A PRODUCT LIFECYCLE MANAGEMENT APPROACH FOR CIVIL ENGINEERING PROJECTS

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ABSTRACT

Product Lifecycle Management (PLM) is a strategic concept to develop, manage and keep control of industrial products over their entire lifecycle. The concept comprises IT-systems as well as methods, business processes and organizational structures. The most essential component of PLM concepts are Product Data Management (PDM) systems, that administrate all the data from initial ideas, drafts and drawings to information on the manufacture and maintenance on a central storage platform. Compared to document management systems, PDM systems provide part-oriented functions required for linking components, corresponding 3D models and drawings as well as any other related documents in a clearly arranged pattern. In addition, they also provide a convenient instrument for transferring and incorporating data from Computer Aided Design (CAD) systems into the central storage platform. Combined with cleverly devised access rights management and an integrated workflow engine, PDM systems appear to be a good information management solution in civil engineering projects.

These systems are designed to serve in-house information management procedures in the mechanical engineering industry, however, they have not been used for civil engineering projects so far. The present paper describes both the concept and the customization of a PDM system to manage data arising in civil engineering projects. It shows how an adapted PDM system originally developed for the mechanical engineering industry enables a company-wide component-oriented management of all relevant data over the entire lifecycle of a building. Beyond that, today's inadequacies and missing features for using PDM systems in civil engineering projects are described.

Keywords: Building Lifecycle Management, Product Data Management, Document Management, Data Acquisition and Storage, Information and Knowledge Management

1. CHALLENGES IN COORDINATING CONSTRUCTION PROJECTS

Nowadays, civil engineering projects have to be conducted in brief completion times. Missed deadlines result in high penalty fees. During the project, an increasing number of individuals become involved in order to finish the work properly and on schedule. At the same time, the amount of paperwork mounts up, including e.g. delivery notes or activity confirmations coupled with a greater demand for quality assessments over the entire lifecycle of a building (Gabrielaitis & Baušys 2006), (Rüppel 2007).

Consequently, managing a civil engineering project is now becoming more and more complex. Various project members need to access numerous data which has to be provided expediently in a clear, user-specific and up-to-date form. It is imperative that this project information is accessible from the very outset, during the planning and construction stages and right through to the operation and maintenance of a building.

Especially in bridge and roadway construction projects, there is currently no satisfactorily solution to manage all the building elements, digital CAD models, documents such as delivery orders and process information arising in a project (Froese 2003). A system classifying bridges and roadways into sections and components and storing all the related data in this structure is required. Besides the structuring of the data, it is important that the required system offers a capable document management module, including customizable document types and corresponding attributes (Gabrielaitis & Baušys 2006), search functions for parts and documents and a comprehensive rights, status and workflow management functionality. Furthermore, a solution for rapidly searching and finding project members with special skills has to be developed.

2. SOLUTIONS FOR MANAGING DATA IN CONSTRUCTION PROJECTS

There are several suitable solutions helping to manage data arising in construction projects. The following section discusses the most feasible ones.

2.1 Electronic Document Management Systems

Electronic Document Management Systems (DMS) help to organize information relating to construction projects by providing a central data platform. It enables people involved in the project to upload and share relevant data. Uploaded files have so-called meta-data attached, for instance, the author or originator, date created or a document description. For this reason, DMS are required to feature two main properties (Crnkovic, Asklund & Dahlqvist 2003; Björk 2002):

(1) a database with tables of meta data and links to the actual files; and

(2) an electronic vault, i.e. a directory where all the files are stored.

One very vital aspect of meta data is the status, which represents a data set’s maturity. For example, it might state 'at the planning stage' or ‘construction approval granted’. This, combined with the ability to link connected data sets, subsequently helps to organize and retrieve the required information.

As all modifications to checked-in files and meta-data are tracked, a transparent documentation of the content’s development is guaranteed. In this regard, data are typically not updated by modifying files, but by creating new versions of these files. A sophisticated rights management tool enables to attach groups and roles to individual users and accordingly to manage the user’s rights to read, modify or store either files or meta data. Users accessing construction data in DMS typically make use of a so-called ‘rich client’, where they can log into the database and, depending on their particular rights, search for or import information. So-called integrations are frequently provided, i.e. data can be imported directly to the DMS from the design system using special gateways. Some vendors also provide a limited ‘web client’ function to aid access to required data directly via the internet browser. Consequently, subcontractors or project members using mobile devices are also able to access the central information platform.

