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COMPUTER ASSISTED CONSTRUCTION PLANNING (CACP) IN THE CONTEXT OF TOTAL PROJECT SYSTEMS (TOPS)

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ABSTRACT

Computer Assisted Construction Planning (CACP) facilitates development of initial comprehensive construction plans, which the user can customize to suit current needs. Comprehensive suggests plans that include work schedules, cost estimates, work methods, organizational structure, etc. Features of CACP include: 1) part of an integrated construction management system (in this case the *Total Project Systems*), 2) based on standard core information models, 3) multiple views at various levels of abstraction of project information. CACP builds on previous research in the areas of automated scheduling and planning, integrated construction planning systems, and information engineering and modeling. Although the concepts from many AI based automated planning efforts are built upon, CACP does not follow the common approach of building a plan entirely from basic components (detailed physical description), but instead relies on stored templates of past planning knowledge. In addition, CACP supports several levels of detail for each aspect of a construction plan, allowing a progression in its development and representation at various levels. The emphasis is toward emerging information technologies and integrated construction management systems which will allow an overall "richer" plan which the user can modify as necessary. The paper presents CACP in its current stage of development and maps out future directions for completion.

INTRODUCTION

Total Project Systems (TOPS) entail the development of new, integrated, computer-based tools to support construction management (CM) and to increase the overall efficiency of construction operations. These tools are the focus of a research program in progress within the University of British Columbia's Construction Management and Engineering group. TOPS are defined by the characteristics of: comprehensiveness: they include a suite of applications that support a broad range of CM functions, integration: all applications contribute to and draw from a shared pool of project information, and flexibility: they operate in a highly modular, open, flexible, and distributed framework, rather than in a restrictive and prescriptive manner.

While each of these characteristics in itself is not revolutionary, when taken as a whole they describe a type of system which does not currently exist. It is an attempt to push CM computer tools past the point of "critical mass", where broadly-applicable computational models become the primary vehicle for practicing CM. This has the potential to significantly improve the manner in which construction projects are managed.

The largest single benefit of TOPS is the extensive information sharing among computer applications. This sharing requires common data structures that can enable the information from any one application to be meaningfully imported and interpreted by another. For broad-scale systems, this requires models of construction projects that are generic enough to apply to a wide variety of applications, detailed enough to represent most of the pertinent information from each application, and robust enough to be adopted industry wide.

In support of TOPS, Computer Assisted Construction Planning (CACP) is a tool that enables users of integrated CM systems to easily develop initial comprehensive construction plans. Following the structure of TOPS, CACP will rely on templates of past construction planning information stored in a format based on a standard model. With an appropriate template the user then is given the opportunity to modify and elaborate or development the plan to suit their current requirements. The result serves to initially populate the pool of planning project information that is then available for use by all other planning tools.

The concepts from many Artificial Intelligence (AI) based automated planning efforts are built upon. However, CACP does not follow the common approach of building a plan entirely from basic components (detailed physical description). CACP instead relies on stored templates of past planning knowledge to begin with and stored types of planning objects to elaborate on a plan. Therefore, CACP supports several levels of detail for each aspect of a construction plan allowing a progression in its development and representation at various levels.

This paper introduces several key topics to TOPS and CACP: information modeling, integrated systems, and automated and integrated planning. Then a visualization of TOPS and CACP is provided, followed by a discussion of two current work topics: hierarchies and classification and the planning approach.

BACKGROUND

Previous research has proposed hypotheses and strategies for how the emergence of information technology (IT) can successfully achieve computer integrated construction (CIC) (Ahmad et. al.

1995; Teicholz and Fischer 1994; Breuer and Fischer 1994). The ramifications of such strategic changes to the industry are recognized, however the focus of TOPS and CACP is not on the organizational changes required but rather on a specific tools required for such changes to occur. As discussed in Froese and Russell (1995), design challenges of supporting tools for the medium sized contractor calls for an increase in the breadth and depth of existing tools which currently support CM. To facilitate these changes consideration is given to the underlying data structure used to support this research.

