RE-ENVISIONING CONSTRUCTION ENGINEERING AND MANAGEMENT RESEARCH THROUGH STRATEGIC PARTNERSHIPS

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ABSTRACT

The process of engineering design and construction is by definition interdisciplinary. Architects, experts in structural dynamics, geotechnical consultants and contractors, hydrologists, transportation engineers, and construction managers come together with members of the trades in the process of constructing even small projects; many research problems in construction engineering and management can only be answered with interdisciplinary methods. Furthermore, researchers and industry professionals are leveraging emerging technologies in an effort to facilitate collaboration between project participants.

In this paper, the authors discuss interdisciplinary research initiatives utilizing emerging technologies and strategic partnerships within the context of the Pacific Northwest Center for Construction Research and Education ("PNCCRE") at the University of Washington (UW). The PNCCRE facilities bring together traditional construction engineering research and education methods with state-of-the-art augmented and virtual reality technologies. Furthermore, the Department of Construction Management has formed partnerships with the Human Interface Technology Laboratory, the Department of Environmental & Occupational Health Sciences, and the College of Education to investigation questions related to construction technology, health and safety, and education. To encourage these collaborations, organizational systems and work processes are being developed to support researchers with diverse backgrounds as they work together on mutually intersecting problems.

KEY WORDS

Construction Research, Interdisciplinary Research, Virtual Construction, Methods and Materials, Construction Education.

INTRODUCTION

Research in virtual and augmented reality is inherently interdisciplinary in nature and brings together researchers from such disciplines as computer science, cognitive psychology, civil engineering and construction management. Just as the civil engineering and construction industries have become more fragmented and specialized, it has been recognized

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that currently researchers and educators work in disparate and specific intellectual environments, where the focus is on developing detailed specialties as opposed to synthesizing information (Gregorian 2004). In an effort to counteract the isolating silo effect of the traditional academic department, funding agencies and research leaders herald interdisciplinary research as an invaluable methodology to address many current research problems. (Gregorian 2004, Jones 2003, Pfirman et. al 2005, Rhotan 2004).

The National Academy of Sciences defines interdisciplinary research as: "a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice." (Committee on Facilitating Interdisciplinary Research 2005) The National Academies then identifies four powerful drivers behind interdisciplinary work "the inherent complexity of nature and society, the desire to explore problems and questions that are not confined to a single discipline, the need to solve societal problems, and the power of new technologies." This paper, and the research underway at the University of Washington, seeks to explore the last of these four drivers and determine the impact of new technologies on research and education as well as the industry as a whole. These research questions can best be addressed through interdisciplinary methods.

Interdisciplinary research requires mutual understanding, consensus building, and communication; investigators often encounter the language and culture of other disciplines outside of their own expertise. The challenge then is to create systems and processes to support academic team building and transition from information exchange into knowledge creation in a collaborative environment across disciplines. Academic interdisciplinary centers provide opportunities for researchers to share knowledge, skills and tools for conducting investigations into complex problems outside the confines of the traditional academic department structure (Rhoten 2004).

INTERDISIPLINARY RESEARCH (IDR)

> "In research, we daily face the uncertainty of whether our chosen approach will succeed or fail. We steep ourselves in elusive, mysterious, and unnamed phenomena, and we struggle to unravel very complex puzzles, often making no visible progress for weeks or months, sometimes for years... " (Sutherland, 1996)

By reaching outside of their own field of expertise, researchers and students seek the support and synergistic energy of varied experiences and backgrounds all contributing to a common problem. However, they also face the fear of the unknown and the foreign. There is a need for systematic and organization support for interdisciplinary efforts.

Huy and Mitzberg (2003) present a triangle of change that describes both the impetus behind change and the social impact of change. Descending from the top, dynamic change initiated by upper level management or external market pressures incites revolutionary

change; pressing in laterally are systematic and organized processes that orchestrate reform; while grassroots organic change filters up from the bottom and nurtures rejuvenation and innovation. Rhoten (2004) applies this conceptual model to academic research environments and the transition to interdisciplinary methods by making the following analogies: funding and research leadership provides extrinsic pressure from above; university management and structure supports and orchestrates laterally; while faculty and students provide an intrinsic motivation for interdisciplinary research from within. Rhoten and others conclude that the funding and research leadership is in place to support interdisciplinary research; faculty and students are epistemologically driven toward interdisciplinary work due to the types of research questions they are pursuing; however, there is a need for systematic implementation at the university and organization levels (Pfirman et. al 2005, Rhoten 2004).

Based on a National Science Foundation funded study entitled "A Multi-Method Analysis of the Social and Technical Conditions for Interdisciplinary Collaboration", researchers have determined that the following methods can be used to achieve successful interdisciplinary communication and knowledge sharing.

