SEAMLESS DATA MODEL FOR A CAD-BASED SIMULATIONSYSTEM

Racha Chahrour[1] , Volkhard Franz[2]

ABSTRACT

Although simulation is proven to improve the analysis process in construction by multiple research works, only a negligible transfer into the practice can be observed. So, simulation is not yet acknowledged as a method for planning and controlling of construction sites. The new approach presented in this paper suggests the integration of Petri nets based simulation with CAD by means of product models in order to simplify the modeling process. The data management within the interface meets present-day data structures and future technical developments of both systems and adopts common organizational schemes from the practical experience. The whole concept is especially developed for road construction projects and prototypically implemented as a software package.

KEY WORDS

Construction management, simulation, CAD, XML, earthmoving.

INTRODUCTION

Discrete event simulation (DES) is considered to be a very promising method for decision making and scheduling in the construction management. This results from a lot of recent research efforts done to implement simulation into this field, CYCLONE (Halpin 1977), CIPROS (Odeh et.al. 1992), STROPOSCOPE (Martinez 1996). DES enables stochastic and dynamic analysis of a system and consequently helps designing and describing its behavior over time and thus utilizing its resources efficiently. In order for the simulation technique to find an intensive use in the construction practice, simplified, graphical and user-friendly modeling methods for a special purpose simulation have to be developed (Hajjar 1998). Furthermore, it is required that simulation will be integrated and shared data with other planning and controlling systems.

Especially for heavy earthmoving construction and logistic operations in road construction projects the use of simulation technique can be very helpful. These operations are very complicated and affected by external conditions like weather, soil, public conflicts, etc. This fact enforces the planer to meet a lot of simplifying assumptions as well as to work with approximated values and thus increases the level of experience needed to carry out such

[1] Research Engineer, Kassel University, Faculty of Civil Engineering, Department of Construction Management, Moenchebergstr. 7, 34125 Kassel, Germany, Phone +49 561 804-2621, FAX +49 561 804-7795, chahrour@uni-kassel.de

[2] Professor, Construction Engrg. Kassel University, Faculty of Civil Engineering, Department of Construction Management, Moenchebergstr. 7, 34125 Kassel, Germany, Phone +49 561 804-2616, FAX +49 561 804-7795, vfranz@uni-kassel.de

operations cost-effectively. Moreover, most decisions are taken subjectively and intuitively. This way of working complicates important processes like making and justifying a decision, knowledge sharing and conflict mediation. A study carried out between 1996 and 2001 in many countries proved that the practiced methods in road projects do not cause them to be performed in an economical way (Castro 2002).

This Paper suggests applying simulation to solve construction and logistic problems in road projects. The specific goals of the simulation are to analyze the resource utilization, to determine the most economical composition of resource groups and to minimize haul distance taking surrounding conditions into consideration. Simulation could even have more potential as a tool to enhance the analysis process in resolving disputes caused by changed conditions. However, the lately is restricted by a continuous achieving of the construction progress. In order to simplify the modeling process and to deal with data effectively, simulation should be integrated with CAD which is included in most road designing and planning systems. In this regard many approaches were introduced to automatically generate a simulation model from CAD. Xu and AbouRizk (1999) developed a product-oriented simulation environment based on three principles: the product hierarchy (PH), the product network (PN) and the simulation model (SM). The PH includes all product physical attributes with their relationships and construction methods, whereas data can be extracted from the CAD model. Within the PN the construction sequence for each construction phase is defined. The simulation product model can be then composed by linking related PH and PN with suitable SM from a modular library. This philosophy was the basis for developing Simphony, an environment for building special purpose construction simulation tools, (Hajjar, AbouRizk 1999). Especially for earthmoving processes another paper extended an add-on program for calculating earthwork quantities within CAD to enable the user to extract and input simulation related data. This data is then passed by an "intelligent data manager" to a simulation model. The simulation model is automatically assembled from appropriate atomic models which are integrated within the simulation environment, (AbouRizk, Mather 2000).

