SUPPORT OF SITE CONSTRUCTION PROCESSES BY PRODUCT DATA TECHNOLOGY

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ABSTRACT

In the last decade or so, design/engineering of building and construction projects is gradually incorporating advanced information technologies, like Product Data Technology (PDT). The main drive for this development comes from the demand for meaningful electronic communication between CAxx systems of various disciplines. Getting rid of the islands of automation and information improves both the design processes and the design results.

However islands of automation and information not only exist in design/engineering, but also in the realization phase. Moreover the design/engineering and the realization phases as a whole, are still very much isolated.

Now that in the foreseeable future main contractors will receive a complete product description, a product model, in electronic format, the question becomes important how PDT can support on-site construction.

This paper reports about a study into the question how to support construction site processes by (1) a standardized product model and (2) a library of standardized work method objects implementing information about construction processes. Initial results of a system that supports the construction site process visualization and simulation from an imported standardized product model.

Keywords: PDT, construction management, work method, operation, processes, work task, core object model, objects, construction site.

INTRODUCTION

This decade and the next, the Building and Construction industry is gradually transforming into a high-tech industry. The paper based information system that supported the design and construction of facilities during the centuries is now changing into an electronic information system. Nowadays, almost every professional is using CAxx systems to support his work. Introduction of IT in Construction invariably is leading to ‘islands of automation and information’. Basically the problem is that we still have to use *two* information systems, one partly paper based and another one partly electronic. That means that we ourselves are often working as translation machines: translating written information into electronic information and vise versa. The bottlenecks thus created are often the reason that our efforts in developing and applying state of the art IT, are not paying off.
Other industries, like Mechanical, Aerospace and Automotive have encountered similar problems. As these industries are more subjected to market forces they already started to think about solutions in the late 60’s and early 70’s. Several approaches to ‘integration’ have been demonstrated, introduced and abandoned. CAD and CAM became CAD/CAM and CIM.

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Standards for electronic data exchange have been developed: IGES, DXF, and much more. Product modeling or Product Data Technology (PDT) started in the early 80's. In the mid 80's ISO STEP (Standard for the Exchange of Product model data) followed the PDES development in the USA. Again the high-tech industries took the lead, leaving STEP AEC behind in bewilderment.

THE CURRENT SITUATION IN OUR INDUSTRY

Bewilderment and fragmentation is still the main characteristic on the integration front in the Building and Construction industry. STEP AEC proved to be the wrong platform for the development of standards for electronic sharing and exchanging of Building and Construction information [1]. More than a decade of development work did not produce anything worthwhile. The main reasons for this lack of success are: (1) the fact that STEP is not so much about standardization, but about pre-standardization research (too many guru's with too many different opinions), and (2) the ignorance and arrogance of the governmental bodies that represent societies interest in IT in Construction (substantially cheaper and better design and construction processes and facilities).

Being unable to agree and to make a fist within ISO, two types of developments seem to take over. The first is an initiative of AutoDesk and Bently to start the International Alliance for Interoperability[3] (IAI) to develop the Industry Foundation Classes (IFC), and the second are information exchange standard developments in other industries that are related to ours: AP221 and AP227 in the Process Plant industry for example.

As other disciplines like Electrical, Mechanical and Installations are often participating in projects in several industries, among which Building and Construction and Civil Engineering, and these other industries are often far ahead in IT usage, integration problems are to be expected.

The effect of these 'islands of integration' is that the information system used in the Building and Construction industry is still partly paper based, but that there now are several partly overlapping pieces of electronic information systems around whose developers struggle for power.

IT ON THE CONSTRUCTION SITE

What is happening in the industry as a whole, is also happening on the construction sites. Most tasks are supported by IT, but most supporting systems are not integrated. Only if a company buys software of one vendor some integration will be achieved. Communication therefore is largely done by traditional means, mainly formalized on paper.

Several researchers are working, or have been working, on solutions for integrated site construction processes. Different approaches have been used to support integrated site construction processes. Some researchers have focussed on bringing AI to the construction site [2]. Others used integrated CAxx [3] or visual simulation systems [4] to support their work. Nowadays, most systems are developed for the purpose to integrate planning and cost-estimating modules with explicit construction site process knowledge. Several of these systems are based on the concept of storing information about experiences from previous projects into construction work databases [5,6,7].

