The SMART System Project: A Strategy for Management of Information and Automation Technology in Computer Integrated Construction

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ABSTRACT

In today's construction industry, information and automation technology must be viewed as potential resources. Computer Integrated Construction (CIC) is an emerging technology, and it is an approach to assisting construction firms respond to the difficult environment in which they are operating currently. There is no standard formula for CIC. A strategy for implementing CIC should be formulated, and promoted at the highest company level. To demonstrate the concept of CIC, a prototype system should be introduced to investigate integration problems. It only presents a way of approaching the CIC.

SMART (Shimizu Manufacturing system by Advanced Robotics Technology) system is a part of Shimizu's strategy for developing CIC based on site automation systems which automates a wide range of construction process. It also integrates a wide range of design, planning and management activities of the project. By introducing SMART system, amount of labour required and the construction period are both reduced significantly, and the planning and management productivity is increased.

The objective of this paper is to describe the strategy in management of information and automation technology development from a Japanese construction company's view point, and to present a prototype model for CIC implementation. Although the prototype system is not established as a comprehensive system, it can be viewed as a strategy toward a total CIC.

Key Words

automation; computer; integration; construction; robotics; information

INTRODUCTION

Today, Japanese construction firms, which might be defined as Architectural/Engineering/Construction (A/E/C) firms are beginning to

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realize that it is vital to have a structured approach to the introduction of CIC technology. One reason for this is that, using CIC, it is likely that a completely different and efficient way of construction process may be developed. The other reason is the tremendous advantage to be gained by enabling computers in different sectors of the company to communicate and exchange information.

However, there is no standard formula as to how a company should adopt CIC. All construction companies operate in different ways and in different market places, and each one must devise its own CIC strategy for success. At present, a full CIC implementation does not exist in any construction firm. Usually the initial problem in the development phase is the lack of a methodology to explore a CIC initiative and there is not a general set of management procedures to address the CIC opportunity. Therefore it is important to improve the theoretical substructure for CIC implementation. Given the complexity of the problems in the construction industry, it is not useful to seek final CIC solutions. Rather, managers must establish a learning environment that will continually guide the company towards improved systems.

The objective of this paper is to describe an approach to CIC implementation from a Japanese construction company's view point, and to present a prototype model for CIC. The model is not intended to be the ideal CIC, but rather for the demonstration of the CIC concepts and strategies. It is essential to recognize that moving towards a CIC system does not mean simply introducing higher levels of computers and automation into an existing system. Adding automation to an inefficient system will likely produce a highly automated yet inefficient system.

CIC Definitions and Expected Benefits

Computer Integrated Construction (CIC) is the adaptation of Computer Integrated Manufacturing (CIM) in the construction industry. It is defined as a strategy for linking existing resources, technologies, processes and organizations to optimize marketing, sales, accounting, planning, management, engineering, design, procurement and contracting, construction, operation and maintenance, and support functions.

For many reasons, mostly political as well as economical, many large construction firms in Japan have started the CIC process with the integration of design and construction operations. However, the ultimate goal in any company should be to integrate all of it's operations. CIC is a concept of a totally optimized, integrated company.

The enhancement of a company's competitive position by CIC implementation in the construction industry has both operational and strategic benefits.

The operational benefits are: (1) Construction and design productivity improvement through automation; (2) cost reduction; (3) project time schedule optimization; (4) quality improvement of design and construction; (5) coordination and management improvements; (6) design integration; (7) flexibility in design and constructing of innovative facilities; (8) concurrent performance by various departments; (9) communication improvement by rapid transmission and availability of data, images, and knowledge; (10) avoidance of similar data entries in design and construction processes; (11) opportunities for further construction robotizaion; (12) opportunities to electronically link with subcontractors, suppliers, insurances, banks, vendors and bonding companies.

The strategic benefits are: (1) Improvement of the company's competitive advantage in the marketplace by specializing in CIC; (2) capture of expertise; (3) better relationship with client; (4) improvement of company's image; (5) increase market share; (6) less dependency on skilled labor; (7) staying at the forefront of technology; and (8) enhancing from local optimization (individual department system) to global optimization (company-wide integrated system).

