SYMBOLIC UNIFIED PROJECT REPRESENTATION (SUPR) MODEL: AN ENVIRONMENT FOR AUTOMATED CONSTRUCTION

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ABSTRACT

The Symbolic Unified Project Representation (SUPR) Model was developed to achieve integration of construction information. It provides modular units, and the environment necessary to model project information in a unified manner, thus enabling diverse systems to collaborate and share information. Construction robots are becoming increasingly important construction resources, and their integration into an overall project representation is highly desirable. The task-orientation of the SUPR Model renders it well suited to accommodate and integrate robotics, while the effectiveness and sophistication of construction automation can be enhanced by having access to compatible project data and knowledge-bases. The automation of construction is too large an undertaking for any one research group or firm. By using a modular, yet integrated representation model, independent projects can provide solutions which will also be useful as building blocks in the overall automation process.

INTRODUCTION

In spite of vigorous efforts and high potential benefits, meaningful integration of construction project information remains an evading goal. Now robotics and automation in construction present further challenges and enticing promises. The SUPR Model, which is a synthesis of work at the University of Illinois (1) and USACERL (2), is designed to provide a unified representation scheme to accommodate the integration of project data and knowledge. This paper examines the model as an interface between design and project management on one hand, and automated construction on the other.

The desirability of the integration of project management information is well established, and recently knowledge-based systems for project support initiated the need to also integrate knowledge representations of project elements. Meanwhile developers of robotics and automation of construction, by necessity, focused on establishing suitable representations posed by their own data representation requirements. At this point there is, however, a need to integrate Robotics with project data, especially project management data. This problem began to attract serious attention only recently.

The SUPR Model is a general purpose domain model, which has established roots in construction project management research (1, 2). The objectives of its design are to: 1) Provide a formalized environment for the representation of unified project data; 2) accommodate the direct exchange of computerized information; 3) facilitate the accumulation of knowledge in a reusable form; and 4) to encourage the development of a family of knowledge-based systems which can interact cohesively.

This paper will present the SUPR Model in synoptic form, and introduce the model's potential as an interface between Robotics and other, more traditional, elements of project knowledge/data.

THE SUPR MODEL

The SUPR Model is based on object-oriented programming (OOP). OOP is an increasingly popular programming technique which bundles data and the appropriate code together in data structures designated as "objects". The main OOP task is to define classes of objects (including their instance variables), the sets of messages the classes can respond to, and their respective behaviors in these responses. Since each object contains a description of its own behavior i.e. how it should respond to messages, these descriptions form the building blocks for more complex knowledge structures. Real-life objects and facts about them are modeled by instances of object classes in the computer data environment.

Previous research (3,4,5,6,7) established OOP as a satisfactory data and knowledge representation technique for a variety of construction related applications. OOP representations also proved to be highly useful to robotics, as shown, for example, by Keiroutz, et al (8).

The integration scheme of the SUPR Model is based on the concept that generic objects which have well defined message interfaces (sets of messages the objects can respond to) can be mixed and matched to form project specific data/knowledge bases. This notion is analogous to the variety of electronic instruments which can be built from the available pool of integrated circuits.

Reusable Objects for Construction (ROCS) were developed as classes of generic building blocks for this purpose. It is hoped that independent workers will be able use and modify ROCS within the framework of the SUPR Model to solve problems of their own interest. In addition to the other benefits of such a uniform framework, the burden of developing new knowledge-based systems will be significantly lightened, by sharing new ROCS, or improved versions of "old" ones.

This process of research which is independently useful, yet contributing to the enormous task of encoding knowledge and data in the construction environment, may provide the necessary momentum to get automation into the construction mainstream. In order to facilitate the process an electronic bulletin board service for the exchange of ROC definitions between researchers, designers, equipment and material vendors, standard organizations and other users will soon be necessary.

The crucial problem of determining a suitable largest common denominator between different types of ROCS was addressed in (1), and the Primitive Element of Construction (PEC) was defined. PECS serve as the integrating elements between ROCS. Special care was exercised in defining PECS to ensure that they not only satisfy theoretical requirements, but are also practical and convenient to use on real projects.

