Computer Integrated Architecture/Engineering/Construction
Project-Centered Learning Environment

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ABSTRACT

This paper describes an on-going effort, initiated at Stanford's Civil Engineering Department, to develop, implement, and test a new and innovative "Computer Integrated Architecture/Engineering/Construction (A/E/C) course. The course takes a multi-site, cross-disciplinary, project-centered, team-oriented approach to teaching. The paper presents the motivation, methodology, computational infrastructure, and initial observations in the experimental A/E/C course. The course is sponsored by NSF Synthesis Coalition and is the result of the collaborative effort of faculty and researchers from Civil Engineering Department at Stanford University, and Architecture Department and Civil Engineering Department, at UC Berkeley. In this computer integrated A/E/C environment a new generation of architecture, engineering, construction students learns how to team up with other disciplines and take advantage of the emerging information technologies for collaborative work in order to design and build higher quality buildings faster.

INTRODUCTION

Communication misunderstandings, coordination, late conflict identification and resolution among A/E/C professionals is emphasized by divergent education. Although architects, structural engineers, and contractors work together to achieve a common goal, that is "build a building," they think and view differently the same product, the building. Each mode of professional thinking could enrich the other, and each would profit from an interchange of viewpoints. However, difficulty in communicating design concepts and decisions among professionals often hinders such knowledge sharing. Communication problems in the A/E/C industry are rooted in the differences in interests and modes of thought of professionals, which are fostered, magnified, and made more rigid by the divergence in their education. Not many students have the opportunity to take courses in other departments and programs. Very few programs offer courses in which faculty or practitioners present a global view of the A/E/C industry and discuss the roles each professional plays in a project team. This paper presents the "Computer Integrated A/E/C" course model that addresses this need.

The goal of the new methodology and computer integrated A/E/C learning environment is to significantly increase the number of A/E/C students who will:

- understand how the A/E/C disciplines impact each other,
- gain hands-on experience with new technologies and learn how such collaboration and information technologies can provide support for collaborative and concurrent A/E/C,
- learn how team building can be supported by the World Wide Web (INTERNET), and
- understand how concurrent engineering and collaboration technology can be simulated from an organizational point of view.

Similar efforts are being pursued in other departments (Toye et al 1993) and at other universities, e.g., CMU (Ferves 1995), MIT/Cornell/Hong Kong and other (Chen, et al 1994), Georgia Tech (Vanegas 1995), Penn State (El-Bibani et al 1993), (Riley 1995).

MOTIVATION

This initiative comes in response to an industry perceived need to improve and broaden the competence of graduate and undergraduate students to understand the acquired theoretical knowledge in a multi-disciplinary,
collaborative, practical project-centered environment. By definition, A/E/C professionals must be technically competent. As we approach the new millennium it is necessary, but not sufficient, to further improve student's technical competence. As complementary capabilities to technical competence, future students should become more knowledgeable in and familiar with project performance, teamwork and collaboration technologies, and management concepts. The critical problems this project-centered course addresses are summarized by the following observations about the current practices in the A/E/C industry and status quo of A/E/C education:

- **Fragmentation:** Fragmentation among A/E/C professionals, which is emphasized by divergent education, is today's status quo. It is my belief that many of the reasons for the current poor coordination and communication among professionals in the fragmented A/E/C industry and among project phases (e.g., planning, design, construction) are rooted in the way education is structured today, by discipline. Emerging technologies promise to provide the means to bridge the gap among professionals and organizations, and to overcome the limitations of both geography and time. However, technology by itself, without improved teamwork, will fail. Because the corporation of the future will be built on information, it will be necessary to educate professionals about the tools that control and manipulate information, and support collaborative and concurrent work. And because teamwork will be the primary work mode, it will be essential to focus on training in consensus building, group dynamics, and problem solving by using diverse technology advances (Davidow 1992). *My thesis is that education that focuses on teamwork and project-centered learning is the key to improved engineering.*

