

A Dynamic Framework for Construction Scheduling based on BIM using IFC

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Summary

Construction scheduling is one of the key processes during the development of construction projects. As Building Information Models (BIM) gain more and more in importance for the design process, the scheduling process also has to be integrated into the collaborative model based working environment. For this purpose a Business Process Re-engineering approach (BPR) was applied to identify potential areas of improvement within the current scheduling and 4D simulation practice. This paper highlights the main findings and describes a novel solution approach consisting of a dynamic collaboration framework tailored for construction scheduling. Several tools were implemented to prove the new concept. The Industry Foundation Classes (IFC) are deployed to ensure open communication within the project team. Further research is ongoing within the European R&D project InPro [1].

Keywords: construction scheduling; building information model; IFC; object versioning; object splitting; object linking; 4D simulation; CAD.

1. A Business Process Re-engineering approach

Business Process Re-engineering is defined as “... *the fundamental rethinking and radical design of business processes to achieve dramatic improvements in critical contemporary measures of performance, such as cost, quality, service and speed.*” [2] The major challenge within BPR is to obliterate non-value adding work rather than just using information technology for automating it [3]. Process modelling is considered to be a key aspect of BPR. It gives guidance for the development of new IT solutions. Within the scope of this research the ‘as is’ scheduling process was modelled based on an in depth analysis within a major European construction company. BPMN (Business Process Modelling Notation [4]) was used as modelling technique.

1.1 The Process Model

The process model showed that scheduling runs concurrently with other key processes like architectural design, cost estimating, etc. Each of these key processes within a project is carried out by stakeholders specialised to fulfil their specific role in the design team. Due to the fragmentation of the construction industry these stakeholders normally belong to separate business enterprises with their own work routines and existing software infrastructures.

The triggering event for the scheduling process is the first need to have a cost and time estimation for the project. As a response well known general purpose project management software (e.g. MS Project, Primavera P6, Asta Team Plan) is used to create the construction schedule. Today, geometry from 2D drawings, trade specific cost budgets and the description of existing project constraints are taken as input by this process. It was found, that depending on the project development stage and the related level of detail of the available design data, four different methods are used to predict the duration of tasks (Figure 1). If the project information is in a very early stage the time estimate can be done only based on human experience from previous projects (D). This method is also used to predict the duration of activities not directly related to construction work, e.g. design or procurement processes. As soon as the cost budget for the project is broken down into the different

trades, this information together with the trade specific portion of labour on the overall cost can be used to refine the schedule (C). If, based on the architectural design, cubature and floor area information becomes available more tangible time predictions can be provided based on amounts per unit and rough performance factors (B). The most precise time prediction can be done only when detailed design information is available (A). In this method the actual quantities are combined with precise performance factors related to a crew definition. Today the needed quantities are calculated manually based on 2D drawings or spreadsheets. It is worth mentioning that within the same schedule all four methods (A-D) can be used for calculation as most appropriate for each activity.

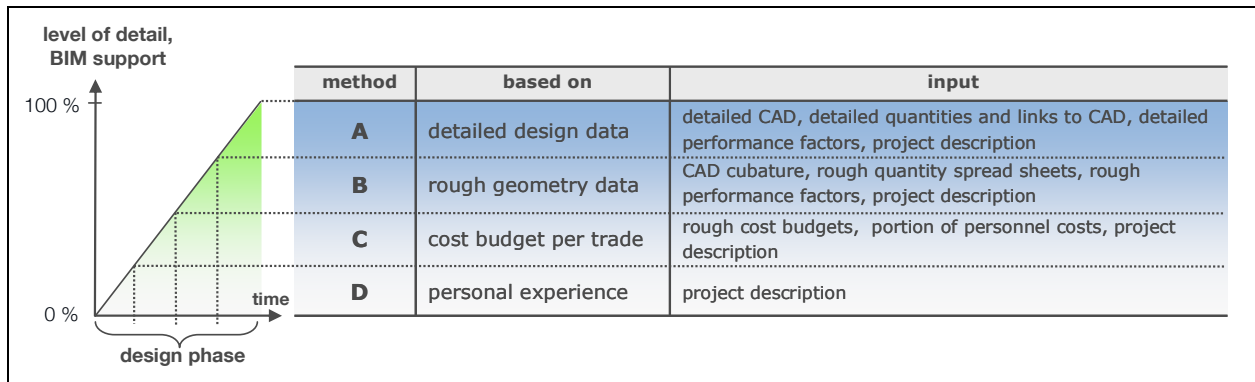


Figure 1: Scheduling methods in correlation to the level of detail and degree of BIM support