The SUPR Model provides a collection of ROCS which form the building blocks of the project representation (physical components, activities, budgets, etc), objects to represent the general and local environment (weather, economy, labor market, etc), and Specialists (expert systems and robot controllers which can utilize the SUPR Model's data and knowledge representations). Real-life projects are

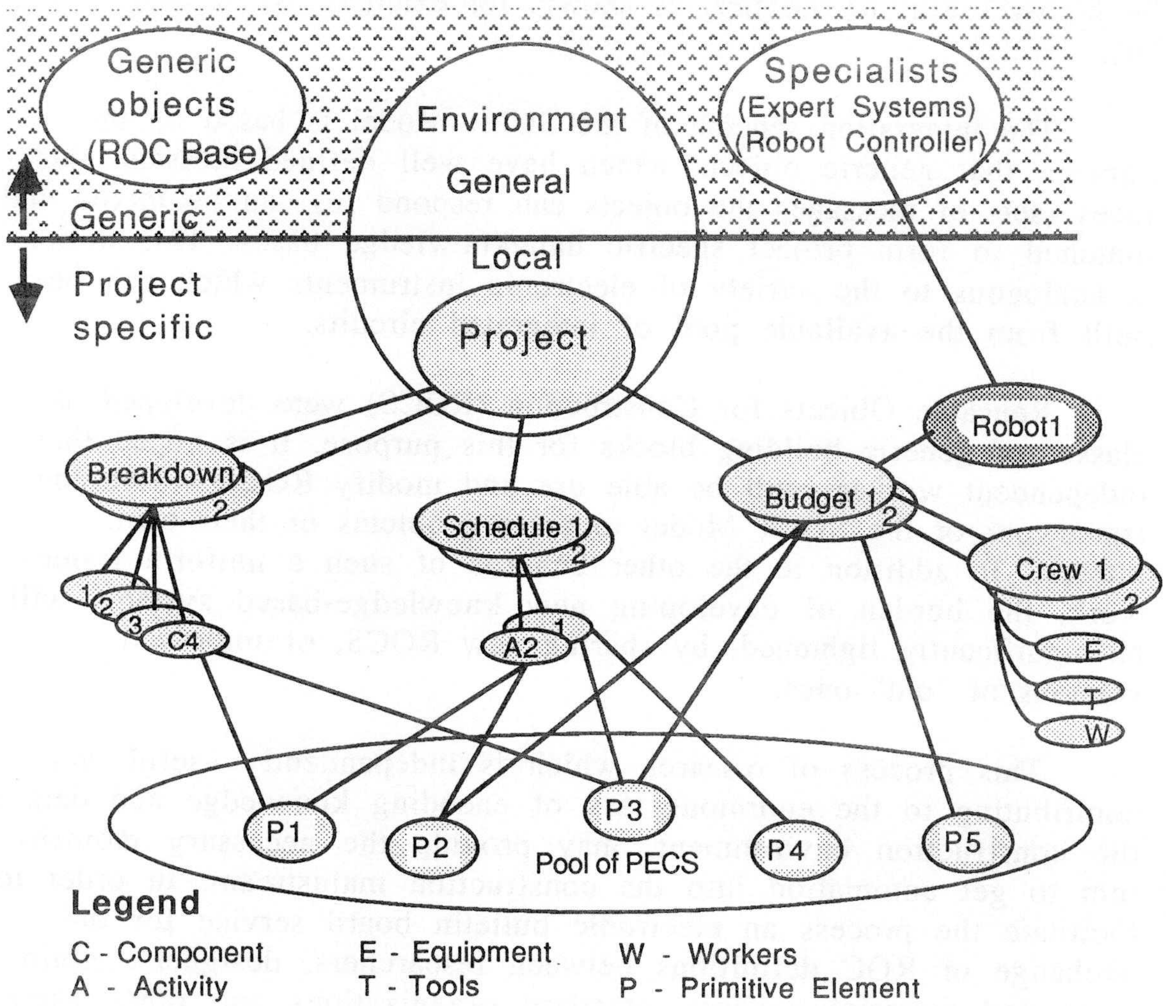

Figure 1: The SUPR Model as Robotics Environment

represented by instances of these ROCS with their instance variables properly initialized to store project specific data. These concepts are pictured in Figure 1 in a simplified manner. In the following discussion ROC classes are bold printed, while instances of ROCS are italicized. The significance and reasons for the design specifics of this representation scheme is available in (1).

Figure 1 shows the project as having two breakdown structures. *Breakdown1* may be (and typically is) a breakdown into a hierarchy of physical components, such as foundations, substructure, etc. Additional *Breakdowns* can represent any number of views of the project, such a spatial or functional breakdown. At the PEC level these different views can be coordinated by the association of PECS to the lowest level *Components* in each *Breakdown*.