Focusing on road projects the new approach discusses a consistent and seamless data structure to integrate simulation and CAD. It takes advantage of new advancements in hierarchical and object-oriented simulation concepts, like Petri nets, as well as in data management technologies, like eXtensible Markup Language (XML), in order to build up a simulation related road product model (SRM).

MODELING AND INTEGRATING CONCEPTS

There are three ways to built up a simulation model. The conventional way is to model each project individually, and it represents a drawback in applying simulation to construction industry. Possible reasons for this fact are:

- variety and complexity of construction processes,
- lack of simulation knowledge in construction management field,
- complexity of the simulation study itself,
- repetitively required modeling effort for unique and non-durable projects in comparison with stationary industries.

New modular, hierarchical, object-oriented and interfacing techniques simplified the modeling process and paved the way for another kind of modeling methods. A special purpose simulation system can accordingly be generalized by using attributes to cover many cases in the same scope. Modeling a specific project means then only to parameterize these attributes to meet the real conditions. A third modeling way can be observed in the stationary industry and is layout-based. Due to the fact that a construction layout does not include all simulation related information a pure layout-based modeling does not have the aimed effects of utilization. A further possibility is adopted in this paper and combines layout-based and parameterized modeling methods through integrating simulation with CAD. A general simulation system for a special application field should be able to be parameterized by CAD which also functions as a graphical user interface (GUI) in this case. While geometric information can be extracted from the layout directly, other non layout included data should be input by means of CAD. Integrating simulation with CAD-systems ensures hereby more efficiency in dealing with data so that data once saved in CAD is also extracted and reused for simulation purpose automatically.

The integration between software environments is classified according to various aspects in the literature. Randell (2002) differentiates three types of integration: application, information and transformation integration. With the application integration both environments not only ‘know’ about the exchanged information, but also about how to perform the interactions, so the integrated applications have to be aware of each other. When information are exchanged or shared in between different applications, the type of integration is called information integration. In some cases the communication can even be bi-directional. STEP (STandard for the Exchange of Product model data) is an international standard (ISO 10303) and represents an example of this kind of integration where product data with consistent structure is shared. Transformation integration is a special case of information integration with which data is transformed and exchanged to be used in a system from a different field of application or domain. The approaches for integrating construction simulation and CAD described in the introduction are all considered to follow the last type of integration. This paper also combines two integration types, i.e. transformation and information integration by developing a simulation related product model for road construction (SRM). Focusing on a specific application field allows to include all related processes with their relationships, hierarchy, work sequence etc. in one model. Product model data can be manipulated within road planning systems - which include geometrical information - and then be passed to parameterize the simulation system. The data structure in the product model is integrated in both systems.

PETRI NETS-BASED ROAD SIMULATION SYSTEM

INTRODUCTION TO PETRI NETS

The history of Petri nets started 1962 with the dissertation thesis of C. A. Petri (Petri 1962). With these nets complex processes can be statically and dynamically analyzed. The basic net theoretical model was also proposed by Petri as condition/event systems. Since then the theory of Petri nets was continuously developed. In general a Petri net consists of three elements that model the statistical state of a system. A place - denoted by a circle – represents a condition, such as resource availability, buffer, input or output data. A transition – denoted by a solid bar – represents an event or activity. The third element, a directed and attributed arc, connects a place with a transition and vice versa. The dynamic state of the system is represented by tokens – denoted by a small solid circle – which are initialized at places and usually model the entities or the flow units of a system, such material, resource, vehicle, etc.

High level predicate/transition Petri nets (PrT) enable defining individual tokens with changing properties (Genrich, Lautenbach 1981). This enhancement allows the modeller to define different types of tokens by assigning more attributes to each type. To manipulate these attributes during the simulation alphanumeric code can be integrated in transitions and executed when they are activated (fired), Fig.1. Modern Petri nets tools based on PrT nets theory and can also model timed, stochastic, hierarchic operations even in an object oriented manner. Only few studies dealt with the use of Petri nets to model complex construction systems (Wakefield, Sears 1997), (Sawhney et al. 1999).