In general a lot of personal experience and imagination is necessary to determine the right method of statement, crew composition and performance factors and to take the spatial context and project constraints into account. To visualize the spatial context of the construction schedule, 4D simulations can be used but only after the schedule has been finished and only if detailed design data is available. As a prerequisite for a 4D simulation a 3D CAD model has to be created and linked to the schedule. This heavy effort related today still impedes the routinely use of the 4D simulation technique.

1.2 Existing drawbacks

The “as is” analysis revealed several drawbacks of the current practice. The most evident is that quantities are taken off multiple times within different key processes during the design phase (e.g. scheduling and cost estimating). This is a tedious and cumbersome task which needs rework for any design iteration and thus a lot of double work. It also leads to inconsistencies in quantity estimates between different key processes.

Another important aspect is the missing support of a dynamic design process. Especially during early phases the design is subject to many changes. From a scheduler’s perspective it is very important to track how these changes in the underlying information affect the construction schedule. In addition, for the purpose of optimisation, several alternative schedules are evaluated for one design alternative which all have to be updated upon changes.

A major drawback today is also the lack of a tailor made editor dedicated specifically to model based scheduling. Traditionally the project scheduler works with general purpose project management software. This software is neither capable to process the different types of information handled within the scheduling process (geometry, quantities, cost budgets, construction schedule, 4D links and visualisation parameters) nor does it provide appropriate change management capabilities. Particularly the spatial context as well as 4D functionalities are not integrated into those software packages due to the non BIM based approach. But also alphanumeric information stored in a BIM, e.g. quantities or cost budgets which are needed to predict the duration of tasks, can’t be accessed by existing scheduling software packages. A spatial editor which delivers this information to the project scheduler and supports him with a visualisation of the spatial context of his planning is not provided. Instead quantities and spatial information are incorporated manually, taken from 2D paper drawings and imagination.

Indeed specialized software for construction scheduling which follows the line of balance method [5] tries to mitigate the absence of spatial information in scheduling software by incorporating it in an abstract and linearized way. But still, this approach doesn’t allow an in depth checking of the

spatial context.

Even though several commercial 4D simulation packages exist which in principle allow full navigation through the model over time [6][7], none of them currently supports the project scheduler effectively during the creation of the schedule. These packages mainly focus on the visualisation of already finished schedules. Reasons for this are the laborious linking between the schedule and the CAD model and the additional work for defining visualisation parameters. Both have to be updated manually if any changes occur in the schedule or the CAD model. Today this additional effort and the implied need for an appropriate 3D model are reasons for the rarely employment of this technique.

It was also recognized, that the scheduling and 4D simulation process often needs CAD and quantity information in a different object break down than other key processes. The scheduler sometimes needs to allocate a portion of a construction element and the related quantities to an activity. This is not supported by existing 4D software packages or scheduling software and thus implies the interference with other processes like CAD model creation and quantity take-off (Figure 2). However, the opposite granularity adoption is possible through a simple object grouping. A principal different approach to support the model based scheduling process is provided by some CAD software packages by allowing the definition of object attributes and related rules used to export a preliminary schedule with related information directly from the CAD system. This can hardly be considered as an improvement since CAD software packages are too expensive, complex and difficult to use for a project scheduler. They can only be utilized by CAD specialists and provide a structure of the exported schedule which doesn't meet the requirements of the project scheduler who also has to deal with several tasks not depending on construction elements. In addition a project scheduler wants to reuse existing schedules from previous projects or schedule templates which is not possible within such an approach.

