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PRODUCT – BASED MODEL REPRESENTATION FOR INTEGRATING 3D CAD WITH COMPUTER SIMULATION

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ABSTRACT

Computer-Aided Design (CAD) is widely used during the engineering design stage of construction projects. CAD generally contains a wealth of information regarding the facility to be constructed; this information can be effectively used for construction decision-making. This paper undertakes an investigation of the possibility of using a "product-based" model representation for integrating 3D CAD with computer simulation to facilitate better decision-making during construction.

The objective is to conceptualize an environment that allows an engineer to specify how construction of the facility will be carried out with CAD. The environment could then extract relevant information to produce simulation models that will enable better understanding of the construction process, better estimating of cost, and more appropriate planning.

1 INTRODUCTION

Computer simulation provides tools that are used to model dynamic interactions between resources within construction activities. Although simulation has gained acceptance in many industries, its use in the construction industry is scattered and limited. The complexities and time requirements of model development have rendered simulation in the construction industry non-cost effective (Shi and AbouRizk 1994). The Simulation Panel of the Computerized Construction Research Workshop (Ibbs 1987) has identified simplifying existing simulation tools as one of the main goals for the research and development of construction simulation.

Computer Aided Design (CAD) systems are used by engineers and draftspersons as tools for design and drawing. CAD systems are now available on personal computers, making them cost effective for use on construction projects of all sizes. Two of the more popular CAD platforms are MicroStation and AutoCAD. These CAD programs are used extensively for pre-construction design, but are seldom used during the construction phase (Mather 1998).

Manavazhi (1997) and Shi (1995) identified the need to integrate simulation with CAD to provide a more effective definition of project models. CAD can increase the amount of information that is provided to the model on an exponential basis. This information can then be used to more accurately simulate the construction operation. This paper focuses on a CAD-based simulation modeling methodology to address the needs identified by these researchers.

2 PRODUCT – ORIENTED SIMULATION ENVIRONMENT

Although construction simulation has been studied in academic research since it was first popularized by 7(1976), it has not been adopted by industry to a significant degree. Most research on construction simulation has been done in the area of process-interaction simulation, which primarily focuses on construction processes or activities. This process-oriented simulation approach results in a gap between the product, the simulated object, and the simulation model. It has the following shortcomings:

- Re-entry of data and information from one phase of the project design or analysis to the other. For example, quantities and dimensions are available in CAD models but they must be re-computed for use in a simulation (or scheduling, estimating etc.) model.
- Inefficient storage and retrieval of data related to the same project. For example, CAD files contain information that is duplicated in other systems.

- Increased complexity of simulation models due to reliance on abstract notation for representing the project.
- Inability to use the simulation results to generate more meaningful reports that the construction engineers are familiar with, such as CPM, estimating, and animation.

Due to the inherent limitations of process-oriented simulation, the development and implementation of simulation models is rather time consuming and requires intimate knowledge of both simulation and the construction operation. As a result, simulation in construction is not widely recognized or accepted.

This paper attempts to investigate an alternative construction simulation methodology from a product-oriented perspective. This methodology focuses on the product, the simulated object, instead of the processes or activities. The product-oriented simulation environment (PSE) applies these concepts to provide a simulation environment that would be integrated with CAD, require minimal simulation knowledge, and be simple to use.

2.1 PSE Architecture

The Product-Oriented Simulation Environment achieves integration between CAD, Simulation and other support systems in construction (e.g. estimating and scheduling) by adopting a product view of the constructed facility. In other words, the system representation and all of its abstractions are derived from the view of the product to be constructed.

At the essence of this approach is the product hierarchy, the Product Network, and the Simulation model which serve as the basis of all representations.

All relevant data related to the constructed facility is stored in the product hierarchy (PH). The PH represents the product physical attributes, their relationships and the methods by which they are constructed.

The Product Network (PN) is a concept used to define the construction sequence for each construction phase of the product thus complementing the PH.

The simulation model (SM) of the project is composed by linking the product model in a given construction phase to simulation models from a library of flexible/modular models. The SM also represents the methods by which the project will be constructed and the process to be followed. The relationship between the PN and the SM is created during this process.

Figure 1 illustrates the PSE architecture. CAD feeds information to the PH in an automated fashion, thus creating the product elements of the project. The Product Network is built from the PH and with specifications from the user to constrain how the product elements relate to each other from a building point of view. For example, the excavation of section 1 takes place prior to that of section 2. The construction methods library is then utilized to specify how the product will be built by referencing the proper process and tying it to the product network, thus creating the simulation model.