A Concept of CIC Implementation

Conceptual Modeling of CIC

To establish a strategic approach to efficiently develop CIC, it is important to share a general model of CIC among project participants and the top-management. Figure 1 shows a simplified model of the CIC system to efficiently integrate A/E/C process. The model is divided into three major elements: (1) Integrated design/construction planning, (2) site automation system, and (3) factory automation. These elements are described in the following section.

Integrated Design/Construction Planning System

Recent innovations in computer software technology in such areas as: knowledge based expert systems, database management, simulation, 3-D CAD systems, engineering and management application software, and object oriented programming have provided a useful mechanism to integrate, organize, and structure complex design and construction planning information.

The major elements of the integrated design/construction planning system consists of: planning (resource planning, site planning, financial planning), preliminary design, engineering, detail design by 3-D CAD, working drawings, cost estimating, procurement, cost control and planning, working drawings, construction planning (scheduling, temporary facility planning, etc). Currently, portions of these systems are integrated under a central CAD system, and research is in progress for total integration.

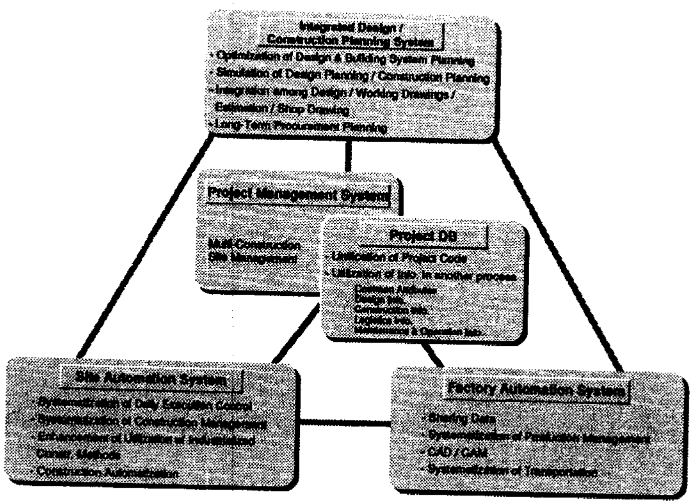

Figure 1. A Conceptual View of CIC Components

The main challenges of CIC in this area are constructability in planning and management. To solve the integration problems there is a need to further investigate and design a well-structured data and knowledge-based system.

Factory Automation System

The second major element of CIC is factory automation. It could be established temporary on a construction site, or it could be a permanent factory in a remote area. Such a system is an automated prefabricated factory of construction units, and its operation is very similar to CIM.

In the automated factory the process of: material handling, process control, inventory management, and production line are to be automated and integrated, that is the Just-in-Time (JIT) way of working. Originally known as 'Kanban' when it was developed by Toyota in Japan the principal of the just-in-time philosophy is that every process in the production cycle happens just in time for the next. For instance, in a construction site, material such as steel for framing arrives at the site just in time to be installed. This is an ideal state of operation for a construction site. Although it is difficult to achieve a JIT system, the philosophy presents a perfect target to have in mind when implementing CIC.

Site Automation and Management System

The third major element of CIC is construction-site automation. Presently, developmental efforts are being focused on fully automated construction systems which can handle major structural assembly operations such as steel frames of medium to high rise building. Site automation as an integral part of an CIC plays an important role. It provides a protected working environment, improves productivity and safety, and resolves some of the difficulties associated with application of single-task oriented robots.

The site automation systems utilizes a self-elevating automated assembly platform which provides an integrated building construction environment. In general, this system consists of: (1) transportation of prefabricated materials from a prefabricated factory (or material supplier) to the construction site (exterior transport system); (2) automated storage facility of material on site; (3) automated transportation of material from the storage facility to the building by conveyor cars, overhead cranes, automated elevators, lifts, conveyors, and/or automated guided vehicles (interior transport system); (4) automated placement and adjustment of the prefabricated material elements; and (5) assembly of elements by robots.

