First International Conference on Construction in the 21st Century (CITC2002)
"Challenges and Opportunities in Management and Technology"
25-26 April, 2002, Miami, Florida, USA

ENGINEERING AND CONSTRUCTION COLLABORATION USING INFORMATION TECHNOLOGY

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ABSTRACT
This paper presents potential applications of IT (information technology) for engineering and construction collaboration. Relevant information technologies, both existing and emerging, for the A/E/C (Architecture/Engineering/Construction) industry are discussed in the context of how these new developments in technology may impact engineering and construction practice, especially in the area of construction engineering and collaboration. Drawn from experiences in engineering practices and knowledge of the latest IT developments, the authors outline strategies that may help engineering and construction firms make decisions in adopting IT initiatives.

KEYWORDS
Information Technology, Collaboration, Technology, Computing

1. INTRODUCTION

Advances in information technology (IT) have gradually changed engineering practices and construction project management. IT, with the potential of breaking the barriers of time and distance, has brought new opportunities and challenges to the AEC (Architecture/ Engineering/Construction) industry and community. There exist opportunities in using IT to streamline existing engineering and construction processes to improve productivity, to shorten delays, and to enhance engineering and construction collaboration/integration. However, being new, fast-paced and uncertain, IT initiatives and investments could also be puzzling and challenging for most companies. Many IT ventures, started as leading edge investments, became the bleeding edge that many companies regretted.

This paper explores the core technologies of IT and presents key technologies that may have significant impact on the A/E/C practice. The organization of the paper starts with a review of the responsibilities of architects, engineers, and contractors working on a construction project, followed by a discussion of the latest advances in information technology. Discussions will be presented to demonstrate how these advances can be utilized to enhance engineering and construction practices. Conclusions will follow to provide recommendations for engineering and construction companies interested in implementing IT applications in their organizations.

2. WHAT IS IT?

IT (information technology) encompasses computer hardware, software, and communications devices that allow the sharing and access of information as conveniently as in a village. IT could potentially break the barriers of time and distance, making the world, although far apart geographically, as small as an "information village." It seems clear from the fast growth of the Internet that the world is getting smaller. People, using information technology, can work remotely, collaborate through the Internet, access information quickly and conveniently, share ideas, live, shop, and play all through the Internet. The rapid growth of the Internet in the world confirms the benefits of global communications and the needs for information sharing. IT and the Internet have in fact affected many aspects of people's lives, including how they work and live. Almost all industries are affected and can benefit from the development of IT. The A/E/C industry in particular has shown vast interest in adopting the new technologies in the area of 3D visualization, data analysis, communications and collaboration, information sharing, and project controls. The use of IT will certainly affect almost all participants and organizations of a construction project.

3. ORGANIZATIONS INVOLVED IN A CONSTRUCTION PROJECT

Many organizations are involved in a construction project. They include owner, contractor, designers (architects/engineers), subcontractors, consultants, and suppliers. These organizations work together and interact with one another, including the general public and government agencies (Figure 1). Many issues cannot be resolved until several parties involved agree on a solution, and a project may be seriously delayed if a problem is not resolved quickly. The scale and complexity of modern construction projects have further complicated the issue of communications. It is not uncommon to have construction projects with participants from different parts of the country or even the world. For example, it is possible to have a project in Hong Kong with U.S. architects, structural engineers from UK, a French project manager, a Japanese general contractor, Australian suppliers, and local subcontractors that hire labor forces from Indonesia. More and more projects are crossing the international borders. If the current trends of Internet use continue, we will see more projects with global participants. The globalization of construction projects makes it extremely important to communicate effectively and efficiently among parties involved. This need for efficient communication and collaboration clearly points to IT as a potential solution.

