated, then reviewed around major milestones. Design development by the architect(s) dominated early discussions in the project. Structural engineering and project management tasks supporting this design development were reactive in nature, with limited critiques being offered to refine or reject design alternatives. The majority of engineering and project management work occurred in the last weeks of the project after significant maturation of the design. We call this a truncated serial approach as the project due date prevented further work on the project. Had the teams been given extra time after the due date, we expect they would have returned to a serial approach.

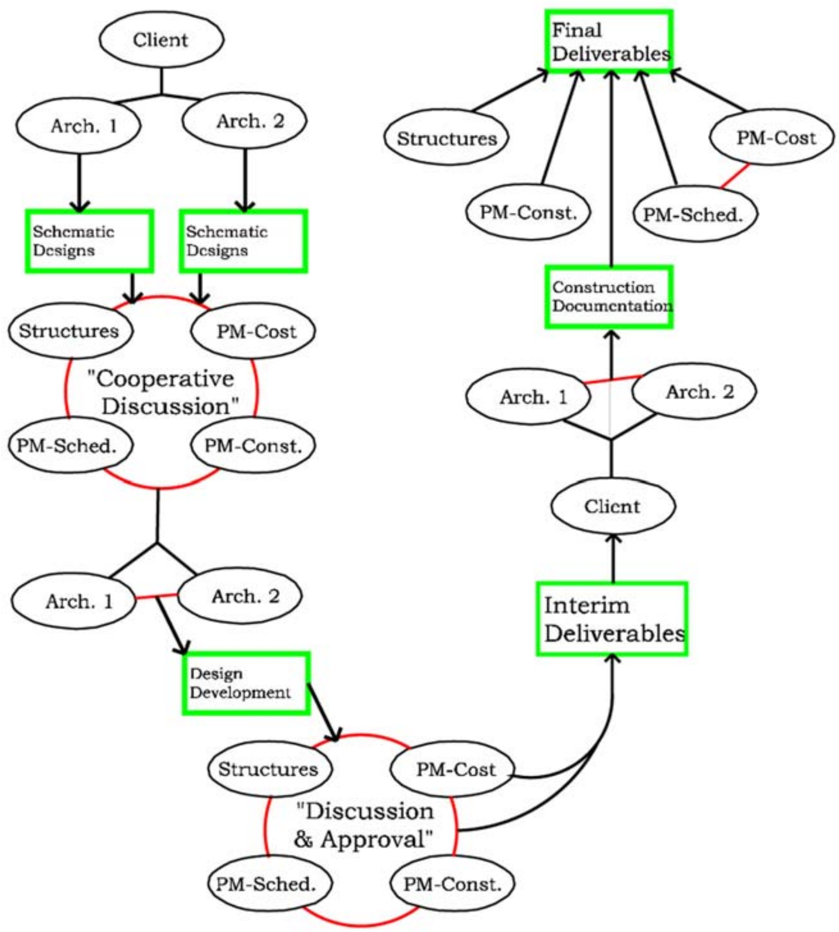

Figure 4: Sample workflow mapped by five-person student team.

Why did the students work in a serial approach given the goals and training about concurrent design methods given in the course? To a limited extent, distance played a role as there was more communication among students on a campus than across campuses. However, 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.

Reflective Critiques: Student Assessment and Recommendations

After completing design projects, students were given a simple self-assessment questionnaire concerning their (individual) beliefs about the quality of their group's design and interaction. Results for 2001 and 2002 are summarized in table 1. Most students felt that the groups performed efficiently and produced high quality designs. However, approximately 20% of the students responded neutrally or negatively about their experience in each question. This corresponds with the instructors' observations; indeed, somewhat more negative assessments were expected given the amount of dissatisfaction and difficulties expressed by students over the course of the design project. We suspect that most students made a positive assessment as, for many of them, the project was the first time they worked on a multidisciplinary design. At the end of the day, despite frustrations and some mistakes, each team produced a coordinated design, schedule, and estimate of reasonable quality. Hence, students had a reason to be generous in self-assessment.

The questionnaire (see table 1) provides a brief snapshot of students' views at the end of the design project. Building from this assessment, students' next task was to prepare a brief (~5-7 pages) individual critique of their experiences and recommendations. We have found that these critiques tend to be the best indicator of a student's perceptions. In several cases, students took it upon themselves to write fairly lengthy critiques of 10-15 pages. The most common comments made in individual critiques concern the ability of the group to have effective meetings, ability of group members to make an effective schedule to manage the design process, ability of members to meet schedules, and limitations of existing technology (both in terms of frustrations when technology did not work and in terms of proposed extensions to the technology). As noted above, beyond comments on technology, the most common self-criticism was that teams needed to better plan their work processes before beginning design work. Similarly, students also suggested the need for further team building practice before starting the project.

Individual critiques were shared with both the instructors and student's teammates. Students enjoyed sharing critiques and the discussion afterwards. They learned much from understanding others' point of view. In many cases students' individual assessments of team performance were common across all members. The biggest differences stemmed from cultural perceptions across disciplines. Perhaps reflecting practice, the architect-contractor divide was the most prominent. Part of this divide may be explained by distance; all architects were based in Illinois while many (not all) contractors were based in Florida. However, it is the instructors' belief that cultural and training factors are more important than distance. A further learning from individual critiques is that larger groups (five persons instead of three) produce more effective group discussions. The broader range of opinions stimulated discussion and allowed a more nuanced group critique.

Table 1

Student self-assessment of collaboration – years 2001 & 2002

Question scale						
1	2	3	4	5	6	7
Q1: How would you rate the design that the group has produced?						
very poor			average			excellent
	1	1	5	9	22	2
Q2: Which number best describes the way the group made decisions?						
very ineffective			neutral			very effective
	1	3	5	10	16	5
Q3: How would you rate group member contribution to this task?						
no one contributed ideas			half the group contributed ideas			everyone contributed ideas
	1	3	3	7	10	16
Q4: How do you feel about the way the group has worked?						
very displeased			neutral			very pleased
	1	3	4	11	12	9
Q5: What do you think about the group's organization during this project?						
very disorganized			neutral			very organized
	1	6	9	10	11	3
Q6: How satisfied are you with the way the group used its time?						
very dissatisfied			neutral			very satisfied
2	2	4	3	9	16	4
Q7: How do you feel about the way the group chose to proceed?						
very displeased			neutral			very pleased
1		1	10	7	18	3
Q8: What do you think about the way in which your ideas were included in the group's design?						
very displeased			neutral			very pleased
	1	1	2	10	13	13

In the group critique, students were asked to combine their experiences and reflections from the individual critique to produce a single document that: (1) appraised their work practices and use of technology, and (2) recommended improved work processes supported by improvements in technology. Student teams were able to perform the first task reasonably well. The first class (Spring 2001) with larger groups generally produced a more comprehensive analysis of their work, but all teams in both years were able to capture the difficulties with their approach. Teams were much less successful in the second task of making recommendations to redesign their work tasks. While students were instructed to focus on certain aspects of work practices (a complete re-design is too large a task), they still had difficulty identifying processes and making specific recommendations. Thus student performance echoes O'Brien's (2000) and Kulak and Guiney's

(2000) observations that professionals have difficulties conceptualizing re-designed tasks and work processes.