Now, in the US, Europe and Japan, several projects have been undertaken to develop CIC technologies from different viewpoint. In general, the US and European approaches are rather conceptual and emphasizes developing computer technologies. Their strategy is mainly to integrate design, estimation and construction planning under 3D-CAD system and project database to improve the productivity of design, engineering and management. In contrast, Japanese approach is more interested in the field of construction automation. The approach is to integrate construction system and automation system under integrated design and construction planning system to improve the productivity of whole project process.

SMART System Project: A Strategy for CIC Implementation

To demonstrate CIC concept depending on the strategic approaches, a prototype system has been developed to investigate integration problems, as an example of full scale CIC implementation. SMART system project is a major challenge of Shimizu's strategy for developing practical CIC which integrate construction process from the foundation to the site management, including structuring, finishing and installation works. When introducing SMART system, a management methodology of automation and information technology should be established to effectively utilize technological and organizational resources in reducing the amount of labour and total project period required. Although it is not developed as a comprehensive CIC system yet, however, major areas are automated. This prototype system describes a step toward a total CIC system.

Formulating of subsystems was started on from several years ago. In the fall of 1990, a core technology for system composition was implemented for the first time. Taking the results into consideration, the technology was introduced in a full-fledged manner at a project commenced in the city of Nagoya in the fall of 1991, and this project is presently in progress.

Project Goals

Final goals are set up by top-management based on the forecast for the shortage in construction labor and innovations in construction processes as following:

Total Project period reduction	50%
Construction labor reduction	50%

To attain the goal, step by step approach and goals are set up to develop components and elements of the SMART system. The development is being performed at the second phase, in which the goals of both construction period reduction and labor reduction are 20% of present norms. Then goals in next phase will be set up as closer to the final target, expanding components and elements of the SMART System.

Project Organization

After goals and project procedures were approved by top-management of the company, project members are assigned to each component of the SMART system. The members of the project should have a general and functionally broad background in order to contribute to define the goal of CIC and to explore the requirements into more functional components and more detail functions as SMART system.

Since CIC presents many changes in working practices to a company's work force, job descriptions become less specific because of the integration of the different functions. For these changes to take place smoothly, the work force must be informed of the intention to implement the CIC technology, and required training must be offered. The work force must feel involved in the development of CIC and the change should proceed in an atmosphere of excitement. Human motivations have as much influence over the success or failure of the project as finance and technology.

Therefore, the leading force for CIC must be a multidisciplinary team. This team not only includes representatives from different departments but it should also feature a mixture of personalities. Those of an adventurous, enthusiastic nature are essential to keep momentum going, while others of a pragmatic and skeptical outlook must also be included. As the SMART system project progresses through its different phases, the skill mix and roles of the team members will change. In the early stages when the requirements are being planned and the concept designed, the work is more exploratory and analytical. During detailed design and implementation, it is more technical.

Automation Technologies in SMART System

SMART system automates a wide range of construction procedures, including: the erection and welding of steel frames; the placement of pre-cast concrete floor planks, exterior and interior wall panels; and installation of various units. The system utilizes prefabricated components extensively including columns, beams, floorings and walls, and the assembly of these components is simplified by the use of specially designed joints. In addition, this assembly process is orchestrated by real-time computer control, resulting in construction site operation in a highly automated way.

The heart of the SMART system is composed of the lifting mechanisms and automatic conveying equipment installed on the operating platform, which is ultimately to be the top roof of the building. Steel-frame columns, beams, floorings and walls are automatically conveyed to designated locations, where they are effectively assembled and mounted with specially made joints.

The steel-frame welding process is also automated with the invention of an automatic welding machine. When one of the floors of building is completed, the entire automated system is lifted vertically and the work for next floor commences immediately. Thus construction work proceeds systematically, floor by floor, until the whole building is completed.

The SMART system also provides complete all-weather enclosure for site, accommodating satisfactory working conditions and safety, and leading to higher quality and durability for the product.