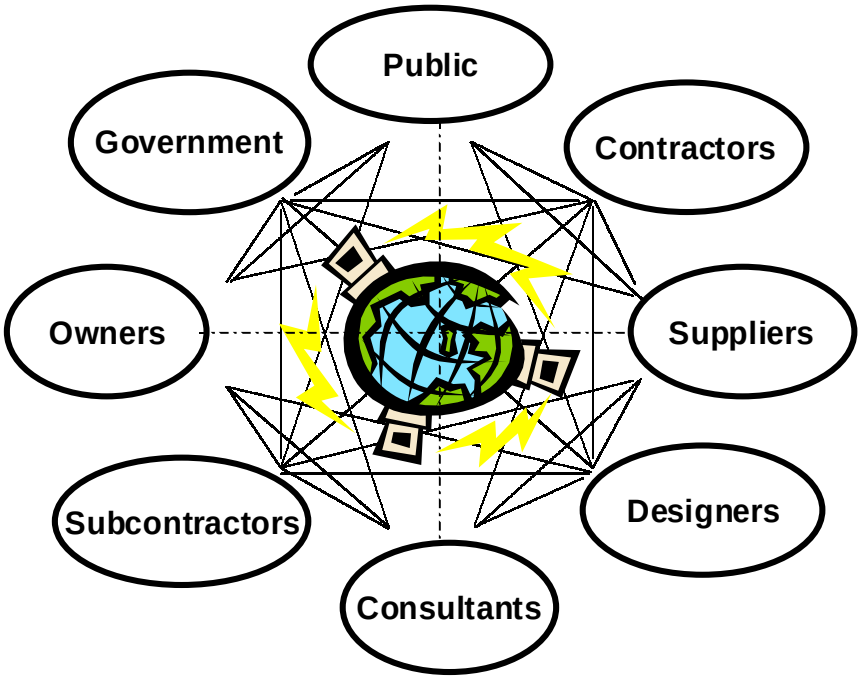

Figure 1. Organizations Involved in a Construction Project

4. IT ADVANCES RELEVANT TO ENGINEERING/CONSTRUCTION TASKS

Among the advances in IT, new developments in communication and collaboration present greatest opportunities for the construction industry. The following sections outline a few of these IT advances.

4.1 WWW, Internet, Intranet, Extranet

The ease of use of the World Wide Web on the Internet has pushed the wide spread use of the Internet from academia to corporations and to homes. The concept of interconnected computers with instant information access has created new ways of conducting business. Based on the Internet technology, computers are connected within an organization to form "Intranet" or to extend to other organizations through the Internet to form "Extranet." The use of WWW, Internet, Intranet, and Extranet have made instant information access possible and enabled companies and individuals to collaborate remotely. They allow synchronous and asynchronous access to project information at different locations and times, breaking the barriers of time and distance for architects, engineers, and project managers to collaborate on project issues/decisions.

4.2 Wireless Communications

The Internet has connected millions of computers in the world. A wireless version of the Internet is gradually developing. Wireless networking has improved dramatically in the last 10 years. The performance of local wireless networks is narrowing the gap with the wired ones. Furthermore, the wide spread use of cellular phones, PDA (personal data assistant), and hand-held computers are creating the need for wide area wireless networking. The increased popularity and usage of wireless data access using hand-held devices have pushed the Internet use into wireless using cellular phones, PDA, and hand-held PC's. These wireless Internet access devices are made possible by wireless infrastructure and standards such as CDPD (Cellular Digital Packet Data) in the U.S, GSM in Europe and Asia, and WAP (Wireless Application Protocol) for Web access. Although the bandwidth is still limited, the concept of anytime anywhere e-mail and Web access has gained serious attention from potential users. For example, many construction contractors in the San Francisco area subscribe to wireless network services, so that project managers, superintendents, and construction engineers can stay in touch with contractors and subcontractors anywhere, anytime.

4.3 3-D and 4-D Visualization and Computer Graphics

The use of 3-dimentional computer graphics has moved the traditional drawings from two-dimensional lines into realistic 3-D renderings. Many CAD systems today offer 3-D capability that makes communication among project participants more intuitive and effective. A 3-D design with photo-realistic rendering of lights and textures facilitates discussion of the owner’s requirements and preferences. Contractors and workers can visualize the design, eliminating misunderstandings and errors. 3-D design also allows engineering disciplines, such as structural and mechanical engineers, to work more efficiently and precisely using a common 3-D model. Several researchers, such as work by McKinney and Fisher [1], extended 3-D models into 4-D (3-D+time), where construction schedules are integrated with 3-D displays to simulate the progress of a construction project.

