A Review of ICT Applications for Design and Management of Construction Projects

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Abstract

The recent innovations in Information and Communication Technology (ICT) have a polarizing effect on the design, management and delivery of construction projects. The construction industry generally believed to be fragmented and labor-intensive, now has the potential of being integrated by the use of ICT. This paper presents a review of the impact of ICT on the construction industry. Emerging trends in automated construction with ICT are examined. The state-of-the-art technologies such as integrated CAD, animated 3-D visualization, virtual designing, model based cost estimation, on-line bidding, shared project databases and on-line project management, monitoring and control are described and discussed with their benefits and implementation techniques.

Keywords

Information techonolgy, CAD and visulization systems, databases, project monitoring and control

1. Introduction

Construction industry is highly fragmented as compared to other industries. This may have caused significantly low productivity, cost and time overruns, conflicts and disputes, resulting in claims and time consuming litigations (Latham 1994, Egan 1998). The fragmentation problem is further compounded by the fact that the construction process typically involves several disciplines, e.g. architects, structural engineers, building services (HVAC) engineers, quantity surveyors, contractors, sub-contractors, material suppliers etc., collaborating for relatively short periods in the design and construction of a facility. Until fairly recently, these disciplines tended to work independently, while making decisions that affect the others (Anumba, 2000).

Another facet of the fragmentation problem is the fact that the construction projects whether they be buildings, bridges, dams, or offshore structures usually involve many stages, starting from the establishment of the client's requirements through to design, construction, utilization and eventual disposal of the facility. These stages of the project's life cycle and the associated activities and tasks are often undertaken as discrete processes, with only limited integration of data/information, participants, tools and procedures etc (Anumba, 2000).

The term integration has been used in the literature as the antonym to fragmentation. Integration can minimize the above-mentioned fragmentation problems (Ahmad and Ahmed, 2001). The development of integrated systems for the construction industry has generated considerable interest over the last twenty-five years. The initial trend in the development of software for this industry sector was based on stand-alone applications developed by enthusiastic for very specific applications (Anumba, 1996). The motivation often derived from the necessity to computerize a given engineering function. However, the

recent developments in information and communication technologies (ICT) have provided a platform to integrate the construction industry. This aim of this paper is to present a review of the state-of-the-art ICT tools and techniques and their applications in the construction industry. It is expected that these ICT tools will help to integrate the construction industry and result in high productivity, better coordination and less delays and disputes.

2. Impact of ICT on the Construction Industry

Information and communication technology (ICT) has first been evolved in helping to synthesize or analyze information. The first two major applications in construction were the finite element analysis program (FEAP) in the 1970s and the drafting software (AutoCAD) in the 1980s (Turk, 1997). During the 1990s, the ICT has brought a revolution in the construction industry. Table 1 compares the traditional and ICT supported technologies in construction.

Table 1: Traditional and ICT Supported Technologies in Construction
(Derived from Turk, 1997)

Needs	Item	Traditional technology	ICT supported technology
Information processing and management	Project	Drafts, folders	Document management, product and process models
	Company	Archive, microfilm	Data warehouses
	Country	Library, building regulations	National construction information systems
	World	Journals, conferences	Global ICT networks
Interaction facilities	Man with man	Speech, phone, fax, mail	E-mail, video conferences
	Man with application		3-D Visualization, virtual reality, graphical user interfaces
	Man with machine	Direct contact	Indirect contact using computers
	Application with machine		Robotics, Remote sensors
Time saving	Just-in-time	Book look-up, library look-up, phone call to expert	Database lookup, internet search
	Just-in-case	Reading books, magazines, journals, schools, visiting conferences	Subscriptions to customized content, distant learning

In the construction industry, ICT is creating new possibilities and, as a result, its advancement is placing new demands upon design and construction organizations. ICT can no longer be viewed as an enhancement to traditional construction procedures but rather as an innovative agent that enables new and different alternatives to organizing and operating construction enterprises. As a consequence, construction organizations are faced with opportunities as well as challenges (Ahmad et al., 1995).

The ICT tools are being utilized in the construction industry in three distinct areas as shown in the following sections.