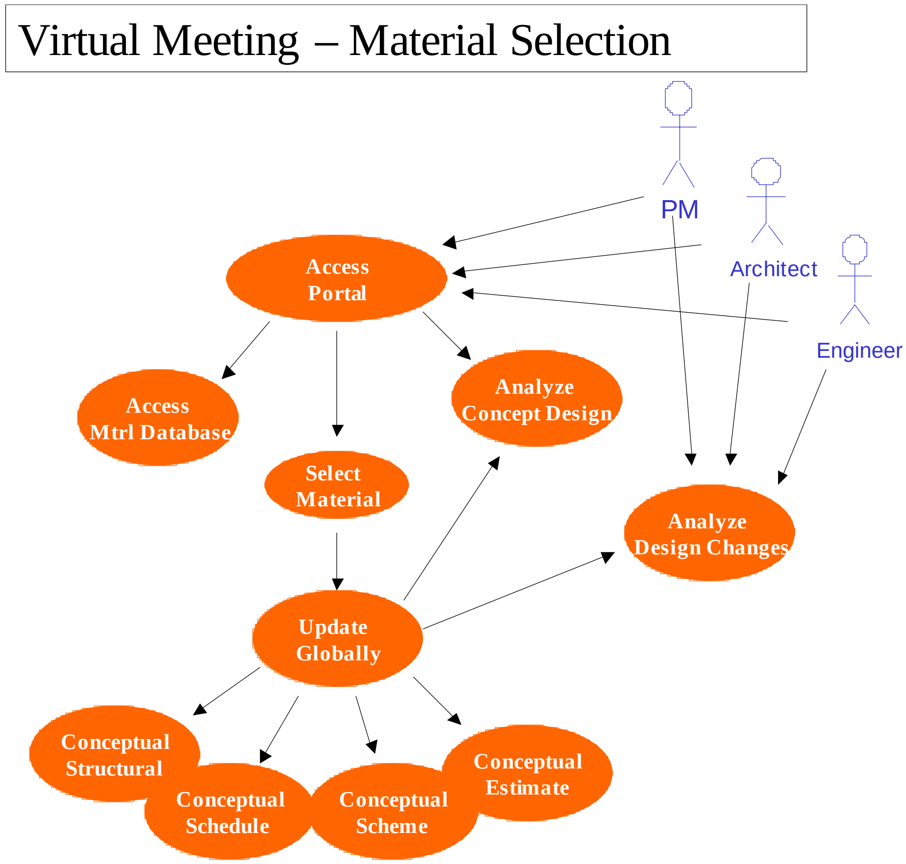

Figure 5: Students' use case schematic for an integrated meeting/design tool.

Despite students' limitations in producing specific recommendations for improvement, a common theme across all teams in each year was the need for better processes and mechanisms to evaluate designs from a multidisciplinary perspective. While students were able to assess a design from the viewpoint of their own discipline, it was very difficult from them to understand the assumptions made by others or to assess the impact of their proposed changes on other disciplines. This criticism included tools and methods for group meetings as well as individual work. Indeed, the most common use case and process redesign centered on enhancements to the whiteboard tool in NetMeeting™. Specific enhancements envisioned concerned adding design and engineering intelligence to the whiteboard, echoing the design constraint theory of Lotazz et al. (1999) and the visual meeting space proposals of Liston et al. (2001).

An example of students' recommendations is shown in figure 5, which depicts a use case scenario for an integrated meeting/design tool to help teams choose materials. The use case concept depicts actors and their interaction with a (component of a) tool, as well as interactions between tools/components. Figure 5 provides a broad view; it is supported by a specific interaction script (not shown) that completes the use case. Figure 5 provides an indication of the scope of the problem faced by a team in redesigning a work process. As multidisciplinary design tasks are complex, it is difficult to simplify or break off small pieces of the larger problem into tractable small problems. Hence, the instructors perhaps ask too much of the students in the redesign part of the group critique. However, the ability to draw a use case scenario such as the one in figure 5 is indicative that the CDP course is effective in raising awareness of new approaches and in helping students develop a guiding vision for improvements.

Concluding Remarks

Overall reaction to the CDP 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 now in practice generally supports these views. Some course graduates express frustration that they are unable to deploy 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 progress from a program assignment to generation of 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 course has several distinct features that set it apart from other collaborative courses. First, students utilize only those information technologies that are readily available to most AEC firms, including NetMeeting™, AutoCAD™, 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 with limited possibility of actually using these tools in the 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 five to six 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.

The combination of instruction (lectures and discussions), action (collaborative design project), and reflection (individual and 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 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. 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. In this capacity, the course offers an important addition to traditional, discipline-specific curricula.

However, our experience suggests needed improvements in both the course and in broader AEC 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 collaboration simply reinforce the accepted over-the-wall method of sequential, rather than synchronous, labor. At the same time, there is also a need to stress the fundamentals of collaborative design activities apart from technology. Technology is both an enabler and a constraint. We need to further stress tools and techniques that provide students the knowledge and skills to reshape the design process. Here, it may make sense to reduce the scope of the projects or extend the class to a two-semester sequence.

There is only so much that can be done in one graduate class that serves as a capstone for years of discipline-specific training. Hence, our broadest learning from the course is that there is a need to gradually reshape the curricula of architecture, engineering, and construction programs 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 focus on refining skills in collaboration in capstone courses rather than learning these skills almost from scratch as they tackle the complexities of a design project.

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The Factors Influencing a Construction Graduate in Deciding upon their Future Employer

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Recent United States construction graduates have witnessed strong competition for their services during the recruitment period. As a result, the majority of construction graduates receive multiple offers from prospective employers. In this environment, it becomes increasingly important for recruiters to understand how students decide what job they will take. A survey of graduating seniors from the Department of Construction Science at Texas A&M University was conducted to identify the reasons why they chose the company they went to work with upon graduation. Graduates evaluated nine reasons for taking employment with the company they chose. Results suggested that construction graduates do not value all the reasons equally. More value is placed on the company's culture, the potential for advancement and type of work. Less value is placed on the entry-level position the graduate was offered and the offer of a signing bonus.

Key Words: College Recruitment, Graduates, Employment

Introduction

Even though the expansion of the construction industry is slowing, and will likely end in 2003, the demand for graduates from the nation's construction programs appears to remain high (Grogan, Ichniowski & Tulacz, 2002). This is reflected in the following quotation from the Bureau of Labor Statistics Occupational Handbook 2002-03 Edition.