4.4 Project Extranet ASP’s

Project extranet ASP's (application service providers) are software vendors providing data storage and management services for a fee. They offer project participants a common platform, an information center to access/post project information. Using only the Internet browsers, participants of a construction project will be able to exchange e-mail, files, view drawings, and update data. The benefits of using the ASP’s are in two main areas: improved communication and accountability [2]. Since data access can be tracked easily, it’s possible to track who causes the delay, making everyone cautious and aware of their responsibilities. Besides, the centralized project database makes the large volume of construction information more manageable. Many of these ASP's offer to create project data CD's for distribution after construction for archival purpose. Figure 2, on the next page, shows an example screen from one of the ASP's, BricsNet. The screen shows a threaded discussion organized by subjects, time, and individuals. This kind of threaded discussion provides excellent records of project as-build information, especially in claims and disputes. The market seems ripe for the ASP’s for the construction industry. Owners welcome the idea of well-documented project as-built information and on-line information access, contractors welcome the

shorter review period for submittal approvals, and engineers/architects can access/exchange project files conveniently. In 1999, the authors counted over 50 ASP's offering project information services, today (2001) there are less than 20. The market for ASP's will likely continue to consolidate due to the woes of high-tech industry, because many of these ASP's were supported by venture capital companies. The on-going U.S. recession after the September 11 terrorist attacks in New York and massive layoffs in Silicon Valley seemed to echo the reality.

4.5 Hand-held & Wearable Computers and Multimedia Data Collection

Handheld and wearable computers are gaining more popularity for use in the construction field. They are used not only to access project information but also to collect important field data, such as manpower and project progress. Many of these handheld computer manufacturers offer attachments such as digital cameras and digital recording of sound, making these handheld computers a convenient way of collecting multimedia information for construction projects.

Figure 2. Project Extranet Example

Figure 3. Hand-held/Wearable Computers

4.6 Video Conferencing/Documentation Sharing

Video conferencing offers an attractive alternative to face-to-face meetings by transferring data, sounds and videos through the Internet. Inexpensive digital cameras and software have made this technology attractive to many engineering and construction firms. Many, however, found that the real benefit came not from seeing the face of partners on the computer screen, but from the software that allows application and document sharing. Application and document sharing allows participants at various locations to view and highlight a loaded drawing for discussion. Although the speed and quality are not as good as TV, most people found it acceptable as an alternative, although many companies insist the technology has not lived up to their expectation because of poor quality video and delays. Due to congestion on the Internet, many companies are finding a common ground by using the phone with a PowerPoint file loaded from the Web server to conduct a collaboration session by looking at a common web presentation.

4.7 Business to Business & On-Line Transactions

The growth of the Internet has created new business models that allow buyers and suppliers to conduct business transactions on-line, eliminating the distributors. Many Internet portals, ASP's, and database hosts, facilitate the linkage for a small fee, by allowing buyers to specify goods/products to buy and suppliers with products to sell. The transactions can be directly linked to each company's inventory and pricing, and ordering information can be taken directly with invoices/payments sent electronically.

5. IMPACT ON ENGINEERING AND CONSTRUCTION TASKS

Among the tasks performed during the engineering and construction phase of a project, many can benefit from the use of information technology. The following sections describe tasks that can benefit from the use of IT in streamlining the processes and/or improving communications.

