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## **COMPUTER-INTEGRATED MANAGEMENT SYSTEMS FOR MEDIUM-SIZED CONTRACTORS**

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### **ABSTRACT**

This paper examines integrated computer systems for the construction industry—in particular, for “medium-sized” contractors who carry out much of the construction work performed in this country. The main focus of the paper is to evaluate the practical barriers, challenges, and opportunities facing the design and development of these integrated systems. The paper addresses the practical organizational and computing context in which such systems must be used, identifies the major project views or perspectives adopted by both project participants and software applications, describes the major areas of potential benefit offered by integrated systems, and outlines three major design and development areas that must be addressed for future systems. In this last section, the paper briefly introduces a number of projects carried out by the authors that address some of these design challenges and presents a road map for an ongoing research program for computer-integrated management tools for the construction industry.

## INTRODUCTION

Much of the current research on computer tools for the construction industry centers around the goal of “integration.” Greater information exchange among sophisticated computer-aided design and management software offers significant potential benefits. While the approaches adopted by various researchers and developers differ, all involve extensive computer use throughout the construction project life cycle. In contrast, the construction industry itself remains slow in embracing even well-established computer tools. In particular, medium-sized contractors, who perform the majority of building construction work, do not seem ready to adopt high-end computer integrated management systems. This paper examines the construction and computing context in which integrated computer tools must operate, identifies the major project views exhibited by construction software, discusses the potential benefits and impediments of integrated systems, and outlines design challenges involved in creating practical integrated systems for medium-sized contractors. It also introduces some of the past and proposed research efforts carried out by the authors in the area of integrated construction management computer systems.

Our focus is on firms that construct projects which range from a few million to tens of millions of dollars—the vast majority of building and civil engineering projects and firms. These firms, which we refer to as *medium-sized contractors*, generally do not offer design services nor possess the resources and expertise required of the sophisticated systems used by EPC firms. The way in which these firms staff and run projects and internally manage project information services has important implications for the design of management systems. *Integrated systems* in this paper refer to systems that offer one-stop shopping through a single software system or, more likely, through sets of separate application programs which share common process models and common databases.

## CONSTRUCTION AND COMPUTING CONTEXT

An assessment of the potential for integrated systems for medium-sized contractors must be founded in an understanding of the industrial, working, and computing environment in which they perform. There are several characteristics of this environment that place unusually difficult constraints on the feasibility and practicality of integrated computing systems. While the physical environment itself is challenging, the organizational and human resource environments provide the most significant challenges. Like other large business ventures, construction projects are carried out by large and complex organizations (hundreds of individuals). Unlike many other ventures, however, this large organization is made up of many much smaller companies (several dozen) whose involvement in the project changes rapidly over the relatively short project duration (one to three years). The cut-throat nature of construction leads to low profit margins and, correspondingly, to small management teams, low investment in computing and other forms of management support tools (it is still common, for example, to have *no* computers in construction site offices), and little investment in training.

To illustrate the typical situation we have encountered with medium-sized contractors, general contractor site staff typically consist of a project manager, a site superintendent, maybe a foreman, a safety officer, a site secretary, and a project engineer or coordinator. Additional support is offered through head office dealing with estimating, cost accounting,

client relations, and so forth. Cost accounting, a head office function, is the one computerized project views that is used and enforced without fail within a firm, and is generally adequately staffed. It also has the advantages of the existence of standards (some government imposed) and relatively comprehensive software systems, which cannot be said for any other computerized view.

