Penn State Computer Integrated Construction Research Program

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Abstract

This paper introduces the Penn State University CIC Research Program and its philosophy. The primary focus of the program is to model the processes and information required to provide a facility. Given these models one can then define and develop better computer tools to integrate the building process. The Integrated Building Process Model (IBPM) was developed as a basic model of the essential functions to manage, plan, design, construct, and operate a facility.

Using this model as a basis, an information architecture comprising several categories of information required to support the process was defined. These elements describe the process, the product, the process control elements, the feedback, and the constraints under which the subject facility is provided. Several projects currently being developed to illustrate the integration of these models from a single user's perspective are presented.

Introduction

Computer Integrated Construction (CIC) is a new emerging research field. Its development is largely fueled by the success of Computer Integrated Manufacturing (CIM), a similar concept in manufacturing. CIC involves the application of computers to better manage information and knowledge in their various forms with the goal of totally integrating the managing, planning, design, construction and operation of facilities [Sanvido 90]. In order to utilize the computer, the users need a clear definition and architecture to organize classify and manage the required information.

Many universities and research laboratories are actively working in the CIC area. Their work in product modeling, process modeling and developing integrated prototypes is represented in large part by the participants at this conference. It is our goal to present a set of conceptual models and our common philosophy among the several application projects in progress. These models are presented to elicit discussion and share ideas.

Penn State Computer Integrated Construction Research Program

The central goal of the CIC Research Program is to define and develop better methods and computer tools to integrate the delivery of facilities. The contribution of this research will be to define a framework for representing and integrating the key decisions and intent of the various participants in the process, and to look for totally new methods that take advantage of the computer's full capabilities.

The (CIC) Research Laboratory was developed to support this research program. It houses ten to twelve researchers with architecture; architectural, civil, electrical, and industrial engineering; and construction backgrounds. Several faculty and industry practitioners interact with these researchers through lectures and collaboration on projects. This work has been supported and funded by several government agencies and private companies.

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Process Modeling - The IBPM

Our first step was to develop a conceptual model, or framework, of the processes and information required to provide a facility. This process model developed from the view point of a "master builder," [Sanvido 92] identifies the essential processes required to manage, plan, design, construct and operate buildings. The Integrated Building Process Model (IBPM) [Sanvido 90) identifies all major functions required to provide an operational facility to the end user over the life of the facility. The model also identifies the information that is produced and utilized by each function. It was developed using the $IDEF_0$ modeling methodology [Harrington 85] to four hierarchical levels of detail. A total of twenty two building case studies were used to develop and test this model.

The IBPM in its original form had many elements and flow lines. In order to simplify the model, the elements that flow between two given sub processes are grouped and designated as one arrow. Secondly, elements that are similar and generic to several sub functions are identified. These generically similar information elements form the components of the Information Architecture.

Elements of the Information Architecture

When examining the process models, it becomes apparent that the information that is used to provide the facility can be divided into five categories [Sanvido 90]. These are: information describing the methods used to provide the facility, or the **process elements**; information describing the physical properties of the facility, or the **product elements**; information describing the management directives to the planner, designer, constructor and operator, or the **process control elements**; information describing feedback loops from the planner, designer, constructor and operator to the manage function, or the **feedback elements**; and finally, information describing the factors that impact the project, or the **constraint elements**. These are defined in detail in Sanvido et al. [92].

Process Elements

The five key processes have been defined as manage, plan, design, construct and operate the facility. Manage Facility includes all the business functions and management processes required to support the provision of the facility from planning through operations. These activities focus on converting a facility idea, time and money through a facility team, documents and contracts, facility management plans, and resources to an operational facility. This function runs for the duration of the facility life and relies heavily on feedback from the subsequent processes.

Plan Facility encompasses all the functions required to define the owner's needs and the methods to achieve these. These activities translate the facility idea into program information expressing the facility requirements in terms of function, form, cost and timing. The Design Facility function translates the program through conceptual, schematic, and detailed design into bid and construction documents and operations and maintenance documents. The intent of these two activities is to define and communicate the owner's needs to the builder.