5.1 Permit Application and Approval Process

Before construction actually starts, many permits must be applied for to various government agencies. Engineers then have to evaluate the design for code compliance. Many government agencies worldwide are starting to use the

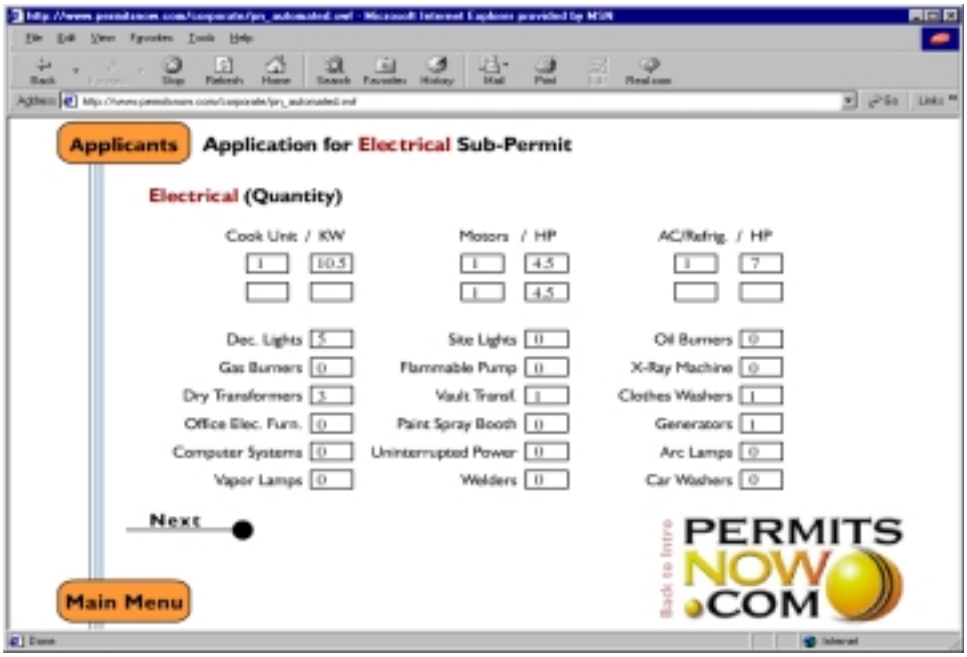

Figure 4. On-Line Permit Application

Internet for owners and contractors to submit permit applications on-line. For example, PermitNow in the U.S. is providing permits on-line services for hundreds of municipal governments. Figure 4 shows an example of using the web to apply for an electrical permit. Once submitted, this permit information and drawings are stored in a database for engineers to evaluate on-line regarding code compliance. Once approved, the permits are issued through e-mail notifications. Some researchers are also developing advanced software systems that will check building codes automatically using artificial intelligence techniques.[3] This kind of on-line permit handling has received a warm welcome from owners and contractors. They can get permits approved faster and the costs of printing numerous copies of drawings are eliminated. Even the government agencies who had to spend resources implementing these new services are voicing support, citing convenience in record keeping and efficiency.

5.2 Architecture and Engineering Analyses

During the design phases of a project, many different disciplines of architecture and engineering are involved. Architects develop building layout based on the functional requirements of the owners. Structural engineers will need to perform structural analysis for building safety, economy and performance. Using an integrated CAD system, researchers are performing tasks such as preliminary design, structural modeling, structural analysis, optimization, strength design, detailing, design evaluation, and construction drawings. These tasks will interface with other engineering disciplines, such as Geotechnical engineers who collect and analyze soil samples to design the foundation needed to safely support the structure. Mechanical engineers will design heating, ventilation, and air conditioning systems to make the building habitable. Construction engineers will develop a construction plan to manage labor, equipment, materials, time, and money. These various architecture and engineering disciplines, acting either as a part of the design team or as a consultant, need to communicate well during the design process because one discipline relies on data from the others to conduct their analyses.

Many engineering disciplines are already using WWW and the Internet to facilitate the exchange of engineering data. Field data, collected by using hand-held and wearable computers, will be transferred in real time to designers to verify design assumptions. Site personnel will be able to consult remote experts through video conferencing to discuss/resolve project problems in a timely manner. In the future, we will see more engineering disciplines collaborating using the Internet.

