Information Technology in Construction Research Initiative – a Large Owner's Perspective

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Background

The Department of Defense (DOD) owns and leases more facilities than any other entity worldwide. Efficiency in DOD operations and readiness of our armed forces depends on cost-effective management of these properties over their life cycle – to include leasing, design, construction, retrofitting, operation, maintenance and ultimate disposal. The past decade has seen a dramatic improvement in the productivity of those responsible for building and maintaining facilities. Global competition has resulted in constant pressure to decrease the Total Cost of Ownership (TCO) of facilities, a term familiar to those in the information management field. TCO is important to owners whether they occupy their own facilities or lease them to others. To the enterprise that occupies a facility, TCO encompasses not only the operating budget for a facility, but also the productivity and effectiveness of its employees.

Information technology plays a decidedly important role in decreasing the TCO for facilities. After almost four decades of steady progress with construction information technology, few would argue that technology alone is a "magic bullet." It is clear, however, that those who take best advantage of information technology tend to prosper, while those who make limited or no use of it tend to do less well. Today's work environment is a complex and interdisciplinary one that requires skill, knowledge, judgment, and new tools to provide a supportive information infrastructure. People AND technology are equally important in today's climate.

Information technology research has traditionally focused on large scale manufacturing with limited attention to the AEC industry. The AEC industry is 6.44 percent (520 billion) of the Gross Domestic Product (1997), but 69 percent (1996) of industry companies have less the 100 people. Unlike manufacturing, this fragmented industry has not been able to support significant research efforts or any national research initiative. Additionally, within the AEC domain, each facility is a one of kind product. Whereas in manufacturing, the design effort focuses on a single product that may be replicated a million times. There is little incentive to improve the delivered product or process because of the problem domain. Critical mass for an effective research initiative will not occur independently. Large facility owners such as the Army can provide the necessary requirements pull to address this important research area. While many facility owners reward lower first costs versus lower life cycle costs, large organizations are now recognizing the burden of poorly designed facilities. The Army has recognized the impact on the life cycle costs of operation and maintenance imposed by the disconnected industry-wide AEC process. The US Army Corps of Engineers has identified construction information technology as a key research initiative to address these concerns that will benefit not only the Army but also the entire AEC industry.

We will present two building block capabilities: Model Based Engineering and Collaborative Engineering, and discuss how we envision them changing the AEC industry. We present this view with the perspective of a large facility owner. Following, we discuss some research issues derived form our future world view and summarize topics we have chosen to focus on. Finally, we declare our intent to work within the context of a cooperative national research initiative addressing AEC information technology that is beneficial to the Army, NSF and the AEC industry.

Model-Based Engineering

Emerging Commercial Technologies

Several important technological developments are maturing. First, techniques for Object-Oriented Analysis and Design are improving the ability of engineers to create and use well-founded models of physical and abstract engineering systems. Second, object database technologies are finding their way into both CAD-integrated and stand-alone products. Third, standards efforts such as STEP have been energized in the facility field by the industry led International Alliance for Interoperability (IAI) Industry Foundation Class (IFC) effort. Fourth, the emergence of distributed and platform independent languages and protocols such as JAVA and CORBA promote the development of code that is portable and interoperable, even when developed by those from different disciplines. Finally, network technology, as exemplified by World Wide Web servers and clients (browsers), promotes the ease of use and readiness-to-hand required by truly useful engineering tools.

The model as an asset of an engineering enterprise

Most engineers are familiar with computational models. Our education and training in the engineering disciplines teaches us to create sophisticated models of engineered systems for use in analysis and optimization. In our traditional approach to using models, however, we tend to think of them as a means to an end rather than as the product of an engineering effort. For example, today's structural engineer might use a sophisticated finite-element analysis software package to analyze a building's structural systems. Although useful during the analysis, the computational model had to be laboriously constructed in the first place and is of little use to others in the design process. Similar arguments apply to other disciplines such as mechanical and electrical engineering, cost estimating, and construction scheduling. It is important to find new ways to use and reuse these engineering models in order to get a better return on the investment in creating them.

Document-based engineering

To use an analogy, the current document-based work-flow process is like a stream of documents that flow through the life cycle of a building. When an engineer needs to perform a task, he/she retrieves applicable documents from the stream, performs the design/analysis task, generates additional documents describing the results, and adds the resulting documents to the document stream. A drawback of this approach is that it results in "islands of automation," in which engineers are forced to manually extract and rekey information. The industry is moving away from the document-based approach to a model-based approach.