Another important feature of DMS is the provision of so-called workflow management modules, which allow users to speed up operational procedures, such as the circulation of plans. Assuming that a construction planner is entitled to change the status of a planning document from 'at the planning stage’ to 'under review', two reviewers can automatically be instructed to survey the plan. These reviewers can now either reject or approve the work of the planner. If the planner's document is rejected, the reviewer can add explanatory notes (*red-lining*) and send the plan back for revision. The status of the document consequently changes either to ‘construction approval granted’ or ‘under revision’, as the case may be, and the DMS records every process as it occurs. Examples like this demonstrate how a sophisticated workflow management system can accelerate and accurately document recurring processes in construction projects. Apart from workflow management, some DMS also support a shared calendar, virtual discussion forums or an integrated task management.

DMS can be used on either a company-wide or intra-corporate level. As so-called Enterprise Content Management (ECM) systems usually manage all the documents generated by a company on an intra-corporate level, virtual team spaces provide an easy-to-use company-wide document management functionality. Thus, contractors, planners or construction companies can always access the latest, valid files.

However, despite the huge range of functions provided by DMS, there are serious limitations in handling product model data. Since they are document-oriented rather than component-specific, it is not possible to depict the hierarchical structure of product models. Files can only be linked with their corresponding meta data which is rather inadequate.

2.2 Product Data Management systems

Product Data Management (PDM) systems enhance DMS by smoothly integrating engineering data. PDM systems originate from two different roots. As designing products in mechanical engineering became more and more computerized, CAD data and corresponding product structures had to be managed with the help of a computer, as well. The first PDM systems to be developed featured this functionality only (Crnkovic, Asklund & Dahlqvist 2003). Over the years, companies noticed demands to manage unstructured documents, such as requirements or data specifications within the PDM environment, too. Accordingly, manufacturers added DMS functionalities to their PDM systems. However producers of DMS also kept their eyes on the needs of the market and likewise generated auxiliary modules for handling product structures and engineering data. This demonstrates the second branch of the development of PDM systems.

DMS and PDM systems differ in the structuring of the data. Whereas DMS only handle projects and documents, PDM systems are additionally interact with component parts. Those parts can be regarded as containers, each with its own unique ID where all the data relating to a particular component is included, such as CAD files or drawings. These CAD-files representing only one single part are geometrically linked to other components in an assembly file. Projects, parts and documents are equipped with meta data. Figure 1 shows a typical data structure of a PDM environment.