The most prevalent computer tools used directly by project personnel at the site or in head office are word processors, spreadsheets, and to a lesser extent, database and CAD software. The value of these tools lies in their relative ease of use, advances in integration and common interfaces, and most of all, the flexibility they offer to the user in crafting procedures and formats that respond to the project manager's view of how he or she wants things done. In terms of project management systems used—most of which focus on planning, scheduling and associated activity-based functions such as resource planning and leveling, cash flow forecasting, etc. (few of which are used)—adherence to a single system is seldom done. The desire to do so, if it exists, is lessened for at least two reasons. First, clients may contractually specify the use of different systems. Second, the restricted set of project management functions treated by these systems means that many of the essential duties performed by project management personnel are little affected by the choice made. Thus, the selection of a project management system can depend on what system the most junior, computer literate member of the project team is familiar with, as this person will be responsible for preparing and maintaining the schedule, with some input at the beginning from the project manager and project superintendent. Further, varying degrees of reliance are placed on the project plan and schedule and the system used to generate it. The schedule is often seen as something more for use by the owner or his agents than by the contractor himself. Consequently, the plan and schedule often lack the detail essential to be useful road maps and strategic tools for guiding the project (e.g., procurement, inspection, and commissioning activities may be missing, logic may be incompletely defined yielding unrealistic float values, etc.), lessening dependency on the system used to generate them. The contractor will often rely mostly on “throw away” short-cycle schedules that are produced either manually, using a spreadsheet, or using a generic planning and scheduling package as opposed to a more complex system capable of supporting a number of project management functions.

We have observed that planning, scheduling, and supporting functions are seldom accorded a prominent role in the firm. Few, if any, resources are provided for formal training in project management software and related functions, and money is rarely allocated to the development of custom software. Those filling the role on a transient basis are either junior engineers or building technologists who have acquired basic planning and scheduling skills and some exposure to current project management software while in school. But they soon realize that there is no future in specializing in planning and scheduling, and inevitably they aspire to become project coordinators, project managers, or occasionally, project superintendents. Thus, there is a lack of continuity in staffing for computerized support of project management functions (the same cannot be said for cost accounting or estimating which are seen as the life blood of the firm). In some cases, this leads to a contracting out of selected project management functions, especially planning and scheduling, resulting in a loss of expertise internal to the firm, ownership of project schedules, and the ability to modify plans and schedules on an ongoing basis in order to respond to actual project environments. (As soon as the service is contracted out, one of the objectives becomes to minimize consulting costs, leading to fewer schedule revisions and updates.)

## PROJECT VIEWS

Fig. 1 categorizes construction related software according to its role in supporting four different but interrelated views that describe a project. The physical and environmental view of the project describes what is to be built in terms of geometry, topology, physical systems, materials, etc., and the physical, economic and socio-political environment in which the project will proceed. The process view—the main focus of this paper—describes how the project will be constructed, who is responsible for different aspects of the work, when it will be done, and where. The cost view deals with the cost structure of individual parts as well as the overall project from various perspectives (subtrades, general, owner), and involves initial cost estimates and cost tracking throughout the construction phase. The as-built view describes what happened during the journey, why, and what actions were taken.

As noted in Fig. 1, some redundancy exists in the software and data used to support the different views. Such redundancy is one indicator of where beneficial integration or communication strategies may be pursued. Currently, much of the input required for use of many of these software applications is derived from other applications, but no interface exists between the applications.

Fig. 1 can be used to classify ongoing research work in terms of its contribution to improving existing tools, developing new ones, developing standards and supporting structures for them, and pursuing integration and communication among functions. Our focus here is on the last three items, although we note that considerable research is still directed at improving existing tools (resource modeling, activity modeling, simulation, etc.). Examples of new applications in support of process views include Hornaday et al. (1993), Tommelein and Zouein (1993), Ioannou and Liu (1993), and Kamarthi et al. (1992). Examples of new applications in support of as-built views include Russell and Fayek (1994), Yates (1993), Russell (1993), Abu-Hijleh and Ibbs (1993), Diekmann and Gjertsen (1992), and Roth and Hendrickson (1991). Work on integration, communication, and product modeling in support of these strategies includes Froese (1995), Teicholz and Fischer (1994), Parfitt et al. (1993), East and Kim (1993), Carr (1993), Miyatake and Kangari (1993), Björk (1994), Evt et al. (1992), and Rasdorf and Abudayyeh (1991). Much of this work explicitly or implicitly assumes an application to large projects with highly skilled users and high-end hardware environments.

Fig. 1 can also be used to help in identifying data flows and overlaps among functions. This analysis can be used to assist in determining which components of the different views could be beneficially integrated (e.g., much of the process and as-built views), what communication links should be developed, and where standard models should be formulated to assist the integration and communication tasks.

