EXPLORING THE APPLICATION OF CASE-BASED REASONING TO COMPUTER-ASSISTED CONSTRUCTION PLANNING

CBR for Construction Planning

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Abstract

Computer-Assisted Construction Planning (CACP) is under development in support of Total Project Systems (TOPS). CACP, as a prototype application, employs a Case-Based Reasoning (CBR) tool, to address the requirements of information retrieval and subsequent reuse for preliminary project planning. The unique aspects of CACP include: 1) a design with respect to an integrated construction management system based on emerging industry information standards (i.e., Industry Alliance for Interoperability), 2) the consideration of quality, organizational, and procurement aspects of planning in addition to time, cost and scope, and 3) the application of CBR to facilitate the re-use of captured planning knowledge. CACP's data structure builds on past efforts of developing data standards within the AEC industry (e.g., ISO STEP and IAI IFCs) and contributes to current efforts with a focus in the construction management domain. With a solid data structure, CACP's planning approach can use organized specialization and aggregation constructs to promote efficient storage and retrieval mechanisms. The CBR tool is then used to guide the user to a past plan that best meets the current project requirements and presents this information for modification to meet all project requirements. The paper briefly describes the data structure and planning approach used and primarily focuses on the application of CBR to achieve a scenario where the re-application of past planning knowledge is possible.

Keywords: integrated construction management, construction planning, case-based reasoning

1 Introduction

The "Total Project Systems" (TOPS) project includes the research, development, and implementation activities involving advanced construction management supporting software applications (Froese et al. 1997). The TOPS project is the focus of a research program within the Construction Engineering and Management Group at the University of British Columbia. Since the project's conception, TOPS have been succinctly described by three primary characteristics: comprehensive, integration, and flexibility. The ultimate goal of TOPS is to explore and demonstrate how integrated computer based tools can increase the overall efficiency of construction management operations.

TOPS accomplish this goal by supporting a broad range of functionality in support of traditional construction management tools such as estimating and scheduling as well as emerging management tools such as those that support construction methods selection or quality management activities. The key to efficiently supporting a broad and comprehensive range of functionality is to have a common source and structure of project information. Access and use of this integrated information must be available in an open-computing environment that is application independent.

A hurdle for the integrated systems described above and also for traditional stand alone information systems is the increasing requirements in the volume of information used. This increase is due to the increased functionality offered in addition to an increase in the number of users requiring access to the information, and the many different perspectives or views of the information required that vary in content and amount of detail represented.

To help overcome the information management challenges a solution based on the re-use of past project knowledge and information is proposed, along with an effective interface for handling this information. Both of these features draw from a shared database of information structured upon a standard industry representation. Computer-Assisted Construction Planning addresses the re-use component.

The approach adopted, therefore, is to structure the project information database on a data model that is consistent with on-going efforts within the Industry Alliance for Interoperability (IAI) and the International Organization for Standardization's (ISO) Standard for the Exchange of Product Data (STEP) working groups. The underlying assumption here is that, at some point, a common industry data standard will exist and be accepted and adopted industry wide. At this stage, the data model is static rather than dynamic (i.e., captures the current standard structures). However, it should be noted that the information modelling and development principles have been ensured, facilitating future changes to the data model to match changes to the data standards.

The user-interface employed is based on a commonly accepted 2-dimensional "tree and detail" scheme within a MDI (multi-document interface) approach. The implementation of 3-dimensional and more elaborate, and perhaps more efficient interfaces, are being pursued in a concurrent research effort at the University of New Brunswick (Rackley et al. 1998). The goal is to support the industry's acceptance of more efficient interfaces for integrated construction management systems. These may indeed be based on 3-dimensional approaches. For example, a 3-dimensional CAD representation for instances where the information is associated with a product centered data model and can be used for other management activities such as scheduling (so called 4-D CAD modelling).

The method by which information is represented in classification hierarchies is also an important ingredient to successfully managing project information. A standardized classification scheme is key to integration among applications and their overlapping functions. Efficient organization of information leads to effective use of the information.

2 Points of departure

The application of re-using past project knowledge and information builds upon previous research that is summarized under four distinct categories: industry standard data models, integrated construction management systems, classification schemes, and case-based reasoning.

2.1 Data representation

The methods of representing information and the structures required of data models for integrated construction management applications are well documented by Froese (1996). The most recent approaches in the field of construction management within the AEC (architectural engineering construction) domain are adopted to guide the structuring of the project database drawing from ISO (1992) and IAI (1996).