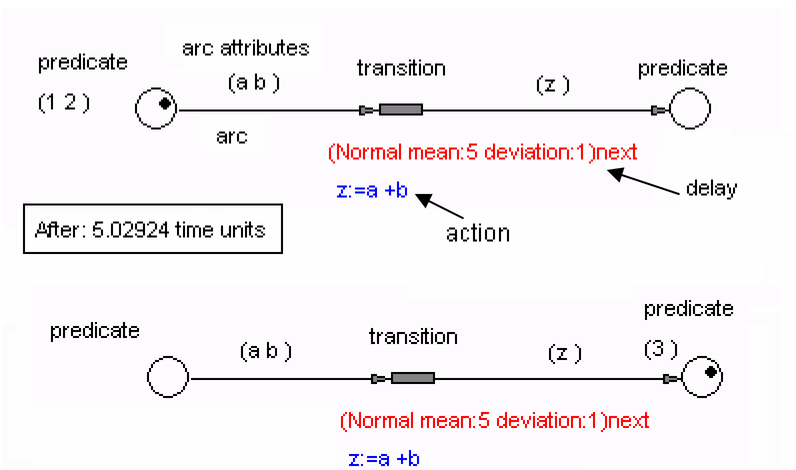

Figure 1: A simple Petri net before and after firing.

THE ROAD SIMULATION SYSTEM

The road simulation system is based on the principles of PrT nets which were specially proven to be appropriate for construction planning and control (Franz 1989). It is supposed to be an integrated component within a whole CAD-based simulation system. A common system for road projects is significantly modeled with the help of PACE®, a hierarchical, object-oriented and timed Petri nets environment for building simulation tools. The object-oriented programming language Smalltalk is implemented among others in transitions in form of inscriptions. There are three types of transition inscriptions: condition, delay and action, see Fig. 1. Moreover, three variable types can be addressed in PACE: a) temporal variables which are significant for a transition and include the connector attributes, b) modular variables which are significant for a hierarchical level (module) including all its submodules. However, their values can be manipulated within other modules, c) global variables which are significant for the whole net. The modeling concept is based on the same structure practiced on construction site. In the top hierarchy there is one module for each type of work regions, in total five: cut, fill, temporary store, haul road and landfill for excess cut material. Even if the road project consists of many work regions from the same type - more cuts or more fills for instance -, they are described by only one module each. The different specifications are modeled by modular variables.