## THE POTENTIAL OF COMPUTER-INTEGRATED MANAGEMENT

While integration of construction computing systems is currently an active research area, we believe that the exact role that integration has to play in the industry and the specific benefits that it has to offer have not been well established. In this section, we briefly reflect on the potential benefits from the viewpoints of researchers, system developers, and end-users.

The benefits of integration are often presented by the research community in terms of increased “*information sharing*”. Computer integration, it is argued, will lead to improved

communication among computer systems which will, in turn, lead to better information sharing among project participants. Not only will this reduce errors and inefficiencies resulting from inaccurate, untimely, or missing information, but it will help foster better coordination and cooperation of the highly-fragmented construction participants. In our view, this argument is at least partially borne out. Fig. 1 clearly shows that many of the construction management processes rely heavily on information produced by others in separate phases or views of the project, and the quality, efficiency, and timeliness of these processes must partially depend upon the quality, efficiency, and timeliness of their required information inputs. From the perspective of the project client, any increase in the quality and quantity of information available to all participants *can only increase* the ability of the participants to serve the client's needs.

However, providing, and even using, this information is not without cost to participants. Information produced within one company for use by others must be of higher quality and rigor than information intended for internal use only since the company no longer has control over how the information will be used. Under current project relationships, a company gains no added value or profit from sharing information, yet it maintains full liability for the information's use or misuse. Similarly, a company that uses information shared from another company will not, without extra effort, have as much knowledge of the appropriateness and accuracy of the information as it would for information generated internally. Even internal information sharing creates increased dependencies among company personnel and departments, and prerogatives for selecting systems to use, especially for site personnel, may be diminished or lost.

Given these barriers, the areas where organizational motivation for increased information sharing may be most likely to exist are, first, information sharing among the various applications used within existing project teams, and second, electronic sharing of information that is already generally distributed in paper form, e.g., project plans and specifications, contracts, schedules, etc.

From a system developer perspective, a case can be made that the more specialized to one audience (e.g., the construction industry) and integrated (e.g., function and feature rich for a specific industry) that software becomes, the less viable it becomes commercially (the market gets significantly smaller and the low price mentality created by "shrink-wrapped" software precludes the high prices implied by a small market). This is an impediment to realizing the potential benefits offered from ongoing research on specialized advisory and planning and control tools for the construction industry. Our view is that integration strategies must be pursued that reflect the realities of the market place while seeking the benefits of full integration. Thus, a modular development strategy is desirable—create a core, generic system that has broad appeal to users inside and outside of the construction industry, and then develop specialist modules for different target markets that are an integral part of the user interface and that employ seamlessly shared product models and databases.

From an end-user or construction firm perspective, motivations for integration must come from any of the following:

- demonstrable cost savings at the level of the firm (e.g., less personnel);
- development of a competitive advantage (e.g., increase speed of delivery, preferential pricing from subtrades because of better coordination and management of a project);

- the capture and use of expertise from past and current employees (resulting in fewer mistakes, oversights, etc.);
- the creation of new opportunities (e.g., the ability to offer reimbursable pretending services in an attempt to acquire negotiated as opposed to lump sum work);
- enhancement of the company's image because it is seen to be on the cutting edge of technology;
- or the ability to support a much broader range of time-consuming project management functions.

## **DESIGN CHALLENGES FOR COMPUTER-INTEGRATED MANAGEMENT**

In this section we outline briefly our thoughts on some of the research and design challenges that must be resolved in order to develop integrated systems that respond to the realities of the working environment in which medium-sized contractors find themselves.

### Functional Design

The first challenge is to identify the function set and supporting information that should be included within an integrated system. While the current planning, scheduling and control process software would continue to form the central core of any integrated management software systems, this core must be extended in several directions. For example, because reference to the physical characteristics of the project on an ongoing basis is essential to construction of the project, information from the physical and environmental views of a project should be accessible. Passive representations (viewing only) of the project should be available in multi-media form. These would include scanned-in site photographs, drawings, finishing schedules and key contract clauses as well as parameter models which describe project scale and physical system characteristics. An ability to associate these representations (photos, building parameters) with other representations (e.g., activity and pay item) of the project is essential.