The project is also represented, from a different viewpoint, by construction schedules. Collections of scheduling activities are ordered logically into scheduling networks. The **Activity** class provide the capabilities necessary to add a time dimension and logical constraints to the construction tasks belonging to it, as represented by instances of **PECS.** *Activities* in turn are associated with a *Network.*

Budgets represent the line items of a typical detailed estimate for a specific cost item such as "Formwork for square columns" or "Column reinforcing", which, of course, include references to specific building elements, represented by *Components*. *PECS* are generated when *Budgets* (or fractions of *Budgets*) are allocated to *Activities.* Bidirectional pointers are thus established between *PECS* and *Components*, *PECS* and *Activities*, and *PECS* and *Budgets.* Note also that cost, attached to *Budgets* through the pricing process, implies that a construction technology choice had been made, which dictates specific resource requirements. Therefore, an indirect association is also created between PECS and resources such as work crews, equipment and materials, via *Budgets.*

Specialists are complex knowledge-based ROCS designed to perform specialized tasks. A **Specialist** can be implemented as a robot controller such as the one controlling *Robot1*, or expert systems such as the Initial Schedule Generator currently under development at USACERL. That project is described elsewhere in these proceedings by Echeverry et al.

THE SUPR MODEL AS A ROBOTICS ENVIRONMENT

The Model's interaction with robots is a natural one, since PECS are objects representing **a specific task to be performed on a specific component by specific resources within a specific time frame.**

If the resource under consideration is a robot, it clearly needs a description of a sequence of tasks to be performed on a specific object. The decomposition of tasks into simpler robot instructions is the topic of numerous other studies. A notable example of a decomposition scheme is the Hierarchical Control Model for Automated Manufacturing Systems implemented in the Automated Manufacturing Research Facility by the National Bureau of Standards (9).

In the SUPR Model resources are allocated to tasks through Budget objects, by their association with PECS. PECS, as mentioned above, have pointers to the physical building components as well as the scheduling activities to which they belong. Using these pointers a robot's production, instructions and feedback can be fully integrated with the project data/knowledge base and Management Information System.

In Figure 1, the tasks represented by *PEC2* and *PEC3* are assigned to *Robot1* through *Budget1*. The sequence of their execution is determined according to the *Activities* they belong to. *PEC3* is performed when *Activity1* is activated, for example. *Robot1* can further determine component information, such as location, materials and dimensions, by following the pointer from *PEC3* to *Component4*. When *PEC3* is due for execution, the *Robot1 controller* decomposes the task contained into robot constructions. Upon completion of *PEC3*, *Budget1* can in turn determine its completion status by comparing *PEC3* with the the total effort (P2 and P3) it represents.

However, the SUPR model represents more than a mere data feed-back mechanism.- it connects the robot to the entire information environment of ROCS, knowledge bases and expert systems for specialized tasks. Generic predefined ROCS raised the environment for knowledge-based systems in construction to a new plateau of abstraction. The developer of a new *Specialist*, such as a robot controller, is able to concentrate on the new, specialized knowledge, while reusing (or modifying) knowledge contained in existing ROCS. The implementation and performance of construction robots can be improved by tapping into this body of knowledge and compatible project data.

A change in the construction schedule, for example, will automatically be reflected in the task list generated for automated construction resources. If *Schedule1* is changed (in Figure 1) and it affects the time frame for the execution of *Activity 2*, then the *Robot1* controller has access to the change through PEC2 (which is associated with *Activity2*).

A recent study (10) concluded that the types of construction tasks most suitable for, or in need of automation are: 1) Bush hammering; 2) concrete placement; 3) drywall installation; 4) painting; 5) sand-blasting; 6) tunneling; and 7) wall finishing. Several of these task are relatively simple operations. However, in most instances, their execution by robots will require extensive input of geometry.

Much of this geometric information is also needed for other purposes in an integrated model, for estimating and physical access checking during scheduling, for example. Our future research plans include the incorporation of three dimensional geometry/topology data and geometric reasoning capability in the component break-down structure of the SUPR Model, related to work such as (4). Trends in state-of-the-art CAD systems, such as three dimensional object-orientation, indicate the eminent feasibility of their integration with the SUPR Model.

The study cited above (10) approached automated construction from a traditional craft point of view, in the sense that it considered construction processes as they are currently executed. An even more important applications of construction robots, as advances are made in product-design-for-automation, will be the expanded use of on- and off-site prefabrication. The coordination problems in such situations will almost certainly demand fully integrated information environments such as the SUPR Model offers.

CONCLUSION

The SUPR Model provides researchers the needed environment to reuse knowledge effectively, and develop knowledge-based products which can interact with each other. It appears feasible to integrate automated construction resources into this data/knowledge representation environment. We envision owners, designers, contractors and vendors eventually communicating project information in terms of ROCS and the SUPR Model, which will enable their various computer programs, expert systems, robots and automated construction resources to "make sense" of the communicated data.

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