NEXT GENERATION INTEGRATED ON-SITE APPLICATIONS FOR THE CONSTRUCTION INDUSTRY

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ABSTRACT: This paper presents the implementation and some early results of an integrated system for on-site application integration. The example applications used in the case study are virtual reality information sharing, site layout and crane planning.

In earlier papers [1,2] we presented an overview of the state of the art of computer usage and application for on-site activity support. Based on the observations we made, we proposed an integrated model for on-site construction.

Here we discuss a system that demonstrates the idea of application integration. The integrated system for on-site application integration is based on this proposed information model, which supports the contractor's view on a project, i.e. the concept of work. The information model has been implemented using state of the art ICT and is now applied in the development of a small number of integrated applications. The paper will explain the advantages of the approach and show some early results.

KEYWORDS: Dynamic information model, on-site application integration, object technology, Java, VR.

1. INTRODUCTION

Miscommunication in the planning and realisation stage of complex building and construction projects is the source of many problems and budget overruns. One way to improve communications is to use ICT. Unfortunately the introduction of ICT in the industry is not only a blessing; it also adds to the problem. The main reasons are: (1) besides the existing paper based Information System (IS) a project also has to cope with a partial electronic IS, and (2) there is not a single format for electronic information exchange, but several, partially overlapping formats, each with its own strengths and weaknesses and each with its champions, and (3) an open (neutral) model for information exchange between on-site applications is not existing.

In 1996, the UK Construct IT Centre of Excellence presented the results of a study [3] in which the use of IT in managing the construction site process by eleven leading construction companies in the UK is compared. One of the main conclusions of this study is that some companies have established integration in one or two specific site process area(s), but that these solutions often are based on an "in-house" development (i.e. *company integration*) or based on solutions provided by one specific software-supplier (i.e. *vendor integration*). An other main conclusion of the study is that although most companies are aware of the fact that integration based on open electronic communication standards (i.e. *model based integration*) is vital to protect their IT investments, product data technology (PDT) is not widely adopted.
In this paper we present the current state of a research and development project that aims at the development of a neutral model for on-site applications. The main focus will be on implementation issues and a case study.

2. WHAT HAS GONE BEFORE

Construction companies require a product model that supports integration of all kinds of applications related to on-site construction, and not only a product model that supports integration in one specific application area. Dado and Tolman published two papers related to this subject. In the first paper [1] is analysed how existing product models support a project view, life-cycle integration and specialised entities, which are required for a product model that supports integrated site applications. The main conclusions in this first paper are:

- Most existing models support a project view, though some ignore the decision and control process.
- The life-cycle dimension is often supported, but implemented differently.
- None of the existing models adequately supports the required semantics.

In the second paper [2], the basic modelling constructs of the existing product models are analysed. The main conclusions in this second paper are:

- Most existing models are based on the root statement**:** **"**Actors perform Activities that result in Results", where Activity is the process view and Result the design/engineering view.
- Activities and Results are decomposed separately.
- Existing models are mainly static models, whose data is stored in en retrieved from a traditional database or file system.

3. PROPOSED INTEGRATED MODEL FOR ON-SITE CONSTRUCTION

Also in [2] the authors proposed a neutral model for on-site application integration based on the contractors view on a project, i.e. the concept of Work. Figure 1 shows the root object called WorkObject (a unit of work).