- **Reactive, discipline-based education:** In many fields of engineering, higher education has been reactive rather than proactive for a long time. Core curricula were developed decades ago based on the then perceived needs of the profession as seen from an academic perspective, and based on educational principles of the past. Curricula have been updated in reaction to professional or research developments, but have not been reshaped to initiate much needed educational changes or accommodate the rapidly changing needs of the profession. A typical example is the conventional structural engineering curriculum implemented at most U.S. universities. This curriculum focuses on independent and unlinked core and support courses that communicate knowledge in fragments, which leaves students confused about the objectives of their education and unaware of many issues that are critical in professional practice. Structural engineering practice is controlled by economic, social, and legal constraints, and by constraints imposed by other professionals involved in the design/construction process of civil engineering structures. It is time to evaluate and change this educational approach, and pose the professional problems to students before they get exposed to solutions, rather than presenting solutions with partial or no exposure to the problems.

### PROJECT CENTERED LEARNING (PCL) ENVIRONMENT

The innovative "Computer Integrated A/E/C" course is aimed at developing a new A/E/C learning culture, an exciting education paradigm, and an engaging computational infrastructure for collaborative multi-disciplinary work.

**Creative multi-site cross-disciplinary A/E/C learning culture.** The "Computer Integrated A/E/C" course aims to create a new culture and a computational infrastructure, which brings together faculty, practitioners, and students from the different disciplines, who will be geographically distributed. One of the innovative features of this course is represented by the role each of the participants plays, i.e.:
- undergraduate and graduate students play the role of apprentice and journeyman, respectively,
- faculty members and researchers play the role of "master builders,"
- industry representatives play the role of mentors.

Exciting education paradigm. Throughout their involvement in this new learning environment students use and exercise emerging collaboration and information technologies as they go through three learning phases:

1. **Role Modeling,** in which faculty and practitioners jointly present real-world projects to provide a global A/E/C interdisciplinary perspective, as well as the roles of different practitioners and their interactions.
2. **Dissect-Diagnose-Design (D3),** in which A/E/C student teams will work on a building project case study to: Dissect: understand how the different building systems interact,
Diagnose: identify potential performance problems, and
Design: propose solutions for identified problems.

3. Creative Teamwork, in which A/E/C student teams will be engaged in complex and challenging new projects.

Traditional courses give students problems that they can solve using theory and knowledge taught in traditional discipline courses, i.e., know-what and know-how. The project-based learning approach will guide students to discover disciplinary and interdisciplinary objectives, and thereby to develop know-why knowledge.

**Engaging computational infrastructure for collaborative teamwork.** The course is intended to provide an environment for inter-disciplinary apprenticeship, enable teamwork, sharing of knowledge and information, visualization of building models, and overcome the limitations of both geography and time.

**METHODOLOGY OF PCL**

The experimental "Computer Integrated A/E/C" course is a collaborative effort of the Civil Engineering Department, at Stanford, together with the Architecture and Civil Engineering Department, at UC Berkeley. The course presents basic principles and concepts of each discipline, focusing on how the disciplines are linked together, what information and knowledge is shared, how information/data of one discipline impacts the other disciplines. Each week is structured in the following way:

- a theoretical lecture focusing on one of the three disciplines and its relation to the other two disciplines, and presenting the issues in the context of a building project case study,
- a lecture that discusses how the concepts presented in the theoretical lecture can be formalized and implemented into computational tools,
- a computer lab exercise in which the students learn to use the new collaboration and information technologies,
- a project assignment that engages students in teamwork and use of the learned computer technologies.

In this teaching environment, emphasis is placed upon team work in a building project that integrates these principles and concepts. Mixed Stanford-Berkeley A/E/C teams of three students each (i.e., each student having a background in one of the three disciplines), are involved in a hands-on building project assignments to model, implement, refine, and document the design; and analyze their team's organization. In addition, each team has an apprentice represented by an undergraduate student. The mixed Stanford-Berkeley student teams adds the "real-world" collaboration complexity to the learning environment, which includes space and time coordination and cooperation issues.