2.1 Information Management and Services

Information management component includes all aspects of ICT for capturing, storing, organizing, and retrieving data. Internal (project/company) and external (industry) standards are essential for maximum integration in the process. Shared databases, data normalization techniques, data warehousing, barcode technology, CAD graphics are examples of advancement in this area (Ahmad and Ahmed, 2001).

Majority of construction companies are now utilizing Internet as one of the effective and efficient advertising tool. The information advertised in a company Webpage typically includes the company profile, services or products, recent projects, job vacancies and public feedback forum. Intranets are also used to provide information presented for the benefit of the employees, such as the company policy, employees' directory, newsletters, and manuals. Extranets can be used to present information regarding an outgoing project to the business partners, such as the project description, contract documentation, project documents, and project directory (Skibniewski and Abduh, 2000).

2.2 Communications

The communications area includes all aspects of communicating data and information such as text, graphics, audio and video. The most common communication tool is electronic mail. The different chatting softwares such as ICQ™, IRC™, Net Meeting™ etc. are also frequently used to allow seamless discussion between two or more parties involved in a particular session, e.g. when the contractor and the engineer need to discuss a solution to an urgent problem encountered on the jobsite. Hyper Text Markup Language (HTML) can also be used for simple communication such as the use of forms, e.g. to send work progress information from the field, which can then be used for the preparation of progress reports (Skibniewski and Abduh, 2000).

Communication tools can help design and construction organizations to coordinate their activities with greater effectiveness and efficiency overcoming the barriers of time and distance. Training tools, such as multimedia, can help train workers. However, there is a profound need for uniform and standard data in the construction industry. Without standard data it is difficult to establish a common performance measurement system or a uniform quality assurance program. Uniformity of procedures and standardization of data would greatly enhance the effectiveness of communication among the multiple construction organizations teaming up to build one constructed facility (Ahmad and Ahmed, 2001).

2.3 Processing and Computing

Processing includes all systems and models developed for processing data. Technologies supporting the process of developing such systems and models underlie this component of ICT capability.

By the advancement of scripting technologies on both the client side and the server side as well as through the availability of plug-in modules, the Internet (including Intranet and Extranet) can be used for engineering and management computing purposes. The most common examples include project scheduling, resource management and project cost control using shared databases through Internet (Skibniewski and Abduh, 2000).

3. State-of-the-Art ICT Tools for Design and Management Processes

Based on the categorization of the ICT tools as shown in the previous section, Table 2 provides an over-view of the state-of-the-art ICT tools that are being used in the design and management operations of construction projects.

Table 2: An Over-view of the State-of-the-Art Tools for Design and Management Processes in Construction Projects

Need / ICT Tools	Design	Management
Information Management and Services	• Integrated CAD systems (Informational databases)	• On-line bidding • On-line building information services • On-line project administration systems Shared project databases
Communications	• Animated 3-D visualizations • Virtual design studios • Simulation techniques	• 4-D project monitoring • Project management and control through web-cams
Processing and Computing	• Integrated CAD systems (structural analysis and design).	• Model based cost estimation • Planning and scheduling softwares • Expert systems

3.1 State-of-the-Art ICT Tools For Design Processes

Computers have been used in the design process for more than 40 years. Early applications in the 1960s included line drawing systems, architectural layout planning systems and structural design systems. The recent Computer Aided Design (CAD) applications that allow 3-D geometric modeling are all based on the same concept (Gero, 2000). These systems provide the following types of integration within the architectural and engineering design processes.

- Integration of 2D drafting and 3D modeling.
- Integration of graphical and non-graphical design information.
- Integration of the data structure and the user-interface.
- Integration of two or more applications (e.g. design and analysis, drafting function and other applications).

An overview of some of these systems is presented in terms of concept, technology, application and implementation requirements.

3.1.1 Integrated Computer Aided Design (CAD) Systems

The Integrated Computer Aided Design (CAD) systems provide a complete solution of architectural, drafting and engineering design problems.

Concept
The integrated CAD systems combine 2-D drafting with 3-D modeling and provide a complete interface with the engineering design softwares. This removes the redundancies in the design process and results in both time and cost savings.

Technology/Software

The softwares available for architectural design are AutoCAD2005®, 3-D Studio Max® and Design CAD. For the structural design, SAP 2000® (Linear and non-linear versions) and STAAD-IV® are popular softwares. Most of these softwares provide an interface to transfer data.