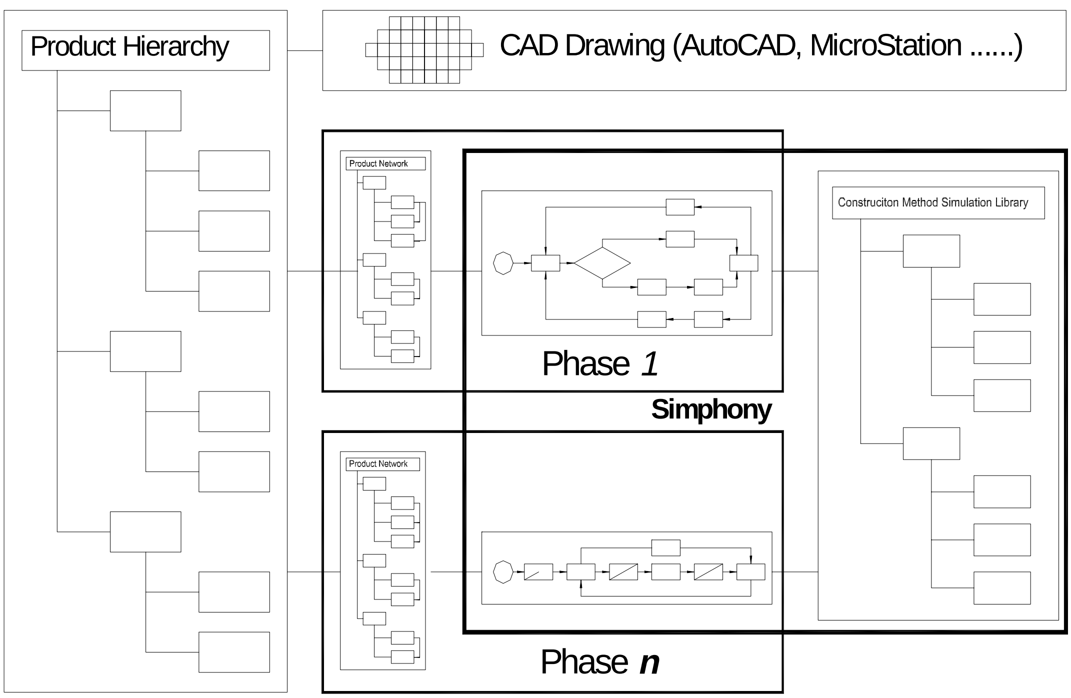

Figure 1: PSE Architecture

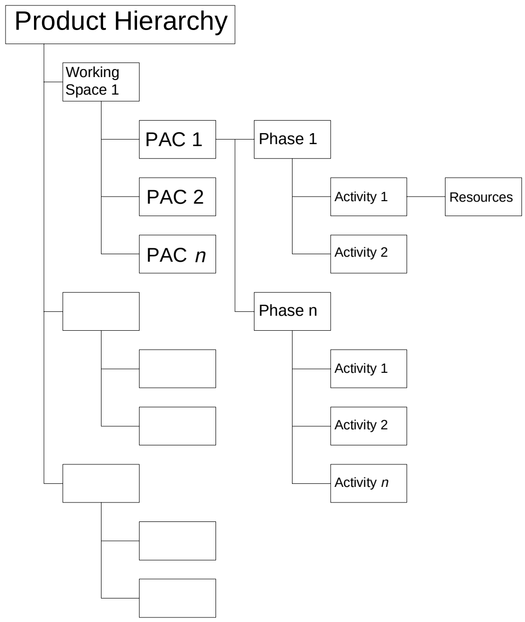

Figure 2: Product Hierarchy

2.2 Product Hierarchy (PH)

The goal of the product hierarchy is to provide a model that integrates physical product attributes, process information, and resource information. The model focuses on two main abstractions: the relationship between the products and activities, and the progression of an object from initial requirements to a proposed object, then to an actual realized object. The object representation of the most basic element of the PH is the Product Atomic Component (PAC). This object maintains and carries all information related to the product. The product hierarchy representation performs an important role in the product-oriented simulation methodology. To create the PH, each PAC that is generated from the CAD design drawing needs to be positioned in the hierarchy according to the dependency that exists among its components. Linking the product and the simulation model is achieved by building the relationship between the product and the simulation model as illustrated in Figure 2. This will be further detailed later in the paper.