2. Solution approach

A collaborative 3D BIM based approach can have a great stake in supporting the scheduling process. The magnitude of benefits thereby depends strongly on the actual design maturity and the related detail level of available design data (Figure 1). As the design proceeds in time, the scheduling process can be further supported by model based working. In this approach 3D CAD, quantities and budget information can be reused across process, stakeholder and enterprise boundaries. The reuse of such information assures data consistency and eliminates double work. Thus, as a major process change, the manual quantity take-off (QTO) is changed to a model based quantity take-off and placed as a central process (Figure 2). Now in this process already commercially available software is used to calculate quantities based on a 3D CAD model. Once the quantities and their links to the related 3D CAD objects are stored in the BIM, they are available for succeeding processes like scheduling and cost estimation. Because the project scheduler selects construction methods and sequences and assigns equipment as well as resources the scheduling process later can give input to processes like 4D simulation, detailed cost estimation, procurement and logistic planning. Especially the relationship between CAD objects, quantities and tasks in the schedule can be used to automate the preparation of 4D simulations [8].

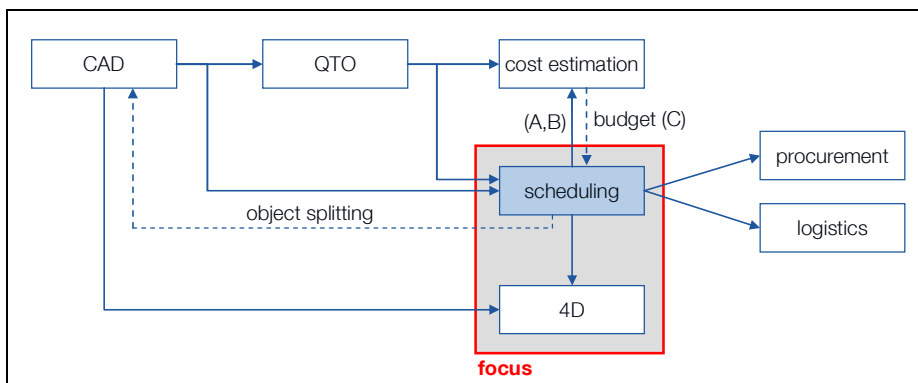


Figure 2: Process and data dependencies relevant for construction scheduling

To exchange the commonly used data within the project team we suggest an Open Information Environment (OIE) with a common project share point for model data and documents, a so called

Open Information Platform (OIP), in its centre (Figure 3). Each client software package communicates with the OIP directly or via a workspace to exchange data shared within the project team. Compared to a direct data exchange between stakeholders a central exchange is preferred since it ensures the availability of the complete design information for all stakeholders and enables project management based on workflow control mechanisms. Thus it enables clients and stakeholders to review the current overall design status at any time. In addition a central share point acts as a bridge between the project partner organisations and their different software infrastructures. It harmonizes the differing and domain specific data formats and links the information to an integrated design model.

In the construction industry it is common practice that business partners differ from project to project. Thus it is also necessary to enable the central share point for such a plug in and out of partners with their own software infrastructure. If the communication between the domain islands and the share point is based on a neutral and open data standard like IFC and STEP ISO 10303-P21, this can be guaranteed with a minimum configuration effort.

The full solution approach provides several improvements compared to the existing situation:

- Improved communication and reuse of information across processes and stakeholders in different companies (3D CAD, quantities with links to CAD, cost budgets per trade, etc.)
- Allowance for a fixed software infrastructure per stakeholder across projects
- Object versioning for improved change management
- A tailored editor with more efficient and powerful object linking and splitting capability