Teamwork is a process of reaching a shared understanding of the design and construction domains, the requirements, the building to be built, the design process itself and the commitments it entails. The understanding emerges over time as each team member develops an understanding of his/her own part of the project and provides information that allows others to progress. The process involves communication, negotiation, and team learning. The projects progress from conceptual design to a computer model of the building and a final report. As in the real world, the teams have tight deadlines, have to engage in design reviews, and negotiate modifications. As the project progresses, information and knowledge is gathered, sorted, modeled, reorganized, and implemented. A team's cross-disciplinary understanding evolves over the life of the project. It starts with individual discipline information and knowledge, definition of concepts, and redefinition of issues, using each discipline's natural idioms. As the project progresses a number of things happen: (1) the concepts are transformed into models, (2) the models become more detailed, (3) discipline models are linked, and (4) information is reorganized so that it can be shared among the participants.

**CURRENT COMPUTATIONAL ENVIRONMENT**

The computer integrated A/E/C course focuses on integration, information, and organization modeling which support collaborative building design. Internet mediated design communication, integration and organization frameworks, groupware technology and multimedia are used in the experimental course:

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• **Team building on the World Wide Web.** The *World Wide Web* is used in a team building exercise and as a medium to disseminate and share conceptual design solutions of the design teams. The "team building on the Web" exercise, is based on generic skill definitions of the A/E/C students and hypothetical project calls for bids posted on the Web. Students have to identify the specific project they can work on among the different calls for bids and publish on the Web their skills, project preference, and request for collaborators from the other disciplines. This exercise exposes students to the Web and one of its future potential commerce and business applications.

• **Role Modeling and Discipline Perspectives.** The "Joan & Irving Harris Concert Hall" in Aspen Colorado was used as a case study presented by Dr. G. Luth, from KLA Inc. and the teaching team. The project team of the music hall consisted of architect Harry Teague, structural engineer G. Luth, acoustician E. Cohen, detailer D. Rutledge, contractor Shaw Construction. The WWW and MediaWeaver (Wei 1994), a graphical database, were used to create an information archive that describes the case study project and can be shared and accessed by both faculty and students "any time, anywhere." MediaWeaver provided a computational infrastructure to capture, index and search graphical information consisting of pictures and AutoCAD files which can be shared over the Internet. Students could learn more about the discipline issues of the case study by searching the project database on a particular discipline of interest (e.g., architecture, structure, construction) and at different levels of detail (e.g., music hall interior view, structural conceptual layout, retaining walls, excavation).

• **Information Sharing. Interdisciplinary Communication Medium, ICM** (Fouchet 1996), is used as an integration environment to support the graphic representation in AutoCAD and symbolic modeling and reasoning of A/E/C in conceptual collaborative design. This shared environment supports concurrent engineering by improving communication among members of interdisciplinary teams. The purpose is to let students explore the different cross-disciplinary issues among architectural and structural form modeling, and constructibility. The key technical concept of ICM is that a graphical design environment (such as AutoCAD) serves as the central interface among designers (human-to-human) and as the gateway to tools/services (human-to-machine) in support of interdisciplinary design. This computer based graphical environment enables designers to share and explore designs, capture multi-criteria semantics, design rationale critiques, explanations, and change notifications. Figure 1 shows the shared 3D CAD model of one of the 94/95 A/E/C team's project and the multi-criteria semantics and performance evaluation from four perspectives, i.e., energy, structure, constructibility.

• **Information Exchange. Federation of Collaborative Design Agents, FCDa** (Khedro 1993) is used as an integration environment among distributed CAD applications, called design agents, by allowing better software interoperability. The design agents exchange design information and knowledge. The communication of design information among linked design agents is coordinated via system programs called facilitators in a federation architecture. The facilitators are also the repository of a shared vocabulary (ontology). The design agents characterize their role in the integrated environment by specifying: (1) interests, which consist of the design information about which the agent desires to be informed, (2) perspectives, which define the attributes and formats in which the agent desires to receive and send information, and (3) behaviors, which describe the agents' activities in the environment.

• **Organization Modeling. Virtual Design Team, VDT** (Levitt 1993) is used to understand how organization structures, project tasks, and collaboration technologies can be modeled and simulated in order to analyze the impact of communication technologies on organization behavior and performance.