Information Modeling

Approaches to CIC generally call for shared databases of information across the participant boundaries of the industry. This concept is also shared by the TOPS and CACP. To allow the sharing of project information, common models of all project information (product, process, cost, organizational, resource, etc.) are required, which completely detail all aspects of a project throughout its life cycle. It is generally accepted that conceptual *core* information models will provide a consistent approach to modeling within a specific application area and increase the capabilities of information sharing and integration. This is also the approach taken in many efforts within the engineering, architecture, construction (AEC) domain, as discussed in Froese (1996).

The approach of core modeling is a layered one. The highest level model (e.g., AEC domain model) provides the basis from which more application-specific data models are developed. The result is a consistent approach to modeling and a supporting mechanism for information exchange among similar applications and between applications within the same domain. Application models are representative of the information required for a specific application within the core domain. Construction management application area examples include scheduling, estimating, and cost control.

To support model development we look toward the International Organization for Standards' (ISO) Standard for the Exchange of Product Model Data (STEP, ISO Standard 10303). STEP is a standard for the computer-interpretable representation and exchange of product data, with the objective of providing a neutral mechanism to describe the product data through the life cycle of the product independent of any particular system (ISO 1994a). Of particular interest is the product data representation of the AEC domain and a subsets of AEC, building construction and construction management, in the form of the Building Construction Core Model (BCCM). In a closely related effort, the Industry Alliance for Interoperability (IAI), an industry-based consortium, is also developing standardized Industry Foundation Classes (IFC's) for exchanging data between computer systems within the AEC industry (Autodesk 1995).

Integrated Systems

A number of research efforts have focused on integrated CM systems. Of these efforts, there are those based on extensively developed construction information models, while others focus on specific application integration (e.g., CAD and scheduling). Noteworthy construction integrated systems under development include the COnstruction Modelling Methodologies for Intelligent information inTegration (COMMIT 1995) and Open Systems for CONstruction (OSCON) (Tracey, et. al., 1996) projects at the University of Salford. These projects build on the earlier Information/Integration for Construction (ICON) project (Aouad et al. 1994). Research at the U.S. Army Corps of Engineers Construction Engineering Research Laboratories (USACERL) involves development of prototype applications which integrate traditional construction applications based on the Integrated Construction Information Model (ICIM), an integrated product and process model (Strump et al. 1996). The scope of these systems generally extends beyond CM alone, to include aspects of product design, for example. Within the CM domain, they support the information requirements for some CM functions, but fall short for the specific CM breadth and depth envisioned by TOPS.

Automated Planning

Automated planning is not a new topic and more recent approaches have focused on artificial intelligence (AI) solutions (Levitt 1988). These approaches are usually centered on basic objects and low level reasoning to derive project components and to generate a time-scaled activity sequence, which could be described as a bottom-up approach. Although the approach has been criticized for its inability to effectively handle the size and complexity of actual projects, it has provided a thorough foundation describing the structure of construction planning. Efforts such as GHOST (Navinchandra 1988), OARPLAN (Darwiche 1988), CONSTRUCTION PLANEX (Zozaya-Gorostiza et. al. 1989), SIPEC (Kartam and Levitt 1990), ACP (Waugh 1990), and CASCH (Echeverry 1991), contribute significantly to this body of knowledge. Of importance in these efforts is the formalizing of construction planning knowledge and the approaches taken to capture this knowledge for future use, as well as the methods used for grouping and classifying the knowledge and the mappings between knowledge objects.

Integrated Planning

The following efforts are in line with a systems approach combining a movement towards integration of applications, a higher level of information representation, use of templates or libraries of knowledge structures, and the use of existing knowledge aggregated and directly applied. Examples include work performed by Yamazaki (1995), Shaked and Warszawski (1995), and Fischer et. al. (1995). The shift is towards information technologies as opposed to a focus on AI solutions. These research projects are more closely related to the end result of CACP and do incorporate some but not all of the approaches under consideration. A middle-top-down approach is required, and this must be based on an object-oriented paradigm, with a standard framework (model), that is applicable to a wide range of construction projects. The effort in CACP is to clearly identify a method by which a hierarchical breakdown is applied within this framework and how mappings are handled between objects across hierarchical levels, this is key to allowing a progression of construction plan development.