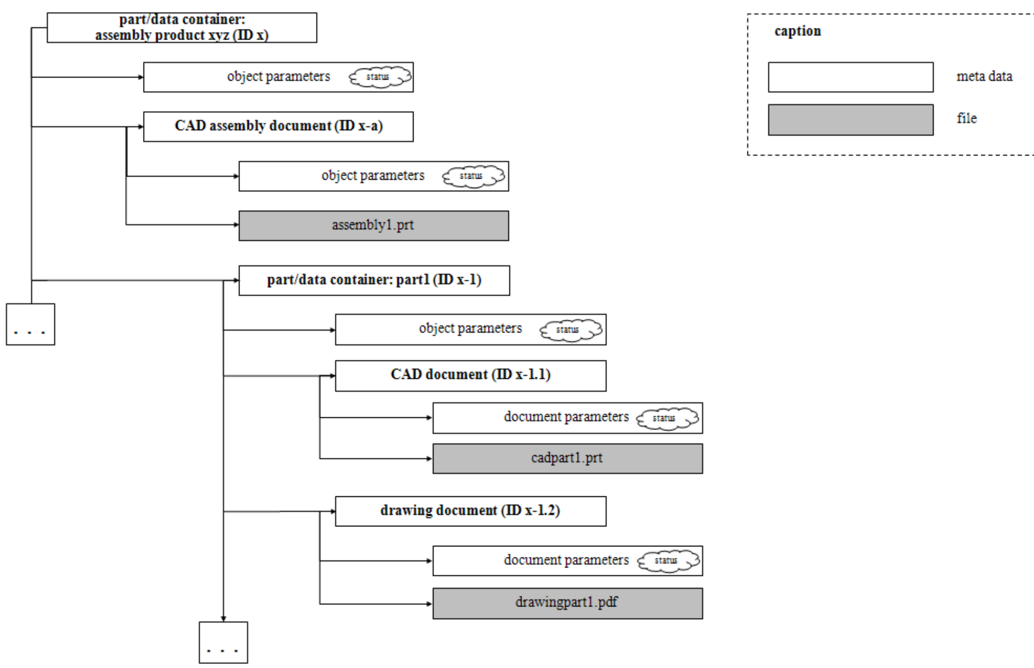

Figure 1: Structuring of projects, parts/containers and documents within PDM systems

The procedure of separating the entire CAD model (*CAD assembly document (ID x-a)*) into several small files (e.g. *CAD document (ID x-1.1)*) representing individual components is typical for the functioning of mechanical

CAD (MCAD) systems. However, this technique is also supported by Architecture, Engineering and Construction (AEC) CAD systems by using external references (XRefs), e.g. in Autodesk AutoCAD or Revit. For each MCAD file or single component, one part is created within the PDM system (cf. *part/data container: part1 (ID x-1)*). Other related documents, such as drawings derived from the 3D model (*drawing document (ID x-1.2)*), are then imported into this container. Unfortunately, this function makes the smallest unit of information concerning CAD model data depend on the granularity of files imported. Consequently, the constructing engineer is responsible for manually dividing the CAD data into reasonable portions of data sets in order to achieve component-oriented results. Assuming the basic operating principles are accurate, however, PDM systems pave the way for part-oriented work and clearly arranged product structures (cf. Figure 1) (Eigner & Stelzer 2001).

Cross-references enable locating components and the quantities involved and access the documents pertaining to this particular part. Bills of material (BOM) are generated automatically on the basis of the product structure. Creating product structures and geometrically linking the parts to one another within the PDM environment is rather convenient, as there are so-called deep integrations for many CAD systems. Here, data is imported into the PDM system directly from the CAD system. Linking parts and creating the product structure are automated background processes. Gateways to Enterprise Resource Planning (ERP) systems ensure the data is embedded properly into the companies' IT infrastructure. Like most DMS, PDM systems offer a preview of content stored in the database within the user interface.

Beyond the scope of services, there are several good reasons why today's PDM systems have failed to penetrate the construction industry market. Apart from AutoCAD and Microstation, the mentioned deep CAD integrations are only available for MCAD systems. Moreover, as PDM systems are used at intra-company level over a long period of time, the producers of PDM systems did not put much effort in making their systems easy to customize. Hence, the costs and labor hours required for adjusting them are immense. In addition, neither templates nor add-ons for construction projects but only for mechanical engineering matters exist.

2.3 Product Model Servers

Model Servers offer a part-oriented management of product models, based upon the standardized IFC format. CAD files are converted into the IFC format and subsequently uploaded to the central Model Server, where everyone involved in the project is able to access the data. The key aspects of Model Servers are (Jørgensen et al. 2008):

- the sharing of product models via data net;
- a rights management concerning data access;
- concurrent engineering on the basis of one central product model;
- version control and model update history;

However, the mode of functioning differs considerably from DMS and PDM systems. In both DMS and PDM systems the lowest information unit for CAD model data depends on the granularity i.e. level of detail of the imported files. It is only by dividing up the entire CAD model, that multiple users can access those sections of the model for which they are responsible or rather lock them and make modifications. By contrast, Model Servers store the whole CAD model in a database, thus making it possible to access data in a high resolution irrespective of the granularity of the file. Hence, users will only check-out single elements of the model and rework them, leaving all the other remaining parts on the server unrevised. Another significant difference lies in the management of changes. As mentioned above, DM and PDM systems lock files when they are modified. Accordingly, they also lock parts of the product model whose range, as already described, depends on the granularity of the separated model during the revision process (*pessimistic concurrency control*). Model Servers, however, allow different participants to modify the same items concurrently (*optimistic concurrency control*). Conflicts or inconsistencies that may occur during the simultaneous modifications have to be resolved manually when the extracted sub-models are re-stored in the central server (Borrmann et al. 2009).