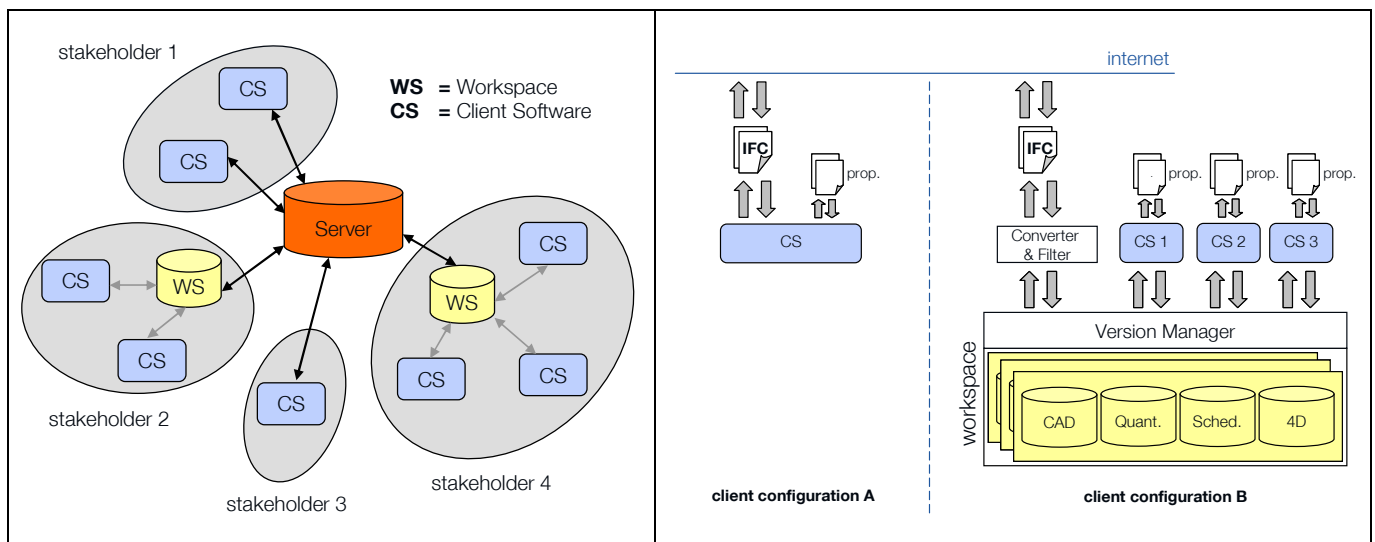


Figure 3: System architecture of the OIE with two different client configurations

2.1 Central Share Point

The central share point is an information hub commonly owned by the project team or the client and accessible by all members. It provides several services: Its core purpose is to integrate all design data from the different stakeholders and to manage the dependencies between these information units. Design data can be provided as structured model data as well as document based information. For all uploaded information the history is managed to allow retracing. Due to the plug'n partner concept the communication with the share point is based on open standards and either file or interface based. To further structure the collaboration within the project the share point provides role based access rights to its information and controls the dataflow by well defined workflows reflecting the business processes running during the project.

The actual implementation of the share point needs a thorough knowledge about the business processes and the related data and exchange needs. In this article we focus on the scheduling process and the related stakeholder site software architecture.

2.2 Local Workspace

Since the scheduling process takes significant time it uses long transactions to edit data on the OIP. To avoid that the data is locked for other stakeholders during that time the process has to work on local copies of the relevant data.

Today there is no software available for model based scheduling which provides all needed functionalities in an integrated package. Thus several software packages are used to operate on the local data, e.g. scheduling software, 4D viewer, external linking tool etc. This implies that there is not only a need for information exchange across key processes but also between different software packages used within one key process. But most of these commercially available software packages don't provide a neutral data exchange interface like IFC or only support a subset of the required entities. Thus a direct communication between the end-user software packages or with the OIP is not possible (Figure 3, client configuration A).

For these reasons we suggest a workspace approach (Figure 3, client configuration B) to enable information exchange during scheduling. This system architecture provides several advantages compared to a direct client to OIP communication:

- The data structure within the workspace can be optimised to the needs of the scheduling process independently from the requirements of the OIP
- The problem of data mapping within the workspace and for the communication with the OIP is limited to the data domain of construction scheduling.
- Since within one company or stakeholder the tool set used for the scheduling process is fixed, a customized data mapping can be applied taking special features of the software packages into account but without having to encroach into the core of commercial end-user software.
- Independently from the use of a global OIP a workspace already enables key process internal collaboration within one company. Since the software infrastructure for a company is stable across projects the configured workspace can be reused in all projects. Thus the workspace concept is already an improvement in itself compared to the existing situation.
- Object based versioning is not available in today's end-user software. With a workspace implementing a comparison algorithm, versioning based on object level can be provided for the scheduling process. This minimizes storage needs because only changed data has to be added during each revision and improves retracing and management of solution variants. In addition schedule activities affected by design changes can be identified automatically.
- When uploading data on the OIP the workspace can provide appropriate owner and history information which is not the case with existing end-user software.
- During scheduling many intermediate model states are generated for all modified sub models and have to be saved for backup. It is not reasonable to share these intermediate states with other stakeholders. Instead they can be kept within the workspace data base. Only information with a certain maturity level is released to be shared.
- A data filter can be used for the communication with the OIP. In this way domain specific information or company know how which is used in explicit form to prepare a schedule but shouldn't be shared with other project partners can be kept confidential within the workspace. Object versioning prevents the loss of data integrity of these information parts.
- It is common practice that each company keeps a copy of all its processed information share as backup to avoid being looked away from its own data in case of a lawsuit with other partners. This need is automatically satisfied by an exclusively owned workspace.

As shown in Figure 3, client configuration B, the proposed workspace for scheduling consists of several bidirectional interfaces for the domain specific end-user software, a version management layer and the underlying database to store the model data as well as references to related documents somewhere in the file system (e.g. proprietary files of the end-user software packages).

2.3 IFC as a central repository for data exchange

The suggested framework solution is based on the use of a central IFC Building Information Model. STEP Physical Files are used for the data exchange between the OIP and the client workspace. An early binding approach was adopted to bind the IFC2X3 schema which is defined in EXPRESS according to ISO 10303-P11 to the Java programming language [9]. The Java Compiler Compiler technology was used to generate the counterpart Java classes. This led to the generation of 980

Java classes representing 117 types, 164 enumerations and 653 entities of the IFC2X3 IFC EXPRESS schema. Built on this Java binding, tools were developed for reading, processing and writing models in STEP-P21 file format. This includes the processing of partial IFC models.

2.4 Mapping IFC data to the client workspace

At the beginning of the scheduling process (or iteration) the workspace is filled with the needed input data. This could be done either via the OIP or via direct import from the source applications. A converter with filter functionality, a so called mediator, supports the IFC based communication. It filters incoming IFC data for information relevant for the scheduling key process and maps it to the workspace internal data structure. Vice versa the public information is separated from confidential or temporary parts and reintegrated in the existing IFC model on the OIP. Moreover, since the workspace supports appropriate change management functionalities via object versioning, the correct instantiation of the objects' owner history information (IfcOwnerHistory) is provided by the mediator, which otherwise only is used as dummy information by IFC export interfaces of the majority of existing end-user applications. For scheduling the mediator specifically enables the export of the construction schedule [10], linked resources and 4D simulation data which is not possible with today's commercial software packages. It also possibly allows to link non IFC data like text documents or proprietary source files to the objects in the workspace. The use of such a mediator per domain model decentralises and simplifies the configuration necessary for setting up a cross enterprise OIE within a project [11] because for both, the workspace and the OIP, the mediator acts just like any other end-user software and can be adjusted to domain specific needs.

2.5 Object versioning of domain model data

Due to its flexibility and wide distribution we use a relational database within the workspace to store the model data and links to related documents. For each domain model the sub set of information used during scheduling is stored in the workspace. The partial domain models are stored separately and put under object based version control. Therefore during data import the data of the new model version is compared to its predecessor and all changes are recorded as delta information. For versioning we distinguish between the history of model versions consisting of a set of objects in a certain version and the history of each object itself.

Both histories of model versions and object versions can be depicted as directed graphs which are entangled with each other. Edges of both graphs represent changes in the model. A uniform table per sub model is used to store the reference information of the currently loaded model version and six additional tables which describe the edges of the two graphs and related delta information. A global master table keeps track of the actual loaded sub model versions.

With the information stored in the workspace it is possible to restore any of the imported model versions as well as to analyse the history of a single object. The aim within the scheduling process is to identify new construction elements as well as those activities in the construction schedule which could be affected by changes included in a new version of design data.