TOTAL PROJECT SYSTEMS

TOPS are comprehensive in that they support a broad range of construction management applications, both traditional (e.g., scheduling and estimating) and newly emerging applications (e.g., technology selection and documentation control).

The integration characteristic is shown by how TOPS applications both contribute to and share from a common pool of project information which is stored in a database or databases established on the structure of a core information model. This enables specific information to be retrieved and committed in a variety of views and levels of abstraction. The use of the shared pool of project information in this way will eliminate duplication of data and dramatically reduce errors of data transfer among the applications. It will also ensure that all the applications use the most current data and share the same versions of the objects.

The flexibility of the architecture of TOPS is demonstrated by being: *open*, in that it is not dependent on specific computing technologies (e.g., independent of database type), *modular*, by avoiding a reliance on any specific applications, and *distributed*, by recognizing the requirements of a variety of users and sources of data.

Visualizing TOPS

TOPS can be visualized as presented in figure 1. A toolbox of CM applications (tools) is available for use, which is selected through a TOPS interface. Each tool, requiring specific information from the pool of project information from different perspectives and levels of detail, is provided for by TOPS. The system also handles the commitment of new contributions to the project information from each application.

For example, the user may be working in the conceptual stage of the project and is making adjustments to the project schedule. TOPS allow the user to bring up the scheduling interface of his choice and then allows the user to call for the scheduling data from the common storage of project information, TOPS recognize the required information to support the current application. Should the user want to commit modifications to the project information, given the proper access, the modifications are performed in the application and information is updated through the TOPS unifying interface.

TOPS is based on a core model of the construction management domain upon which application models are based. It is in fact a collection of the application information models that provides the structure for the databases used in TOPS. TOPS are described as modular, and this holds true for the DBMS used. As long as the databases are structured based on the information models, one or many types of systems (i.e., relational, object-oriented, distributed) may be used for storing and retrieving data. This is particularly important for the use of "off the shelf" applications that contain built-in databases.

Both traditional and emerging construction management applications are supported by TOPS. The architecture allows for a "plug-in and out" feature whereby applications of similar functions can be used for the same purposes (e.g., different scheduling software packages). Application interfaces remain intact when they are used, however there is also an overall interface for TOPS, which gives the effect of a seamless construction management application. Rules are available for interaction with the user and selection of appropriate applications as well as control over retrieval of and commitment to project information.

COMPUTER ASSISTED CONSTRUCTION PLANNING

CACP then is simply one of the tools available in the toolbox as described above. It is a key tool for giving the user a "head start" in many planning tasks. The interface of CACP is envisioned to consists of three parts: the Viewer, the Browser and the Planner.

The Viewer allows access to project information in a variety of views and levels of detail, the Browser acts as an interface to data sources and the Planner allows consultation with the knowledge based system (KBS) for the development of a plan, as well as invoking add-on applications for continued refinement of the generated plan. The KBS is based on two categories of rules, the first are used to control the overall development of a construction plan, the second are planning rules, invoked in a specific planning context (e.g., scheduling). Knowledge is stored in type libraries and structured according to the information model (with the addition of a standard classification scheme) and aggregated in planning templates. Other data sources include standard industry data.

All project information is stored in the TOPS common database as structured by the core information model. The applications used to further modify the plan developed include the traditional scheduling and estimating components, as well as an elaboration on planning information including detailed methods statements and organizational structure for a given project.

CURRENT WORK

Work on CACP and TOPS, to date, has concentrated on the structuring of data models in support of construction management and their relationship to current efforts of standardizing industry information (i.e., the BCCM and IAI IFCs). The kernel construct for the BCCM contains the entities product, process, resource, and control. The entire model, in its latest version (BCCM T.1.0) currently contains over 240 entities. Briefly, these kernel entities are described as follows (BCCM T.1.0):

- product object - an item manufactured or supplied for incorporation into the building construction.
- process object - an action or sequence of actions taking place in building construction with the intent of acquiring or constructing a product object.
- resource object - an item provided to assist in the process of building construction.
- control object - a specification, regulation, constraint or other requirement applied to a product or process whose requirements and provisions must be fulfilled.