Although Model Servers seem to be a feasible solution for a part-oriented management of data arising in construction projects, they have not been able to widely penetrate the market so far. One reason is that neither proprietary CAD files nor unstructured documents characterizing parts such as special requirements or quality related reports can be attached (an exception is a demonstrator program developed in the ICSS project) (Froese

2003). In addition, practical work with IFC files, which Model Servers require, often fails due to conversion errors (Jørgensen et al. 2008, Björk 2003). Finally, today's Model Servers hardly support workflow management features and get into difficulties with large amounts of data.

3. A PRODUCT LIFECYCLE MANAGEMENT CONCEPT FOR CIVIL ENGINEERING PROJECTS

As the remarks in the last sections show, a company-wide and part-oriented product data and document management system covering the entire lifecycle of a building activity is not yet state-of-the-art, especially when workflow processes and knowledge management features also have to be taken into account. Having these ideas in mind, the German research cooperation 'Virtual Construction Site' (ForBAU) decided to investigate how this vision can become reality by adapting concepts from other industrial sectors. PDM systems, originally deployed in the stationary and automotive industry and introduced in Section 2, form the basis of our Product Lifecycle Management (PLM) concept for civil engineering projects. The first step was to identify and structure the requirements for a system supporting our PLM concept. Based on a list of requirements, the next step was to choose a suitable PDM basis. That in turn was enriched with construction-specific templates and special add-ons.

3.1 Definition of Requirements

To identify the construction industries' needs for a PLM concept based on PDM systems, interviews and workshops with construction planners, building firms and software manufacturers such as *SSF Ingenieure GmbH - Consulting Engineers, OBERMEYER Planen + Beraten GmbH, Max Bögl Bauservice GmbH & Co. KG, BAUER AG, RIB Software AG* or *Siemens Industry Software GmbH & Co. KG* were held to gather and structure as many requirements as possible. Major demands included:

- confidentiality of data sets, i.e. a sophisticated rights management;
- multilingual user interface, as many construction projects are international;
- user-friendliness (pricey courses of instruction are only profitable intra-company);
- personalized user interface (favorites, recently used data, etc.);
- independence in terms of operating systems;
- independence in terms of CAD systems in charge;
- workflow management module enabling the release of groups of components and multiple status which can be defined freely;
- preview of important construction documents (e.g. PRT, DWG, RVT, IFC, JT, PDF, DOC, XLS, MPP, etc.);
- quick and easy customization, as construction projects are unique;
- long-term preservation of construction data;
- web-client functionality to tether mobile devices or project partners not having installed the PDM client software;

Those and further requirements were clustered and documented. Subsequently, all requirements were weighted according to their importance. Apart from serving the purpose of a well-structured documentation, the result also paved the way for benchmarking different systems.

3.2 Evaluation and selection of a feasible PDM basis

In order to benchmark PDM systems based on the weighted catalog of specifications, it was first necessary to develop an evaluation system. The degree of performance of each requirement was quantified on the basis of the 'Münchner Vorgehensmodell' (Lindemann 2009). Qualitative information was converted into quantitative data by means of value functions. The requirement's total degree of performance was calculated by multiplying its general degree of performance with the weighting factor (*value benefit analysis*). Figure 2 illustrates the evaluation system.

1. Requirements cluster abc			**PDM system xyz**	
1.1 requirement	weighting factor (1 – 3 – 9)	point rating system (created individually for each requirement) 1 = requirement not fulfilled, nor parts of it 2 = part x of the requirement fulfilled, part y however not 3 = requirement completely fulfilled	scores achieved in the point rating system (1 – 2 – 3)	requirement's degree of performance (req. 1.1 TOTAL) = weighting factor x scores achieved in the point rating system

Figure 2: Point rating system for PDM systems as a basis for managing data in construction projects

By summing up the total requirement's degree of performance (right-hand column) of each requirement, it is possible to assess the relevant degree of suitability of each PDM system. Before analyzing the market in order to identify an adequate PDM system as a basis, conclusive criteria such as 'workflow management module enabling the release of groups of components and multiple status which can be defined freely' (cf. Section 3.1) were defined to set limits. This helped to reduce the number of key feasible systems from 43 to 9 in the analysis. The remaining products were classified systematically according to the rating system presented. Amongst other factors, the assessment is based on live demonstrations, interviews, statements from reference customers, course of instructions and experience with test installations. Figure 3 shows the result of the PDM benchmark for construction lifecycle management.