[3] A nice word that means integration between CAxx systems

The purpose of the research reported here is complementary to what is going on in the field. The first subject of interest is the question: how can the work of a Main Contractor be supported by IT if we assume that in the near future the project description (the product model) will arrive in a standardized electronic format? And the second question is: how can we support the re-use of earlier process plans etc. and improve the re-use of existing construction knowledge by means of Product Data Technology?

DEFINITION AND TERMINOLOGY

Before starting a discussion, there must be a clear mutual understanding of what a construction process exactly is. It is generally agreed that if you ask 20 experts to define process, you will get twenty different answers.

A process can be viewed from different perspectives and can include different things. In the construction industry a construction process is often defined as a sequence of activities performed by different resources (both equipment and human) on construction objects. In this context, process is often associated with terms such as activity, cost-account, operation, work task etceteras. Therefore, we need to establish clear definitions of terms.

In this research, we adopt the preposition that any methodology for the consideration of operations and processes of construction must immediately consider the hierarchical nature of construction.

In construction management, six relative levels of hierarchy are definable[8]:

1. *Task level*. The task level is concerned with the identification and assignment (i.e. work assignment) of elemental portions of work (i.e. work task) to resources (workforce, equipment). A work task is the basic descriptive unit in construction practice. A work assignment is the collection of work tasks specially assigned to resources for performance. Work assignments involve sequences of work tasks appropriate to a certain trade and skill level of the resource and they define a construction process.
2. *Process level*. A construction process is unique collection of works tasks and work assignments related to each other through a technological structure and sequence and represents an identifiable part of a construction operation.
3. *Operation level*. The operation level is concerned with the technology and how construction is performed. A construction operation results in the placement of a definable segment of a product and is a synthesis of construction processes.
4. *Activity level*. A construction activity is a time and resource-consuming element of a project defined for the purpose of time and cost control by a scheduler or cost-estimator and is directly related to a definable segment of a product. An activity is an aggregation of operations and processes for the purpose of scheduling and cost estimating and therefore it has only implicit information about how construction is performed.
5. *Project level*. The project level is dominated by terms relating to a project breakdown into smaller accounts for the purpose of time and cost control (i.e. project activity and the project cost account). Also the concept of resources is defined and related to the activity as either an added descriptive attribute or for resource scheduling purposes.
6. *Organization level*. The organization level is concerned with the company structure and business of a firm, the various functional areas of management, and the interaction between head office and field agents performing these management functions. The

organizational level is dominated by terms relating to information about all the acquired and running projects like status, total cost, duration, cash flow and percentage completed.

An example of terms related to a hierarchical breakdown is given in figure 1.

Organization	Project #1: ………. Project #2: ………. Project #3: High-rise concrete building with masonry walls.
Project	In-situ concrete works, masonry works, foundation works.
Activity	Activity #1: Lay first brick wall, $100.000, 20 days, 12 laborers.
Operation	Bricklaying operation using laborers forklift and scaffold.
Process	Erect and adjust scaffold process. Brick delivery process by laborers and forklift. Cut and lay brick process by laborer.
Task	Break open brick pallets. Load forklift with bricks and deliver to mason laborers. Select, cut and fit brick

Figure 1 Example of terms related to a hierarchical breakdown **.**

By adopting the preposition of considering the hierarchical nature of construction management for analyzing construction processes, we recognize that an organizational context contributes to the definition of the construction process and its representation. Therefore, a complete definition of a construction process is a complex specification of process requirements and a variety of related models in an organizational context.

WORK METHODS

In recent studies, many researchers in the field of automated scheduling and cost-estimation discerned the importance of the ability to deal with explicit information about construction methods [5,6,7]. The main idea about construction methods is that experiences from previous projects are stored in standardized computer-interpretable models. By representing these construction methods in an electronic form, an organization, such as a main contractor, is able to exchange information with other organizations and assemble a repository of techniques, and can be used to support automated scheduling and cost-estimating.

Existing scheduling and cost-estimating systems, implementing the idea of computer-interpretable construction methods, have been based on the concept of breaking projects into activities. Therefore, construction methods have been defined as a systematic way of grouping activities together as higher level activities for the purpose to support the selection of activities at various level of detail. According to this approach, a construction method model has been defined by a hierarchical breakdown of its constituting lower level activities.

In this research, we adopt the idea of storing information about experiences from previous projects in standardized computer-interpretable models. In stead of storing information about activities in a construction method or production method database we store information about operations in a work method database. Therefore, a work method is defined as a higher level way of grouping processes and work tasks.