5.3 Design Details and Shop Drawings Approval

During engineering and construction phases of a project, design details and shop drawings are prepared according to the specifications by the contractors or subcontractors. Due to the complexity of modern construction, many revisions are made and the costs for shipping the drawings and specifications are high. IT will dramatically change the current process of handling design details and shop drawings by allowing the exchange of design files electronically. With the design file, many contractors can perform the detailed design tasks quickly. For example, design CAD files can be used to drive a laser steel plate cutter on the factory floor, eliminating the possibility of human errors and data reentry. Technologies, such as video conferencing and documentation sharing, will bring remote experts to resolve fabrication problems, saving travel time and costs.

5.4 Project Coordination and Controls

During construction, the control of people, payroll, labor hours, productivity, equipment, payments, and materials require rigorous planning and management to ensure smooth progress of a project. For larger projects, thousands of people work daily on the construction site. Project managers and construction engineers need to handle tasks such as processing progress payments, managing RFI's (request for information), processing change orders, and handling disputes or claims, and collecting as-built information. These tasks typically require timely processing; otherwise, costly delays may occur. With the advances of IT, many of the field data collection tasks will be performed using the hand-held or wearable computers. Figure 5 shows an example of field data collection using a hand-held computer. The computer contains a digital camera and can collect multimedia information, including text, images, sound, and video[4]. The new Palm and Pocket PC computers offer many features that make construction field data collection convenient, such as database synchronization and form/checklist entries. Some of these hand-held devices even offer wireless communications, so one can surf on the Internet and upload/download project data directly in the field.