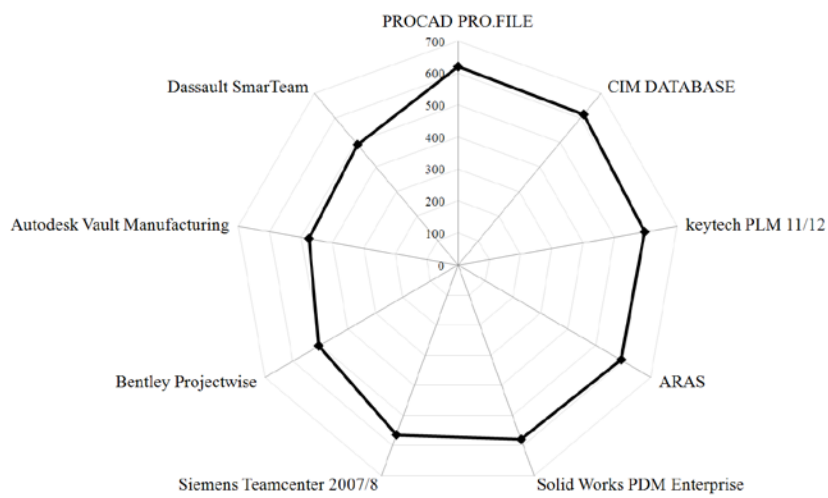

Figure 3: PDM system benchmark for managing data in construction projects - results

The result shows that there are few differences concerning the total points, especially with the most feasible systems. As Procad PRO.FILE fulfills most of the requirements apart from a sophisticated project management functionality, CIM DATABASE is very good at managing and monitoring tasks and schedules within the PDM environment. Regrettably, the user friendliness is inferior to PRO.FILE. ARAS is an open source PDM-tool providing large functional range including document and product data management, workflow management and project management. Unfortunately, again the user friendliness lacks compared to keytech PLM, Procad PRO.FILE and Solid Works PDM Enterprise. The latter in turn has a suboptimal rights management and can only deal with a few CAD systems. keytech PLM 12 appears to be a suitable PDM basis, but unfortunately version 12 was not completely finished at the time the PDM benchmark was executed. Siemens Teamcenter indeed fulfills various requirements but lacks in customization and maintenance effort as well as user friendliness.

In conclusion, the impartial benchmark test resulted in Procad PRO.FILE being the appropriate PDM basis. Although there are some weak spots concerning the project management functionality, it illustrates a proper solution for part-oriented model and document management. Furthermore, it is easy to use and customize, which was one of the key requirements.

3.3 Development of building-related templates and add-ons for PDM systems

PDM systems only come with base functions and cannot be used out of the box. For each case of application, an implementation concept has to be developed. The following section describes both the conceptual design and the implementation of a PDM system originally developed for mechanical engineering for the needs of civil engineering projects (bridges and roadways). Figure 4 presents an overview of basic PDM functions and the work carried out within the ForBAU-project. As many building related templates can be created by configuration (adjustment), special add-ons had to be developed by programming (customization).