CORE OBJECT MODEL

In this section, we will discuss the core object model used in our research. The core object model presented below has to define the construction management hierarchy, the different types of objects that play a major role, and the interactions between the two.

Basically the idea is to define two groups of objects: ManagementObjects and ProjectObjects. A ManagementObject is an abstract supertype of all the different management levels found in construction. Figure 2 shows ManagementObject and its subtypes in one model, expressed in Express-G [9].

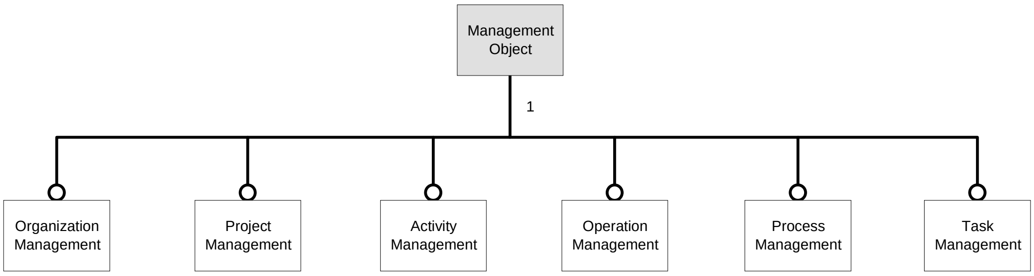

Figure 2 ManagementObject as an abstract supertype of the different existing management levels.

A ProjectObject is a part of a project that is interesting enough to capture information about. Basically we distinguish three groups of lower level objects: ProductObjects, ConstructionProcessObjects and ResourceObjects. Also the lower level objects are still abstract supertypes. Figure 3 show the three groups and their relations in one model.

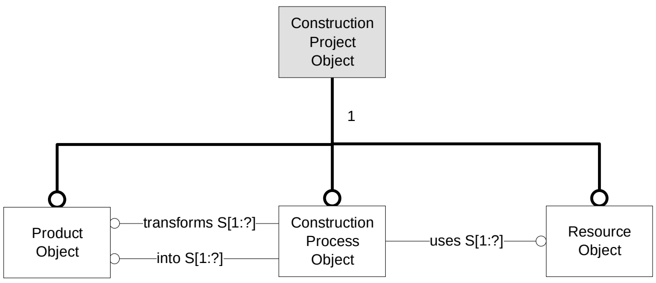

Figure 3 ProjectObject with its subtypes. The basic statement is that ConstructionProcessObject transforms ProductObjects into a different state, while using ResourceObjects.

For site automation, ConstructionProcessObject together with its related ResourceObjects is the most important. ConstructionProcessObjects transform ProductObjects into different states; usually from the state that they have when they arrive on the site, to the state that they have once they are assembled into the facility[4].

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[4] Note that also an information model is a *model*, and that a model is an abstraction of something in the real world with more or less the same properties.

As said the two groups of objects are related. Figure 4 displays the relation.

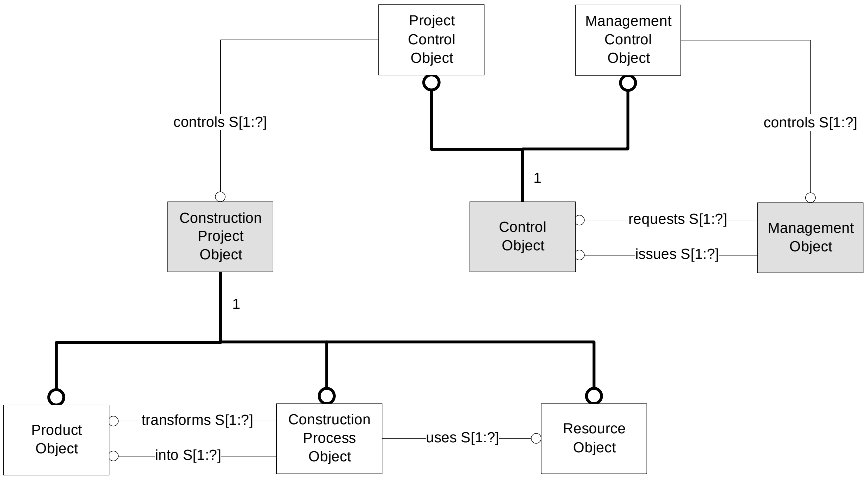

Figure 4 ManagementObject and ProjectObject related in one schema. The relation is made through a third group of objects, called ControlObject. ControlObjects (see figure 6) control lower level ManagementObjects or ConstructionProjectObjects.