Next, the Construct Facility activity translates the owner's needs, represented by bid and construction documents and criteria using appropriate resources (e.g., materials) into an operational facility. Finally, Operate Facility comprises all of the activities which are required to happen within the constructed facility to provide the user with an operational facility. These process elements decompose into several hundred sub activities in the process model.

Product Elements

"Product Information" comprises the information elements which are unique outputs of the functions of the model, that are used to describe and communicate the facility in is various stages of development. These elements progress from the facility idea and the site data to the planning information (project execution plan, program and site information, etc.), the design information (design documents, bid documents, etc.), the constructed facility, and construction information to the operational facility.

These elements all represent the same product, the building design, and are linked through a product model. The model is based on IDEF1X modeling methodology, and the generic scheme proposed by Khayyal and Sanvido [90]. This is an approach to break down a facility and its assemblies into objects with information attributes. In order to store these attributes in the proper location and avoid redundancy, a hierarchical structure was used to organize information. Items are stored according to their primary functions.

The product model comprises the following levels: Building/Site; System; Sub-System; Assembly; Component; Sub Component; and Part. At the upper level, the facility is divided into the land, infrastructure and building elements. At the Building level, each is further subdivided into their sub elements. For example, buildings are divided into separate buildings, then at the system level, into the architectural, structural and technical systems. The Architectural system subdivides into the envelope, floors, and the vertical connector subsystems. Finally the room, an assembly, is divided into its components namely the surfaces, finishes and fittings, which again decompose into sub components and parts. Each technical system also decomposes through systems into parts.

The various design packages identified by the process model correspond to the product model levels as follows: program - system level; schematic design - sub system and assembly level; design development - components and sub components ; and construction documents - the part level.

Process Control Elements

The elements required to control the process of providing a facility are those which the management function must supply (outputs) to the subsequent operations. Three process control elements considered are the team and its experience, contracts, and resources.

The whole project activity is driven by people assembled by the owner into the facility team. This starts with the facility champion and increases in size to include various members of the management, planning, design, construction and operations teams throughout the project's life. The facility experience, another output, influences the quality of the current project, and the subsequent projects performed by each team member.

A key output of the manage function that controls the composition of the facility team, its behavior, and the resources that are distributed among these groups is contracts, obligations and changes. The contract is an important tool in controlling the process. It essentially spells out or clarifies the responsibilities and actions of each party in the relationship. The project team is composed of many members who work independently and are simultaneously interdependent on others. The contract is the legal document which can reinforce these responsibilities and ensure that team members work together.

Contracts can take various forms and involve numerous strategies. The contract segment of the process control model is based on common generic portions of most major contracts. These areas include cost, time and scope of the contract, to name a few. These areas were extracted from numerous contracts written by various professional agencies. The model does not specify the drafter or agency responsible for the format, length, or content. Instead, the model is based on the "relationships" that typically exist on a construction project. The relationship will generate a lower level of "areas" which are commonly present in contracts between these entities. These "areas" are further broken down into "sections" which closely parallel the articles of a contract. The final level or "clause" is an attempt to match the lowest element with an actual clause number from a contract particular to the relationship dictated three levels above. This link to actual contract formats used in U.S. practice today helps delineate specific process control measures to be utilized by the members engaged in the contract.

The key element used to keep the whole process moving is the resources, an input of the manage function. This includes all resources provided for the facility by all participants (money, time and man-hours, permanent materials and equipment, energy, information, equipment, temporary materials, tools, and work place or site). These resources must be redistributed and supplied to the subsequent processes in accordance with payment schedules and contracts. This model uses the following four abstraction levels: system, class, type, and unit. The facility team then, for each sub function, uses resources within the constraints of the contract and certain feedback to produce their specific end-products.

Feedback Elements

Two generic feedback elements from sub processes that affect the control of the overall process are performance information, and optimization information. Optimization information is planning information about possible methods of design, construction, operation or maintenance which is used to improve the efficiency of the provision of a facility. Performance information addresses the progress of activities which, when compared to the plan, is interpreted to assess the status of the project and the appropriateness of the plan or method selections. In a simpler context, optimization information is forecasting information used to make decisions and performance information is actual progress information used to review and update decisions. The existence of this information and its quality, directly influences management decisions that control the process. The flow of the process control elements to the subsequent sub processes are influenced by decisions made using elements.

