Using Product Data Management Systems for Civil Engineering Projects – Potentials and Obstacles

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Abstract

Product data management (PDM) systems are well established in the mechanical engineering industry. Here, they form the standard solution for the central storage of all data concerning a product and the processes involved in its fabrication. Especially the consistent management of CAD models including sophisticated versioning techniques and access rights management as well as the integrated workflow management are attractive features for using PDM systems also for civil engineering projects. The paper investigates the technical concepts behind PDM systems and discusses in detail the potentials and obstacles for using them in civil engineering projects.

1 Introduction

While large parts of the processes of architecture, engineering, construction (AEC) projects are realized today by means of computers, the industry struggles with an enormous data management problem. In the worst but not uncommon case, the various digital documents produced during the planning and realization of a construction project, including plans, text documents and 3D models, are neither stored centrally nor linked to each other. This results in high effort for searching when specific data is required, and usually extra costs for the entire construction project, since the risk for delivering erroneous or inconsistent information to the construction site is extremely high.

On the other hand, the manufacturing industry which faced identical data management problems at the beginning of the 1990's has meanwhile introduced powerful IT solutions that are capable to solve large parts of the data management problem. This is especially true for the automotive industry, where almost all enterprises today make use of a centralized product data management (PDM) systems.

The reasons for the technological gap between these two industries are manifold: The most important one is their diverging structure. While the automotive (manufacturing) industry is dominated by so-called Original Equipment Manufacturers (OEMs), which manage large parts of the engineering and production processes and can thus determine the IT infrastructure, the construction industry is heavily fragmented into small and medium-sized companies, and the planning and construction processes are usually strictly separated from each other.

In response to the demands of the construction industry for improved data flow and data management, the research cluster ForBAU, sponsored by the Bavarian Research Foundation, was created. ForBAU aims at providing the technological foundations for creating a "Virtual Construction Site" where planning and realization of construction projects are closely integrated through the intense use of digital models, computer-based simulation, ident technology and modern logistics approaches[1]. One of the main goals of the project is the identification of suitable IT solutions for an improved data management. The results of assessing the well-established PDM technology are presented here.

Before discussing the details of PDM systems, we want to clarify the distinction between Product Data Management and Product Lifecycle Management (PLM), since these terms are often used inconsistently. In our definition, which closely follows (Saaksvuori and Immonen, 2004), Product Lifecycle Management describes the strategy of data management over the entire lifecycle involving a variety of different software solutions, whereas a Product Data Management system is a specific software product with well defined functionality.

2 Electronic Document Management Systems

In order to understand the technology PDM systems are based upon, we will first shortly discuss electronic document management systems (EDMS), since they can be seen as predecessors of PDM systems and are already in use in the construction industry (Björk, 2001, 2003; Gabrielaitis and Bauys, 2006).

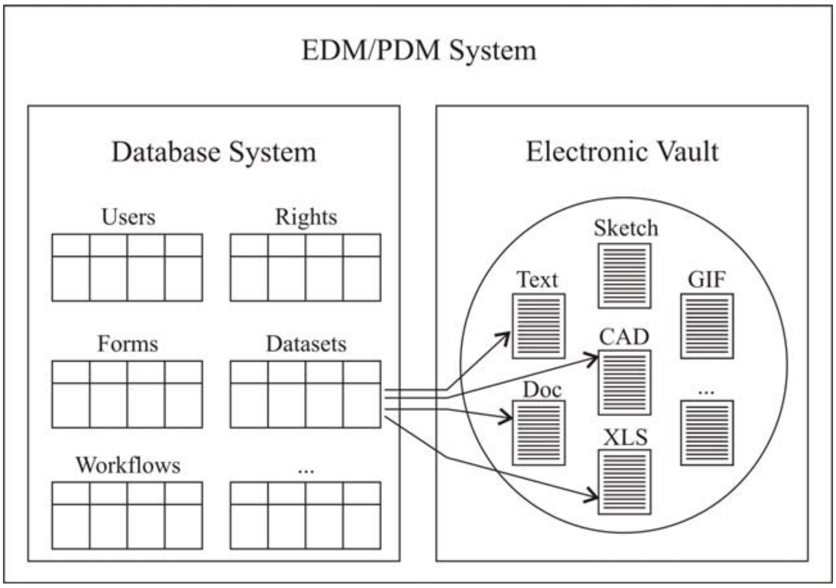

Fig. 2-1: EDM as well as PDM systems consist of two basic components, a database managing the meta data and a "vault" containing the original files.