In order to couple ManagementObject and ProjectObject we introduce the notion of a third group of objects, called ControlObjects. Management is seen as a control function that issues ControlObjects to steer lower level hierarchies, and requests ControlObjects to measure its effects. ControlObject is therefore an abstract supertype for all the control information that plays a role in a project.
Note that the model of figure 4 allows us to describe how different levels in the construction management hierarchy communicate (through ManagementControlObject) and how ProjectControlObjects steer the transformation of ProductObjects into the final facility.

To integrate the three different types of object, we create a root object. This abstract root object is called the Construction Core Model (CCM) object and describes the three objects as subtypes, as shown in figure 5.

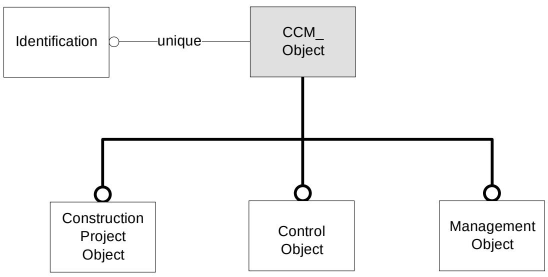

Figure 5 CCM_Object and its subtypes. Each object in the model inherits from the CCM_Object. CCM_Objects have a unique identification.

The models in figure 4 and 5 show the basic objects, subtypes and relationships. In order to give the objects meaning, we have to extend the objects with details. Figures 6-11 show the basic objects and its subtypes in more detail[5].

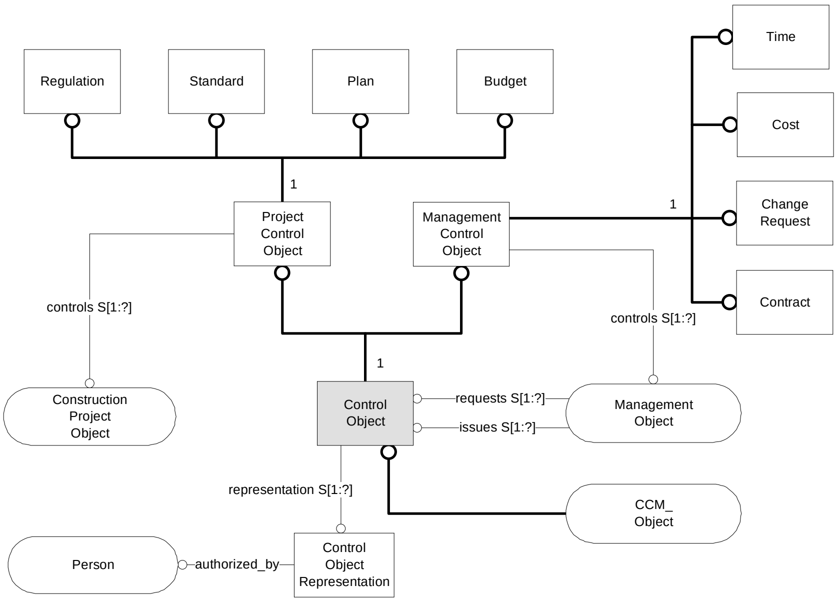

Figure 6 ControlObject in more detail. Both ProjectControlObject and Management ControlObject are detailed, and the notion of ControlObjectRepresentation is added.

A typical characteristic of a ControlObjects is that a person or organizational unit authorizes them. Another typical characteristic is that they require a verifiable representation. At the moment such a representation is mainly on paper. In future electronic representations, like HTML web pages, E-mail etceteras, become available.