For a comprehensive representation of all physical elements within a project the PH given in Figure 2 is used. As demonstrated in the figure, the project is broken down by first identifying the various “work spaces” forming the project (if required). A work space is a physical description of a part of the project where construction will take place; it is constrained by the design, the underlying topological conditions of the site, and the technological limitations of the method of construction employed. The process can be automated utilizing parameters specified by the user, thus removing the user’s burden of identifying large numbers of work spaces from a project. The work space is further defined by the PAC elements that compose it. Each of the PAC elements is then characterized by the various construction phases that are required to build them.

Each PAC may pass through a number of different construction phases or operations. A construction phase represents a period of the life cycle of the PAC whereby it is transformed into another product. The project phase is defined by the activities required to complete the phase. Activities are completed with resources as shown in Figure 2.

2.3 CAD Model

The CAD model resides within the native CAD environment where it was created (e.g. AutoCAD). The model is extracted and embedded into the PH using a utility designed and implemented for this purpose. Information such as geometric data (position, attributes, etc.), volumetric data, and pertinent site characteristics are captured from the CAD model and stored into the PH for use within the simulation. Using the same approach, the data residing in the PH can be communicated to the CAD model during or after simulation for the purpose of model update or for presentation.

2.4 Product Network Representation

The PN outlines the logical relationships between the physical components of the project. It offers a visual means by which the order of construction of the PAC elements is specified. A PN is generally required for each phase of construction as the specified product is evolving. Once complete, the PN contains definition of the sequence of all PAC elements for a given phase of construction.

In order to facilitate better project definition, the concept of a “construction section” is introduced. A section defines a group of PACs that can be constructed together and are only constrained by other sections. A space buffer between sections can provide further constraints to ensure that a whole section is complete and a certain time has elapsed prior to the start of another section.

2.4.1 Construction Sequence

In construction operations, a process does not take place until the necessary prerequisite components have been met. The second layer of the excavation pit, for example, will not be removed until the first layer has already been excavated for the same section. The order of processing of components is defined as the construction sequence. Components in the same hierarchical level will commence when their prerequisite components have been complete according to the order that is defined in PN. If there are no prerequisite components assigned, the component will be undertaken based on the order that appears in the PH. The order in PH is the order of creating the PACs. The construction sequence of each component can be automatically determined at creation time for simple projects.

2.5 Construction Simulation Model Representation

The approach adopted for simulation model representation is the special purpose simulation approach. It has the advantages of simplicity from the end user perspective and focus/specialization for integration purposes.

The strategy of implementation is based on Simphony (Hajjar and AbouRizk 1999), which is a discrete event simulation system that arose as an object-oriented implementation for special purpose simulation. The event-driven algorithm simply scans the module for an event that could possibly be scheduled for execution. The event selection is based on resource availability, logical constraints, other module constraints, and random phenomena. The selected event is routed to the appropriate process where future events can be scheduled (AbouRizk and Hajjar 1997).

In addition to event scheduling support, Simphony also provides numerous other forms of support such as a “low level” modeling element designer that allows a developer to develop special modeling elements using Visual Basic scripting (VB-scripting), and a simulation model editor that allows users who do not have a simulation background to build the simulation model based on the built-in modeling elements.

2.5.1 Simulation Product Model (SimPM) Object

In order to integrate CAD with Simphony, PSE takes advantage of Microsoft’s ActiveX technology to provide an ActiveX object, namely: the “Simulation Product Model (SimPM) object”. SimPM contains the required simulation information as well as links to the PH and PN thus facilitating integration of CAD information with the simulation model.

The integration between SimPM and Simphony is implemented through the Simphony designer. SimPM is embedded in Simphony where its instances can be created. When the developer creates the entity modeling-element in Simphony, a new SimPM instance is created simultaneously with its PM’s reference set to the entity. In other words, the entity becomes a product-based entity with the product model attached. As such, the SimPM object can be accessed through the “PM” attribute of the entity.

The SimPM object implements a variety of methods through which the simulation model can communicate with the PN and PH outside Simphony. The SimPM object acts as the message sender that proceeds through the entire construction operation and keeps sending messages to the PN, and through the PN to the PH.

2.5.2 Product-Based Modeling Element

Simphony modeling elements are made to resemble the corresponding physical or logical real world elements. The simulation model is built by the user by assembling these different modeling elements (reader is referred to Hajjar and AbouRizk 1999 for a detailed description of how this takes place). The product-based modeling elements inherit their attributes from Simphony. Additional features associated with the product model are added to achieve the integration with the product model. The following explains the two special modeling elements that are distinct to this approach and how they are implemented in Simphony.

2.5.2.1 Entity

Entity is defined as an object that flows through the simulation model. An entity can represent a part, person, message or other objects. It can be thought of as an information packet with a set of attributes.