• **Face-to-Face Meetings in Cyberspace. Video conferencing** (i.e., Kodak systems and ProShare) capabilities enable sharing of AutoCAD, Word, Power Point, etc. applications. This provides the necessary medium for the A/E/C teams to have virtual face-to-face meetings between: (1) team members at Stanford and Berkeley, and (2) design teams and "owners," who are in two different geographic locations, to discuss the design solution in real time. Figure 2 illustrates the use of ProShare (Intel's videoconferencing tool), in which one member of the teaching team meets with students and shares in real-time an AutoCAD drawing of their proposed design and a Notebook page with diagram.

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Desktop Sharing in Synchronous Distributed Collaborative Design. Multi-disciplinary design teams are usually geographically distributed, which implies a large time budget allocated for traveling to meeting places. Two software applications, XMI (Bazik 1994) and zmove (Slomita 1994) are used to address some of the space barrier and the need face-to-face meetings in a geographically distributed setting. These enable sharing of both

Figure 1. A/E/C Building Project (1) Shared 3D Building Model, (2) Discipline Perspectives, (3) Discipline Semantics and Design Rationale, (4) Discipline Critique that Evaluates the Design Performance

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graphic and symbolic information. XMX provides a master/slave style and xmove a floor control strategy. The use of groupware, such as XMX and xmove in combination with telephone for audio communication enabled desktop sharing and collaborative teamwork for the geographically dispersed teams, that is, between Berkeley and Stanford students. These groupware tools enabled the team members to share and work concurrently on the same desktop, Xwindow, or application (e.g., AutoCAD). The team members can share design proposals, interpretations, critiques, and explanations as they negotiate alternative solutions.

Figure 2. ProShare Video Conference Session: Sharing a CAD Design Proposal and Diagrams in the Captured Notebook

CONCLUSION

The experimental "Computer Integrated A/E/C" course provides an opportunity for A/E/C students to be exposed to a holistic view of the A/E/C industry, teamwork, and collaboration technologies. It is also an excellent testbed to observe the impact of such collaborative technologies on team dynamics and performance. Initial observations include:

1. Change in team dynamics. The students learn to:
   - re-group as the different discipline issues become central problems and impact other discipline,
   - use computer tools supporting specific discipline tasks, and information sharing and exchange for collaborative work.
2. Change in design process and collaborative teamwork, such as:

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• time for specific tasks and collaboration significantly reduces rework (e.g., proposing design solutions, sharing and exchanging information, multi-criteria critiques and explanations) when using the integrated environments.
• increased number of explored alternatives since the students who are able to interactively edit the model and exchange information.
• mode and frequency of discussions and interactions changed from paper-based, frequent collocated, face-to-face meetings to computer-based cooperation.

The use of ProShare videoconferencing and desktop sharing software indicated an increased productivity, dramatically reduced the costly and time consuming effort to commute, and changed the sequential collaboration process into a concurrent one. A long term consequence of this positive result is the plan to use ProShare and desktop sharing applications to support distant learning interaction between the teaching team and the students, as well as active involvement of industry professionals in this exciting learning environment.

The A/E/C course will affect the way students will view their disciplinary tasks based on a holistic understanding of the cross-disciplinary impacts and constraints, and will prepare them to adapt to the rapid changes in today's technologies. The effects of the "Computer Integrated A/E/C" course on institutions in which "Computer Integrated A/E/C" course models will be explored and tested, will include:

• an increase in interdepartmental efforts to close the gap among A/E/C practitioners.
• a framework for cross-disciplinary collaboration and exchange of research and teaching ideas related to this educational model, and
• an integrated computer environment that is flexible, modular and extensible, enabling the addition of new and exciting spin-off research prototypes developed at those institutions, and
• knowledge and resource sharing among programs and universities.

The computer integrated A/E/C course will provide:
• A methodology for adapting research prototypes to "hands-on" computer lab exercises.
• A test-bed for evaluation of the emerging technologies.
• Observations on the way students adapt and improve their performance by using different computer tools which support teamwork.

Finally, the "Computer Integrated A/E/C" course provides a model to teach a new generation of professionals to perform more effectively in today's global markets.

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