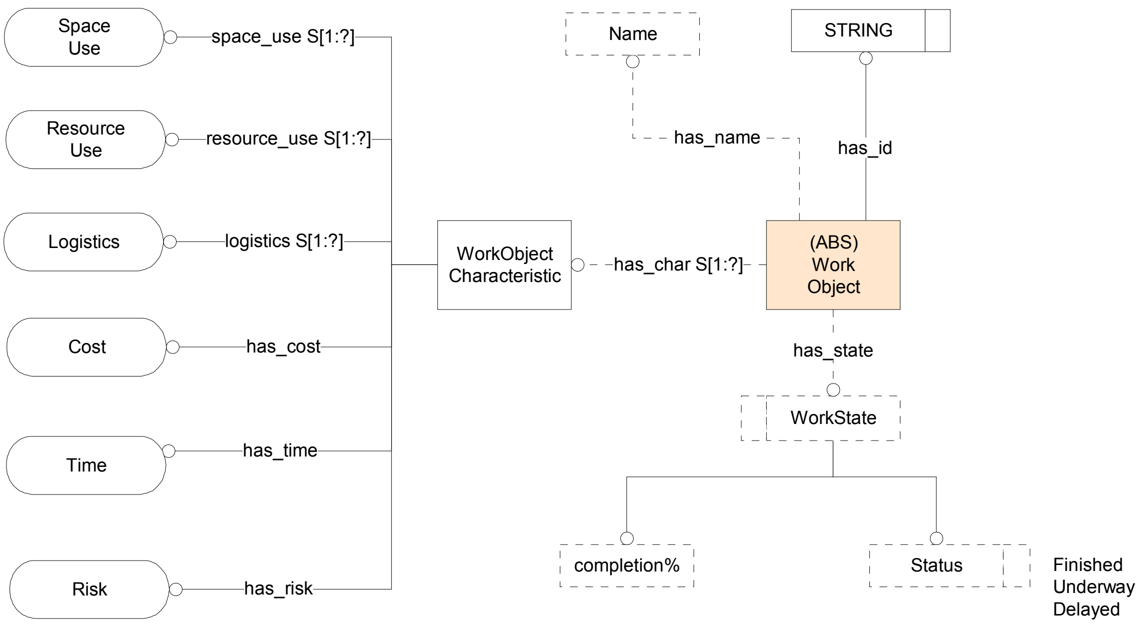

Figure 1. WorkObject is the root of the model[1]. Each WorkObject can have one or more characteristics: Space Use, Resource Use, Logistics, Cost, Time and Risk

[1] Note that off-page references are represented by rounded rectangles that, unlike true Express-G, here contain the object name instead of a reference number.

A WorkObject has a set of characteristics that are important for most works (see figure 1). Some of these characteristics are further detailed on other pages (i.e. off-page references), as shown in figure 2.

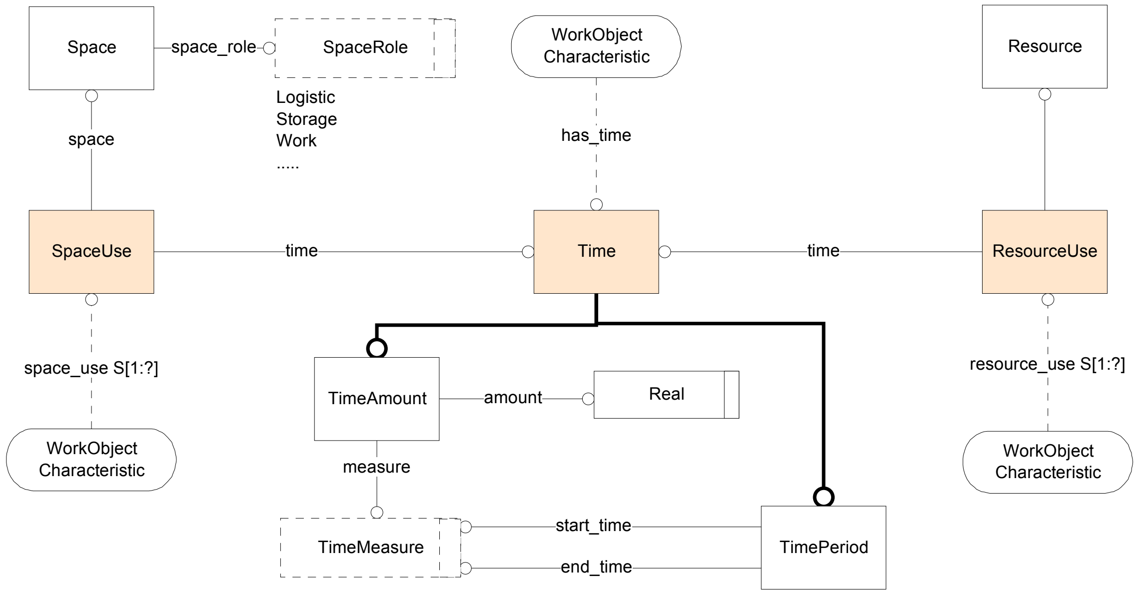

Figure 2. Some characteristics of WorkObject in more detail.