Model-based engineering

In the evolving model-based paradigm, the work-flow changes to one in which an engineer focuses on the production of computable models that are useful to those downstream in the process. Instead of building engineering models from scratch, based on project documentation, engineers will have tools that can interact directly with models created by other disciplines, automatically generating more detailed models as needed, and creating additional model information to pass on. Documentation and graphics will be generated from the model as needed by each discipline, but the format of these views may change to be more targeted to specific uses.

One phase of the building life cycle that is rapidly moving towards model-based engineering is Computer-Aided Facility Maintenance (CAFM) and/or Asset Maintenance Management software (MMS). Although there is not yet an accepted standard modeling schema, facility managers are learning to operate based on a computable model of the facility (often based on a relational database system). Today, implementation costs for CAFM or MMS approaches can be prohibitive because of the need to inventory equipment and generate the database. Moving to a model-based process throughout the building life cycle in which the constructor turns over a populated model with the building would significantly decrease the start-up expense.

Agent-based tools

Software agents are computer programs that can monitor data - in this case changes in engineering models - and proactively initiate analytical programs, coordinate changes in the model with other disciplines, or offer specialized advice as design decisions are being made. With roots in the field of expert systems, the potential for software agents is in areas such as checking engineering models and running energy or seismic analyses at appropriate times. With more widespread use of engineering models, it will become possible to create software tools that are more proactive and modular. Research prototypes have demonstrated a variety of software agents that can check building codes and automatically generate construction schedules. Before these models can realize their potential to assist architects and engineers, however, the profession must make the paradigm shift to model-based engineering.

Collaborative Engineering

One of the greatest payoffs that the move to model-based engineering will deliver is an increased capability for virtual teams engaged in engineering enterprises across organizational and geographic boundaries. Today's virtual teams, using network-based technologies (project web pages, electronic mail, shared whiteboards, chat rooms, CAD and GIS servers, internet telephony, and video teleconferencing) are still working in an essentially document-based environment. Model-based engineering will allow all of these activities AND the ability to rapidly model and analyze engineering subsystems on a virtual team.

The ability to do model-based engineering in a virtual team has been the subject of ongoing research in the field of *collaborative engineering*. I believe that fielding this technology will require an evolutionary process in which the building industry proceeds through several stages: shared documents, tele-engineering, shared models, engineering conflict management, and finally, net-mobile software agents. Briefly:

- shared documents: Currently, virtual team members can share documents electronically through e-mail, project web sites, electronic meeting software, etc.
- tele-engineering: Tele-engineering combines shared documents and tele-presence to support "engineering at a distance." Although the value of video tele-conferencing has not been firmly established, it is clear that the computer industry is on the verge of making video tele-conferencing ubiquitous. Within the Corps of Engineers, demonstration projects are underway with a "Digital Hardhat," developed at the University of Illinois, that has the potential to substantially decrease travel costs associated with bringing experts onto construction and maintenance sites to consult. A new initiative within the Corps, tele-engineering capability is being developed to enable engineering offices in the United States to support requirements of forward-deployed forces anywhere in the world at substantially lower cost than is currently possible.
- shared models: Shared engineering models based on object-oriented and relational databases are the next major step in Collaborative Engineering. With the transition to model-based engineering and high bandwidth network access, geographically dispersed virtual teams will be able to work together on the same engineering model. Shared models will help minimize some of the coordination and versioning problems that exist today in the document-based model.
- engineering conflict detection and management: Once engineers are working in shared models, software can automatically detect engineering conflicts between virtual team members. Although unlikely to have encoded the engineering judgment to resolve the conflicts, information technology can assist in detection and tracking of the conflict events earlier than otherwise possible.
- net-mobile agents: Building on a common basis of model-based engineering, engineers will be able to send software agents that represent their area of expertise to advise other virtual team members. A classic example would be a structural engineering agent to advise an architect if changes were likely to cause a major cost increase or seismic vulnerability.

Research Issues

Research issues that we identify recognize that information technology alone cannot provide the results desired. People and social/organizational behavior and processes must be included in the development of requirements and metrics. Whether this means one to one human computer interaction or complex organizational behaviors, the human participants must be included.