Two additional objects which are representative of important relationships with each of the kernel objects are the cost and actor objects:

- cost object - each kernel object is characterized by a cost.
- actor object - each kernel object is related to, in a variety of ways, various actors (or participants) in the project.

It is in terms of these objects that we continue the discussion.

Hierarchies and Classification

As mentioned earlier, the information required in support of CM applications is of various levels of detail for specific users and at specific stages of a project. In the construction industry it is common to represent various levels of detail based on a hierarchical structure. For example, most construction firms have their estimates broken down according to a classification scheme. This scheme can be internal or, as frequently practiced in North America, based on an industry classification scheme, such as MasterFormat (CSI 1981). These types of hierarchical schemes apply to all project information in one form or another. This classification of information is provide for by the BCCM in the form of a classification object which is related to all the kernel objects and their subsequent elaboration.

However, complexities arise when establishing the relationships between objects. For instance, placing concrete (process) requires concrete (product). However, the level of detail in which the placing of concrete and the associated concrete required are represented each vary depending on the stage at which they are considered and for what reason. To examine these complexities and the proposed solution, we introduce the concept of views.

We can look at a project from many views, as presented in figure 2. Figure 2 shows a partial representation of project information from three distinct views: product, process, and cost (many other views such as organizational are also possible). If we consider the project first from the product view, we see that the information is organized in a hierarchical structure and also that there are required relationships for the items identified. For example, we know that there is a relationship between the product *Main Floor Structural Slabs* (P1.1.1.4) and the process *Main Floor Pour Slabs* (A1.1.1), but at what hierarchical level should this relationship exist. For instance should we relate the *Slabs* with *Pour Slabs* or *Rebar* with *Place rebar* or both? Similar questions arise with other views such as Cost, also shown in the figure. The approach becomes a matter of aggregating objects, from a selected view, and then defining their relationships (or mapping) with objects of other views.

Our approach is based on the use of a standard classification scheme, or set of classification tables. This set of tables must be broad enough to enable coverage of all the views of construction information. The work of ISO technical committee ISO/TC 59, *Building construction*, subcommittee SC 13, *Organization of information in the process of design, manufacturing, and construction*, addresses these requirements (ISO, 1994b).

The interface then allows the users to select a primary view (e.g., product) and aggregate (roll up) the objects in accordance with their requirements. The secondary views (e.g., process and cost) can also be aggregated in the same way. Defining the relationship between objects in the primary view and objects in the secondary views can be simply a matter of graphically aggregating each and defining the link. This should be simplified with each object hierarchy based on the same classification scheme. This type of interface, hierarchically based with aggregation capability, is also very useful for examining and manipulating the large quantities of information generated for a typical construction project.

Planning Approach

The hierarchical representation then supports the computer assisted planning approach. The planning approach is based on determining the *technical solution* for *functional requirement* pairings (Gielingh 1988). For example, the functional requirement of build a building could be described in terms of the product objects (building components) and the control objects (owners requirement), whereas the technical solution is described in terms of the process objects (construction activities) and resource objects (materials and equipment), as depicted in figure 3. Planning then becomes a matter of an elaboration of the general objects into more detailed objects, for example, build a wall with concrete blocks (more detailed technical solution) to enclose a sound proof room (more detailed functional requirement). The result is an aggregation of planning objects, describing the construction process.

To support the elaboration process, type libraries are available which allow the user to select the appropriate objects based on there defined characteristics and supporting industry knowledge (in the form of rules). The advantage of using an object approach is that these type libraries can be structured according to specialization hierarchies, as they will be accessed based on a given level of plan detail.

CONCLUSION

The approaches of both TOPS and CACP have been presented as a means to support the push of CM tools past the point of "critical mass". Future work will focus on the completion of the CM core data model and full development of the CACP environment. This paper is partially based on Froese, Rankin, and Yu (1997).