"Excellent employment opportunities for construction managers are expected through 2010 because the number of job openings arising from job growth and replacement needs is expected to exceed the number of qualified managers seeking to enter the occupation. Because the construction industry often is seen as having dirty, strenuous, and hazardous working conditions, even for managers, many potential managers choose other types of careers".

These excellent employment opportunities have led many academic institutions to report almost 100% placement of their construction graduates (Bilbo, Fetters, Burt & Avant., 2000). A survey of construction companies attending the spring and fall career fairs at Texas A&M University identified that there were approximately three jobs for every graduating student (Burt, 2001). It would appear that in an environment such as this, construction graduates have some flexibility when deciding which company they go to work for after graduation.

So, what are the reasons for taking a job with one company and not another? There are many factors that might influence a person taking a job. Some of these might be unique to an individual, such as a family member working for the same company. Others are more general in nature, such as salary package, location of employment etc. Zingheim and Schuster (2001) argue that in order to attract the most talented people to an organization, a *"Total Rewards"* package is required that has four major components: compelling future; individual growth; positive workplace, and total pay. They want to work for companies that have a positive vision, and a set of values they can support. They also want to grow and develop themselves through meaningful training. They want a pleasant place to work, where the physical environment is as important as the people one works with. Finally, people want a total pay package that includes base pay, variable pay to reward positive results, benefits, recognition, and celebration. A survey of over 2000 college students by the corporate recruitment solutions provider, WetFeet Inc. in 2001 identified challenging assignments, good colleagues and bosses, and training for future growth, as the most important factors in their employment decisions. These were the same factors identified in 2000 (Anonymous, 2001).

In recent years, faculty have noted that signing bonuses are becoming more common. In construction, signing bonuses are considered necessary to attract employees at all levels, however, there is concern they are only effective because everyone uses them (Poe, 1999).

The nature of the construction industry is such that graduates from 4-year degree programs are usually hired as assistants to project managers, field engineers, schedulers, or cost estimators (Bureau of Labor Statistics, 2002). The construction graduate, therefore, has a choice in the entry-level position they accept. The construction industry is also a worldwide industry and students have some choice in the initial location where they will work. Many of the top recruiters of construction graduates have projects and offices in number of states.

Graduates from the nation's construction programs have a number of different factors to consider when deciding who to go to work for. This study seeks to identify how much value graduates from the Construction Science program at Texas A&M University place on nine specific reasons for taking employment with a company.

Methodology

Study Population

Graduating seniors from the Department of Construction Science program at Texas A&M University from the Fall of 2000, the Spring and Summer of 2001, and the Spring and Summer of 2002 were issued with exit surveys. Of the total 212 students graduating, 182 students completed the surveys, a response rate of 86%.

Data Collection

The Department of Construction Science program at Texas A&M University has been surveying its graduates prior to graduation since the fall of 1997. The exit surveys are very comprehensive and collect data on a vast range of issues such as the student's perceptions of course suitability, internship programs, and faculty. Information about the number of interviews and job offers the students had as well as the details of the job they accepted were requested. The exit interview questions have been modified over the years, and in the fall of 2000, a series of questions were added to the survey to evaluate the reasons for taking employment with a company. The particular reasons for taking employment were developed from the current literature and from small focus groups of graduating seniors. Table 1 shows the nine questions used to gain information about the reasons for taking employment with the chosen company. Students were asked to rate their responses using a standard five point Likert scale. Information was also obtained on job offers that the students received as well as the starting salary of the job they accepted and any signing bonuses they were offered.

Variables of Interest

The variables of interest are the number of responses in each of the five Likert rating scales. Values of 1 to 5 were assigned to the responses from strongly disagree to strongly agree. This allows for a mean response to be calculated for each of the nine questions.

Hypothesis

It is hypothesized that students do not place equal value on all of the nine reasons for taking employment. If this is the case, then at least one of the mean responses to the nine questions should be different. The null hypothesis is that the mean responses to the nine questions are equal. An Analysis of Variance (ANOVA) was used to test this hypothesis. ANOVA relies on the assumption that the data is normally distributed with an equal variance. As the responses from Likert rating scales tend to be skewed, it is unlikely that the normality assumption would be met. There are also concerns that using a measure of location such as the mean response may oversimplify the analysis (Clason & Dormody, 1994). In order to compensate for non-normality, and provide greater rigor to the analysis, a non-parametric procedure was used to test the similar hypothesis that there is a statistical difference between the distributions across the 5 Likert rating scales for the 9 questions. The null hypothesis is that the distributions are equal. A Chi-Square test of independence was used to test this hypothesis.

Analysis and Interpretation

Descriptive Statistics

Not all of the 182 students that completed the surveys answered all of the nine questions. A total of 1625 responses were analyzed (182 responses from the 9 questions). The mean response of all 1625 responses was 3.96, indicating that the average response was “agree”. This also confirms the concern that the responses are skewed toward the upper values. Information was also obtained on the number of job offers that the student received. The average number of written job offers was 3.00 an approximately 62% of the graduating seniors received 2 or more written job offers. Table 1 indicates the student’s responses with percentages and mean response value for the reasons for taking employment with the company.

Hypothesis Tests

In order to test the null hypothesis that the mean responses to the nine questions were equal, an analysis of variance was conducted. The results are shown in the table 2. The results indicate that we can reject the null hypothesis that the mean responses are equal (p value < 0.0001). This shows that construction graduates do not place equal value on all of the reasons for taking employment. The next step is to identify those reasons that construction graduates placed more or less value on and a post-hoc analysis to determine a ranking of reasons for accepting a position.

Table 1.

Questions and responses with percentages and mean response on the reasons for taking employment with the company the student chose.

Reasons	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**	**Mean Response**
	5	**4**	**3**	**2**	**1**	
1. I accepted the position because of the **location** of the company and/or the **location** I would be working.	85 47%	51 28%	30 17%	4 2%	10 6%	4.09
2. I accepted the position because of the **salary package** I received.	46 26%	81 45%	35 19%	10 6%	8 4%	3.82
3. I accepted the position because of the **signing bonus** I received.	13 7%	31 17%	78 44%	37 21%	19 11%	2.90
4. I accepted the position because of the **potential for advancement** within the company.	104 57%	64 35%	10 6%	1 1%	2 1%	4.48
5. I accepted the position because of the **company culture.**	111 61%	53 29%	15 8%	0 0%	2 1%	4.50
6. I accepted the position because of the **entry-level position** I was offered.	38 21%	78 43%	54 30%	7 4%	4 2%	3.77
7. I accepted the position because of the **size of the company.**	52 29%	79 44%	40 22%	8 4%	2 1%	3.94
8. I accepted the position because of the **training** the company **offered** me.	62 34%	58 32%	52 29%	6 3%	3 2%	3.94
9. I accepted the position because of the **type of work** the company perform.	75 41%	76 42%	25 14%	4 2%	2 1%	4.20

A further set of hypothesis tests was then carried out to see which of the mean responses to the nine questions were not equal to 3.96 (the mean of all 1625 responses). A one-sample t-test was used to identify those reasons that had a mean response of greater or less than 3.96. It was assumed that if greater or lesser value was placed on a reason then the mean response should be greater or less than the mean response for all 1625 responses. The null hypothesis was that the mean response for each reason is equal to 3.96.