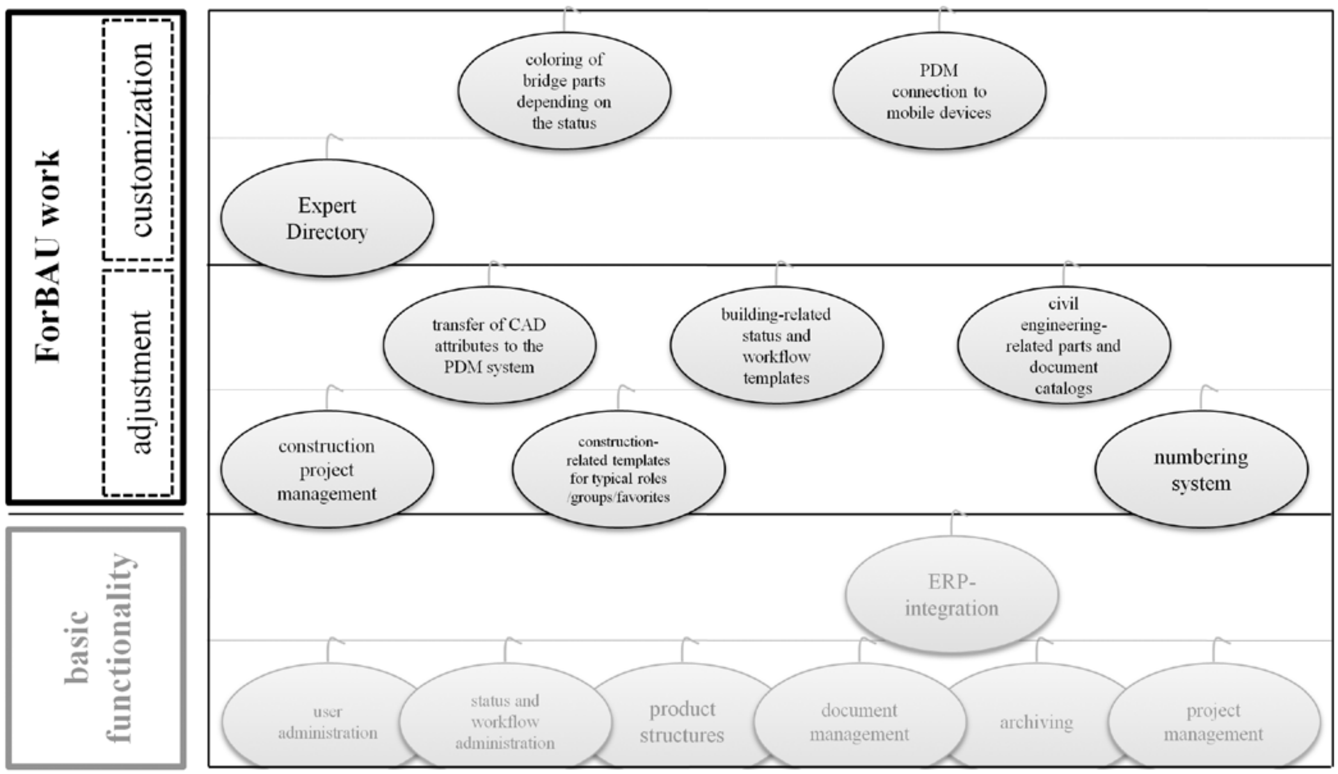

Figure 4: Basic functionality of PDM systems vs. work carried out within the ForBAU project

3.3.1 Civil engineering-related parts and document catalogs

Since there are neither parts catalogs nor templates for characteristic parts required for bridge and roadway construction projects, they had to be developed. For bridge parts the ongoing work on the IFC bridge standardization held feasible information and could be used as a basis (International Alliance for Interoperability (IAI) 2010). In concept workshops with renowned construction planners, building firms and software manufacturers such as *SSF Ingenieure GmbH - Consulting Engineers*, *OBERMEYER Planen + Beraten GmbH*, *Max Bögl Bauservice GmbH & Co. KG*, *BAUER AG*, *RIB Software AG* or *Siemens Industry Software GmbH & Co. KG* the needs were documented and subsequently the PDM-database was enriched with the corresponding data. The screenshot in Figure 5 shows the wizard popping up when creating a new part of a bridge in the ForBAU-PDM system.