A. Well-funded, independent physical location and intellectual direction apart from traditional university departments.
B. Clear and well-articulated organizing principles (problems, products or projects) around which researchers can be chosen on the basis of their specific technical, methodological, or topical contributions.
C. Flexible, intermittent but intensive short-term research appointments that fulfill specific project needs rather than administrative mandates.
D. Encourage and reward for alternative outputs such as Congressional testimonies, public policy initiatives, popular media placements, alternative journal publications, or long-term product developments.
E. Graduate programs that educate future scientists to be experts in the methods, techniques, and knowledge of their chosen discipline, but have broader problem-solving skills that require learning, unlearning, and relearning across disciplines. (Rhoten 2004)

The National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine of the National Academies formed two committees to investigate the current state of research in science engineering and public policy. In 2005, the Committee on Facilitating Interdisciplinary Research and the Committee on Science, Engineering, and Public Policy (2005) made the following recommendations:

A. Researchers and faculty members desiring to work on interdisciplinary research, education, and training projects should immerse themselves in the languages, cultures, and knowledge of their collaborators in IDR (inter-disciplinary research).
B. Researchers and faculty members who hire postdoctoral scholars from other fields should assume the responsibility for educating them in the new specialties and become acquainted with the postdoctoral scholars' knowledge and techniques.

C. To facilitate the work of an IDR team, its leaders should bring together potential research collaborators early in the process and work toward agreement on key issues.
D. IDR leaders should seek to ensure that each participant strikes an appropriate balance between leading and following and between contributing to and benefiting from the efforts of the team.

METHODOLOGY

Fundamentally, working collaboratively means that we have to change the way that we do research. Truly working together to create new information is a challenge when we are trained to work independently in more traditional research settings. The University of Washington's Pacific Northwest Center for Construction Research and Education (PNCCRE) has embarked on an ambitious project to develop a 28,000 sq. ft. facility to foster strategic partnerships, interdisciplinary research, and education in construction engineering and management. The PNCCRE's goal is to create a dense network of researchers and projects, that invigorate, inform, and encourage each other. To support integrated teams, the writers propose four organizational methods, which are described in the following sections.

PNCCRE LABORATORIES – A RESOURCE FOR INTERDISCIPLINARY RESEARCH

A dedicated academic space is allocated specifically for IDR at the University of Washington. The PNCCRE is divided into three major areas: the Virtual Construction Laboratory (VCL), the Methods and Materials Laboratory (MML), and the Construction Education Laboratory (CEL). Based on the support of strategic partnerships, the PNCCRE laboratories will be developed as a resource that is accessible for IDR efforts, providing an independent physical location and intellectual direction apart from university departments. Therefore, these laboratories will be a place apart from the more traditional disciplinary academic department silos, where interaction and collaboration is fostered and rewarded.

Strategic Partnership #1

Developed in collaboration with the University of Washington's Human Interface Technology Laboratory, the Virtual Construction Lab will focus on information technology research through the application of modeling, simulation, and visualization. It will house a 1,200 sq. ft. Holosuite (an unobstructed space with advance imaging systems to support virtual and augmented reality applications) and includes a 120 degrees projection screen (30' x 15').

Strategic Partnership #2

Developed in collaboration with the University of Washington's Department of Environmental & Occupational Health Sciences, the Methods and Materials Lab will focus on productivity, safety, and health research. It will incorporate two primary components: a large high bay space in which construction systems can be used to work on specified building components or materials using standard or innovative techniques, and an integrated high-

speed data acquisition system to capture multiple-feed digital video and instrument signals using high speed wireless telemetry.

Strategic Partnership #3

Developed in collaboration with the University of Washington's College of Education, the Education Lab will investigate different pedagogical approaches related to construction education. It will house a two-way teleconferencing classroom with experimental tele-observation and tele-operation capabilities, which will foster collaboration efforts across the PNCCRE programs and projects. It will also incorporate a state-of-the-art digital video production facility to create a variety of educational materials.

Each of these laboratories will be available to the strategic partners as well as the greater research community for interdisciplinary projects. As an illustration, we can look at the area of virtual and augmented reality. Most, if not all, of the built environment exists in a four dimensional world with three spatial and one temporal dimensions. Throughout the history of engineering, researchers have sought to model the action of forces and resulting system reaction. Virtual and augmented reality technologies allow researchers to simulate physical, spatial and temporal relationships and issues in the four dimensions.