High priority should also be given to integrating the following process, cost and as-built views with the core software: initial schedule generation; short cycle scheduling (i.e., detailed hour by hour schedules); pay item reporting and applications for payment; documentation management; change order management; daily site reporting; automated analysis of current project status; completion report generation (post project analysis).

Challenges arising from these priorities deal with definition and support of other project representations, mappings to connect different representations, and the ability to work with knowledge in large chunks. Current process management software describes projects in terms of activity, organization and resource hierarchies (work breakdown structure, organization breakdown structure and resource breakdown structure). However, estimating, cost accounting and/or pay item representations used by head office or the client are not always derivable from these hierarchical structures, and yet project staff must analyze performance and report using them, as well as others such as physical and as-built documentation records (photos, correspondence, drawing list, etc.). Thus, generalized mapping schema in the form of many-to-many relationships are essential to broadening the function set supported. Enhanced usability of management systems could also arise from the ability to incorporate standards and previous experience in systems so that information can be manipulated in large chunks, coding can be standardized, and automated analysis schemes

devised. Examples include standard trade, phase, activity, cost code, and problem classification lists, subproject networks that can be scaled up or down depending on project parameter values, etc.

Several of these functions have already been integrated around a core project planning and scheduling software developed by the second author. These include computer-based daily site reporting (Russell, 1993); automated interpretation of daily site records to suggest corrective actions (Russell and Fayek, 1994); pay item and records management (English and Russell, 1995); and initial schedule generation (Russell, 1991).

### Data Representation

A second and fundamental challenge deals with the definition of the various representations supported by the integrated system. This requires rich and flexible formulations of product and process models for building form and systems, activities, resources, organization entities, cost accounts, pay items, documents, etc., along with the ability to create associations among them. The creation of standards for these models to facilitate general integration and communication is also a major challenge.

The first author has been involved in several aspects of developing such representation models, particularly models of the construction *process* to be used for integration across application areas. Some of these efforts include the GenCOM (General Construction Object Model) which provided a shared central representation for OPIS (Object-Model-Based Project information System), a series of prototype integrated applications that provided importing of a product model from a CAD system, automatic generation of a project schedule, project estimating, and scheduling, (Froese, 1992, and Froese & Paulson, 1994a). The Information Reference Models for AEC (IRMA) was developed at a workshop in 1992 as an exercise in combining several independent AEC project models (including GenCOM) into a single model of construction information (Luiten et al., 1993). While this model was intended more as a reference and comparison tool than an end product, it has served as a useful vehicle for further conceptual development. In 1993, the model was the topic of *IRMA-tica '93*, a electronic mail conference (Froese, 1993).

More recently, international efforts to develop standards in this area are gaining momentum (Froese, 1994d, 1995), most notably within the ISO International Standard 10303, STEP, (STandard for the Exchange of Product model data) (ISO 1994a). A work item is currently underway within the STEP AEC community to develop a building construction core model to be used as the basis for consistent information models throughout the domain of AEC projects and for exchanging information among these application areas (ISO 1994b). The general form of these standard core AEC project models is to define entities or objects that represent the primary elements of the construction project domain, e.g., product components, processes or activities, resources, actors, participants, etc. The models also define relationships among these elements and refinement hierarchies that represent the many specific types of products or resources, for example. Fig. 2 illustrates a simple, high-level core of such a model (Froese, 1994b).

### Application Architectures and Interfaces

A third major challenge is to define an architecture and interface for an integrated system. A schematic of the organizational schema and components to be included is depicted in Fig. 3.

The base module mirrors much of what is available in current project management software systems, except that it would support cost accounting and pay item views with appropriate mapping tools, and all of the optional add-on modules shown below would appear in the base system interface. Design of the add-on modules would be based on the product models used for the various representations supported by the base system. The actual implementations of these add-on modules need not (perhaps should not) be components of a single software program. Various integration mechanisms exist, such as common databases, standardized application programming interface sets, or general purpose translator tools.