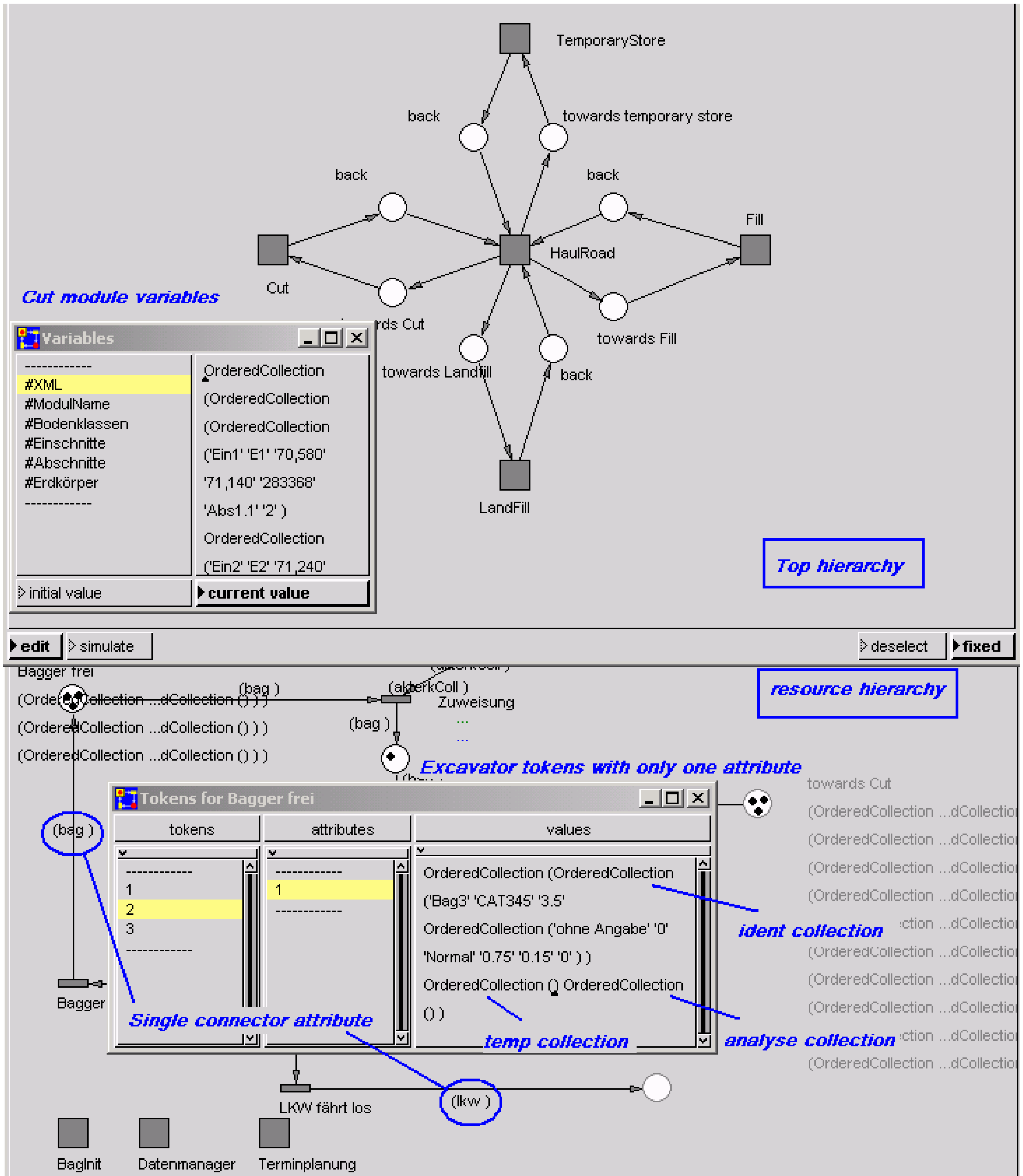

Figure 2: Modeling methodology in PrT nets.

As the system is resource oriented, each module includes other modules for possible resource types which can probably work at a specific region, for example a cut can include excavator module, scraper module, etc. A resource module consists in turn of sub modules which represent the repetitive processes of this resource modeled with the help of static net elements, i.e. transitions, places and connectors. Resources are modeled as tokens with many attributes. The 'dynamic' tokens pass through the 'static' processes and thereby consume time and change attribute values. The most common method to carry out earthworks in road construction projects is to use a group of excavators with dump trucks feeding each. Therefore the simulation system only includes an excavator module exemplarily.

In view of the big number of resource attributes a unique structure is developed to express all of them in a consistent manner. All attributes are integrated in a single resource collection attribute which also includes other collections. A resource collection consists of identification collection (ident), temporal collection (temp) and analyse collection, see Fig. 2. The first collection includes all identifying attributes which are adopted from the interface with CAD, i.e. the SRM, for example an excavator identification collection includes bucket capacity, cycle time density function etc. The second position in the resource collection is taken by a temporal collection where all temporal attributes are saved, for example an excavator temporal collection could include soil volume to be excavated, number of loaded buckets etc. The analyse collection takes the third position and collects all result related attributes to make the end simulation analysis, for example an excavator analyse collection could include waiting time, utilisation, productivity etc.

With this methodology it is possible to express all resource specification using tokens with a single attribute which also appears on connectors as a connector attribute. Otherwise all attributes of each resource should have to be listed on each connector accordingly, and the net would be very indistinct, see Fig. 2. Tokens and module variables can be generated automatically after the SRM had been read within the simulation system. With this step a model of a specific road project is built up by assigning values to all variable attributes.