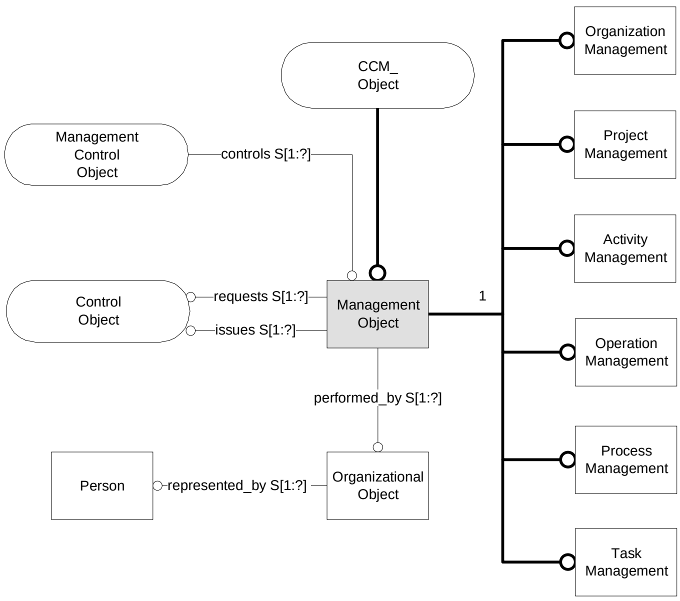

Figure 7 ManagementObject in more detail. A typical characteristic of ManagementObjects is that an OrganizationalObject performs them. OrganizationalObjects are represented by one or more persons.

[5] Note that off-page references are represented by rounded rectangles that, unlike Express-G, here contain the object name instead of a reference number. Further we note that entities described as objects are abstract supertypes and not marked with (ABS) in the model.

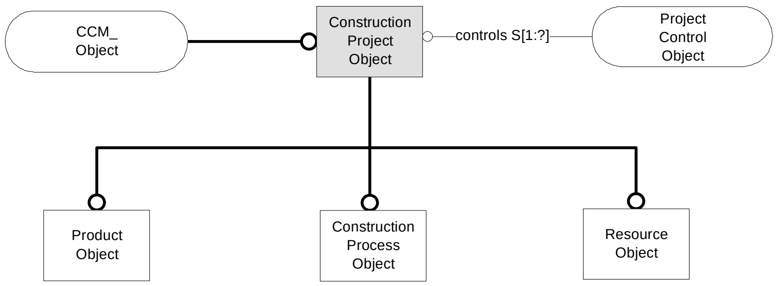

Figure 8 ConstructionProjectObject in more detail.

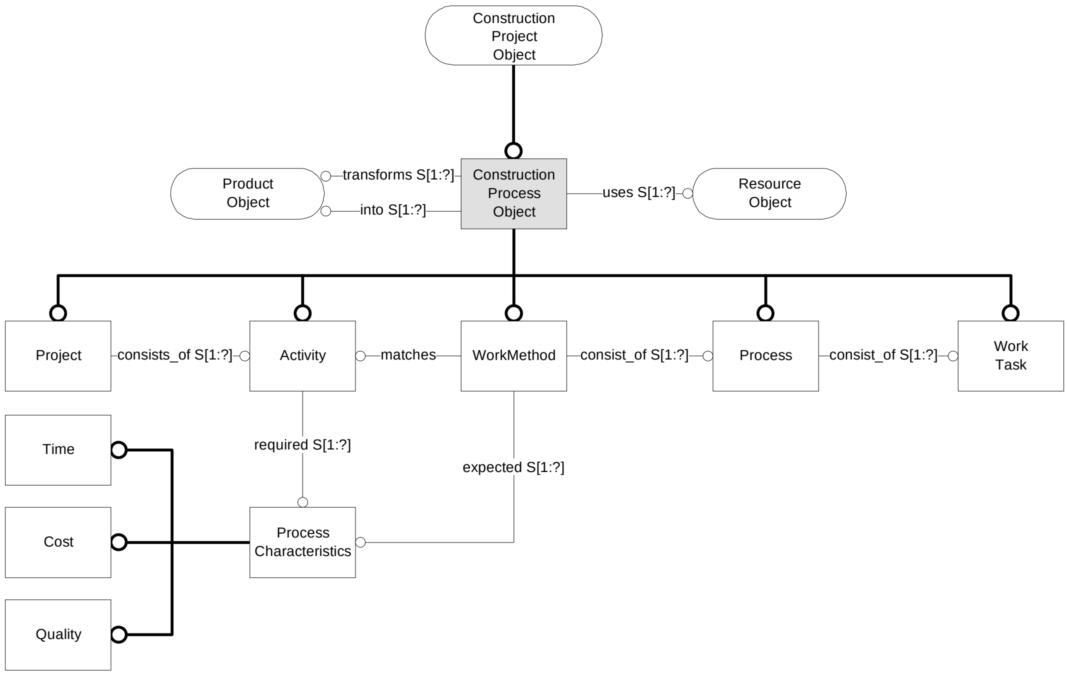

Figure 9 ConstructionProcessObject and its subtypes in more detail. Note the "matches" relation between Activity and WorkMethod.