2.6 Tailor made graphical editor

A lightweight, easy to use 3D viewer with editing functionality dedicated specifically to model based scheduling is being implemented to improve the linking process. The editor provides a rule based linking mechanism which allows selecting construction elements and related quantities based on:

- the product break down structure / building topology
- the type of construction elements
- related object attributes
- the spatial location of objects (relative to a user defined axial grid or zones)
- the model version of the underlying domain models (CAD, quantities, schedule)

It is worth mentioning that similar computational geometry algorithms are already used in Geo Information Systems (GIS) but do not exist in CAD. Adopting this approach should help mapping CAD elements to their corresponding tasks in the schedule and to provide the project scheduler with related items in the bill of quantities.

Compared to the manually linking approach which is the standard method in today's 4D simulation

software packages the rule based mechanism speeds up the linking process dramatically and eases updates if changes occur in the underlying domain models [8]. In addition to object grouping the linking mechanism also allows the splitting of BIM objects and thus supports the project scheduler to break down the building model as needed by the tasks in the schedule. Today this case would require going two steps back in the process chain (Figure 2): First editing the CAD model and then updating the quantity take-off. Because of the complexity of the involved software packages this can't be done by the project scheduler and thus requires other actors in order to proceed with the scheduling key process. A splitting functionality built into the visual editor dedicated for the project scheduler abandons this obstructive requirement. The granularity of the objects in the model is no longer fixed to the presetting by the draftsman which in case is of particular importance for an adequate 4D simulation. The split object parts are stored as children of the original object and thus are part of the versioning tree just as the parent object.

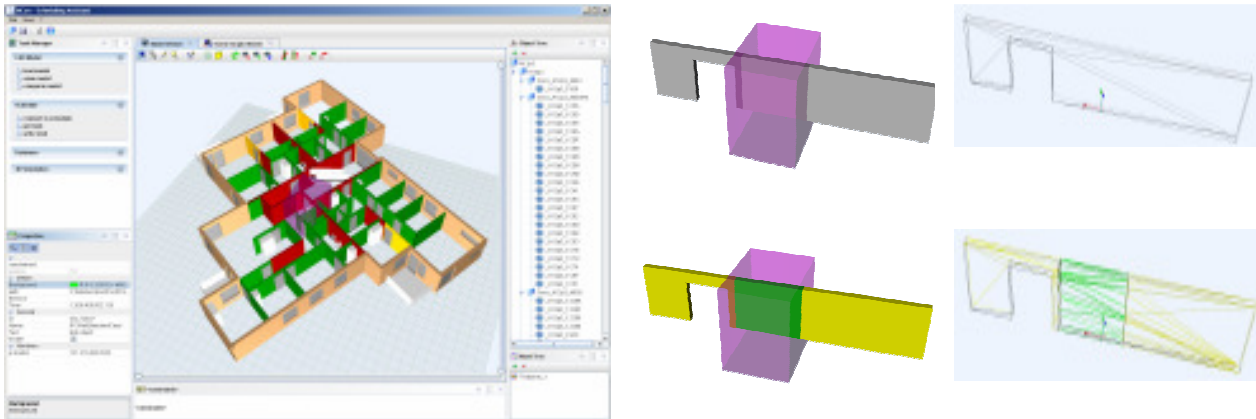


Figure 4: Pilot implementation of a graphical editor with object linking and splitting functionality

In our current pilot implementation we use a third party IFC to VRML converter and then visualize the 3D geometry of the model within Java3D. Because the implementation maintains the persistent IDs of the objects it is possible to link related information like object attributes and quantities from the BIM. The product break down structure can be received directly from the IFC model. The actual object splitting functionality is based on a modified Boolean operation algorithm used within constructive solid geometry (CSG) modellers. Currently the algorithm only supports geometry splitting but not splitting the related object attributes and quantities.