SIMULATION RELATED ROAD PRODUCT MODEL

ROAD PRODUCT MODELS-OVERVIEW

The uniqueness of products in civil engineering was not only an obstacle for applying simulation but also for product model approach. The reason is that both technologies are based on the idea of developing a model of a product – here a project. Recent concepts and techniques in both research fields reached an enhanced level of applicability and thus helped realizing many promising approaches and developments. With the approach presented in this paper the product model of a road should be extended to be also used in simulation. Existing product models do not meet the demands of simulation regarding hierarchy, sequence, resources, etc. The core of all road models is the geometry, which is also relevant for simulation. However, the structure of the whole model meets more the requirements of road planning and design and less construction management or simulation aims.

A great deal of road planning and design applications in Germany implemented the product model of OKSTRA3 (Objektkatalog für Straßen- und Verkehrswesen), and is coordinated by the German federal institute of roads (Bundesanstalt für Straßenwesen).

[3] See: www.okstra.de, last accesses February 2006

OKSTRA is a very comprehensive approach for exchanging road design, maintenance and traffic data. It is represented by a complex network of objects, described by using NIAM, EXPRESS, SQL and XML.

Also LandXML[4] is a common format for archieving and exchanging road data. It is being developed very fast by the LandXML Industry Consortium. Meanwhile it also exists in Germany, although it does not adopt some applicable regulations. According Rebolj (2002) the idea of a total product model incorporating all possible views is unreasonable. In his view such kind of model should rather be a network of manageable particles, which can be linked together to generate an efficient and less complex product model. After all, the previously mentioned product models become continuously more complex. Taking this into consideration the SRM is developed independently from a 'root' product model and primarily shares geometry with it. However, in order to enable the suggested methodology to be integrated in a product model, the same IT infrastructure is used for implementation, i.e. XML[5]. XML is actually an internet technology but additionally used to describe product models as schemes.

THE NEW APPROACH, SRM

The same hierarchical structure described in the simulation system is also adopted to build the simulation related road product model SRM. This model has twofold aims: On the one hand it delivers a seamless data structure between the integrated environments. The reason is that the SRM should be implemented in all related systems. On the other hand different variants of simulation parameters can be independently archieved.

According the SRM a road project consists also of four classes: cut, fill, temporary store and landfill for excess cut material. These classes are linked together with an additional class which represents the haul road. The model focuses on the cut region exemplarily. The cut is accordingly divided into sections and these in turn into soil blocks. Soil blocks have relationships to an excavator that is served by a truck. A truck uses then a haul road to reach a specific placement region, see Fig. 3. Soil blocks and resources will be turned into tokens in the simulation later on. Each class in the model has many attributes which are considered necessary to parameterize the Petri nets based simulation model.

SRM is described and saved in XML format. XML is a fundamental Internet standard derived from the Standard Generalized Markup Langauage (SGML) (ISO 8879) and is widely used to exchange data on the web and in between applications. It is recommended by the World Wide Web Consortium (W3C) and expressed by a simple text format that consists of flexible formatting rules. A well-formed XML document should meet some constrains which are defined by a schema, and it represents a kind of grammar for writing XML. From many available schema definition languages the XML Schema Definition (XSD) is chosen for the SRM. In order to work with XML data within an application an XML document should be parsed by a parser. There are many parsers available which generate class libraries by transforming the XML document into a document object model (DOM) with a treelike structure. DOM is then linked with the integrated environments and allows thereby using XML data programmatically.