In order to create a Work Breakdown Structure (WBS), WorkObject is specialised into: Project, WorkSection, Work and WorkElement, as shown in figure 3.

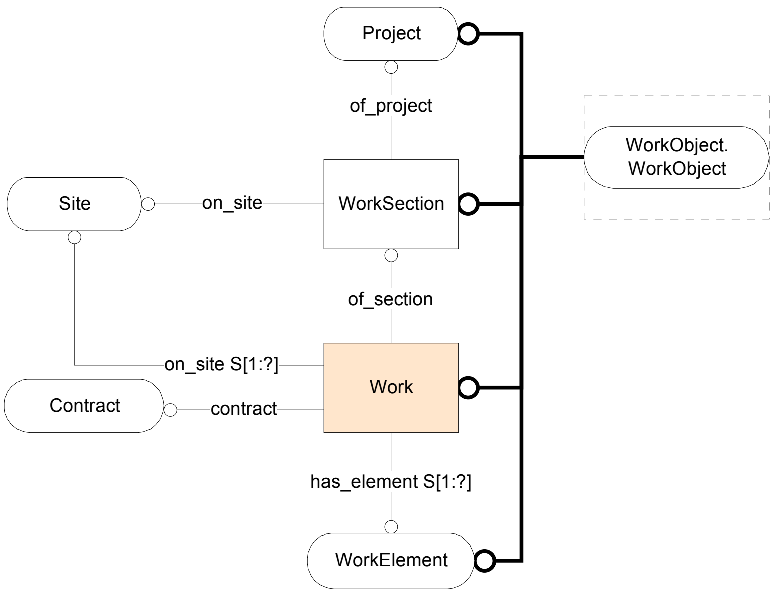

Figure 3. Work in its context (as part of an actual project). Project, WorkSection, Work and WorkElement are specialisations of Work Object. Note that in our definition Work is what is specified in a Contract, it is somebody's responsibility.

Finally, figure 4 shows how a specific piece of work, Concreting in this example, can be described as a specialisation of Work. Note that the Site-Works schema connects to the design/engineering view on the project as described in the design/engineering product model.