Information Technologies in SMART System

Information management systems in SMART system has been developed and tested through several construction projects. Figure 2 shows a current architecture of information integration, which covers three major components: 1) real-time monitoring of transportation and assembling process of building elements, 2) management of design and construction planning information, 3) management of construction process information and logistic information, with mixed utilization of several kinds of databases and networks.

The first category is mainly to support data and information transaction between operators and machines depending on the sophisticated real-time computer control system which orchestrates whole assembling process, resulting in construction site operation in a highly automated way. Some machines have an autonomous style in information systems. The automated welding machine determines welding conditions and position of welding equipment using lazar sensor and database which stores knowledge of skilled workers. Also, the automatic material transportation system transfers materials and parts for fitting decorations based on transportation scheduling system.

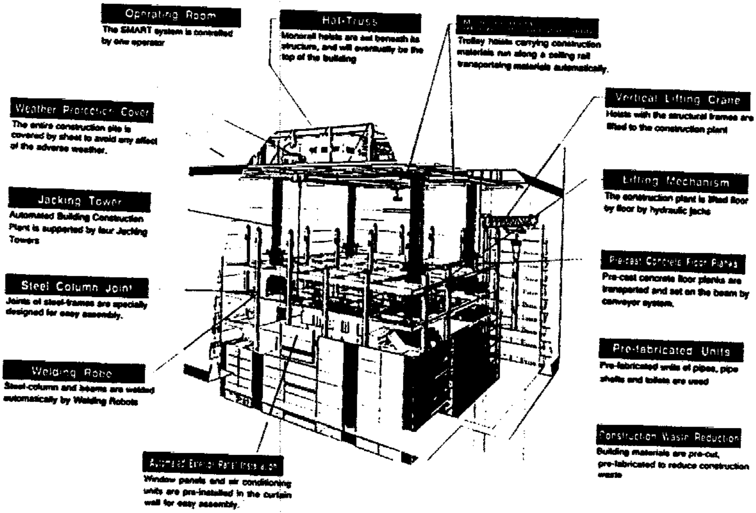

Figure 2. Components of SMART System

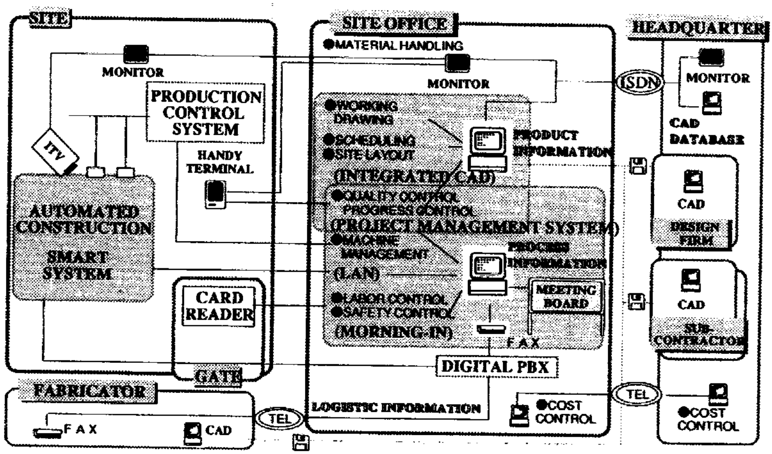

Figure 3. Information Integration in SMART System

The second category is mainly to support cooperative decision making among designer, engineer and construction planner effective utilization of

CAD system. When an automated construction system is to be introduced to a construction project, design documents and specifications are not completely defined by designers and engineers, that means cooperative investigation among designer, engineer and construction planner at project planning stage is extremely important. The CAD system support the cooperative investigation through distributed responsibility for producing design and construction information, which are stored in particular layer of database and are managed their consistency.

The third category is mainly to support communications among site managers, subcontractors and suppliers depending on site management system, which efficiently produces and transfers production information and process information utilizing computers, handy terminals and IC cards as data input and acquisition tools, a electric board as a presentation tool, and LAN and ISDN as networks.

The first category of information system has been developed to only be applied to the SMART SYSTEM at present, but other two categories of information systems have been developed and tested in several construction projects and been improved and integrated for the SMART SYSTEM. Thus information management at the site is made efficient with SMART system as well, thereby reducing the amount of the waste, and improving overall site management and scheduling.