4 See: www.landxml.com,, last accesses February 2006
5 See: www.w3.org/xml/, last accesses February 2006

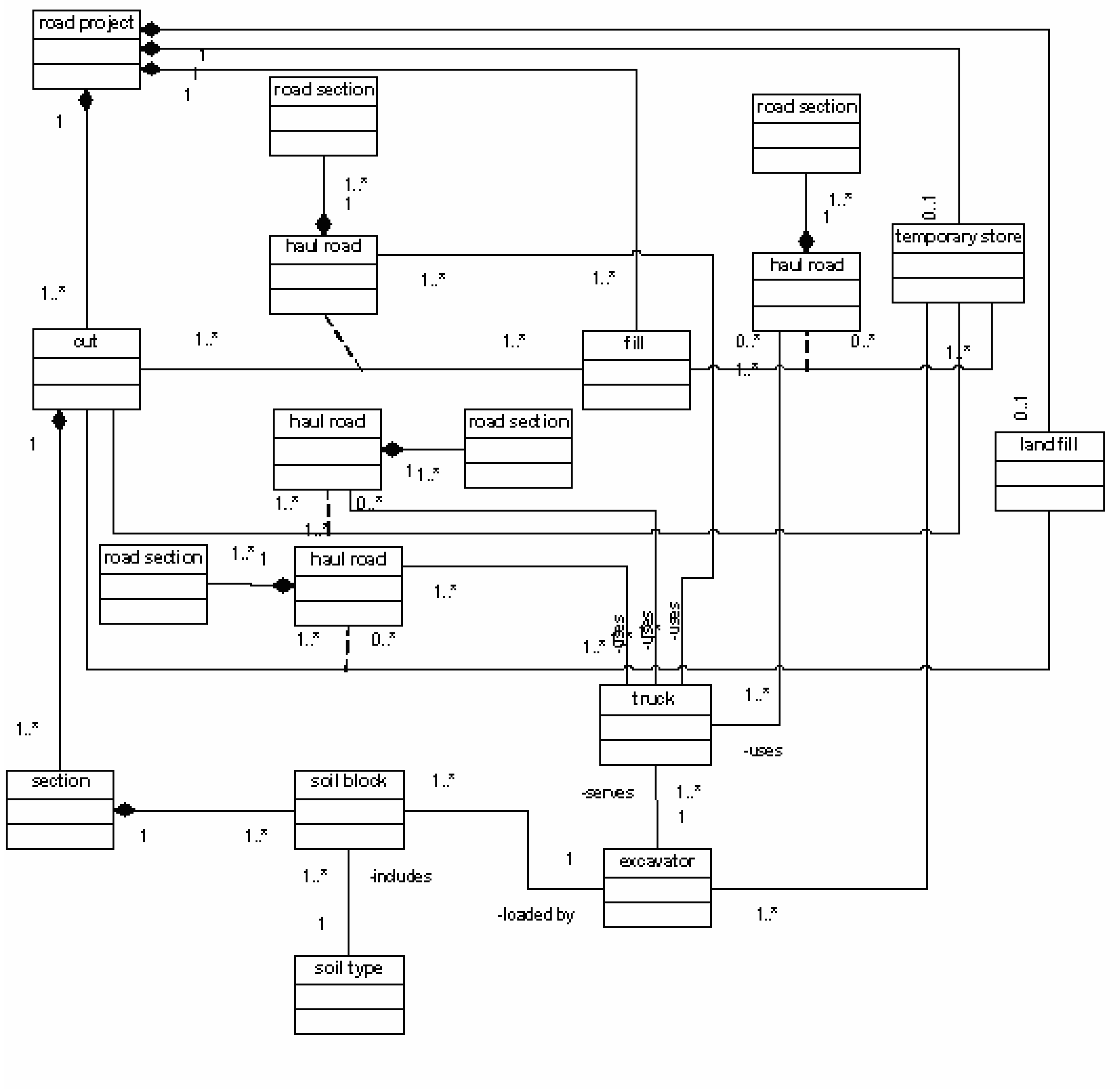

Figure 3: The SRM classes

PROTORYPE IMPLEMENTATION

During the study of some construction sites and the parallel search for the best road planning system to implement the developed SRM, the following problems could be pointed out. Despite of the availability of road product models and the fact that they are implemented in a lot of road design and planning software systems other exchange formats are still widely in use. While the Drawing EXchange Format (DXF) is generally used to exchange drawings among project participants in the practice, road data including alignments, cross sections, etc. represented by coordination points are exchanged in REB format (Richtlinien für elektronische Bauabrechnung) in Germany, (REB 1979). REB is a set of guidelines for electronic construction accounting which is especially applied to calculate quantities. Especially temporal haul roads are often documented only in DXF format.