The results of the hypothesis tests are set out in table 3. The null hypothesis was rejected and the alternate hypothesis that the mean response was greater than 3.96 was accepted for company culture, advancement and type of work. The null hypothesis was rejected and the alternate hypothesis that the mean response was less than 3.96 was accepted for entry position and signing bonus. The null hypothesis could not be rejected at a significance level of $p = 0.5$ for location, training, size of company and salary package.

A Chi-Square test of independence was used to test the null hypothesis that the distributions across the 5 Likert rating scales for the 9 questions are equal. Table 4 shows the results of the test. The null hypothesis is rejected and it is accepted that there is a difference in the distributions across the 9 questions. This confirms the results of the ANOVA test.

Table 2.

Results of the ANOVA procedure to test the null hypothesis that the mean responses to the nine questions are equal.

Class Level Information
Class Levels Values
REASON 9 ADVANCEMENT BONUS CULTURE LOCATION POSITION SALARY SIZE TRAINING TYPE

Number of observations 1625
Reasons for Taking Employment
09:29 Friday, December 6, 2002

The ANOVA Procedure
Dependent Variable: SCORE SCORE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	324.734308	40.591789	47.75	<.0001
Error	1616	1373.823230	0.850138		
Corrected Total	1624	1698.557538			
	R-Square	**Coeff Var**	**Root MSE**	**SCORE Mean**	
	0.191182	23.27634	0.922029	3.961231	

Table 3.

Results of hypothesis tests testing that the mean responses to the nine questions are equal to 3.96 (mean response of all 1625 responses).

Reasons	**Mean Response**	**t-statistic**	**Df**	**Prob>t**
Company Culture	4.50	9.71	180	<.0001
Advancement	4.48	9.51	180	<.0001
Type of Work	4.20	3.812	181	0.0002
Location	4.09	1.614	179	0.1082
Training	3.94	-0.310	180	0.7570
Size of Company	3.94	-0.25	180	0.8028
Salary Package	3.82	-1.898	179	0.0593
Entry Position	3.77	-2.885	180	0.0044
Signing Bonus	2.90	-13.532	177	<.0001

Table 4.

Results of the Chi-Square test of independence to test the null hypothesis that the distributions across the 5 Likert rating scales for the 9 questions are equal.

The FREQ Procedure

Statistics for Table of REASON by SCORE

Statistic	**DF**	**Value**	**Prob**
Chi-Square	32	420.8362	<.0001
Sample Size = 1625			

Discussion

The results of the ANOVA and the Chi-square test of independence suggest that equal value was not placed on the nine reasons for taking employment with the company they chose. The results of the t-test suggest that graduating seniors place greater value on the culture of the company they go to work for, and the potential for advancement within the company, while less emphasis is placed on the entry-level position the student is offered, and the offer of a signing bonus.

The results support Zingheim and Schuster’s (2001) view that, to attract the best people, employers need to have a package that offers a compelling future with individual growth, and a positive workplace. Construction graduates appear to place no greater emphasis on the salary package they are offered. This is supported by the fact that of the graduating seniors that received two or more offers, approximately 53% of those accepted the position that offered the higher salary. This is supported by the data, which indicated that almost half of the respondents (47%) accepted an offer that was not their highest offer received (as measured by salary).

The literature suggests that the offer of signing bonuses is prevalent within the construction industry (Poe, 1999). This study would seem to support this as approximately 50% of the graduates that accepted a job received a signing bonus ranging from $750 - $8,000. The literature also suggests that the offer of a signing bonus is not an effective tool for recruiting. This is reflected in the results of this study that indicate students place less value on the offer of a signing bonus.

The results of the study should aid recruiters of construction graduates during the recruitment process. Recruiters should focus on those reasons that graduates place the greatest value. Greater emphasis should be placed on promoting the culture of the company and the potential for advancement within the company.

The results of this study are from a survey data collected over a three-year period at one university and the findings may not be applicable to construction graduates as a whole. Further studies should be conducted at other institutions to see if the findings are consistent.

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Three Success Factors for Simulation Based Construction Education

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Construction education needs to emphasize more on practical knowledge and efficient tools that will enhance the students' thinking, problem solving and interpersonal skills. Simulation has emerged as an important approach to meet this need. However, simulation based tools are greatly under-represented in construction curricula. As an effort to address this issue, three success factors for the implementation of simulation tools are proposed. Their application to construction education is demonstrated through two case studies. With dynamic simulation models developed based on system dynamics, we discuss the effectiveness of the proposed success factors in education for fast-tracking and resource management. The findings obtained from the case studies would provide useful guidelines to the development of simulation tools for construction education.

Key words: Construction education, Simulation, System Dynamics, Tradeoff, Feedback

Introduction

Traditionally, construction education has been carried out with clear demarcation between the education sector and the industry. Universities have provided students with discipline-based education and basic skills, while the industry has trained them into professionals (Gann, 2000). However, this distinction is recently becoming blurred under rapidly changing industry environment. As a result, universities try to provide more practical education (Gibbons et al., 1994), and focus on interdisciplinary research and collaboration with industry participants.

The enhanced mode of educational delivery includes internships, simulation of practice, gaming, case-based instruction, service integration, field trips, student follow-ups and application papers (Senior, 1998; Chinowsky, 1998). Among these, simulation has emerged as an important approach to provide practical construction knowledge. Simulation is the construction of an abstract model that represents systems in the real world (Davies and O'Keefe, 1989). By exposing the student to situations in the real world and allowing repeatable experimentations under controlled conditions, simulation helps to build up students' thinking, problem-solving, reasoning and interpersonal skills (Chinowsky, 1998; Banks et al., 2000; Burr, 2001). Particularly, in industrial education where the educational goal is for students to transfer and apply the knowledge to real-world problems, the use of simulation in class can be an effective learning strategy (Gokhle, 1996).

Despite the claimed benefits of simulation, there have existed some hindrances to using simulation in education. The educational effectiveness of simulation tools depends on how well they represent real world situations, while keeping their application simple and easy to access.

The complex structure of a simulation tool often makes it difficult for students to understand the concepts intended to deliver (Al-jibouri & Mawdesley, 2001) and the development of such a tool requires enormous efforts in terms of time and resources. Meanwhile, the high level of assumptions in simplified simulation tools can be detrimental to the understanding of the real construction process (Senior, 1998), which may misguide students, failing to achieve the target educational goals. Particularly, the exclusion of human factors that significantly influence the construction process can result in less realistic simulation and limited educational effect (Park, 2001). In addition, the development of simulation tools has not kept pace with the development of computer technologies. As a result, many simulation tools are still text-based, whilst most computer application programs have moved to a graphical user interface (Al-jibouri & Mawdesley, 2001). In the case of some state-of-art simulation tools, they run on a specific platform, which makes students' access to them limited.