Applications/Benefits

Integrated CAD systems offered the following benefits: reduction in ambiguity, better coordination, reduction in the potential for errors, obviation of the need for physical models, automatic generation of properties, exploded views and sections and the possibility of extension to other applications.

3.1.2 Animated 3-D Visualizations

The use of animation to depict three-dimensional views of a building product/facility provides a useful view of what a finished product may look like as shown in Figure 1.
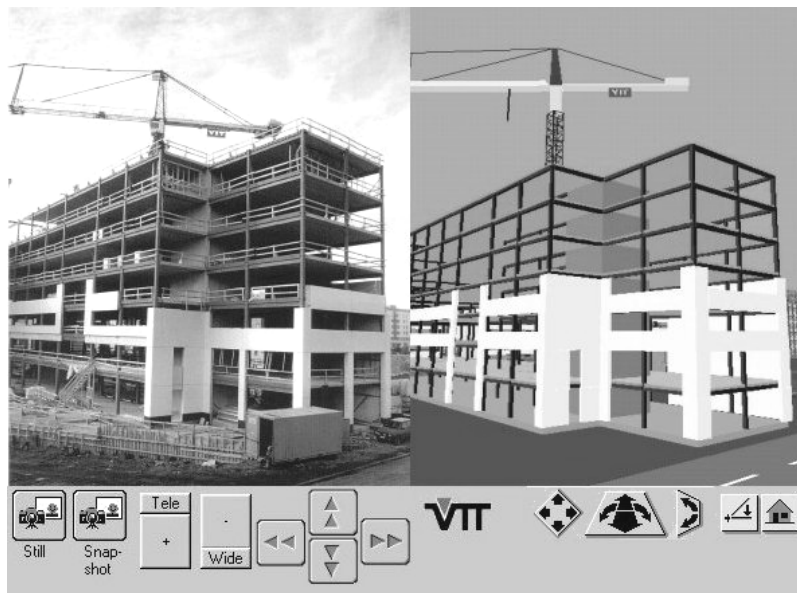

Figure 1: Use of 3-D Visualization in Construction (Source: http://www.vtt.fi)

Concept

The core concept of "Animated 3D Visualizations" is to provide a "near-real" replica of the finished product/facility from the basic design to the operation of the facility. Not only this provide a better platform for the architect and more "imaginative flexibility", but also the customer a better "feel" of their desired product/facility. They also provide a nice visual description to the designer/contractor responsible for designing/constructing the product/facility (Hannus and Kazi, 2000).

Technology/Software

Basic technology required for "Animated 3-D Visualizations" consists of high performance personal computers or workstations connected over a network. Additionally a video studio for digital editing and animation recording graphic cards are required. Different softwares available for this purpose are 3-D Studio Max® and Adobe Premiere®.

Applications/Benefits

The applications extend from the project development to the facility operation and management stage. All project participants are able to increase the quality of both the design and construction process. Moreover,

instead of browse through pages of documents, users could navigate through a model and then through simple mouse clicks to access the relevant information.

3.1.3 Virtual Design Studios
The virtual design studios allow designers and experts from different places to interact using audio and video conferencing as shown in Figure 2.

Figure 2: Virtual On-line Design Studios (Source: Turk, 2001)

Concept
The main concept behind virtual studios is to allow designers to discuss any matter related with design or construction without the need to travel. They can share the same screen and same program thereby entering the same virtual reality space.

Technology/Software
The technology includes high-speed computers or workstations with fast Internet access. The software available is AutoCAD 2005® On-line.

Application/Benefits
The main benefit lies in the fact that experts and designers from any part of the world and at any time discuss a design issue and propose an immediate solution.

3.2 State-of-the-Art ICT Tools For Management Processes

Information and communication technology (ICT) offers unique opportunities for managing projects effectively by utilizing automated means to capture, store and retrieve data; efficient ways to process data into information; and powerful techniques to transmit data/information quickly and in vast quantities (Ahmad and Ahmed, 2001).