The product-based entity is an entity that carries SimPM along with it. As entities flow through the simulation model, the SimPM also proceeds through each construction processes in the model. After the SimPM completes all required activities in the model, a construction phase is completed.

The product-based entity is an object that is created in the simulation model and combined with the SimPM to carry out the product-oriented simulation methodology. Entities created in the simulation model can represent anything the user desires. They only serve as containers to carry the SimPM to perform the simulation. The SimPM, which is carried by the entity, controls the simulation process.

2.5.2.2 Activity

Activities are the modeling elements that represent work to be performed using the required resources. Each instance of an activity has its own duration that represents how long it takes to do the associated work. Activity instances also hold those specific resources that were acquired in order to start the activity.

A product-based activity works like a regular activity, while providing the following special features that present the synthesis of the product model and simulation model.

- **Creation of the SimPM**. The product-based activity in PSE creates the SimPM before the activity is started (in general terms). The creation function in the activity triggers a method in the PH to create the SimPM based on the entity's information. When no product is available, the entity will be added to the queue until the prerequisite activities or phases provide more products.

- **Communication with PN and PH.** Product-based activities support complex messaging mechanisms, which explicitly pass information to the PN and PH. This information reflects the on-going state of the simulation. In PSE, these messages are hidden from the modeler. From the modeler's perspective, this suppresses unnecessary complexity. As the entity transfers into the activity, the activity will send a message to the PN, and through the PN to the PH, in order to inform them that the activity is starting. Before the entity transfers out, it also sends messages denoting that this activity is completed. In the meantime, information, such as start time, end time and resource usage is collected and stored in the PH for later use.
- **Hierarchy.** The hierarchical structure of an activity provides more flexibility to run the simulation at different levels. With the hierarchy feature, each activity can have its own sub-model that is made up of other low-level activities.

2.5.3 Construction Model Simulation Library (CMSL)

PSE furnishes a Construction Model Simulation Library (CMSL), which comprises common simulation modeling elements such as entities and activities as well as special purpose simulation modeling elements derived from the common modeling elements (e.g. excavating from activity, and truck from entity). Most of these elements have attributes which users can manipulate to modify the outcome of the simulation. Each modeling element provides a specific functionality and allows users to manipulate the internal behavior through its parameter attributes.

PSE is intended to simplify the modeling process and automatically generate models. To achieve this, the specific construction method simulation model library that targets a specific type of project such as dam, earthmoving, and pipeline installation is built in the system. The user then develops the simulation model by selecting construction methods from a simulation library and assembling them into a final product-oriented simulation model. Models are built hierarchically in a top down fashion. Higher level elements generally represent overall operations with lower levels incorporating more details regarding the specific process.

3 CASE STUDY

A CAD-based product-oriented special purpose simulation template, called "CAD Earthmoving", was developed to demonstrate the product-oriented simulation concept. Users are able to model preparation, loading, hauling, dumping and spreading operations in a simple and straightforward way using this template.

3.1 Earthmoving

Earthmoving is a specialized construction field where large amounts of earth are moved from one location (referred to as the source), to an another location (referred to as placement). Earthmoving projects consist of many interacting processes such as preparing, loading, hauling, dumping, and spreading.

Allocation and optimization of the resources involved in earthmoving is quite time consuming. Estimating the cost and duration of an earthmoving project involves a large number of assumptions about the effect of environment and resources on the overall system production. Simulation offers an effective way to solve these problems.

3.1.1 Product Hierarchy and Product Network

For common earthmoving operations, two product hierarchies must be created to represent source and placement respectively, and three construction phases are involved, namely preparing, moving and spreading. Preparations are localized to a given construction source and as such require one PN to define their sequence. The Moving processes involve the source and placement and as such require two PNs for their definition. The spreading is similar to preparation. Figure 3 demonstrates the three phases of construction and the resulting PN is each phase.

3.1.2 Simulation Model

Three special purpose models are built for three different construction phases involved in the earthmoving operation.

The source model is used to represent the preparation activity if the earth is not suitable. A preparation cycle models the source preparation operation. A dozer created in conjunction with the SimPM at run time works as a product –based entity and the preparation is an activity in the source model. The placement model is similar to the source model. The major difference is that the source model refers to source PH and placement model refers to placement PH.