2.2 Integrated systems

Integrated construction management systems had their early start with the automation of scheduling and planning through the use of emerging AI techniques (e.g., Levitt et al. 1988; Waugh 1990). It was found that starting from so-called "first principles" and regenerating all the necessary information that is required for a single application, let alone integrated applications, was a challenging task. Work in this area then took a turn towards integrating the applications that are more widely accepted (scheduling and estimating), through the application of broader information technology approaches, with a higher level of information representation and use of templates or libraries of knowledge structures (e.g., Yamazaki 1995; Strumpf et al. 1996). To date, it is generally accepted that integrated construction management systems will be conceptually based on a central information source with which integrated applications and the industry participants will interact (O'Brien 1997).

2.3 Information classification

Interfaces and classification schemes have been around for many years and have evolved with the industry. In North America, MasterFormat (CSI 1995) is the best example of an indexing scheme that is used to support various organizing functions (e.g., technical requirement definition, and cost tracking and control). There are examples found in other countries as well, such as the European based Ci/SfB (Ray-Jones 1976) and its index tables. In light of the recognized importance of standard classification schemes to more sophisticated management systems within the industry, there has been a revamping of existing classification schemes. Evidence of this trend is found through the work of ISO sub-committee (ISO TR14177, 1994) and the British derivative of this work, the Unified Classification for the Construction Industry (UniClass 1998). In North America there is a new trend towards a product-centered scheme entitled UniFormat (CSI 1998). Although the UniFormat also serves the industry better in the definition of performance based work (the expected origin of its development), it also serves as an improved scheme for integrated management system approaches.

2.4 Case-based reasoning

The original hype of Case-Based Reasoning (CBR) began with Riesbeck and Schank's (1989) Inside Case-Based Reasoning; a text built on the flourish of Case-Based Reasoning research performed at Yale University in the late 80's. Today CBR is presented as a methodology for dealing with large quantities of information (Watson 1998) where various technologies (nearest neighbour, induction, fuzzy logic, SQL, etc.) are applied to the original algorithm.

As applied to planning, people do not construct plans from first principles, rather they try to find the best previous plan and adapt it to the current situation. A "case-based reasoner" solves new problems by adapting solutions that were used to solve previous problems with its elements of a case library and methods of storage, indexing, matching, and adaptation.

The basic algorithm that is applied is: 1. input the problem, 2. find the cases similar to the current problem (characterize the input problem, retrieve cases with matching features, pick the best match(es)), 3. adapt a previous solution to fit the current problem. In addition, concepts are required to support the ever-changing knowledge base that the CBR uses. To support these dynamic memory requirements, common information management concepts of inheritance, aggregation, specialization, and attribute definition are required.

3 CBR Applications to the A/E/C domain

Applications of CBR to engineering and construction include design (proportionally much higher), contracting, the application of building regulations, scheduling, and estimating. The following research is noted due to its similarity with the approach adopted for CACP, while bringing to light the issues involved with this application of CBR.

3.1 Design and design selection

Various systems that apply CBR to support design assistance and design automation are discussed in Maher and Gomez de Silva Garza (1997) along with the difficulties of their implementation. Voß (1994) describes a retrieval method for the selection of appropriate designs for building projects in the context of reusable parts rather than entire designs. Sycara et al. (1992) apply CBR to act as a designer's assistant in the design of mechanical devices. While Bilgic and Fox (1996) discuss case-based retrieval as used in engineering design within the context of an enterprise system. Finally, Flemming, U. et al. (1994) present CBR in support of early phases of building design. Although the area is not mature enough to lead to a generally accepted approach, there are many recurring themes noted that are equally applicable to the application of CBR to construction management.

In general, the two goals of re-using previously stored design information are to provide access to a large memory of past solutions, and act as an aid by providing designers with an initial solution available for editing by the system or user. Addressing these goals for construction planning is also the motivation for CACP. The first step is a solution to the representation of complex cases, where generalized knowledge and experience must be formalized. The common approach is to represent this information in an object-attribute schema while also maintaining categories for the various attributes (e.g., relation, function, behavior, and structure). Also, the reuse of solutions is applied across many phases of a projects design cycle (e.g., conceptual design to detailed design) and therefore retrieval must be available across a problem that is decomposed in a hierarchical structure.