EDM systems manage files at a central location and control all access to these files. They provide a comprehensive rights management which allows to assign roles to

[1] ForBAU website: www.virtualconstructionsite.com

individual users. These roles in turn define the rights to read or write individual files or directories. Another essential feature is the implicit locking of files: A file stored in the EDMS is locked by user *A* when he starts to edit it, thus preventing modification by any other user at the same time. As soon as user *A* has finished his modifications he releases the file. This mechanism is also called *Check-Out/Check-In*; it provides *pessimistic concurrency control*, i.e. it prevents inconsistencies by disabling simultaneous modification of the same data (Menasce and Nakanishi, 1982).

EDM systems log all file access and can thereby realize modification tracking, a very valuable functionality that provides information about who has changed what at which time. To be able to follow the individual modifications at a later point in time the system saves all revisions of that files.

All these functionalities are realized by a hybrid system consisting of (1) a central file storage and (2) a database that stores the so-called meta-data, i.e. the users' names, their roles, the roles' rights w.r.p. to individual files, the revision history and so on. Meta-data usually also comprises additional tags that can be attached to the files in order to make them easier to look-up. Direct access to the central file storage is prohibited, since this would lead to inconsistencies with the stored meta-data.

However, when EDM systems are used in civil engineering projects we are facing a granularity problem: The system can keep track of the modification of files as a whole, but it does not have any knowledge about which modification has been performed within the file. The same applies to the locking of files: Only an entire file can be locked, the locking of parts is not possible. The granularity problem is discussed in more detail in the next subsection.

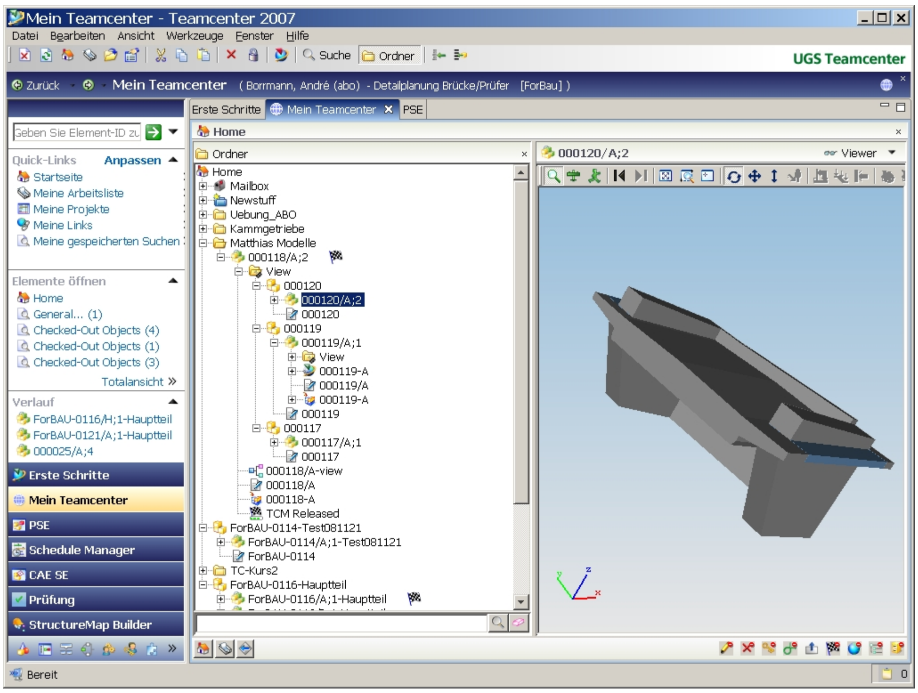

Fig. 2-2: Screenshot of the rich client application of a PDM system. In the center, the project file structure is shown, on the right hand side the preview of a CAD model is visible.

Access to the entire EDM system is provided through either a special client application (a so-called “rich client”) that offers the full range of EDM functionality (Fig. 2-1) or through a web portal with limited functionality (thin client). The latter version allows for access to the EDM from outside the company which is not only required to integrate third-party suppliers, but also to gain access by mobile devices from a construction site, for example.