As an effort to address these issues, we propose the following three success factors for the development of simulation based construction education tools:

- Considering human factors involved in the construction process and feedback effects triggered by them,

- Focusing on tradeoffs associated with managerial decisions and construction policies, and

- Developing an easy-to-use standalone tool that runs on any platform without other supporting programs.

The application of these success factors to construction education is demonstrated through two case studies presented in this paper. With dynamic simulation models that have been developed based on system dynamics, we discuss the effectiveness of the proposed success factors in education for fast-tracking and resource management. The findings obtained from the case studies would provide useful guidelines to the development of simulation tools for construction education. Following a brief introduction of previous simulation education tools and system dynamics, case studies are presented.

Simulation based Construction Education Tools

Many simulation based construction education tools have been developed targeting either university students or industry professionals. Some examples categorized by their application areas are listed below.

Estimating

Caldwell (1991) developed TAKEOFF, which is an interactive Quick BASIC program that can be used to educate calculation and estimation skills in quantity surveying. With this tool and given a random set of dimensions for building components, the student can practice taking-off and have a feel of what the estimator in a construction firm does. Computer Aided Drafting and Design (CADD) interactive systems also provide educational estimating software (Wallace, et al., 1990). One example is Estimator (DATACAD LLC., 1984-2003). By using this tool, students can perform quantity take-off and price the item out for a given sample of construction data.

Bidding

A simulation game developed by Nassar (2002) allows users to explore the bidding process. By providing a tool to analyze the bid prices of the competing teams, it improves the ability to develop a bidding strategy. A networked classroom computer system that can simulate the construction bid process was presented by Mead (1995). This system focuses on helping students to understand how construction teams work during the bidding process. By simulating the process of collecting bids from sub-contractors and suppliers, and analyzing them, students experience how work is delegated and managed by project team members during bid preparation.

*Construction Process Managemen*t

Al-jibouri and Mawdesley (2001) developed a simulation game to teach the planning and control of a rock and clay fill dam construction project. Having equipped with a graphical user interface (GUI) and the Internet hookup, this game helps user to experience situations encountered during dam construction. Game participants act as different role players. The educator sets simulation conditions for the contractor's office, and the student acts as the project manager whose actions are responsible for the project performance.

Equipment Management

Nassar (2002) developed a multi-player EQUIPEMNT REPLACEMENT simulation game. It aims to assist students in understanding the effect of equipment buy/sell strategies on the operation of contractor firms.

Evaluating

A simulation tool that can be used for educating the external review of a construction firm's financial condition was developed by Perreault (1989). With the provision of this tool, he suggested that financial audits should be included in construction management curricula.

System Dynamics

Since its development in the late 1950s, system dynamics has been applied to analyze industrial, economic, social and environmental systems (Richardson, 1985; Turek, 1995). The most powerful feature of system dynamics lies in its analytic capability (Kwak, 1995), which can provide an analytic solution for complex and non-linear systems. Owing to this special feature, a system dynamic modeling approach is well suited to deal with the dynamic complexity of construction projects, as demonstrated by some researchers (Ng et al., 1998; Peña-Mora and Park, 2001).

Education is also an important area of application for system dynamics. In helping to understand how complex systems change over time, system dynamics forces the learner to become actively involved in the education process (SDS, 2003). In particular, the wide range of applications for system dynamics makes it an excellent tool for integrating the material of many subjects in education (SDS, 2003). Models can be constructed from the micro worlds of academic disciplines, and the understanding of their structures and behavior transcends any particular discipline (deSantis, 1999).

Case Studies

The educational tools presented in this section are being used in construction management courses in the Department of Building at the National University of Singapore. These tools have helped students to acquire core educational concepts associated with fast tracking and resource management. To show the usefulness of the proposed success factors for simulation based education, we review their educational objectives and important issues in developing them, focusing on human factors and tradeoffs involved in the construction and decision process. We also demonstrate how they can be used as standalone tools, with which students can manipulate and test policy scenarios without the help of other supporting software and equipment.

Fast-tracking

The fast-tracking delivery method has been widely used for faster project delivery. However, fast tracking often results in unexpected costs and does not necessarily lead to a desired shorter project duration (Fazio et al., 1988). This is mainly attributed to the increased level of uncertainty (Russell et al., 1991) during the design and construction process. The simulation tool presented in this case study (the Dynamic Fast-tracking Simulator; DFTSim) exposes students to uncertain conditions and makes them appreciate the potential effects of feedback processes involved in fast tracking. As a result, with the opportunity to analyze and suggest strategies, students can acquire decision-making skills such as overlapping strategies, workforce control policies, and schedule adjustments that can minimize the negative impacts of fast-tracking.

Feedbacks in Fast-tracking

Fast-tracked construction involves many feedback processes including those depicted in Figure 1. Overlapping between the design and construction increases the possibility of design changes for several reasons, e.g., increased assumptions by the designer and frequent design changes by the owner (Tighe, 1991). Consequently, more construction changes can occur, which result in more work to be done. Construction schedule, however, cannot be simply extended due to time constraints. One possible control action to meet the schedule is to increase work hours, either by hiring more workers or putting them to work overtime. This control action can facilitate the delayed construction process. At the same time, it can result in unanticipated side effects due to vicious feedback processes. Workers newly involved in the construction team may affect the team’s average productivity and adopted overtime may lower productivity by increasing workers’ fatigue (Sterman, 2000). Lowered productivity, then, can further delay the process (R1 in Figure 1). Meanwhile, workers’ fatigue can also deteriorate work quality, which results in more construction changes and a rise in construction costs (R3 in Figure 1).