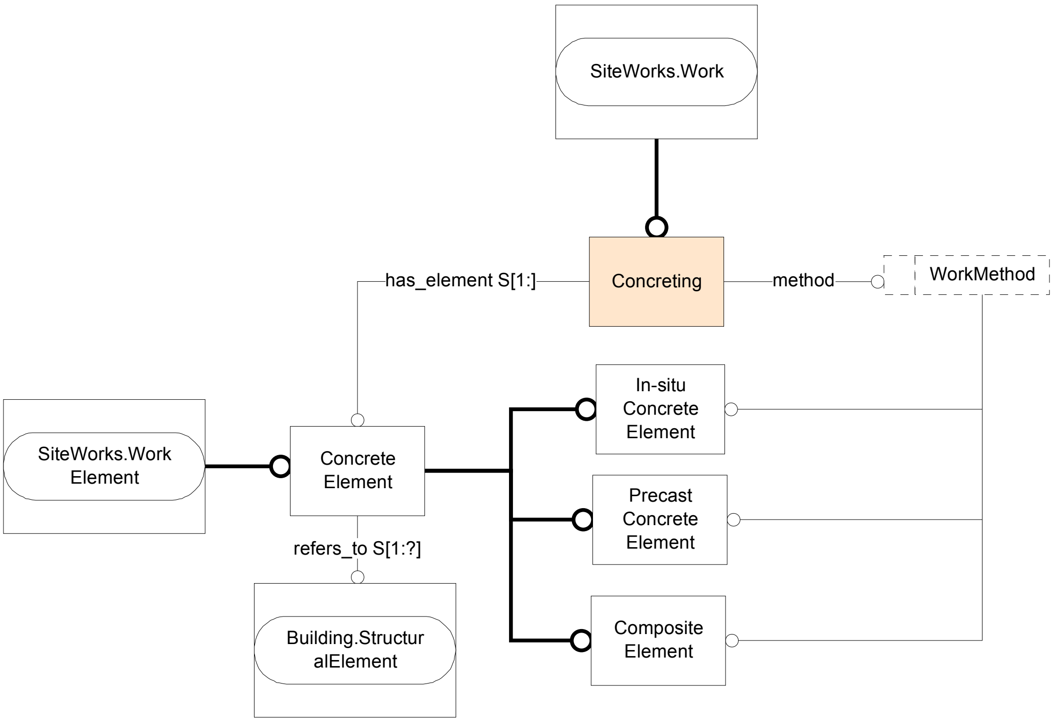

Figure 4. Concreting as a specialisation of Work. ConcreteElement with its subtypes (In-SituConcreteElement, PrecastConcreteElement and CompositeElement) is connected to the design/engineering Building schema.

Because Concreting is a subtype of Work, there is a Contract that describes the contractual terms. And because Work is a subtype of WorkObject, it has all the characteristics as shown in figure 1 and 2.

If, for example, we want to describe a large building project with say an in-situ concreted shaft that connects a steel structure, which carries concrete floor elements, we implicitly have the ResourceUses and SpaceUses available. In this case we probably need one or more tower cranes and hoists as Resource. Also a number of crews is needed. For the realisation of work spaces are required (e.g. work space, logistic space etc.). We need to allocate these spaces for different works in time. Mostly, these spaces are a part of the site (SiteArea) or part of an already constructed building floor (FloorArea). Crane, hoist and Crew are modelled as specialisation of Resource, SiteArea and FloorArea as specialisation of Space. In figure 5 these specialisations are shown. In practice, uses of areas and resources are made very globally and adjusted per day.

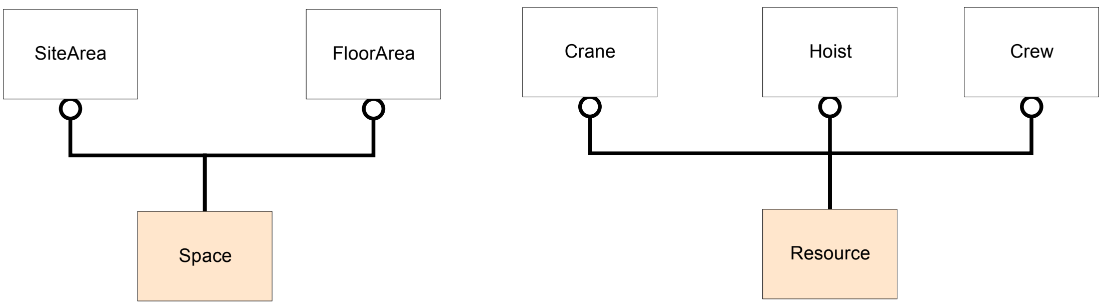

Figure 5. Specialisations of Space and Resource. SiteArea and FloorArea as specialisations of Space and Crane, Hoist and Crew as specialisations of Resource.

4. IMPLEMENTATION OF THE MODEL

The three-layer specialisation hierarchy described above is implemented in a dynamic Java model that drives the information exchange between the different on-site applications.

4.1 A Dynamic Model Approach

Supporting on-site application integration is different from supporting design/engineering application integration, because some on-site applications require immediate (if not real-time) response. Think for example about a Crane control system that suddenly has to change its execution plan because of an accident, or a Logistic control system that has to re-schedule some incoming resources, because of something unforeseen like a sudden thunderstorm.