ConstructionProcessObject is an abstract supertype of all process information that plays a role in the project. Basically we distinguish five lower level subtypes: Project, Activity, WorkMethod, Process and WorkTask, conform to the hierarchical construction management breakdown, as described in the previous sections. Subclasses are mutual connected by a "consist_of" relationship. As said earlier, operations and their expected characteristics are stored in a work method model. The connection between an Activity and a WorkMethod is established by a matching procedure. This matching procedure matches the required characteristics of an activity and the expected characteristics of alternative WorkMethods.

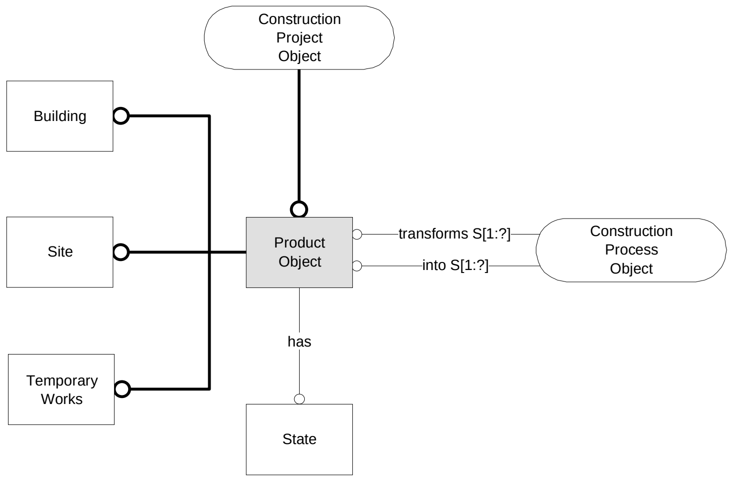

Figure 10 ProductObject in more detail. A typical characteristic of ProductObjects is that they have a state.

ProductObject is an abstract supertype of all product information that plays a role in the project. Basically we distinguish three lower level subtypes: Building, Site and TemporaryWorks. Further, we note that a state is a time-object function for every ProductObject a Construction ProcessObject affects. A ConstructionProcessObject transforms ProductObjects into different states: usually from the state that they have when they arrive on the site (begin state), through sequence of interval states, to a state that they have once they are assembled into the facility (end state).

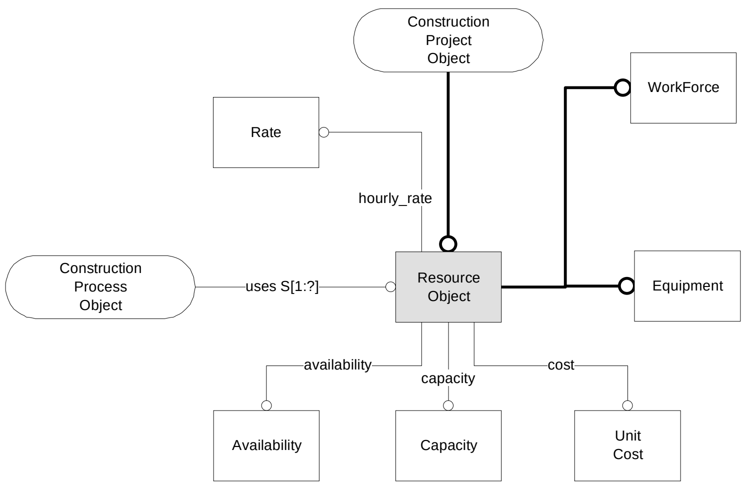

Figure 11 ResourceObject in more detail.

ResourceObject is an abstract supertype of all resource information that plays a role in the project. Basically we distinguish two lower level subtypes: Equipment and WorkForce. Main characteristics of a ResourceObject are Availability, Capacity, UnitCosts, and Rate.

IMPLEMENTATION

In the previous section, we discussed the core object model used in our research. A goal of our research is to develop a prototype system for visualization and simulation of construction site processes by incorporation advanced information technologies, like PDT, object oriented programming, internet and virtual reality.