Construction is a multi-organizations process with heavy dependence on exchange of large complex data and information. The successful completion of the project depends on the accuracy, effectiveness and timing of communication and exchange of those information and data between the project team. In today's ever complex and dynamic construction project decision-making environment, most decisions are based on the availability of paper-based information or, in some cases computer generated or supported information. Unfortunately, however when a decision maker is not on "location", or does not have updated information, decisions are based on the information available. The available information may not be up to date, and may also not be sufficient. In such circumstances, if proper information usage is to be made for effective decision making, up to date and sufficient information must be accumulated (Akinsola et al 2000).

Technological advancement in ICT such the usage of the World Wide Web (WWW) for information exchange management, independent of time and location constraints is fast becoming a medium for distance communications. This section will look into the different ICT tools and systems that could help to make quick and effective management decisions.

3.2.1 Model Based Cost Estimation

The model based cost estimation provides an easy tool for consulting, contracting and maintenance corporations to generate quick and accurate cost estimates despite different data formats and standards as applied by different project participants.

Concept
The main idea of this technique is the transformation of heterogeneous design information into a product model for cost estimation and construction planning. This is made possible through a product model as illustrated in Figure 3.
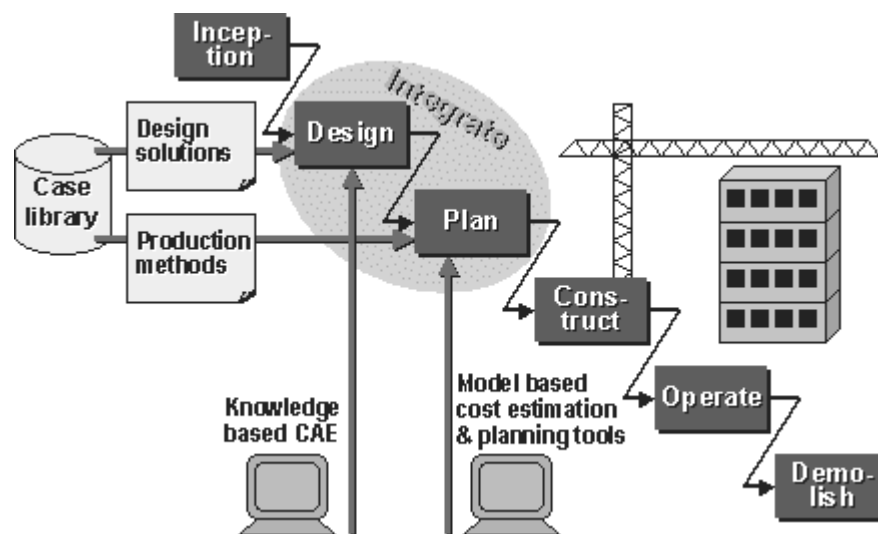
Figure 3: Conceptual Illustration of COVE System (source: http://www.vtt.fi)

Technology/Software
Model based cost estimation could be implemented through a software application COVE® (Cost and Value Engineering). This is a CAE (Computer-aided engineering) tool that generates a product model based on heterogeneous data and information feed-ins. COVE is used through design++, a knowledge engineering tool. All user inputs are passed through a user interface to Design++, which then accordingly controls the CAD engine. In summary, heterogeneous data is "intelligently" transformed to yield an object-oriented product data model (Hannus and Kazi, 2000).

Application/Benefits
The application of this technology is primarily for designers and contractors during both cost estimation and tendering stages. Through the developed product model, significant reductions in tender preparation time may be achieved in addition to more accurate cost estimates and the possibility to reuse standard company solutions.

3.2.2 On-Line Bidding

On-line bidding facilitates the bidders to submit and edit their bids on-line thereby resulting in great time and cost savings.