In order to implement a dynamic model that could support nearly real-time message passing, we decided not to use the traditional layered models as seen in ISO-STEP and IAI-IFC, but to create a common model in Java as a pure specialisation hierarchy. If you look back to the figures in section 3 you will see that the hierarchy is a specialisation hierarchy. In Java it is possible to implement mechanisms that support fast message passing (i.e. using the concept of event listeners) so that complicated applications like say crane control systems can interact with their environment.

4.2 The graphical user interface (GUI)

In order to present the users with a nice user interface we decided to use a three-dimensional Virtual Reality (3D-VR) type of GUI. In earlier research we often used VRML (Virtual Reality Modelling Language), but not with great success. The main reason for this dissatisfaction stems from the fact that VRML is not supporting end-user interaction; you can only look at the scene, but not interact with the scene. Using Java for the model implementation gave us the chance to use Java3D for building the GUI. The Java 3D API is a set of Java classes that provides a collection of high-level constructs for creating and manipulating 3D geometric objects, which serves as the interface to a sophisticated 3D VR system.

4.3 Implementing 'Interaction'

Following an idea of Tolman [4] we developed a model implementation that viewed the world as to consist of four types of objects: point-like objects, line-like objects, face-like objects and volume-like objects. These four types of objects have two types of relations: (1) bounding relations and (2) location relations. Figure 6 shows the basic set-up in Express-G.

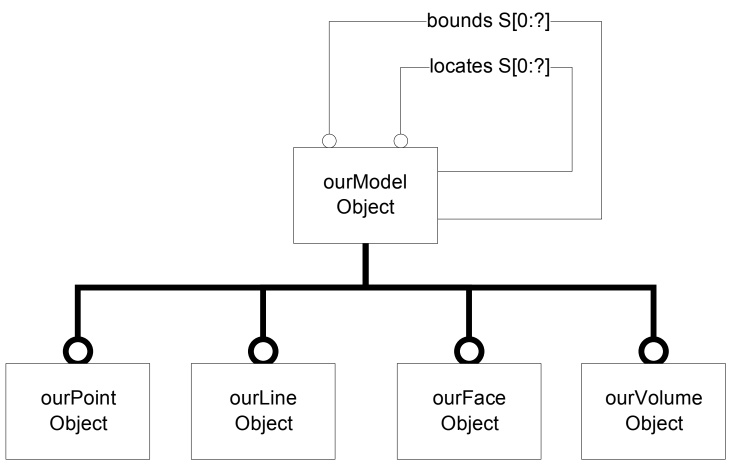

Figure 6. The world consists of 4 types of objects, point-like, line-like, face-like and volume-like with 2 types of relations.

The next step is to develop shape representations for each of the four object types that can be evaluated on the Client PC and to develop a semantic model with real-life construction objects like building, beam, road, crane and such as subtypes of these four basic objects. By doing so it becomes possible to develop a common GUI that is able to support interaction. For instance the end-user can be presented with a VR model of a room with walls and on the walls electricity outlets. If he wants to change the position of the outlets that are represented as point-like objects located on a face-like object, it is possible (within limits); also over the Internet. In this paper the features of this shape model are used to describe roads on a site (line-like objects located on face-like objects), and so on.

5. THE WORLD PORT CENTRE CASE

In this section we will discuss a first case study performed with the tool. The project is the World Port Centre in Rotterdam, The Netherlands. The case study will focus on the actual integration aspects, showing to the end-users what application-integration of on-site applications really is.

5.1 The World Port Centre (WPC) Project

The WPC project involves the construction of a large office building. The building consists of 32 storeys with a total height of approximately 125 meters. The main contractor is Hollandse Beton Maatschappij (HBM) and the client is ING Vastgoedontwikkeling B.V. The contract sum of the WPC project amounts to 70 million Dutch guilders. Figure 7 shows the WPC building under construction.

Figure 7. World Port Centre (under construction)

5.2 Integrated Applications

In the next subsections we describe three integrated applications: a crane planning tool, a site layout planning tool and a VR project information front-end.