Potential solutions must have a dynamic indexing mechanism because the retrieval process is iterative (i.e., the level of representation of the problem varies). Throughout the retrieval process the user is quite involved with the pruning process as a design develops and additional information is added. Therefore, using a hierarchical approach (relation attributes) allows access to potential sub-solutions.

A retrieval process is normally simplified by establishing the context of the problem through definition of a set of constraints. The context issue is dealt with up front by making it an explicit part of the query. Then, for each retrieval, a clustering of cases is performed based on the context. The method of retrieval and the means of indexing during retrieval are central to the process. First, the context of the information to be retrieved is established, then, the attribute-value pairs that will be used for retrieval are selected.

3.2 Other CBR applications

CBR has also been considered for application to other areas within the AEC industry. Yang and Robertson (1995) provide a framework for interpretation of building regulations, through abstraction hierarchies of legal rules from statutory regulations and previous relaxed cases. This example fits into the domain of CBR as applied to legal applications. Ng et al. (1998) apply a CBR tool and address case representation, indexing and retrieval, and adaptation for contractor pre-qualification by guiding the user through the processes of criteria formulation, screening and reviewing, final assessment based on financial and performance issues. Both examples show the potential of CBR as an effective aid to applications within the AEC industry.

4 Computer-assisted construction planning

CACP supports integrated systems by supplying the initial information required in a planning mode. Rankin et al. (1998) describes the functionality of CACP. The key components (features) of CACP are:

1. Data modeling - is based on an integrated data model with its roots in a general integrated project management data model.
2. Type and part information storage structures - allow efficient storage and retrieval, support multiple levels of detail during development through representation of general information (libraries), and specific information (current project).
3. CBR - employs artificial intelligence methodology for plan development, CBR presented as a methodology rather than a technology (the assisted component).
4. RAD (rapid application development) - tools are used for its development in consideration of integration and ease of implementation (low cost for a low cost technology industry) while also providing sufficient functionality.
5. Interfaces and classification - follow a growing trend in representing information that is hierarchical in nature by using an effective 2-D representation of information in a "tree and detail" combination.

4.1 The data model

The data model details the structure of the database used to store both general planning knowledge and current project planning information. This structure supports the common project management planning perspectives of time, cost, scope, and additionally supports performance and organization. The scope of the model for CACP is a subset of the Project Management data model described in Froese et al. (1997) and, as previously noted, is based upon on-going standard industry modeling efforts.

The data model was built using a customized database application built with Microsoft's Access and represented with Visio's graphical software. Therefore, the data model is static in its structure as opposed to the dynamic data model described in Gorlick and Froese (1999).

4.2 Construction planning

The "planning approach" is similar to that discussed in Froese and Rankin (1998). Briefly, the model supports the kernel information entities (product, process, resource and control) in “part” and “type” hierarchical relationships and fundamental relationships among these entities (e.g., process *applies to* product). A plan is developed by drawing from the general planning information, while considering the *context* of the current project (e.g., the specific project information available). For example, Fig. 1 illustrates selection of a process (build concrete column) to result in a given product (concrete column). By drawing from general planning information a process type is selected (e.g., build concrete column with conventional forms) which may contain sub-parts (e.g., set forms, place re-bar, pour concrete, strip forms).

Guiding this selection is the consideration of the *constraints* identified to this point in the project plan development (e.g., conditions that may limit specific column building operations). The mechanism for this retrieval process is the CBR component of CACP.