A generic feedback cell describes the methods to be used. Each method cell decomposes into cost, schedule and quality for each given method. Each cell in turn contains optimization information or goals on the left side and performance information on the right side. The cost cell is based on the resource mix proposed in the method and their costs, the schedule cell describes the production rates of given resource teams, and the quality cell measures the quality of inputs, outputs, constraints and methods used. This generic cell can be mapped against each process and each product level. A matrix of the possible combinations could have the manage, plan, design, construct and operate processes on one axis and the product levels from the project through the part levels on the other axis.

Constraint Elements

A construction project will be heavily influenced by limitations that companies place on their assigned staff and factors beyond their control. The limitations or rules under which all team members and processes required to provide a facility must work are project constraints. These form boundaries of the decision making and working environment. The two main categories of project constraints are External and Team Member Constraints. External constraints are the global issues that can not be overcome without incurring some degree of difficulty. Team Member Constraints are induced on the project by one of the team members. Six subtypes of constrains have been identified: economical, political, technological, environmental, labor, and legal.

Applied Research

In order to test portions of the Information Architecture presented in this paper, we have developed and continue to work on several industry applications. These projects try to select a key decision in or viewpoint of the delivery process and develop a method or tool to assist a professional in their project role. In developing the solution, we define the role or viewpoint in terms of elements in the information architecture and pose several scenarios to the model. The overall Information Architecture is then clarified or further developed.

Recent Research

Three recent projects are described. First, an information framework for facility operators [Beckett 91] defines and classifies the essential information that a facility operator needs to better operate a facility. This framework (which is based on the CSI scheme) can be used to store and retrieve this essential information in multiple formats. Secondly, [Perkinson 92] defines and classifies the essential information that should be contained in a Facility Program. This framework contains the information that is the basis for a design and should be used to evaluate the design or to select alternatives. The third project defines the rules behind a project delivery selection system [Vesay 92]. It assists an owner in selecting the desired organizational structure, and the contract strategy for a given project. It considers project requirements and risks as well as team characteristics and uncertainties.

Two prototypes [Evt 92], and [Kamarthi 92], were developed to explore the use of hypermedia to store product information, and to compare expert systems to neural networks in selecting a formwork system respectively. Both projects illustrated the limitations and strengths of the software.

Current Research

Currently six project are underway in our laboratory. Each focus on industry applications and will develop software where appropriate to illustrate the solution in terms of the information architecture. The first project, a site material management system [Riley 92] is a tool to assist a construction manager in developing, implementing, and adjusting a detailed material handling plan for a construction site. A second project is an information architecture that will aid site level personnel in completing their day-to-day tasks by identifying what information they need and where it can be found. This information system will be broad enough to accept knowledge and expertise from all levels of the project and information in different formats.

A third project is a concurrent process planning system to assist in the planning of design, manufacturing, and construction of precast concrete construction. It is a collection of integrated database and decision assistance tools. A fourth project defines a generic method for classifying constructability information for the conceptual through schematic design phases of a construction project. The system should enable ease of information access and sorting for the various discipline views. This will benefit construction companies which seek to develop "lessons learned" databases for increased competitiveness.

A fifth project develops pre-construction guidelines for pharmaceutical and/or health care facilities which outline the roles of each project player in controlling common retrofit constraints. The use of these guidelines will establish a cohesive, well prepared team early in the project. Finally, the last project is a system to assist an experienced owner in selecting appropriate members for a design/build project team. It should provide a guideline to maximize project success through proper selection and evaluation of the project team.

Conclusion

This overview of the Penn State CIC research program has illustrated the development of a process model and its analysis to develop the resulting Information Architecture (IA). As shown earlier in the paper, we have used the IA as the basis for all of our applied research. This gives the laboratory projects an overall goal and focus, and the success of the projects are an excellent test bed for the IA itself. Clearly we have a long way to go, but I believe that we have a basis and plan for future work.

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