3 Product Data Management Systems

3.1 CAD model management

PDM systems are document management systems specialized in handling engineering data (Liu and Wu, 2001). This particularly applies to 3D models created by a CAD application for which the PDM system provides a “deep integration”. Deep integration includes the following features:

- 3D preview of CAD models within the PDM front-end
- Possibility to launch the CAD application from the PDM front-end
- Automatic check-out/check-in from the CAD system
- Support of the CAD model hierarchy
- Automatic revisioning

In most cases, a deep integration exists primarily for the CAD system developed by the same software provider. PDM systems currently available on the market include amongst others AutoDesk ProductStream, ENOVIA MatrixOne, ENOVIA SmarTeam, PTC Windchill, Siemens UGS Teamcenter and SolidWorks Enterprise PDM. Table 3-1 depict some PDM systems and the primarily supported CAD system provided by the same vendor. It is important to note that the deeply integrated CAD systems are with no exceptions made for mechanical engineering[2].

PDM system	**Corresponding CAD system**
AutoDesk ProductStream	Autodesk Inventor
ENOVIA	CATIA
PTC Windchill	Pro/Engineer
Siemens UGS TeamCenter	Siemens UGS NX
SolidWorks Enterprise PDM	SolidWorks

Table 3-1: Available PDM systems and the corresponding CAD systems by the same vendor for which the ‘deepest’ integration is provided.

[2] An exception is the CAD system AutoCAD, which is used in both AEC and mechanical engineering.

This is due to the fact that in modern mechanical engineering 3D-CAD systems, each part is stored in an individual file. The (hierarchical) composition of the parts is then stored in corresponding assembly files. This allows for an easy reuse of once designed parts – a strongly required, cost-saving feature for the manufacturing industry, but of less importance in the construction domain. This might be the reason for the fact, that almost all available AEC CAD systems store their entire model in large, monolithic files.

For mechanical CAD systems, the aforementioned granularity problem does not occur, since the file that is locked during modification contains only one part, which corresponds exactly to the desired granularity of access. However, for current AEC CAD models the granularity problem persists: Whenever one of the user starts to modify the CAD model by checking out the respective monolithic file, the entire model is locked. This has to be seen as inadequate for AEC design and engineering practices, since here the participants from the various domains work simultaneously at individual parts of the building model. It's very common that, for example, the HVAC engineer starts to design the heating equipment of a building while at the same time the architect is detailing the building's facade.

To continue our investigations we therefore decided to use a mechanical CAD system for designing the building models under consideration, thus profiting from the multi-file storage approach that allows a high degree of concurrent engineering. However, this decision has some serious limitations for practical use. On the one hand, software applications designed for the AEC domain offer a lot of specialized functionality that is required to speed-up daily work. This includes modules for designing reinforcement, generation of construction specific plans, for example. Such functionality is typically not provided by mechanical engineering CAD systems[3].

On the other hand the "one system does it all" philosophy that is prevalent in the manufacturing industry and is enforced by the dominant role of the OEMs is not applicable for the AEC industry where we are facing highly specialized products for a number of different domains that typically work at eye level. This situation is aggravated by the diverging national regulations and has led to a diverse software market which on the one hand is more competitive but on the other hand results in a serious compatibility problem.

International standards such as the Industry Foundation Classes (IFC) promise a solution for the interoperability problem, but have been adapted very slowly even by the AEC software providers, and have so far not been recognized by PDM vendors. In fact, the philosophy of an integrated model management using product model servers (Kiviniemi et al., 2005) stands in contrast to the technical capabilities of PDM systems. Product model servers do not rely on files but instead store the entire model including geometry and all additional attributes in a central database. The most important technological difference is that product model servers realize optimistic concurrency control: Sub-models which are checked-out from the full model and stored in files for further modification by one of the participants are not locked, but instead a possibly concurrent modification of the same items by another participant is allowed. Conflicts or inconsistencies that may occur during the simultaneous modifications are

[3] One exception is Digital Project by Gehry Technologies that is based on the mechanical engineering CAD system CATIA.

resolved when the extracted sub-models are re-stored in the central server (merging). While some of the conflicts can be resolved automatically, most of them have to be resolved manually since they require active decisions by the stakeholders including the finding of suitable compromises.
Pessimistic concurrency control as provided by PDM systems does not allow for concurrent modifications and thus prevents any inconsistencies. However, this can result in much time spent by the engineers for waiting for the locks to be released when using usual AEC-CAD systems. Since design and engineering in the AEC industry is typically realized within *long transactions* (Weise et al., 2004) taking up to several weeks, the optimistic variant of concurrency control has to be judged more flexible and thus more adequate.
However, since on the one hand, important questions concerning the realization of optimistic concurrency control are still under research, including the specification of the content of the sub-model (Weise et al., 2003), the cutting and healing of the object-network (Nour, 2007), and the realization of diff/merge algorithms on product models (Koch and Firmenich, 2006), and on the other hand, full-grown, commercial Product Model Servers offering the entire set of the required data management features are not yet available, PDM systems can be seen as a suitable interims solution for the moment.