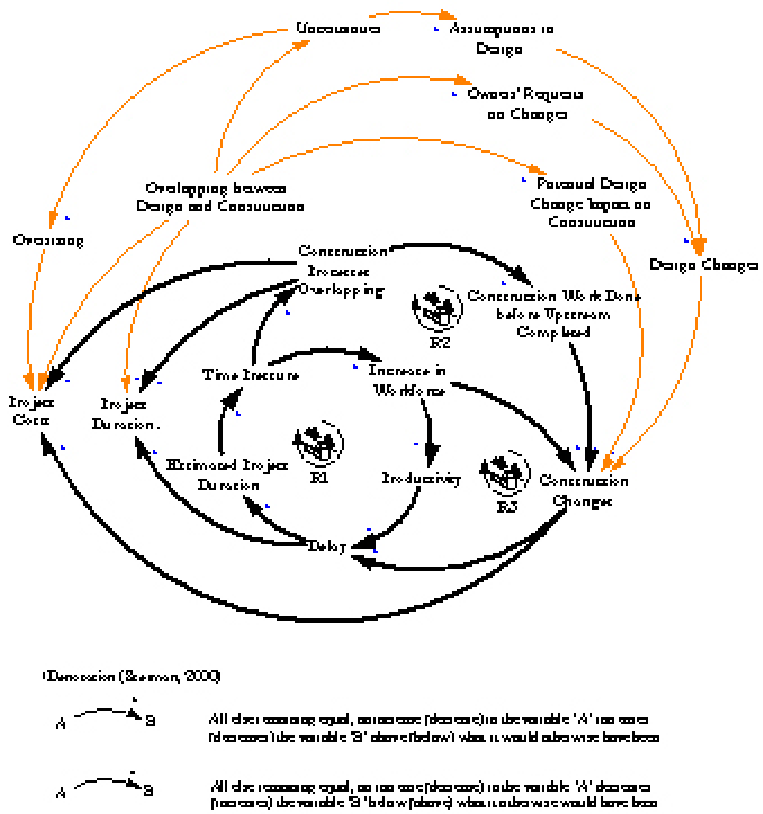

Figure 1: Feedbacks Involved in Fast-tracking Construction (Pena-Mora and Park, 2001)
Another possible way to meet the schedule is to run more project activities in parallel by overlapping the activities (R2 in Figure 1). As a result, the predecessor work does not have enough time to absorb the impact of changes made during successor work. This can lead to an increase in construction changes and further delays, which, in turn, requires more overlapping of the construction processes. Consequently, these feedback processes can produce more construction changes by self-reinforcing their vicious loop effects, which results in schedule delays and cost overruns.

Depending on the size, the complexity, and the project team, the feedback processes discussed thus far can have a significant impact on the project performance, especially when a project is fast-tracked in a heavily constrained environment. To effectively manage a fast-tracking project, these feedback processes should be identified before physical execution is undertaken and it should be carefully monitored throughout the project duration.

Work Productivity and Quality

In representing the construction process, DFTSim dynamically handles work productivity and quality throughout the construction duration, focusing on changes in workers' responses rather than simply applying a different productivity and quality level according to construction stages. As a result, DFTSim simulates work productivity and quality based on workers' experience on the project involved (learning effect), and the effect of schedule pressure and fatigue. Details are discussed below.

- Learning Effect: The productivity and quality of workers vary depending on the construction progress over time. For example, workers' productivity and quality are usually low in the beginning of construction due to the lack of knowledge of the work environment but productivity and quality tend to be enhanced, as construction progresses and when they become more familiar with the environment.

- Schedule Pressure and Fatigue: Lasting schedule pressure can lower work quality, since workers often attempt to achieve the target schedule by cutting corners. In addition, when overtime continues after a certain threshold, workers' fatigue would possibly lower work productivity and quality.

Cost-Benefit Tradeoff

The effectiveness of fast tracking cannot be measured solely based on economic principles because there can be many intangible benefits. However, except for cases when market conditions change rapidly and require owners to beat their market competitors with an earlier completion of their projects (Tighe, 1991), the cost-benefit tradeoff can be useful for comparing the effectiveness of different fast-tracking strategies. In Figure 2, the cash flow of a typical construction project during the project life cycle is conceptualized. The tradeoff of different fast-tracking strategies can be calculated by subtracting the increased cost to reduce the project duration (A-C in Figure 2) from the possible capital gain through the shortened project duration (B in Figure 2).

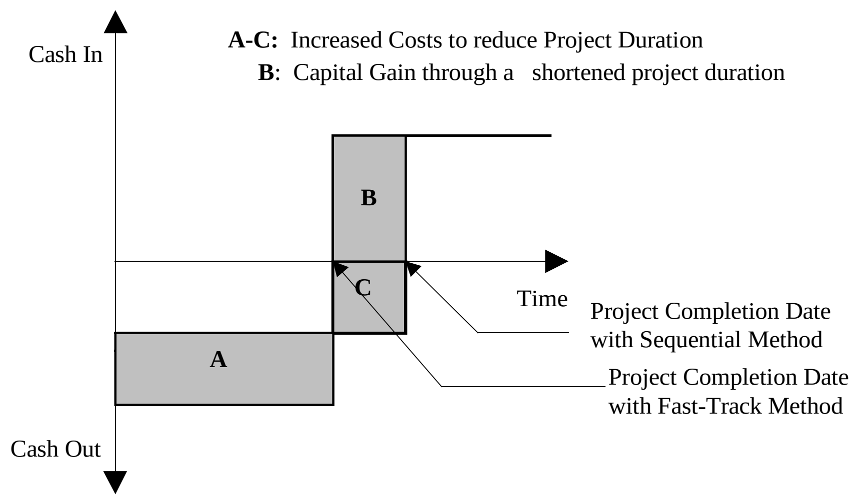

Figure 2: Cost-Benefit Tradeoff of Fast-tracking

Capital Gaming for Fast-tracked Construction

By incorporating the concepts discussed thus far into system dynamics model structures, DFTSim was built to simulate twelve design and construction processes of a building construction project, using Vensim (Ventana Systems Inc., 1996-2002) as an underlying engine. This tool provides students with an opportunity to simulate fast-tracking building construction projects with different scenarios and to find out ways to ensure their effective delivery without driving up costs (see Figure 3). While attempting to balance the increased cost due to fast tracking with the expected capital gain obtained through the earlier completion, students come to 1) appreciate the significance of human factors and their feedback effect during policy applications; 2) realize the potential benefits of fast tracking in the context of the cost-benefit tradeoff; 3) understand the importance of an appropriate construction policy such as labor control, design and construction overlapping; and 4) come up with policy implications such that:

- The planning and management of a fast-tracked project requires a systematic approach because of the diversified and dynamic feedback processes involved in fast-tracking construction process.

- The synergetic effect of feedback processes makes workers' productivity continuously vary throughout the construction process, which requires a flexible labor control.

- The decision-making process in design and construction should be shortened, since time delays can magnify the ripple effects of the feedback processes under time and resource constraints.

Resource Management

Construction progress can be considered as being constrained by either work availability or resource availability. Work availability at a certain time of the project is governed by the work dependency within the same activity (e.g., structural steel erection on the second floor can start only after completion of the first floor work) or between activities (e.g., a finish-to-start relationship between foundation and excavation). Work dependencies are normally beyond the project manager's control as they are determined by the nature of work. In contrast, resource availability is determined by resource plans and managerial decisions. This suggests that construction management is nothing but resource management.

The simulation tool presented in this case study (the Dynamic Resource Management Simulator; DRMSim) aims to build up students' decision-making ability in construction resource management. To do this, DRMSim provides a tool to examine the effectiveness of resource management policies during construction and focuses on feedbacks involved in resource management and the tradeoff of resource coverage and project performance. With this capability, university educators can equip students with decision-making ability and help them to gain indirect experience in classroom environment.