Java is a very popular object-oriented programming language, widely adopted by the (construction) industry. Java's popularity can be explained by the fact that it especially is designed for the Internet. The powerful capability of Java to create animation and real time functions, and its accessibility to any operation systems has technically improved the Internet. Most recent development is the integration of Java with the Virtual Reality Modeling Language. The Virtual Reality Modeling Language (VRML, often-pronounced 'vermal') is the file format standard for 3D multimedia and shared virtual worlds on the Internet (VRML Consortium, 1998). At the time of writing, official language bindings for Java, JavaScript and a subset of JavaScript known as VRMLScript exist. Appendix C. Java Scripting Reference from the ISO VRML (VRML97) specifications describes the Java bindings of VRML to the script node. It also describes the classes and methods of the Java VRML 2.0 API.

EXAMPLE

In the previous sections we discussed the core model and the implementation techniques used in our research. The core model is an abstract model which can be used in the implementation of specific problems. To illustrate this, consider a masonry subcontractor on a building project. Firstly, he receives a product model in an electronic format and transforms it into a contractor's view model. Secondly, the required activity characteristics are added by one or more applications. Thirdly, he matches the expected characteristics of alternative bricklaying work methods with the required characteristics and chooses one or more work methods. Figure 12 shows the visualization of a simulation of a bricklaying work method.

What we see in figure 12 is in fact a visualization of two different bricklaying work methods: (1) bricklaying using a forklift and (2) bricklaying using a crane.

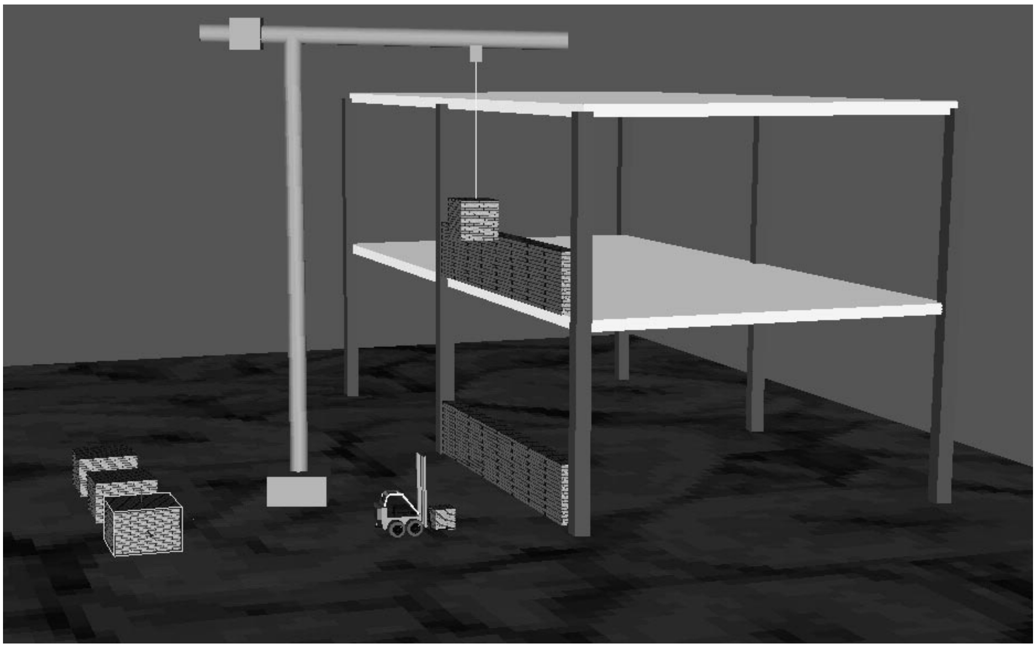

Figure 12 Visualization and simulation of a bricklaying work method.

CONCLUSIONS AND FURTHER RESEARCH

The paper discusses the development of integrated IT support for on-site construction applications.

Starting point is the development of a Construction Core Model (CCM) for the integration of site applications, which incorporates multi-level management control.

The model can be used for the integration of site construction applications and the implementation, visualization and simulation of on-site construction processes, or work methods.

A product model that has been received is transformed into a contractor's view-model. One or more applications add the time and cost data required to choose between different work methods. The result can automatically (without manual labor) be visualized and simulated, like shown in figure 12.

Though the research is not yet finished, the basic idea can already be demonstrated and meets a lot of enthusiasm.

In the coming years the definition of a contractor's view model on the product will be elaborated in detail and the work method base will be filled.

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