3.2 Management of process data

Besides the pure management of data described in Chapter 3.1, PDM systems also provide a means of including process information in the data records. The data deposited in the system are structured in such a way that datasets that belong together, such as 3D model and corresponding drawing, are grouped in one item or item revision. This is a kind of data repository that can be clearly identified in the system with the help of a number. The repository can be enriched with additional information. For example, it is possible to attach lifecycle information to building components. This allows users of PDM systems to see not only the data record itself but also its maturity at a glance.

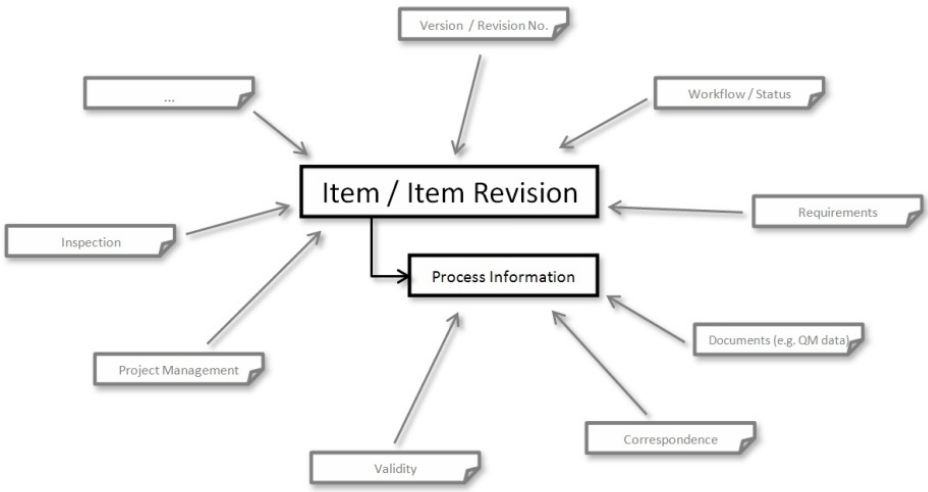

Fig. 3-1: Item or Item Revision and various forms of collated process data

The simplest way to insert such a maturity level in an item / an item revision is to create a new version, or revision. Revisions are frozen data sets which can be retrieved in any event at a later date, whereas versions are normally overtyped and only a certain number of the more recent amendments are stored (as back-ups) in the system. Another way of depositing process information within an item is to enter things like volume or material, e-conversations or a limited validity period. The latter would mean that a recurrent part, such as a bolt, would be barred from use as from a certain expiry date, due to a new standard coming into force on that date and prohibiting its further usage. In addition, many systems also provide support in the field of compliance management. This makes it possible to insert official regulations, for instance, so the product can be checked for conformity with the requirements from the point of view of its constituent parts, etc. In this way, problems could be avoided in advance, particularly when planning projects abroad. Certain datasets can, moreover, be attached to the item in the form of a link, thus making it possible to tie in quality-related documents, assessments, approvals etc. during the course of the development and usage of a structural element. A PDM system also allows the inclusion of comments or requests for changes to existing items (red-lining). The system always records the time and date of the attachment as well as the name of the person who added the document concerned.

Closely associated with this, some systems provide a so-called *requirement management* function, with the help of which certain requirements can be matched to corresponding building components. So a design engineer has access to additional, linked information pertaining to his target structure from the very start. With the help of an integrated project management feature, the system also allows certain details, like operations, to be linked to certain items. In future, whenever completed products that are already in use are due to be tested, they can be managed within the system. It is accordingly conceivable that the member of staff who is responsible for Quality Management may receive notification of an inspection assignment. Another means of depicting the maturity of a product is to allocate an appropriate status. An item that is currently at the planning stage would then be given the status "in process of planning"; another, for instance, the status of "building permission granted", or maybe "accepted by contractor". Amendments to these status designations usually involve inspections and approvals, which come under the heading of Workflow Management in a system of this kind. So it is possible for certain items to be passed through ready-made, electronic workflow templates.