Strategic Approaches to CIC Implementation in the SMART System Project

To develop the SMART system, CIC implementation activities consist of four major task-forces to efficiently explore research and development activities shown in Figure 4: cooperative research projects, concurrent technology development, implementation in pilot projects, and establishment of infrastructure.

Cooperative Researches

Relevant innovative computer based technologies are known as: OOP (Object Oriented Programming); KBES (Knowledge Based Expert Systems); DBMS (Data Base Management Systems); CAD (Computer Aided Drawing/Design and visual computing); Robotics and automated systems; Computer Aided Engineering (CAE); Computer Aided Testing and Quality control (CAT); and Local Area Networking (LAN). Also automation technologies such as Robotics and Real-time Monitoring play an important role in CIC implementation.

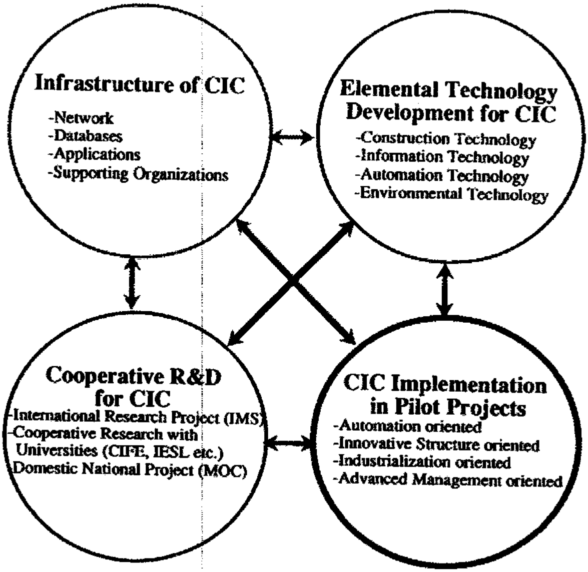

Figure 4. A Strategic Approaches in CIC R & D and Implementation

These CIC technologies should be tested by reflecting situations of the construction industry both at present and in future and then a scenario for a computer integrated construction system should be established through applications of such innovative technologies to construction technologies. Also, the move towards CIC must be accompanied by a change in philosophy and method of organization, to approach the Intelligent Manufacturing System (IMS), which manufacturing industry aims to develop as international collaborations.

Cooperative research projects are usually set up among industry, academia and government at the beginning of research stage, to efficiently introduce innovative technology at less risks with economical, regulating and organizational problems.

After evaluating and acquiring the technology, participants start their original development programs based on the initial research efforts.

Technology Development at Component and Element Level

Technological aspect of CIC is divided into three areas: 1) extensive utilization of information technology, 2) practical application of automation technology, and 3) improvement and innovation of construction technology including design, engineering, planning and management methodology.

To efficiently develop innovative systems, it is important to clearly define product characteristics and explore their requirement to elemental technology development programs. Since these technologies to be developed are critical among several products, development projects are often established at the element technology level, in which these technologies are concurrently developed, as shown in Figure 5.