Concept

The concept behind on-line bidding is the same as behind other on-line applications. The contractors can submit their bids on-line using secured servers. After the closing date, the client can download all submitted bids and make the decision. An illustration of how an on-line bidding system works is shown in Figure 4.
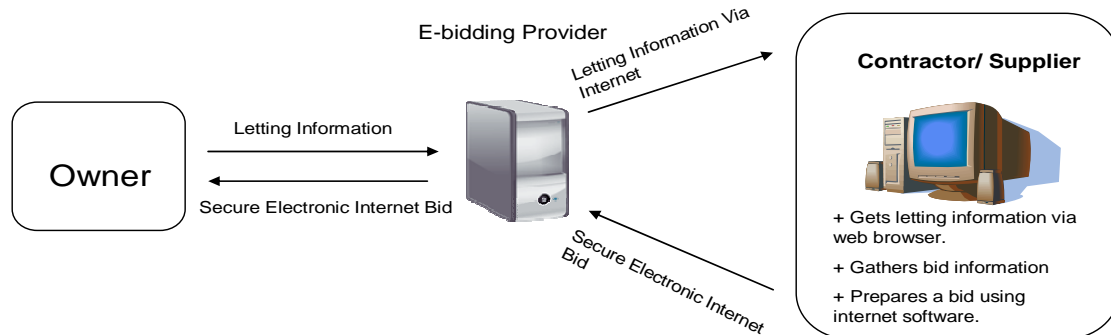

Figure 4: How the E-bidding Works? (Source: http://www.bidx.com)

Technology/Software

Different on-line bidding systems are now available in the market such as Invitation to Bid® and Bid Express®. The Bid Express™ is operated through the web-site http://www.Bidx.com. Contractors that want to submit the bids over the web must subscribe to *Bidx.com*, which costs $25 a month, and must have a digital signature on file at the exchange side. They submit bids as encrypted files to be held in an electronic lockbox until the deadline. When the time comes, the box contents are downloaded by the client, which uses electronic keys provided by registered contractors to open the bids. Until the moment of delivery, the client does not have access to the bids and the exchange service does not have the service to decode them. This setup ensures the security of the system to stop any act of fraud and hacking (Sawyer, 2001).

Benefits

The on-line bidding allows the contractors to submit their bids at any time and from any place and the flexibility to edit them till the closing date.

3.2.3 Shared Project Databases

Shared project databases are gaining wide acceptance in the realm of construction information management. They allow the storage and retrieval of data from a central location independent of time and locational constraints as depicted in Figure 5.

Concept

The basic idea behind shared project databases (or data warehouses) is to gather all relevant project information in a central location to allow for all project participants to access the same information. This in turn helps speed up the decision making process, reduces data and information redundancy, and hence contribute to cost reduction.

Technology/Software

Technology/Software requirements for implementation of shared project databases are not complex. A databases server is required with which project participants may establish remote connections to retrieve and provide information to the project database.

Application/Benefits

The use of shared project databases extended to virtually all project participants. Usage typically is during the project life cycle. Upon completion of the project, the information stored within the project database may be used as historical information feed-in for future projects. Participants can contribute to and gain from the shared project databases from any location with a connection to the Internet.
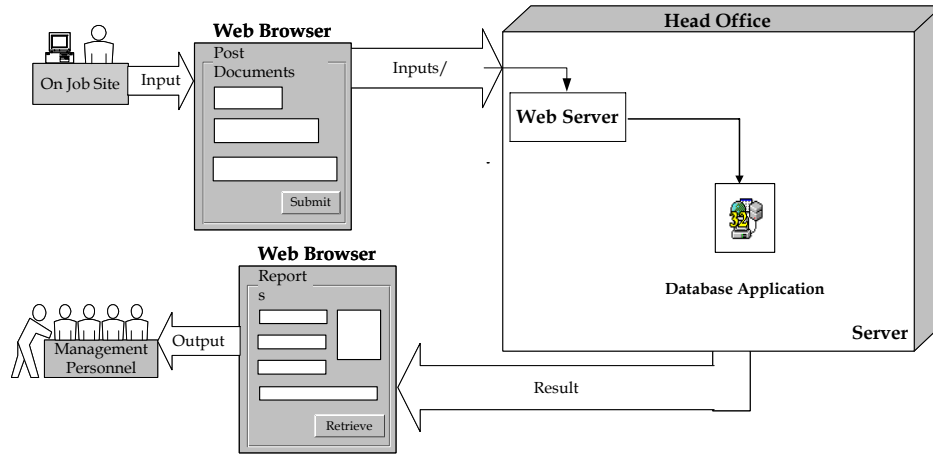
Figure 5: Schematic View of a Web-based Shared Database System

3.2.4 On-Line Building Information Services

The On-line building information services include well-documented indices and catalogues of building products and services provided by different companies.

Concept

The main concept of such services is to guide the potential customers about the desired products and provide them quick details and cost estimates.