5.2.1 A crane planning system

In many construction projects, like the WPC project, the planning of cranes is critical for the overall performance of the project. Cranes are the most expensive resources within a construction project. The planning of a crane directly influences the overall planning, selection of work methods, productivity on the site, safety of labourers, space-time constraints, logistics and such. Many factors can influence the day schedule of a crane, like weather changes, delivery problems and accidents. If such events occur, re-scheduling of the day crane planning is necessary. Therefore, a crane planning system, which interacts with all kinds of other site applications is evidently interesting. An early prototype of a crane planning system is shown in figure 8.

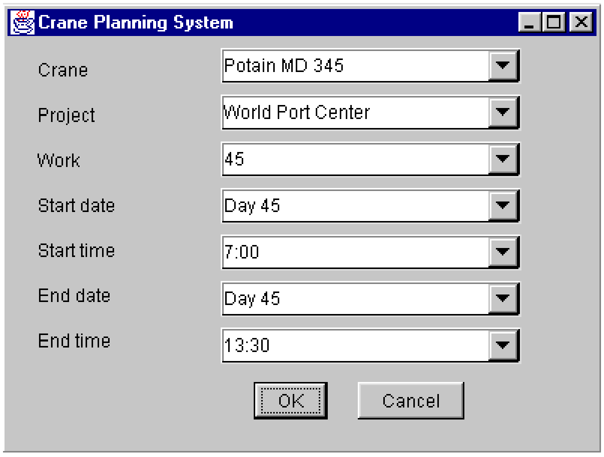

Figure 8. An early prototype of a crane planning system

5.2.2 A site layout planner

Site layout planning is all about allocating spaces in time. In the past, space scheduling did not received the level of attention given to other activities, like for example activity scheduling, resource allocation and cost estimation. One of the main reasons was the fact that space scheduling requires a large amount of very detailed information. Without a fast computer it is a difficult task. For example the allocation of resources (e.g. materials, equipment, labour) requires information about the space need (e.g. dimensions, shape, quantity, stacking ability), timing (e.g. duration, material handling, capacity) and location (e.g. access, overlap, environment). While nowadays, construction managers are using computers to support their work and the paper-based information system is automated, space scheduling is getting more attention [5,6,7]. Site layout planning could greatly benefit from the approach as discussed in this paper. An early prototype of a site layout planner is shown in figure 9.