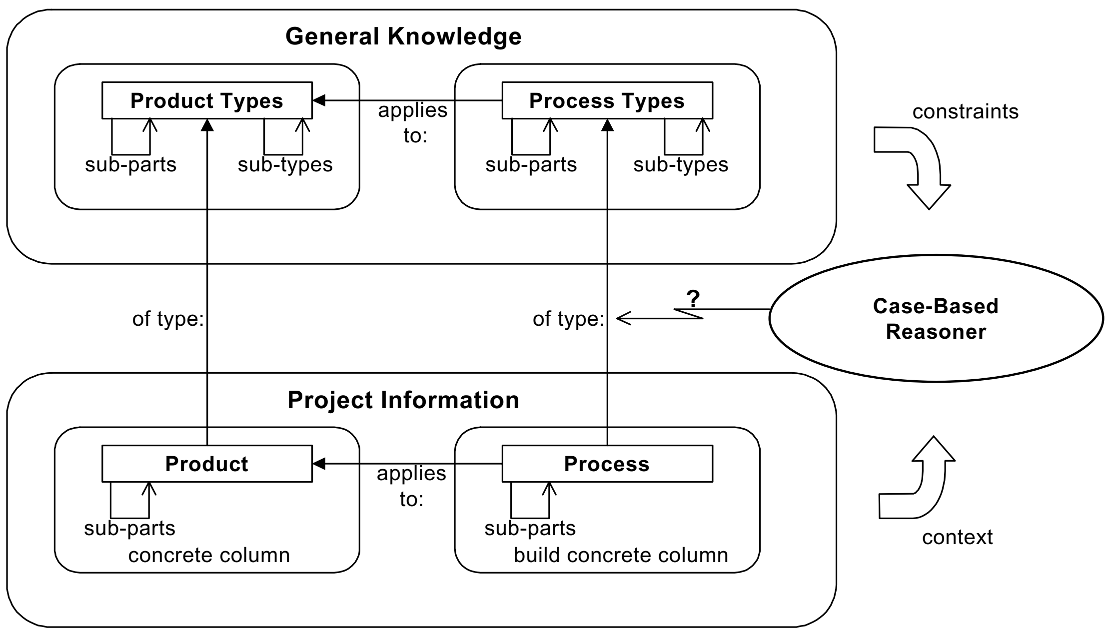

Fig. 1: CACP's planning approach

4.3 Case-based reasoning

The elements of CBR, as they relate to the implementation in CACP, are summarized in Table 1. As with the previously noted CBR applications to design, the primary issues surround the representation of cases, in consideration of the methods of indexing for effective retrieval and adaptation.

Representation of cases - the data model and its implementation is currently restricted to capturing simple attributes types (e.g., textual and numeric) without consideration for information of a graphical nature. The representation supports a hierarchical approach and follows sound information technology principles and the direction of standard industry data model efforts within the construction management domain.

Indexing - partitioning of the information stored is based on the kernel entities of the standard industry data model (i.e., products, processes, resources, controls). Clustering of information is achieved through use of a classification entity with a relationship to each kernel entity. The criteria for retrieving information will change as the project constraints are revealed and therefore the attributes selected for indexing must be dynamic and generated during each retrieval session.

Retrieval - cases are retrieved based on similarity matching of selected attribute fields while satisfying the constraints defined. Which attribute will be selected and priority of this selection is flexible to the user.

Adaptation - at this point adaptation will be left to the user, with minimal assistance provided by the system.

Table 1: Case-based reasoning implementation for CACP

CBR Option	CACP Solution	CACP Implementation
Representation of cases:		
Attribute-value pairs	• attribute-value pairs	• object model
Representation model	• a model that supports part and type hierarchies	• industry standard information model
Attribute types: text, numeric, images, & drawings	• text and numeric, not images or drawings	• restricted to MS Access relational database
Domain	• restricted by representation model	• building construction core model
Indexing:		
Partitioning	• storage based on the kernel objects	• library structure
Clustering	• classification hierarchy or reasoner generated	• classification entities
Dynamics	• indexing generated by existing constraints (dynamic)	• problem is defined by constraint storage
Retrieval:		
Context	• guided by relationship attributes	• object model
Nearest neighbour, induction	• similarity matching on attribute fields	• reasoner
Constraint satisfaction	• will guide selection from system perspective	• reasoner
System control	• constraints	• industry rules
User control	• matching priority flexibility	• assistance from system
Adaptation:		
Reformulation of problem descript.	• none	• tree interface (editing capabilities)
Assistance	• guidance provided	• tree interface
Automation	• minimal	
Implementation:		
Reasoning	• CBR shell	• Haley Easy Reasoner
Storage	• relational database	• MS Access
Interface	• graphical	• MS Visual Basic

Implementation - the entire system is built in Microsoft's Visual Basic, making use of the Microsoft relational database engine with tables structured according to the model. The case-based reasoner is The Haley Enterprises "Easy Reasoner". The Easy Reasoner functionality is provided through a Visual Basic control and requires a minimal data conversion to flat dBase files during a reasoning session.

5 Conclusion

In support of TOPS we are searching for a tool to support the management and effective application of the large quantities of information required of integrated construction management systems. The application of CBR appears to hold promise in this regard.

CACP has been implemented as a very basic prototype with a minimal general information database. To this point work has focused on the development and implementation of the data model and an effective interface. The system will be populated with more examples as a means of further exploring the application of this methodology to construction management systems while contributing to further improvements in data model and interface developments.

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