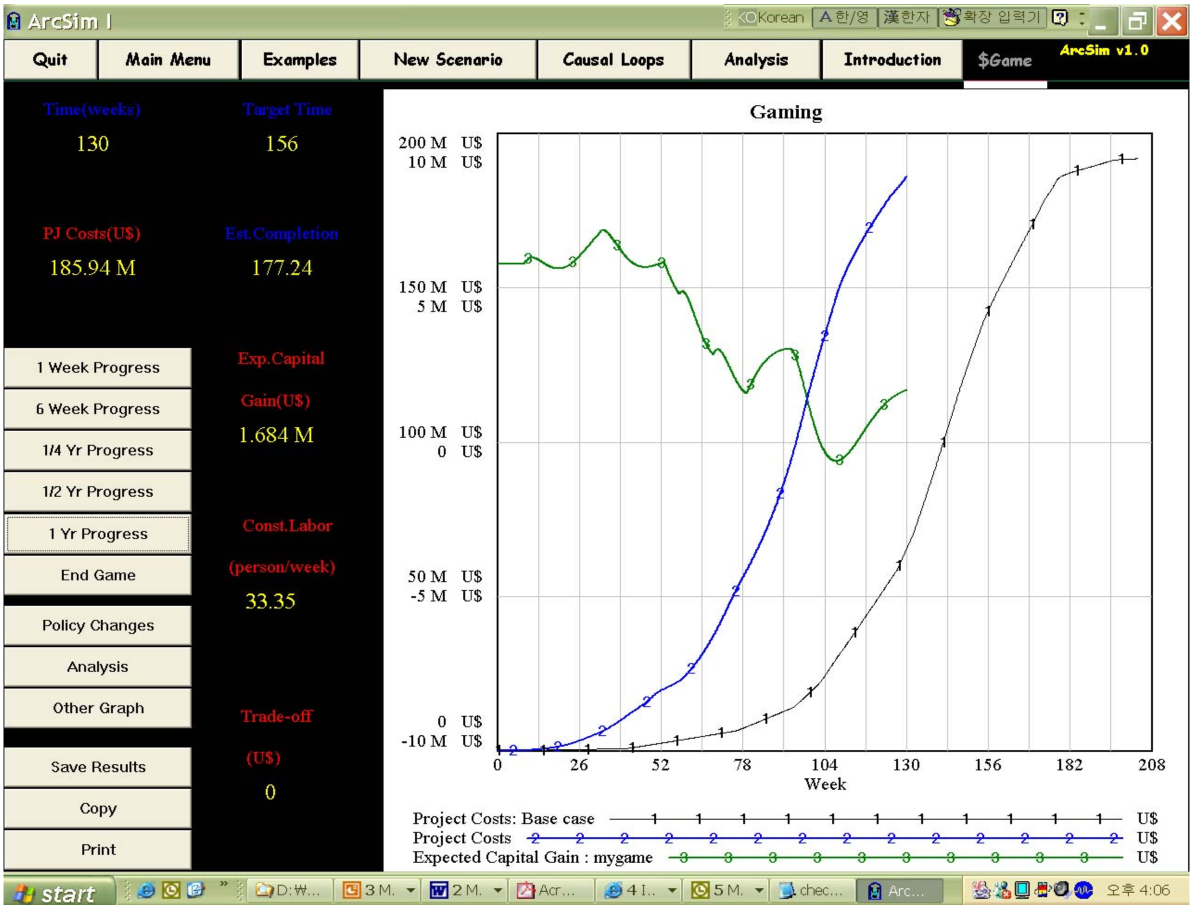

Figure 3: Fast Tracking Simulation Tool

Construction Progress Determinants

We discussed that construction progress is constrained by either work availability or resource availability. As shown in Figure 4, the available quantity of work at a certain time is determined by construction progress and work dependencies (internal and external, Ford and Sterman, 1997). Higher progress and lesser work dependency introduce more work. For example, only 20% of concrete skeleton work is available at the beginning of 5-storey building construction due to the work dependency caused by a physical constraint, and the remaining work becomes progressively available in proportion as construction progresses. In contrast, if the construction work pertains to a single-storey building where work dependency does not exist, then the total amount of work becomes available with the start of construction. Work availability determines the potential construction rate (‘work-based construction rate’), which in turn determines the actual construction rate, when it is less than ‘resource-based construction rate’.

Meanwhile, resource-based construction rate is mainly determined by resource availability and productivity. Resource availability is affected by resource management policies such as resource coverage and resource allocation. Productivity varies according to construction conditions (e.g., schedule pressure under sluggish progress) and management actions (e.g., fatigue resulting from overtime). When resource-based construction rate is less than work-based construction rate, it governs the actual construction rate and progress, triggering the feedback processes in Figure 4. As discussed thus far, the interrelationship between construction progress and its determinants, and the feedback effect caused by them make the construction process highly dynamic and unstable. Thus, it is difficult to allocate necessary resources in a timely and economic manner, which often results in resource overshooting and process interruptions.

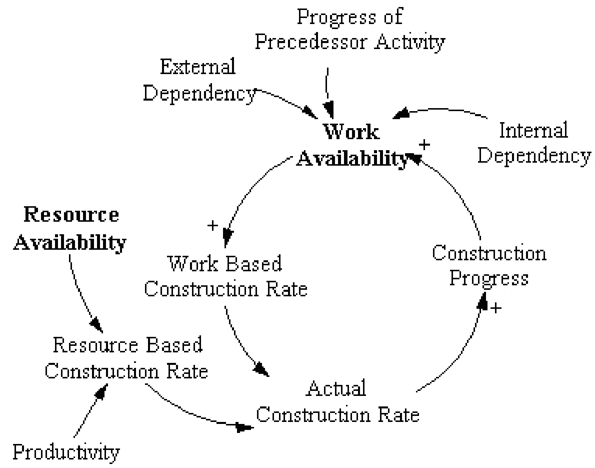

Figure 4: Construction Progress Determinants

Tradeoff in Resource Management

One important issue associated with resource management is how to set target resource coverage (e.g., the workforce level or the number of days of the expected material consumption that the project manager seeks to maintain). The tradeoff between resource coverage and project performance is depicted in Figure 5. When target resource coverage and, accordingly, the actual resource coverage have been increased to meet the schedule, resource availability is increased, which would reduce the chance of construction being interrupted by resource bottleneck. As a result, the project could avoid schedule overruns that have been anticipated. However, the increased resource availability would result in low resource utilization and more resource idling and waste. This tradeoff can also be observed in the opposite case, in which decreasing resource coverage could reduce cost overruns at the expense of construction schedule. Therefore, it is important to target the proper level of resource coverage that leads to achieving the planned project performance rather than attempting to minimize resource idling and waste.