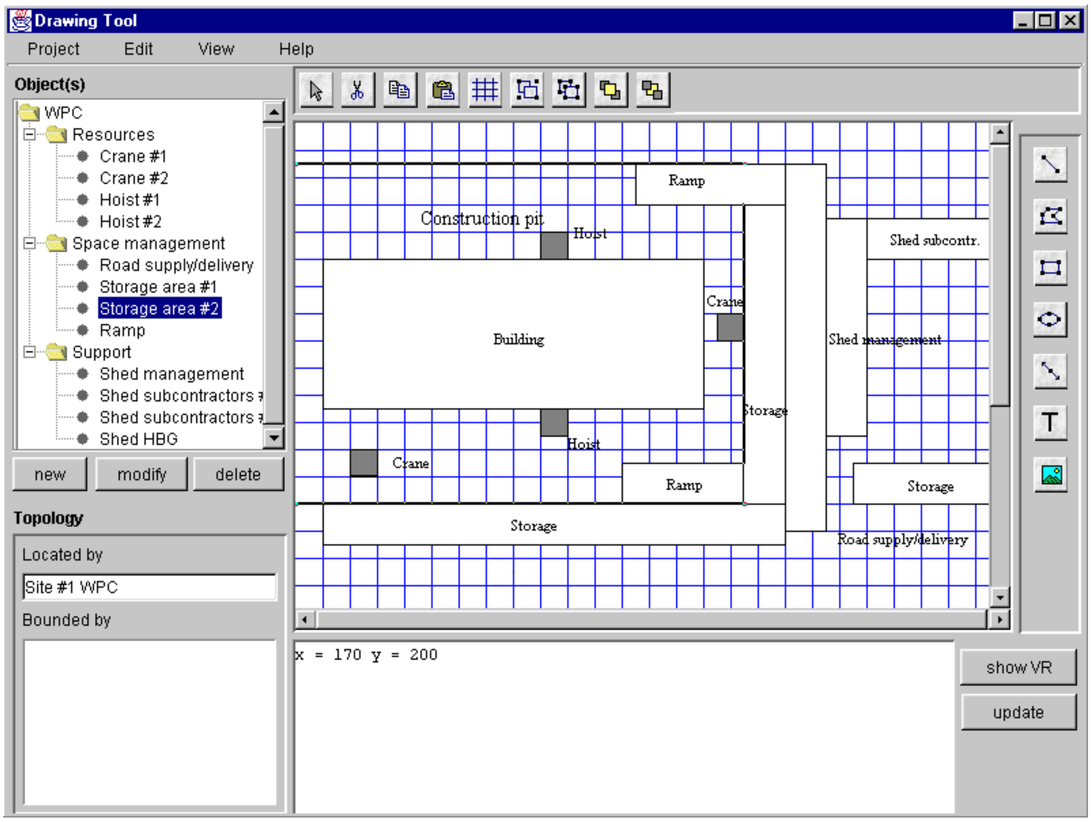

Figure 9. An early prototype of a site layout planner.

5.2.3 A VR project information front-end

Based on the shape model described above we created a Virtual Reality information front-end for general use that can be accessed over the Internet. This VR information front-end is shown in figure 10.

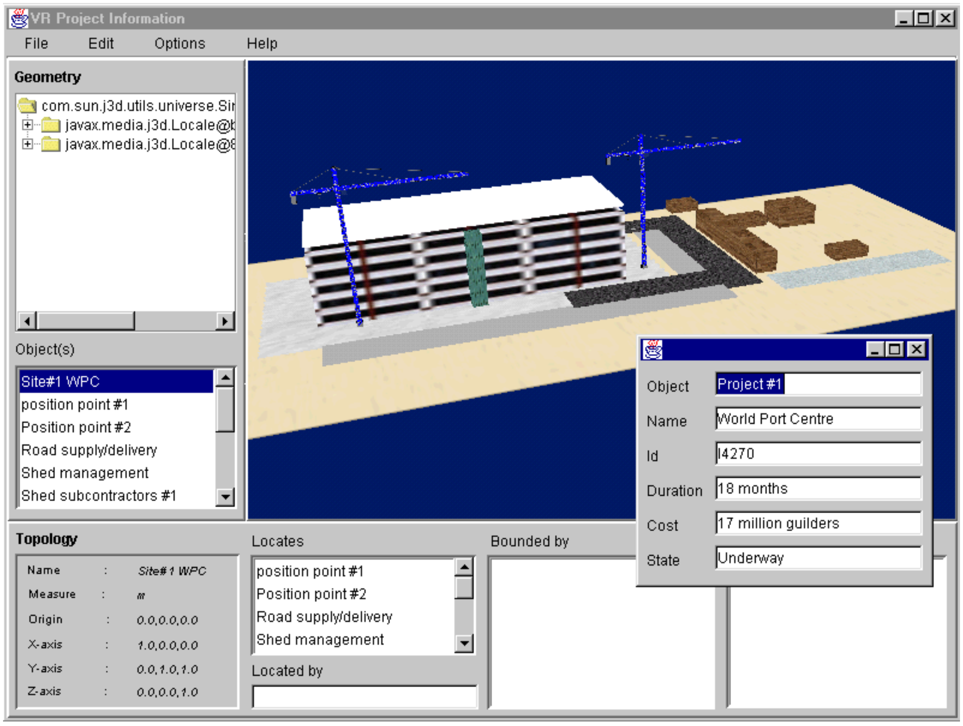

Figure 10. A VR project information front-end.

Basically the idea is that the user can access information about certain objects displayed in the scene by pointing and clicking.

5.3 Evaluation

The WPC case was intended to get a first impression of the real meaning of integrated on-site applications. Although only a few integrated applications have been developed yet, the case study already shows the great advantage of the approach. On the fly communication of complex information between project participants, is something that humans cannot do, but computers can.