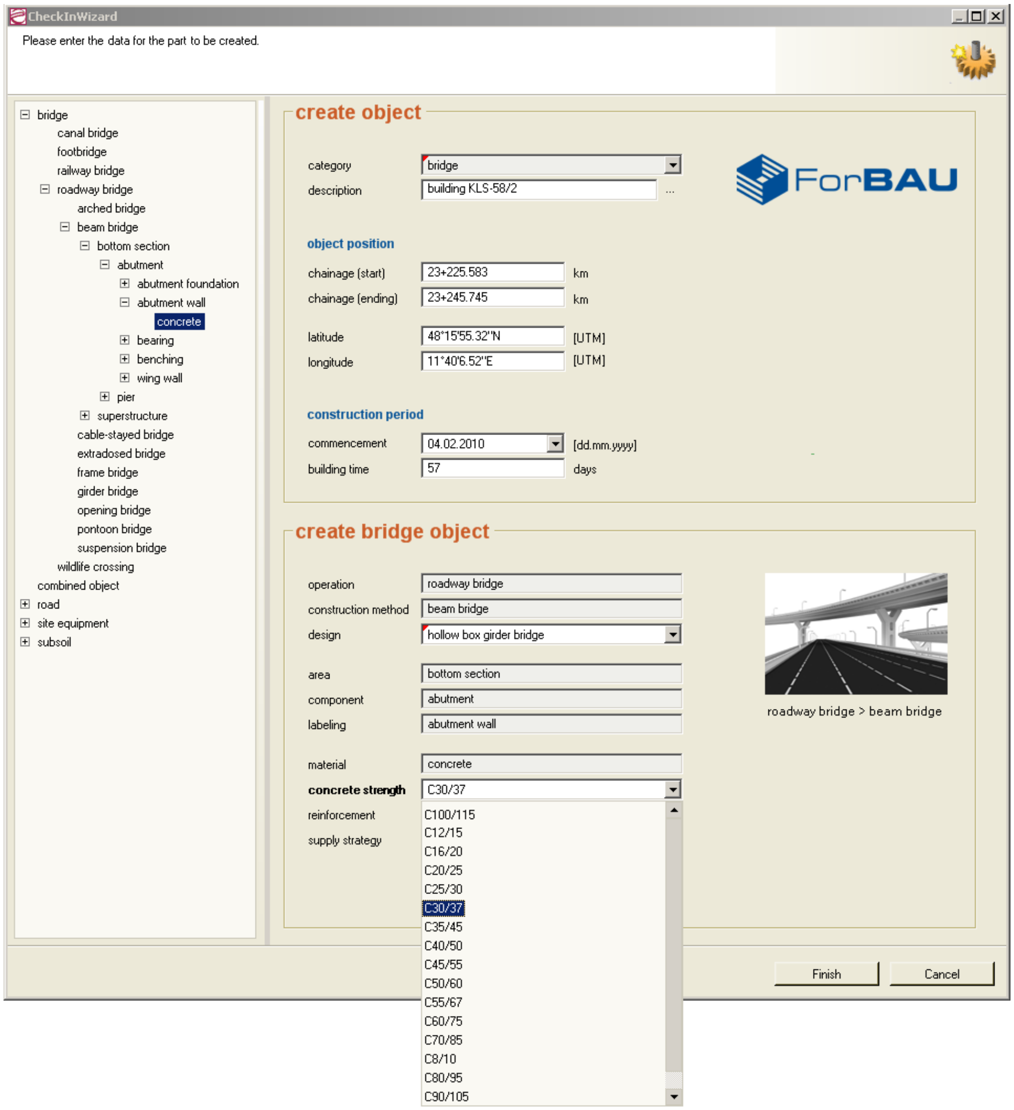

Figure 5: Wizard popping up when creating a new part of a bridge in the ForBAU-PDM system

The user can choose what kind of part should be imported to the PDM environment. As shown in Figure 6 above left, he can pick either

- bridge
- road
- site equipment
- subsoil

The top right section of Figure 6 illustrates how the user enters fixed object parameters such as geo-coordinates, chainage or commencement, whereas the bottom right section indicates the labeling of the part, the material or the delivery concept that can be chosen from the drop-down boxes. In the current example the user creates an abutment wall. The information is saved in the database by clicking ‘Finish’. Hence, all parts or components of bridges and roadways can be created within the PDM environment and attached with descriptive attributes.

Similarly, more than 20 typical document types occurring in construction projects, such as

- quality reports
- receipts
- minutes of the meeting
- CAD documents
- notifications of claim
- pictures
- webcams
- surveying results

can be categorized. All those document types in turn comprise different attributes, which can either be filled out manually, with the help of predetermined lists or automatically. For CAD documents, e.g. an add-on developed within the scope of ForBAU calculates volume, mass and bounding box of 3D models within the CAD system Siemens NX and passes the data automatically to the PDM system. Accordingly, it is possible to query the PDM database for parts that are heavier than 300kg but do not exceed 1 x 1.5 x 2 meters.