The moving model comprises excavating, hauling and dumping. In order to form a truck cycle, the return activity is added into the model to represent the truck back cycle. In this model, the excavating activity has a sub-model that

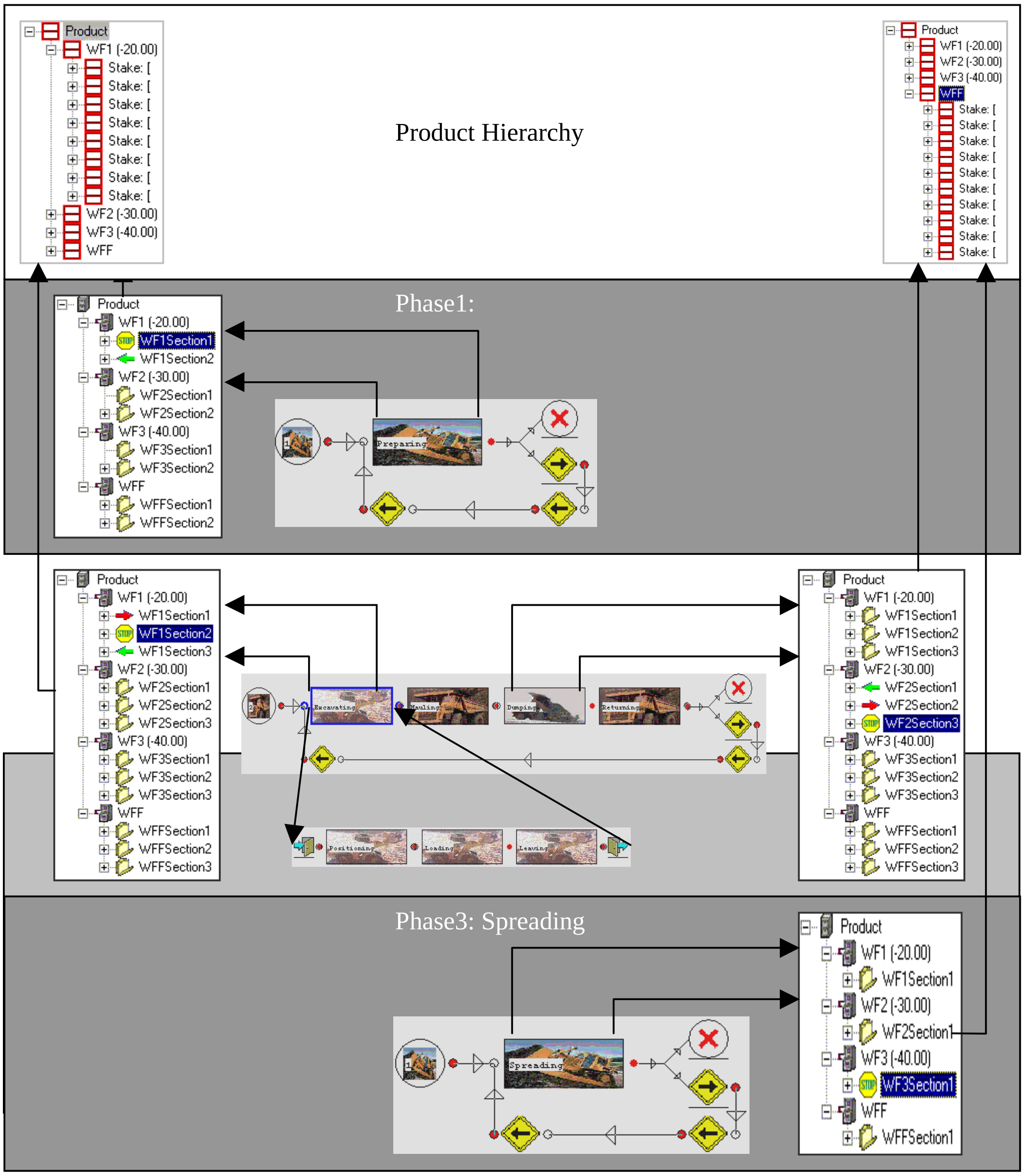

Figure 3: Product-Based Earthmoving Simulation Architecture

consists of truck positioning, loading, and truck leaving to simulate the excavation in more detail. The application is implemented within three environments that work in a harmonious manner. The CAD representations are in AutoCAD. The simulation model specifications and the experimentation part reside in Simphony. The integration through the product model is implemented in Visual Basic and through ActiveX technology. The system is outlined in Figure 3 and is available by contacting the second author.

4 CONCLUSIONS

This paper investigated a product-oriented simulation methodology. PSE was developed to prove the concept and provide a simple and straightforward way to build simulation models using product models based on CAD.

Further work is required to make the implementation of this approach cost effective. In particular, further automation of the generation and assembly of the PH and PN as well as the construction of the simulation model is desired.

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