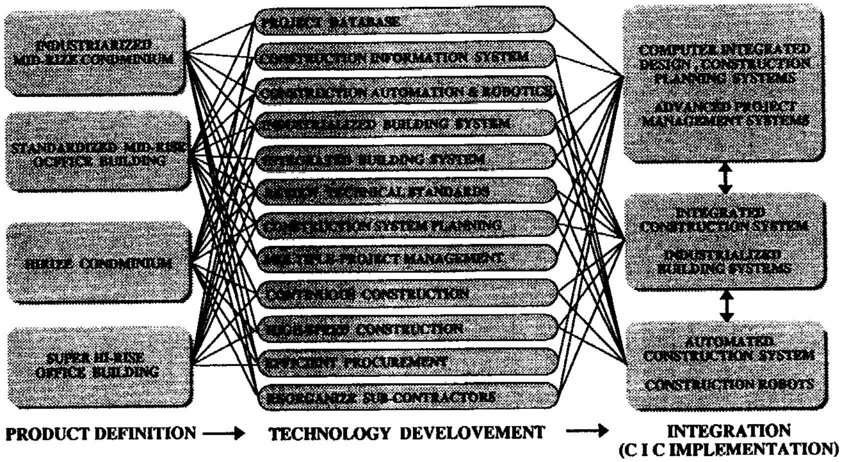

Figure 5. A Configuration of Technology Development Process in CIC

Information technology and automation technology have been identified as essential components of construction technology development programs since the beginning of 1980's as well as industrialized construction technologies and innovative structural technologies. Through this phase, several construction robots for steel erection work and material transportation work have developed as parts of SMART system, as well as industrialized building systems, integrated construction systems and sophisticated information systems.

At present these programs are integrated into the development integration technology for CIC including the SMART system project. The systematized construction technology development programs have been supporting the foundation of research and development strategy in Shimizu, and promise efficiency and productivity in technology development process.

CIC Implementation in Pilot Project

According to the progress of technology development, it is important to totally implement and evaluate CIC systems in several types of construction projects, because integration problems are often identified in interfaces between components and elements. Since evaluation methodology of productivity, efficiency and performance of innovative systems is difficult to set up at the beginning of development, integrated application of subsystems poses high priority on implementation of CIC in pilot projects. Several types of pilot projects are chosen to be applied CIC subsystems under development, which focuses are rather different according to project initial conditions.

The first total implementation with SMART system was experimented in one of our laboratory buildings to investigate efficiency of automatic conveying and assembling system by computer control. Availability of special joints of steel-frame and lifting mechanisms of operating platform were also evaluated with collected data to improve their mechanism.

Through simulation using the data collected through the experimental construction and applications of sub-systems, the current project goal were setting up to reduce 20 % both in productivity and construction period. Thus goals are step by step setting up based on the evaluation.

Establishment of Infrastructure

Communication system is the backbone of every CIC implementation, which allows the transfer of information from one person and/or computer system to another. Different computers and information generators must be able to communicate with each other. It should be realized that communication is needed at several levels in a construction process. Establishing an effective communication network as major infrastructure of CIC is, however, more difficult than it may at first appear.

It is important that messages being originated almost simultaneously receive the correct priority, and that accurate data arrives at the desired final destination. Three major factors to be considered in the infrastructure establishment are: compatibility, expandability, and reliability. Therefore several types of networks were chosen in the SMART system project as shown in Figure 2.

Evaluation of Productivity and Efficiency in SMART System at Current Stage

This section summarize the efficiency and productivity of SMART system at present. Through simulation using the data collected in the experimental construction and application of sub-systems to real construction projects, we have already achieved 20 % of our final target in both productivity and construction period at the first experimental construction of our building two years ago.

With steel-frame erection activities, 40% of labor reduction and 20% of construction period reduction is forecasted with simultaneous application of assembling system and transportation system . With steel column joint activities, 200~300% increase in labor productivity is forecasted, by introducing automated welding machine.

With the application of information integration, productivity is hard to measure, but procedures of construction process are continuously improved and project participants are highly motivated.

In the future, the SMART system is developed even further, reducing labour and the construction period to the half of the present norms, and attaining highly motivating environment.

CONCLUSIONS

In today's construction industry, information and automation technologies must be viewed as potential resources. CIC is an emerging technology, it is an approach to assisting construction firms respond to the difficult environment in which they are operating currently. There is no standard formula for CIC. A strategy for implementing CIC should be formulated. The implementation needs a clear policy relative to four issues: cooperative research, elemental technology development, implementation in pilot project, and establishment of infrastructure.

The greatest impact of higher efficiency and productivity in A/E/C industry will be brought by construction process innovation, that is CIC. Shimizu is now trying to develop a practical CIC system. One of the key challenges for CIC is the SMART system. The challenge will go into the 21st Century to be explored to space construction. Therefore, CIC implementation needs a clear strategy for long term and promotion at the highest company level. Also, international and inter-disciplinary cooperative research and development among academia, government, and private sector are required in order for these challenges to come to their fruition.

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