In the design phase of a project, the engineered system is not yet a reality. Engineers and architects have struggled for centuries to communicate their design concepts to others, and most design documents have been trapped on the flat land of two dimensional paper surface (Tufte 1990). Prior to 3D computer models, to work in 3D, small-scale physical models were constructed. Testing of more complex forcing functions, such as wind or earthquake loading scenarios, scaled models were tested in wind tunnels and on shaking tables. Virtual reality technology provides the capability to simulate force systems and structural reactions, allowing engineers the capability of optimizing designs before creating physical models or prototypes. (Miller et.al. 2006) In the PNCCRE, researchers from construction, civil and other engineering disciplines will have the ability to test new theories, models and designs in virtual reality, while conducting the tests in a physical laboratory. The capability to leverage both the virtual and physical spaces allows researchers to verify conceptual models, optimize design innovations, and try numerous what-if scenarios in virtual reality before spending time, materials and resources in the physical laboratory. On the other hand, it can also allow for the results obtained from empirical tests to be expanded into simulated models of an entire system.

When it comes to communicating the design to the construction, much of the industry still uses two dimensional line based documents. The limitations of the medium of 2D become apparent in the field when coordination issues arise. Much work has been done in the 4D scheduling area to support construction planning and coordination. (Gao et. al 2005, Fischer 2004, Sawyer 2005). Strategic partnerships between the Department of Construction Management and the UW's Human Interfaces Technology Laboratory, among others, will allow researchers to develop virtual and augmented reality interfaces to answer construction engineering questions, while allowing students to define, evaluate and manipulate construction plans and coordination methodologies through simulated what-if scenarios.

Unlike the final product of engineering projects, construction is active and temporal with forces changing throughout the process. The PNCCRE's Virtual Construction Lab will not

only support construction planning and sequencing research, but using the simulation environments, structural models could be integrated with construction sequencing simulations to evaluate temporary forces and loading on equipment and permanent building components. Research teams made up from faculty and students from environmental and occupational health and safety, as well as civil and construction engineering can address questions related to the uncertain and temporal project process.

Teaming up with the Colleges of Engineering, Architecture and Urban Planning, and Eduation, allows construction engineering and management researchers to address education and training problems related to all phases of the project process, including design, construction, start up, operations and maintenance. Currently, companies in the Process and Power industries utilize 3D models of facilities to train operators in virtual simulators before the plants are complete (CommonPoint 2006). Training and education research might also extend to emergency planning and response, where first responders plan and execute scenarios in the virtual environment to test the plan's effectiveness (i.e., evaluation).

Furthermore, students of design can visualize the impact of their designs in the context of a virtual environment that mimics the actual built environment. For instance, students can see the impact of a high-rise building in a downtown area. Lighting models can display how the new building affects sunlight and shadow on neighboring buildings. Students can also model traffic patterns on city streets to realize the impact the occupants of the new building will have on current traffic congestion.

Collaborations across the laboratories at the PNCCRE will foster a deeper understanding of the concepts and problems, as well as provides a means for the researchers to proof out virtual reality concepts in the physical environment. For instance, the PNCCRE seeks to foster collaboration between the research in the physical laboratory of the Methods and Materials Lab with the resources of the Virtual Construction Lab whereby building on a strong scientific tradition to inform the use of emerging virtual research. For example, collaboration between researchers from construction and environmental and occupational health sciences can leverage the physical space for ergonomic testing and analysis, while the Virtual Construction Lab allows them to develop and test theoretical models, improve labor techniques, and test for exposure to hazardous materials.

Furthermore, construction engineering and management educators can use simulation models in the virtual environment to teach means, methods, planning and scheduling. For example, the Construction Education Laboratory (CEL) will allow researchers and educators to contribute formal simulations to a central repository to be used throughout the research and higher-education community as well as the industry. The CEL will provide certification of these simulations to maintain academic integrity standards and protocol. For instance, to be considered an "educational exercise", a simulation should properly identify authorship, supported decision-making skills, intended audience, and other relevant characteristics, including the disposition of the authors to allow postings of third party evaluations of their exercises. Certification will not be required to register a simulation with the CEL, but it will provide educators and learners with the assurance that those simulations that are certified comply with a minimum set of standards. In this way, the PNCCRE plans to not only leverage partnerships within the University of Washington, but also seeks to establish a greater construction engineering and management community.

PROJECT SPECIFIC RESEARCH TEAMS

Research teams will be formed through strategic partnerships during the proposal process or shortly thereafter, bringing researchers into the center on a project specific basis. Since the drivers behind IDR are the research problems themselves, the writers suggest that facility and student participation in the PNCCRE will be on a project-specific basis. As the needs of the project are determined, an interdisciplinary team is formed either during the proposal process or shortly after the project is awarded. The PNCCRE is established as a means for collaboration between researchers on an as needed basis; consequently, researchers are not tied to one center, institution or project, but can come into the center on a per project basis. This allows Principle Investigators flexibility bringing in expertise that matches the problem, while at the same time allowing researchers the flexibility to come into the PNCCRE at different levels of commitment. Some researchers will be involved fulltime, with administrative positions, while others will utilize the PNCCRE resources to consult on specific projects.