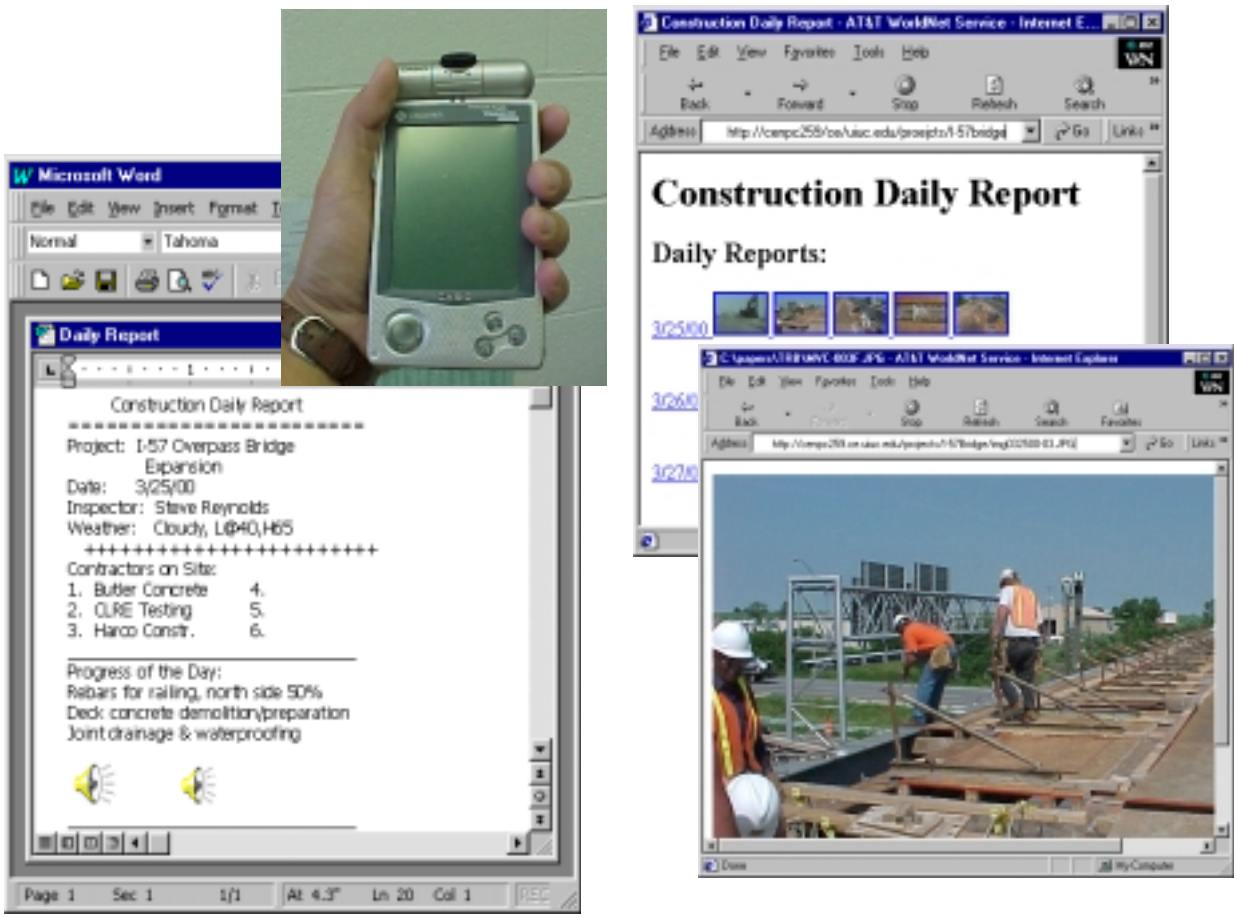

Figure 5. Hand-held Computerized Inspections

6. VISION OF ENGINEERING AND CONSTRUCTION COLLABORATION

6.1 A Bright Future Ahead

Judging from the existing IT developments and the fast pace with which they were developed, we are optimistic about the future of IT applications in engineering and construction. The computing speed will continue to improve when the wired and wireless infrastructure is upgraded. Computer hardware and software are getting more stable and mature, while the prices continue to drop. We envision that future engineers will be able to work more efficiently and productively. Owners, architects, and engineers from different parts of the world will be able to collaborate easily and globally.

6.2 New Processes To Be Discovered

IT creates new ways of doing old engineering work. IT also provides opportunities to develop new processes that can help engineers work more efficiently and effectively. Many engineering firms focus on the effort of replacing old computers with faster ones. In fact, the real benefit of IT may lie in developing new processes of conducting work collaboratively, sharing information and knowledge. It is necessary to understand the existing process before embarking on any IT initiative. While many companies are resistant to change, the successful ones benefit from understanding the technologies and adapt to new processes that are made possible by the technology.

6.3 Evolutionary IT Adaptation

We envision the pattern of IT adaptation in the A/E/C industry as an evolutionary one. Most engineering and construction firms already invest heavily on their computing infrastructure. New IT advances that are accepted quickly will likely to be the ones that are compatible with a company's existing infrastructure. Compatibility is key to introducing new IT tools into engineering and construction firms. Compatibility issues must be resolved at two levels: within an organization and among various organizations of a construction project. It's exciting to see more standards for data exchange being developed, and many hardware manufacturers are developing devices that can communicate directly using these standards.

7. STRATEGIES FOR IMPLEMENTING IT INITIATIVES

The vision presented in the previous section may seem promising. Many companies nevertheless suffer from costly IT investment failures. Common reasons for these failures include compatibility, training, and technology mergers. Being so new, IT tools typically lack standards that allow different systems to communicate efficiently. Many companies failed because of the lack of training of their employees. Another common reason contributes to the fact that most IT firms are initially funded by venture capitalists that tend to buy, sell, and merge rather quickly. Facing all these uncertainties, engineering and construction firms could consider the following strategies:

- Form an IT committee within the firm to constantly evaluate new IT developments.
- Evaluate new technologies and weigh the benefits vs. costs.
- Pilot-test promising technologies on small-scale projects.
- Compare competing technologies.
- Backup key business data.
- Invest not only in hardware but also in training
- Communicate with partners, contractors, and subcontractors on technology compatibility issues

8. CONCLUSIONS

The advances in information technology have created new ways of performing engineering and construction tasks for a construction project. These IT advances allow project participants to collaborate without the barriers of time and distance. Engineering and construction in the future will certainly rely on these tools to shorten the time to process permits, perform engineering analyses more collaboratively, approve shop drawings and submittals, and control project progress and resources. The globalization of construction project participants will make IT a necessity to participate in a construction project in the future. We need to keep in mind that information technologies are tools. They do not replace years of engineering training. If implemented properly, IT can greatly enhance the engineering and construction practice.

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