The ERDC internal research objective is to increase understanding of the fundamental principles of collaborative engineering and to develop sound methodologies to improve the facility delivery process. These principles and methodologies will be used as the foundation for future collaborative engineering frameworks. Key research issues focus on rapid generation of engineering solutions, rigorous evaluation of decisions, fundamental understanding of the nature of collaborative design problems and decision theoretic approaches to engineering conflict management. Better understanding of collaborative engineering principles will lead to more effective design and use of complex systems composed of people, corporate knowledge, engineering processes, and automation technology. Our experience to date suggests a key fundamental capability is a requirements-driven design process (Griffith 1999). By explicitly representing requirements, design solutions are contextually grounded.

As an agenda for the research community, we offer the following categories: Design Automation, Case-based Design, Information Models and Collaboration. Design automation in the AEC industry is the starting point within the AEC life cycle. Design professionals need tools and methodologies that leap frog current practice while at the same time integrate within the total life cycle information flow. As an example, most tools and methodologies available to designers work within a piecemeal fashion and don't interrelate with other tools or design professionals intelligently. Design models, if produced at all, are built one piece at a time. Innovative and demonstrated capabilities to leverage computational repetition are required. Examples today include spatial grammars (Flemming and Woodbury 1995), genetic algorithms, constraint networks, and simulated annealing.

Second, case-base design holds great promise to leverage future information technology foundations. It meets a practical need in the industry. Most design and construction solutions are adaptation of previous examples. With the imminent arrival of widely available model based design tools, it is feasible to envision case based design methodologies that retrieve and adapt a previous solution to a new context. This has been conjectured within the body of research, but not proven. Most of the case base design methods do not support adaptation within a context, but retrieve designs solutions much like retrieving library material. Further, extending the foundation to include design requirements and design intent, and utilizing design requirements and intent in a case base approach needs investigation.

Third, information models are the next major hurdle in developing a life cycle approach for the AEC industry. Current efforts such as STEP and IAI have developed data models, not information models. While necessary and beneficial, data models inherently are static definitions of data form and structure. They don't describe the behavior characteristics or insure response across applications. Behavior and internal model consistency is a key building block for the future (Eastman 1997). These information models must be capable of living and evolving for 50-100 years. Without internalizing process and flow into the model, it is possible and probable that intelligence will be lost as applications, operating systems and computers evolve.

Fourth, collaboration within the context of the emerging commercial technologies has the most promise of changing the AEC industry. The ability to share and co-mingle work through model based design will provide a revolutionary capability, but many issues that are hidden will suddenly arise. There is little understanding of how a technical group of people actually collaborates. Add large organizations with multiple departments with competing interests and objectives to the technical group and the dynamics change more. Further complicating the issue, the AEC industry is fragmented across organizations. Determining and managing what is not shared may be just as important. Technical virtual teams are formed for specific projects between and across multiple organizations that change and evolve over the life cycle. They are temporal in nature. Additionally, if a technology can identify conflicts, how can the resolution of the conflicts be supported? Finally, it may be possible to capture group design intent. These questions need to be answered to provide a new foundation that mixes technology, social science and technical knowledge.

Personal Background

Dr. Michael Case has been a member of the CERL research staff for 15 years. His focus has been on information technology during the design, construction and maintenance of facilities. He received his Doctor of Philosophy from the University of Illinois in Mechanical Engineering. He is currently the Chief of the Engineering Process Branch within the Facility Division. He oversees approximately 20 principal investigators and 40 projects dealing with various aspects of the information technology within the AEC domain.

Mr. Eric Griffith has been a member of the CERL research staff for 12 years. His focus has been on design automation and collaborative engineering. He is currently a principal investigator. He received his Masters degree of Architecture with a specialization in computer science from the University of Illinois. Projects he is working on include collaborative engineering, advanced design automation, technology transfer of research products through the Modular Design System and developing recommendations for how information technology can be leveraged within the Corps of Engineers 2 to 5 years out.

Partnership

The Information Technology in Construction research agenda is vital to the entire AEC Industry. While the Army has significant self-interest, partnerships with other leading research organizations are necessary to be successful. Many large facility owner organizations have identified similar problems and will experience the long-term returns, but they need to be proactive in establishing the requirements pull for the agenda. Obviously governmental agencies such as the Army need to participate, but large private owners should not be excluded. The success of CIFE and ABSIC are excellent industry partnering examples. Partnering with the National Science Foundation at the program level provides many leveraging opportunities that promise to be mutually beneficial.

References

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