Technology/Software

No complex technology is required for such a service. The service is provided through the Internet in addition to packaged CD-ROMS by many vendors and suppliers.

Applications/Benefits

The application of such a service provides a valuable source of information to construction professionals. Major usage of this service is during design and procurement stages.

3.2.5 On-line Project Administration Systems

The on-line project administration systems can provide round the clock information about the project such as project status; directory of contractors, consultants, vendors and suppliers; project drawings and specifications; project control reports and the facility to submit on-line change orders (Ahmad et al., 2002).

Concept

The concept behind such systems is to facilitate better communication between the head office and the remote project sites, which could result in both time and cost-savings.

<u>Application/Software</u>
Various softwares are available such as Webster for Primavera®, MS Project for Net® etc. Other technology required is high-speed computers with fast Internet access.

<u>Benefits</u>
These systems provide a way to make dispersed construction groups to work collaboratively together as an effective single team sharing pictures, documents, and real-time videos.

3.2.6 On-line Project Monitoring and Control

On-line project monitoring and control can be done effectively through the use of Web cams which provide continuous pictures of the project site regardless of weather and safety conditions for monitoring and control purposes as illustrated in Figure 6.
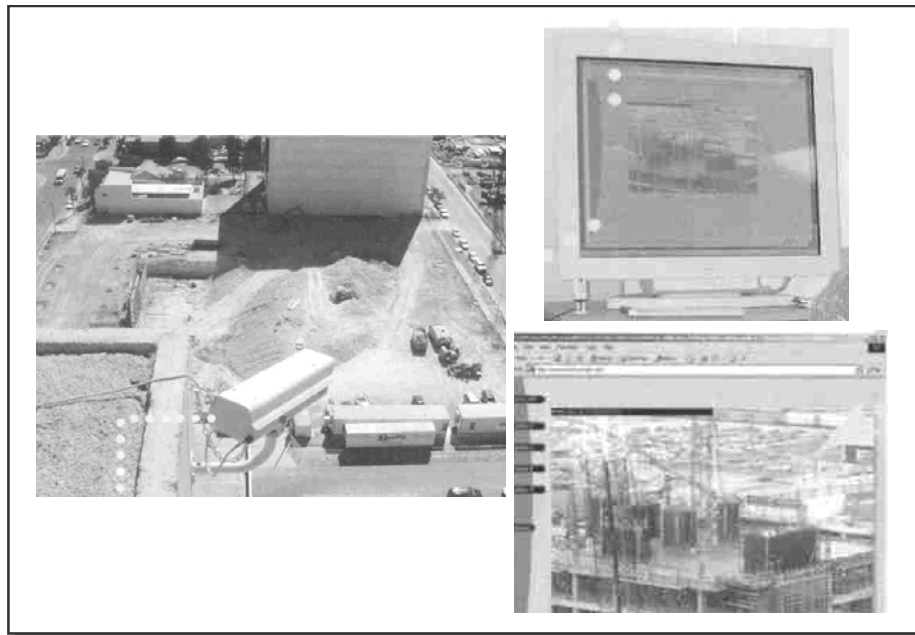

Figure 6: On-line Project Monitoring using Web Cams

<u>Concept</u>
The concept behind this technology is to get round-the-clock digital views to monitor and control project while sitting in the head office or at a remoter place.

<u>Technology/Software</u>
A typical construction site uses three cameras, two stationary and one pan tilt, which costs $10,000 to purchase, install and set up. The cameras typically shoot one picture per hour but the system can be handled as many as one shot every 30 seconds. The pictures are transferred through Internet to the company's head office or wherever required.

<u>Applications/Benefits</u>
Web cams could be used for project monitoring and dispute resolution. They can help resolve critical-path delays caused by other parties or by Act of God such as floods and can also be used to stop workers' compensation fraud.

4. Conclusions

In this paper, it is shown that the information and communication (ICT) technologies could play a vital role to bring greater integration in the construction industry. Significant benefits can be realized by developing appropriate ICT solutions for the construction industry. It is expected that with the easy availability of cost-effective ICT tools, the traditional concept of project management will be replaced by revolutionary ideas. This change would result in significant savings in time, cost and resources. Less disputes and better coordination are expected as a consequence of increasing use of ICT solutions.

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