COLLABORATION AND A CENTRAL REPOSITORY

Web-based collaboration technologies will be used for major research areas and specific projects. This technology will include central databases for information, data, techniques and methodologies, while project teams can create a web-based project specific tool for collaboration that is hosted by the PNCCRE.

The Internet has revolutionized today's concept of community by allowing people who are physically distant to communicate instantaneously. To leverage this technology and bring the construction engineering and management community together, The PNCCRE proposes to utilize web-based collaboration technologies to create repositories and virtual communities for construction research and education.

> "We are rapidly moving toward a world in which knowledge is constructed collaboratively at a distance by multidisciplinary teams, supported with an electronic communications and information infrastructure. The exponential growth of knowledge has made it nearly impossible for any organization to exist in isolation." (Kanfer, et. al 2000)

Academics and industry alike stand to benefit from communication and collaboration technologies (Gregorian 2004). The research goals of the PNCCRE include building partnerships not only within the University of Washington, but between researchers and initiatives at other colleges and university. The PNCCRE seeks also to develop partnerships between the academic community and the industry to leverage resources and expertise in order to generate a richer research and educational environment. Research and educational

programs at different institutions exhibit different competencies. Sharing these competencies and other resources through on-line collaborations broadens participants' horizons.

Just as the design and construction have found benefits from web-based collaboration tools (El-Mashaleh and O'Brien 2004, Rojas and Songer 1999), the writers propose to create a central portal or repository for key areas of research. These portals will fulfill a variety of research and education needs. First, the portals will allow researcher access to centralized databases of information related to major research areas. Second, researches can establish project specific portals for web-based collaboration. Third, students will become familiar with emerging technologies that are used in the industry.

In studying both the implementation of technology and interdisciplinary research, the writers have found several correlations. The barriers to interdisciplinary research closely parallel those for the implementation of new collaboration technologies such as web-based project management system (WPMS). Both IDR and WPMS requires project participants to share information, data, techniques, tools, perspectives, concepts, and theories in a new way, and the resistances to change are present in both endeavors. We can then both learn from the industries implementation of WPMS as well as utilize this technology in an academic setting.

In working with implementing collaboration technologies, many have found that instigating collaboration requires a revolution in the work process as well as the participants' attitudes towards collaboration and technology (O'Brian 2000). The barriers to implementation include:

- Resistance to change and the need for (new) job descriptions.
- Password barrier and the problems with boundary spanning.
- Communication and information density and the problem of yet another channel.
- Team tools and the problem of something for everyone.
- Collaborative maturity—knowledge is power.
- Related legal issues—review burden under the new regime.

To address these challenges with web-based collaboration, the writers address issues relating to people, program and process. For successful implementation, there needs to be support from university administration and the research leaders. To this end, champions within the PNCCRE administration and membership will be identified. Research into emerging technologies is a core area of focus for some of the current PNCCRE members. These research efforts will help establish best practices for collaboration technologies and tools. The goal then is to make the new system the easiest way to get things done. People are like water; they find the path of least resistance. Furthermore, it has been found that for successful implementation, the new technology must be integrated into the daily work processes of the users (Griffis 2006). If the software tool becomes an add-on to existing processes, it will be the last on the list and infrequently utilized. However, if the software tool is integral to the daily work processes of the management team, it will become instrumental.

The CEL will allow the University of Washington to provide research and education to a broader audience through the dissemination of on-line information, simulations, experiments,

tele-observations, tele-operations, seminars, and other activities. Traditional research conferences are only available to those who can be present when and where the conference is offered. The CEL changes this traditional paradigm, as every student has access to a variety of learning opportunities across the globe.

TOPIC SPECIFIC COLLOQUIUM

Furthermore, the PNCCRE will establish an ongoing colloquium where ongoing research is presented and discussed for all PNCCRE project participants, member department faculty and students and guests. Research has found that although technology is a very useful tool, it complements rather than replaces face-to-face interaction (Rhoten 2003). It has been found that both the creation of new knowledge and the sharing of information relay upon interpersonal and spontaneous interactions of researchers (Kanfer 2000). Consequently, a key part of the PNCCRE's IDR program will be problem-topic specific colloquiums, where researchers will gather at weekly, bi-weekly or monthly sessions to share ongoing research initiatives with their IDR community. Relationships and discipline intersections can be stimulated by these colloquiums both in the formal setting of a presentation or informal discussions.

CONCLUSION

The National Academies concludes that researchers do not work in a vacuum, but rather are motivated by pressures from their institutions, funding agencies, professional societies and publications. Researchers not only need to have the need and drive to collaborate across disciplines, but they need to be supported and rewarded for their efforts. (Committee on Facilitating Interdisciplinary Research 2005) The writers envision the PNCCRE fulfilling the needs of researchers and students, industry and academia, by bringing together interdisciplinary teams to tackle the complex problems we face in construction engineering and management.

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