Another problem is that the most road design and planning systems are not open-source-code software and therefore difficult to be extended. In addition and because the developed system is supposed to be adopted in many project phases, only a general, mostly available or easily acquired CAD environment is acceptable. The final decision was to extend AutoCAD® and to import the required geometry data for the simulation from DXF and REB. However, according to the same methodology for the prototype implementation shown in Fig. 4 the SRM can be implemented in each road design and planning software and within different road product models.

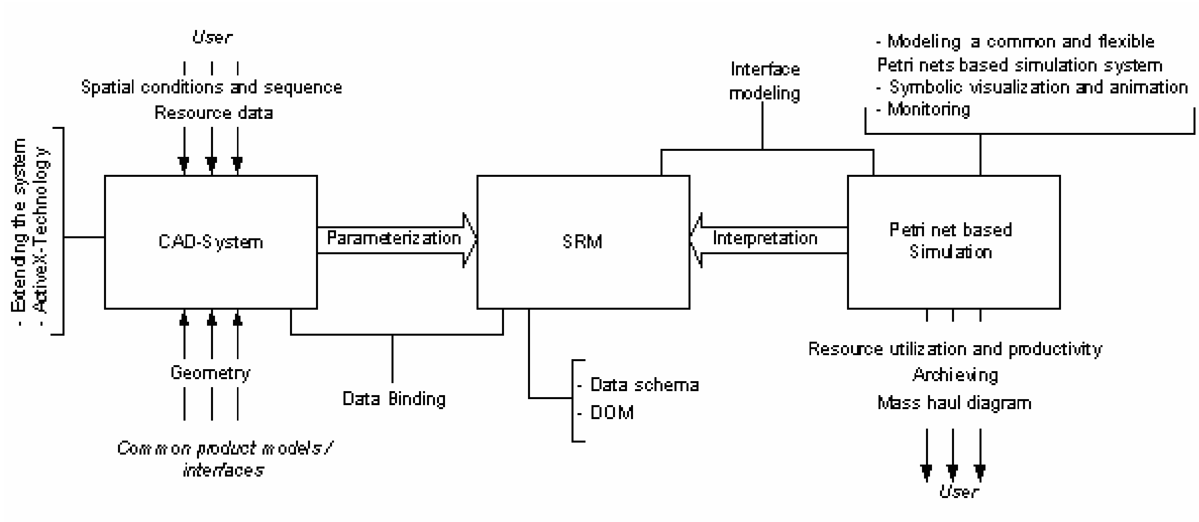

Figure 4: The prototype implementation

As shown in Fig. 4 the CAD system should be extended in order to serve as a user interface. This step involved some technologies, like Visual Basic for Application (VBA) and ActiveX-Technology which are implemented within AutoCAD as well as Data binding which helps manipulating the XML document of the developed SRM. The package is then accessible through an additional menu in AutoCAD with the name 'Simulation'. The user can save his simulation input variants in two forms. First, as an XML document that includes the attributes required for the simulation, i.e. data referring to work regions, resources, soil blocks haul roads etc. Second, as graphic documents like site plan with temporal haul roads as well as side roads and sample cross section plans with specified soil blocks. Sample cross sections define soil blocks to be carried out from a specific excavator or in a specific sequence. They are required for each work section where other constrains and conditions are expected. The package includes also an earthwork quantity calculating toolkit according REB, in order to estimate the volumes of soil blocks individually.

CONCLUSION

This paper introduces a seamless data model to integrate simulation with CAD. The data structure is developed in a neutral environment as a simulation related product model to be linked to the involved systems. Using the most modern technologies in exchanging data in between applications for developing this model enables its connection with other common road product models. The simulation related product model is then used to parameterize a simulation system for improving the analyses of road construction projects.

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