Ongoing projects at UBC touch on several of these and other issues mentioned above. A “Good Practice” project being pursued by the second author is aimed at capturing the expertise and knowledge that goes into high quality planning and scheduling for high-rise construction and presenting it in a form that practitioners can utilize in planning their own projects (this functionality addresses several of the firm-level motivations for integrated management tools described above). A computer-based implementation of this template, StartPlan (Froese and Yu, 1994c), is being developed as a testing vehicle for the standardized process models described above. The basic approach adopted by StartPlan to capturing, generating, and storing a wide range of project information in a fairly generic manner and translating output information into a variety of application formats could be expanded into an architecture for a general purpose construction information storage and translator tool.

#### A Computer-Integrated Management Tools Research Program

The authors are currently formulating a multi-project research program that builds on previous contributions towards an overall objective of applying computer-integration and other information technologies to provide a set of comprehensive, integrated management tools for construction practitioners that recognize the practical barriers described in this paper. Several distinct but inter-related thrusts emerge from this objective (see Fig. 4). These parallel the three areas of design challenges outlined previously, plus the additions of a further examination of the practical business case for such tools and the continuing capture and development of basic construction expertise. The deliverables of the research program include a greater understanding of the role and technology for integrated computer tools, research prototype systems, and possibly specific, fully functional software modules that can help to provide construction managers with a more powerful, well-integrated tool kit for viewing, analyzing, and managing projects, thereby improving the efficiency of the construction industry.

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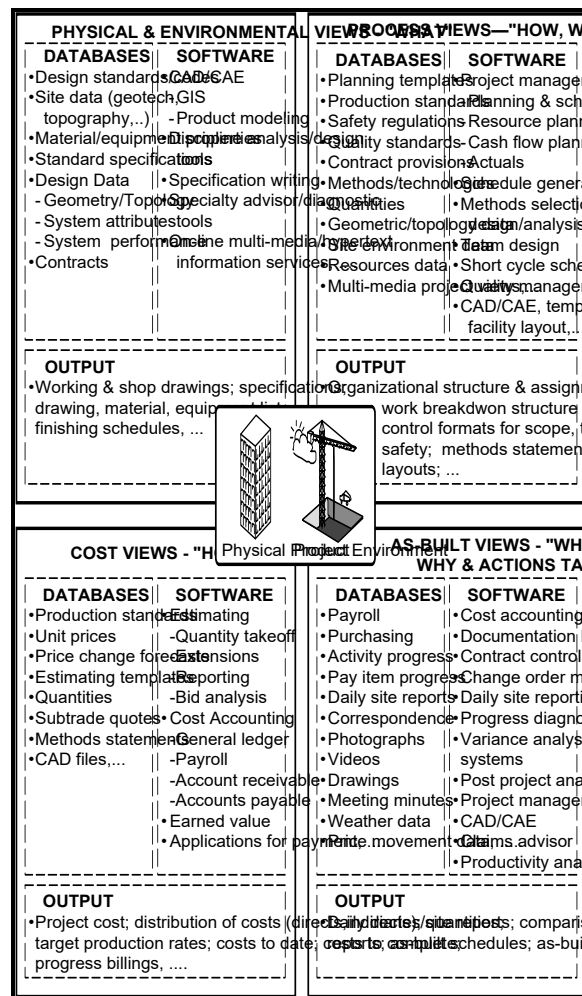


Figure 1. Contractor Project Views.



Figure 2. An AEC Process View Model.

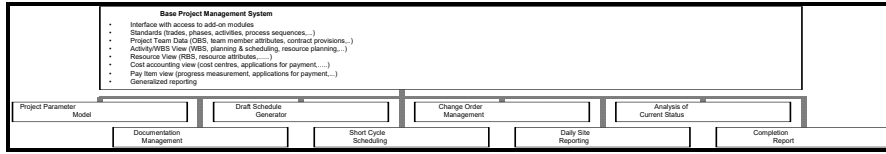


Figure 3. Schematic of Integrated System Components.