A common user interface is used to support end-users. Within this GUI, two different applications can be launched, each interacting with the other. Therefore, changes made in one application automatically update the other application and are visualised in a 3D world. For example we can plan a certain site area, that is 'known' by the crane. With a logistic application (not yet implemented), we can plan the logistics on the construction site, using information created by the site layout application (spaces, time, location). With the information retrieved from the two other applications, the crane planning system, can determine directly for each crane where and when it is required.

In the future computers will support individual cranes. These computer applications can greatly benefit from our approach. Firstly, for safety reasons, because cranes will known each other's schedule and motion, and are aware of the site constraints. Secondly, for efficiency reasons, because scheduling and re-scheduling can be realised much faster and much more detailed.

At the WPC site we observed that cranes mostly are used to support the construction of the carcass. For the construction of the other parts, platform hoists are intensively used for vertical transport, even while a crane is not being used at all. Re-scheduling of these vertical transport-means over different jobs is too complicated and simply not done. Computers can realise a better rate of optimisation than humans can, because they can have access to each other's planning.

In the future we will increase the number of integrated on-site applications. Most existing applications today are not model-driven, and therefore not easy to integrate. In that case, we have to build such model-driven applications from scratch.

Also interesting is the application of the shape model as described in section 4.3. By using the scheme as discussed, it is not only possible to view the 3D Virtual Reality image of the project under construction; it is also possible to *interact* with the model. If, for example, someone wants to know something about say one specific site area, he just clicks on it in the VR scene and a window pops up that gives details about its planned or actual usage's, its size, or what is most relevant.

Ultimately this GUI will support all the participants in the project as the viewable presentation of what the project is going to accomplish. Scrolling in the time dimension (4D CAE) and simulation can be made available over the Internet.

6. EVALUATION AND CONCLUSIONS

Application integration of on-site applications could greatly benefit by the common application of a vendor independent (open, neutral) information model; especially if the model is implemented with the dynamical type of technology as discussed in the paper.
The research reported here produced a suitable model that can serve the needs of those involved in planning and realisation. Planning and realisation needs a different view then that of the designers and engineers, not a *product* view but a *process* view. In an earlier paper the concept of work and a work-based model have been introduced. In this paper the implementation of the model has been explained. The idea is that in the realisation stage application systems of different partners should be more tightly coupled then in earlier stages. If possible the consequences of changes or errors should be propagated immediately. If say a car accident somewhere causes a delay in the delivery of pre-cast concrete elements that were scheduled for tomorrow or even today, suddenly the project manager has a problem. How to re-schedule this afternoon's work? Can the cranes be assigned another useful task, or is this a wasted day? This and similar decisions have to be taken daily. The weather changes, accidents happen, things brake down, things don't fit, are delivered too late, or are not what you want. If ICT research can provide a tool that is able to support these hectic episodes and help to quickly proceed on another track, a lot of waste can be removed, and competitiveness increases.

Though in this paper not yet proven 'beyond reasonable doubt', on-site application integration using a neutral model is mandatory for the future of our industry. Company integration or vendor integration is not the required solution. The current tendency to EDM is a step in the right direction but only a step. True integration is not only achievable in the document world, it requires also a foot in the production world. Especially a dynamic model approach is useful for BC project support, because it supports on the fly rescheduling of groups of interacting processes. An accident happens, what shall we do. A delivery is long overdue. A storm is coming up. Hundreds of causes for trouble and problems. Too many to plan for a counter attack.

With the dynamic product model based interaction described in this paper it is possible to do something smart and to do it quickly. Rescheduling and distributed control is what computers are good in. Also very interesting is the VR project information front-end. In the future members of the management board of Construction companies will sit in their boardroom and watch large VR screens where they will see what was planned and what is actually happening. Not only locally, but also abroad. Interaction with the model is possible, as is simulation and time scrolling.

We don't claim to build that future but we sure are interested to see if such an approach is feasible and if it will help to increase the competitiveness of our industry.

The paper presents the very first results of a case study where the model and some integrated tools are being used. As a first impression it is reasonable to say that the Building and Construction people are suddenly interested.

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