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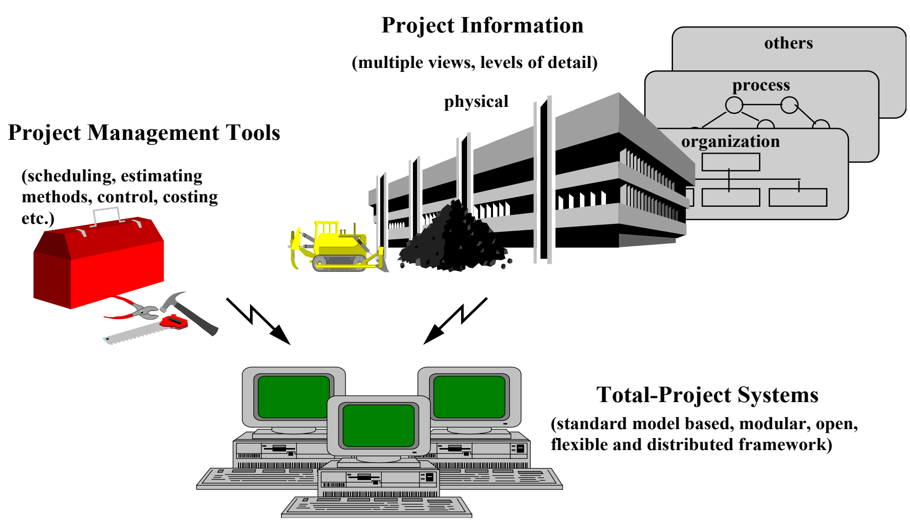

Figure 1: visualizing TOPS.

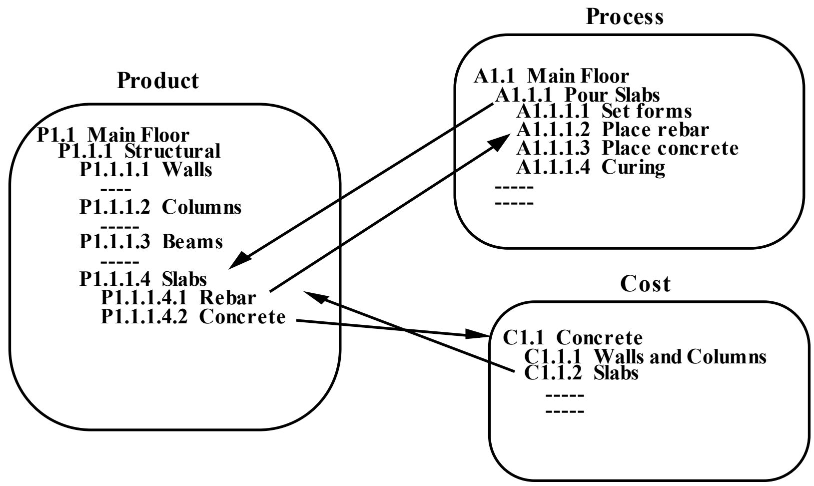

Figure 2: linking objects at different hierarchical levels.

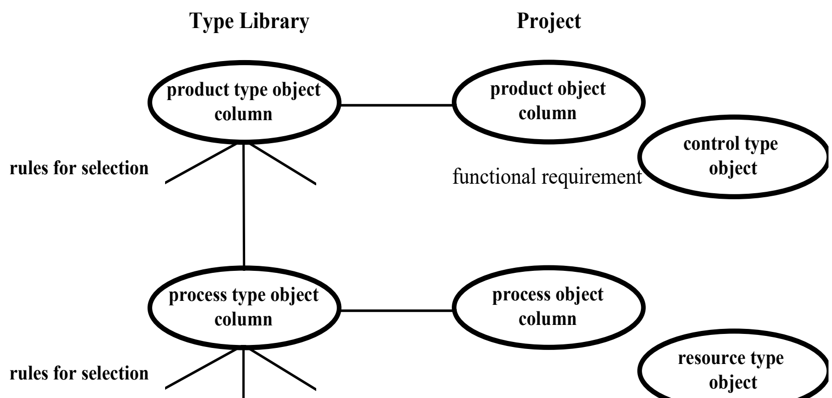

Figure 3: a simplified scheme of construction planning.