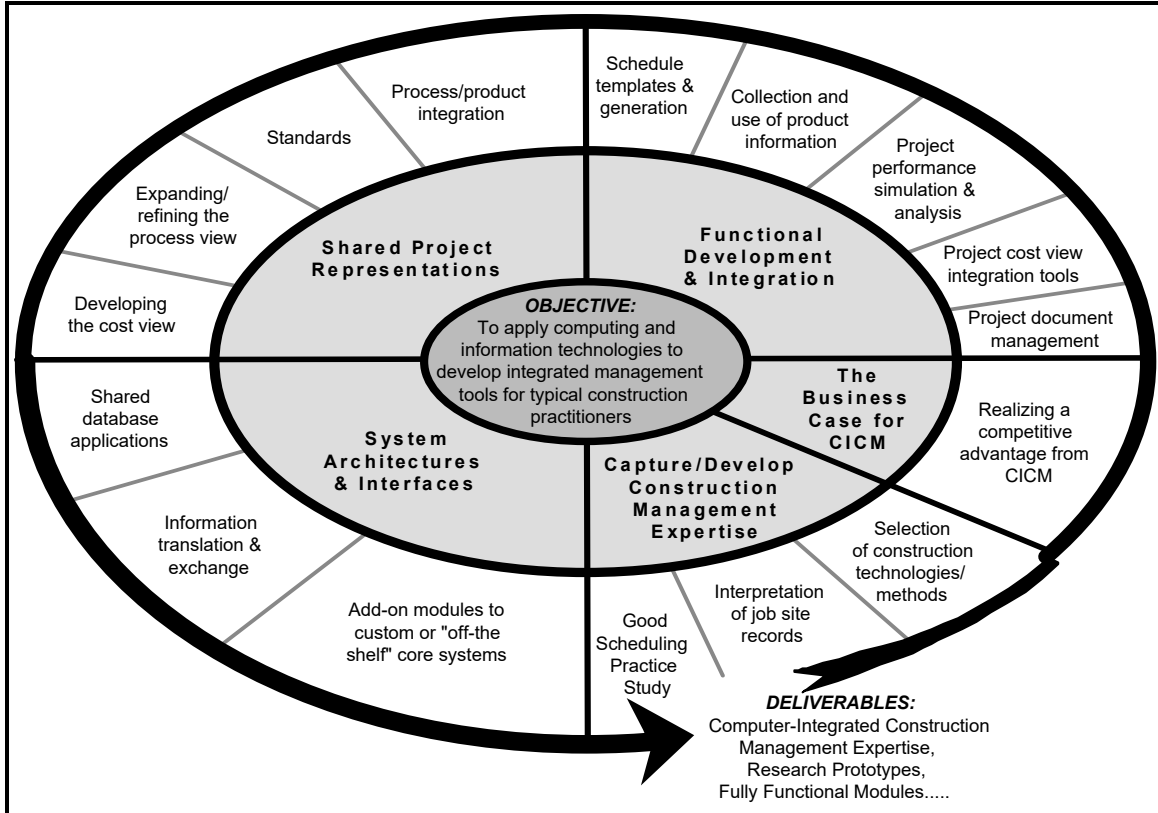


Figure 4. Elements of a comprehensive computer-integrated construction management (CICM) research program.

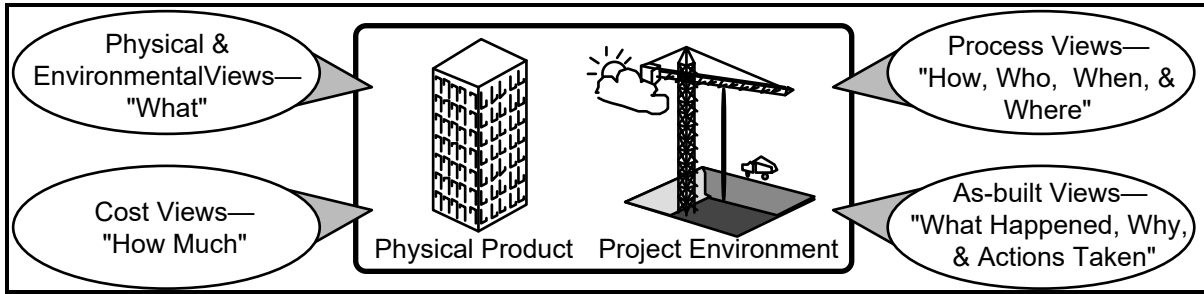


Figure 1. Project Views.