As all construction projects are unique, the templates developed in the ForBAU project are very easy to adapt. Predetermined lists such as the labeling of the part can be exported to Microsoft Excel, revised and re-imported to the PDM platform. To structure the data, parts and documents can be linked to each other during the importation process or after the data has been indexed and imported.

3.3.2 Building-related status and workflow templates

The last few sections mainly introduced solutions for managing construction data, but not the construction processes. In the ForBAU-PLM concept, several status representing the maturity of parts and documents such as

- planning completed
- construction approval granted
- delivered
- under construction
- construction completed
- maintained

were developed and implemented. Thus, all the parts and documents contain information concerning the construction progress. Subsequently, workflow templates for recurring processes such as

- integrated planning of roadways & bridges
- construction change management
- request for construction simulations
- request for target/actual analysis

were created. The workflow template ‘integrated planning of roadways & bridges’ for example makes surveying data for the road construction engineer accessible, as the status of the surveying data changes to ‘surveying completed’. Afterwards, the road construction engineer designs the alignment. When finished, he changes the status of the concerning data to ‘road planning completed’. Instantly, the bridge construction engineer is informed that he can start modeling the bridge, as the layout of the line is now fixed. This example of one of the developed workflow processes accelerates the planning process, helps to keep everyone involved informed and controls access to the imported data over the building’s lifecycle. The rights management can be adjusted for each status and construction section.

To keep records of the construction work, building progress information such as ‘component delivered’ or pictures of damaged parts can be entered and directly transferred into the PDM environment by means of a mobile handheld device. Vital components such as concrete precast elements are attached with a Radio Frequency Identification (RFID) tag during the manufacturing process. By using the same ID both on the real part’s RFID tag and the digital part in the PDM system, the information is automatically attached to the corresponding part in the PDM environment. A paper introduced at the RFID-SysTech 2010 provides further information regarding this special PDM add-on for construction projects (Klaubert et al. 2010).

In addition, depending on their status, the parts are colored in a different shade. This special building add-on was programmed with the help of NXopen-Java and alleviates depicting the building progress.

3.3.3 Expert Directory

We have described ways of speeding up processes with the help of a smooth information management system, previously. However, not all processes in the planning and operations phases of a civil engineering project can be solved via workflows. There must also be opportunities for discussing acute problems with specialists involved in the project over the phone or in person. Especially in temporary project formations locating the right contact person is anything but easy. Thus, an directory of experts has been set up within the PDM environment. This is a knowledge management-based method of locating experts in particular projects, classified according to their field of expertise (Boppert 2008). Typical fields of knowledge were defined and from a list the user can chose either searching for experts, advanced learners and project members with basic knowledge or no knowledge. The scale comprises four stages in order to avoid stating average results. This enables the site supervisor, e.g. to search the system for an expert on topographical surveys who additionally has at least basic knowledge in using a special CAD-system. Once an expert has been selected from the given list, the system will display contact details, other fields of expertise and a picture of the expert, on request.

4. CONCLUSION AND OUTLOOK

The paper describes a Product Lifecycle Management (PLM) approach for civil engineering projects. Challenges in product data and process management were met, concepts were developed and implemented based on a suitable PDM basis. Those PDM systems originally developed for the mechanical engineering sector differ from IFC based Model Servers, as the CAD-user actually decides about the granularity of the model data. Benefits that set the ForBAU PDM-system apart from other solutions are a sophisticated part-, document-, status- and workflow management including building specific templates, an experts directory, the coloring of parts depending on their construction progress and the tethering of mobile devices for building progress management.

The noticeable interests of the building industry asking for a system developed in the ForBAU-project may persuade manufacturers of PDM systems to provide deep integrations for AEC CAD systems such as Autodesk Revit, as well. Currently, the system is equipped with a gateway to a geographical information (GIS) system and evaluated on a pilot construction site. The future will show whether building-related PDM systems, Model Servers or even another concept will become widely accepted and contribute towards solving the problems of data management in building projects.

ACKNOWLEDGMENTS

This work is funded by the Bavarian Research Foundation (Bayerische Forschungsstiftung) within the research cluster ForBAU - Virtual Construction Site.

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