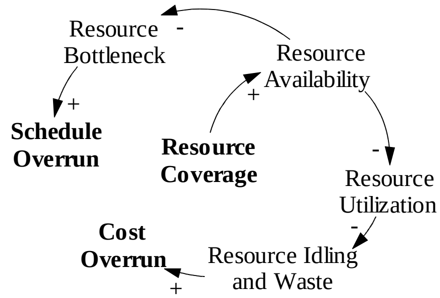

Figure 5: Tradeoff in Resource Management

Resource Management Gaming

With the capability to simulate the dynamics of the construction progress and the tradeoff in resource management, DRMSim provides an automated tool that is capable of assessing the effectiveness of resource policies for a virtual construction project, using Vensim (Ventana Systems Inc., 1996-2002) as a simulation engine. As shown in Figure 6, the value of the parameters used in simulation can be adjusted through the tool's easy-to-use interface. Target resource coverage can be controlled at each simulation time interval. Manipulating construction settings such as work quality, and time variables for monitoring, procurement, and labor control is also allowed. DRMSim is simulated with optional time intervals, and results are displayed graphically and in the numerical format. The simulation output includes material inventory coverage, labor utilization ratio, productivity, cost incurred, estimated completion time, and the construction progress. It also identifies dominant project progress determinants at a certain control time.

This tool helps students to appreciate the dynamics involved in the construction progress, and the tradeoff between target resource coverage and project performance. While attempting to achieve the targeted project performance in terms of schedule and cost, students can acquire decision-making ability for effective construction resource management and obtain policy implications.

Some examples of implications are:

- Project performance does not change linearly with different resource coverage. This nonlinearity is mainly caused by the feedback process involved in the construction progress.

- Schedule performance is more sensitive to resource coverage than cost performance due to the construction progress dynamics.

- Lowering target resource coverage does not always lead to project cost saving because of a situation where heavy resource bottleneck causes considerable material waste as well as long workforce idling times.

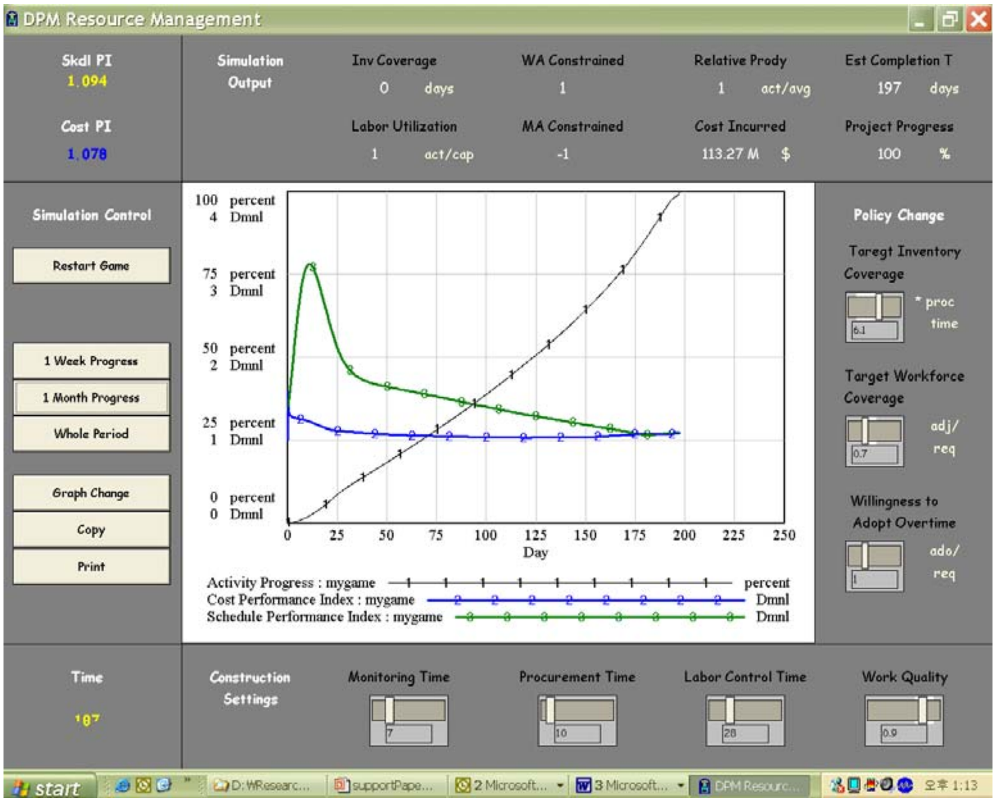

Figure 6: Resource Management Gaming

Applications

The validity, usability and applicability of the simulators presented in this section have been tested in the classroom environment. Taking the application of DRMSim as an example, students are lectured about the basic concepts and terminologies associated with resource management before using DRMSim. Then, the instructor allots an assignment and a standalone executable file of DRMSim to students. The assignment is structured to find resource management policies that can achieve the best combination of the time and cost performance of a project under different conditions, by manipulating the parameters in the simulator. The outcomes from students' assignments are discussed in class. During these processes, learning happens, as students think about the factors that drive project performance in terms of time and cost. Students compare different decisions made by different individuals and see how the construction system responses to the given policies. To enrich educational contents and increase usability, students' feedbacks are incorporated into the advancement of the tool.

By applying these two simulators, we found that students' understanding on construction resource management and fast tracking was considerably improved. Particularly, focusing on human factors and tradeoff in the construction process and decision-making process helped students appreciate the project manager's role under uncertain conditions, while maintaining the application process simple. In addition, the provision of standalone files made it possible for students to operate the simulators in their own computers, which was found to facilitate the learning process.

Conclusions

With the world advancing towards higher level of computer and Internet technologies, construction practices have to change in tandem to improve its productivity and production quality. Education in this field has a role to play in bringing about this change. It needs to emphasize more on practical knowledge and efficient tools that will enhance the students' thinking, problem solving and interpersonal skills so that they can face the challenges ahead and emerge as competent leaders in the industry after they leave the universities. In this context, simulation has emerged as an important approach to provide practical construction knowledge. However, simulation based tools are greatly under-represented in today's education on construction curricula.

As an effort to address this issue, we demonstrated that a simulation based education tool can be an effective vehicle to teach students how to handle abstract, complex and uncertain issues commonly found within the construction process. For a simulation based tool to be more widely used in construction education, we proposed three important factors for the successful implementation of simulation tools: 1) taking into account human factors and feedback effects triggered by them; 2) focusing on tradeoffs associated with managerial decisions and construction policies; and 3) developing an easy-to-use standalone tool that runs on any platform without other supporting programs. Two case studies presented in this paper demonstrated that the application of these success factors helps represent real world situations, while keeping their application simple and easy to access. Although the effectiveness of the proposed success factors needs to be further investigated by more industry-linked research and applications in class, the findings obtained from this research would provide useful guidelines to the development of simulation tools for construction education.

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