3. Conclusion and future prospects

A detailed process and software analysis of today's scheduling practice revealed several existing drawbacks and unsatisfied information needs. Depending on the available design data and its level of detail, four different methods are used to calculate the duration of activities in the schedule. The implied information needs today can only be provided through manual input. By integrating construction scheduling in a collaborative BIM based design process the situation can be improved significantly through the reuse of already available information. This eliminates double work and improves change management. But existing software packages aren't adapted to the needs of such a collaborative, model based scheduling approach. They don't provide appropriate access to the underlying data and lack two important functionalities: an efficient linking mechanism between product and process model and the ability to adjust the object granularity of the existing model to the needs of the project scheduler.

In addition the fragmentation of the construction industry and the related varied software infrastructure within construction projects has to be taken into account when designing a collaborative and dynamic framework which copes with the identified shortcomings. The following measures are suggested to improve the present situation:

- changing the quantity take-off to a model based approach using already available software packages and establish QTO as a central process prior to scheduling and cost estimation
- use of a domain specific workspace which exchanges data with other project partners through a central data share point based on the open exchange format IFC

- applying object based versioning on the design data to be able to track the history of changes
- providing a simple 3D editor tailored for model based scheduling with efficient rule based object linking and object splitting capabilities as well as access to quantity and cost information to support the project scheduler during his work

Especially for large projects with a high amount of data, complex dependencies and several project partners significant advantages are expected in terms of efficiency, data consistency as well as ease of change management and visualisation. Several components of this dynamic framework are already implemented but research is still ongoing. The following extensions are envisioned to be implemented:

- IFC model loader for Java3d instead of an external IFC to VRML converter
- build-in 4D visualisation functionality for the editor
- simplified definition of visualisation parameters based on templates
- configurable mediator between workspace and OIP

In addition the solution approach has to be further verified with real and full scale project data.

4. References

- [1] Open Information Environment for knowledge-based collaborative Processes throughout the lifecycle of a building (InPro), Integrated Project funded within the Sixth Framework Programme for Research and Technological Development of the European Union, www.inpro-project.eu
- [2] Hammer M., Champy J., "Reengineering the corporation: A Manifesto for Business Revolution", Harper Business, Chap.1; http://www.harperbusinessessentials.com/hbe_reengineering.html
- [3] Hammer M., "Reengineering work: Don't automate, obliterate", Harvard Business Review, p.104-112, Jul/Aug. 1990.
- [4] Object Management Group, "Business Process Modelling Notation", <http://www.bpmn.org/>
- [5] Kankainen J., Seppänen O., "A Line-of-Balance based schedule planning and control system", International Group for Lean Construction, 11th Conference, Virginia, USA, 2003
- [6] Heesom D., Mahdjoubi L., "Trends of 4D CAD applications for construction planning", Construction Management and Economics, Vol. 22, Feb 2004, p.171-182
- [7] Leen-Seok K., Yong-Su L., Jung-Min K., "4D-Modellsystem, Funktionsanalyse für die Bauplanung", Computer Spezial - Software für Architekten Ingenieure Bauunternehmen, Bauverlag, 02/2004, p.13-15, www.computer-spezial.de
- [8] Tulke J., Hanff J., "4D construction sequence planning – new process and data model", CIB W78, 24th Conference, Maribor, 2007
- [9] Nour, M., "A STEP ISO 10303-P21 Parser.", Reihe Bauinformatik, Shaker Verlag, Aachen September 2004. - ISBN 3-8322-3233-4, S. 231-237
- [10] Serén K., Karstila K., "MS Project – IFC Mapping Specification" 4D application development, VTT & EUROSTEP 2001, www.eurostep.fi/public/4D/4D_Mapping_V1_0.pdf
- [11] Tibaut A., Rebolj D., "Towards a virtual product model", International Journal of Internet and Enterprise Management, Vol. 1, No. 2, 2003, p.210-222
- [12] Tanyer A. M., Aouad G., "Moving beyond the fourth dimension with an IFC-based single project database", Automation in Construction 14, 2005, p. 15– 32
- [13] Dawood N., Eknarin S., Mallasi Z., Hobbs B., "Development of an integrated information resource base for 4D/VR construction processes simulation", Automation in Construction 12 2002 p.123– 131