One example of this would be to circulate plans in an electronic format rather than using the tedious, time-consuming postal system. The inspector, or inspectors, such as the building contractor, would be sent an e-mail with instructions to examine a document, which might be a plan or perhaps a 3D model. Using the aforementioned red-lining tools, the inspector can indicate any changes required in the PDM system and send back the document for rectification. As soon as the first remark has been dealt with, the design engineer responsible receives a message containing the amendments requested by the inspector. Once all the amendments have been carried out by the design engineer responsible, the inspector sends his approval electronically and the item revision is given a new status. No further editing of the item revision is permitted now; instead, a new revision would have to be created and released in its turn. Corporate processes, such as changes, can be rendered more transparent and comprehensible in this way. All the details of reasons for a rejection, a release date or of individuals granting their approval are recorded by the system. The modelling of such workflows is normally done graphically and can be executed without the need for any special programming skills. The diagram below shows a workflow template that was created using the Siemens Teamcenter product.

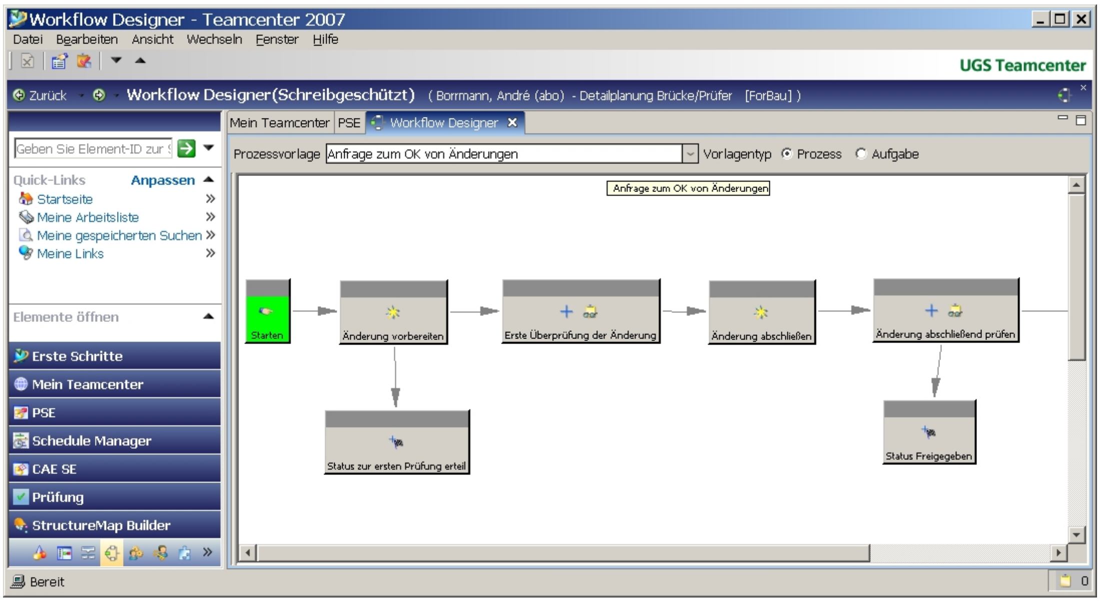

Fig. 3-2: Screenshot of a simple workflow template (Product: Siemens Teamcenter 2007)

At big machine-manufacturing plants and in the automobile and aircraft industry, these amendment processes are called "engineering change requests" (ECR). Often, those ECRs are certified from the point of view of quality management so they satisfy the official product liability requirements. Workflows may be initiated by users who have been granted the relevant rights. It is also possible to link the launch of a workflow with a particular occurrence: when a certain milestone in the project plan has been reached, for instance.

As the aforementioned account suggests, a system of this nature provides an all-round means of managing the entire lifecycle of a product. Digital workflows bring transparency to the decision processes. The valuable data could open up far-reaching optimization potential for the execution of a building development in particular. It must be emphasized, however, that even in connection with the management of process data, the tools used in the manufacturing industry cannot simply be transferred to the building sector. As in the case of CAD model management, the main problem lies in the monolithic individual files that are generated by the AEC-CAD systems. Apart from the fact that simultaneous engineering is not a feasible option for the time being, as mentioned in Chapter 3.1, lifecycle and process management are also extremely difficult. The status, the approvals based on workflows, the requirements and even the quality-related documents usually refer to a partial model, just a section of the geometry, but not to the model as a whole. The world of AEC-CAD, which is characterized by monolithic data sets, accordingly cancels out a huge slice of the benefits of PDM systems.

One of the core aspects of the ForBAU research alliance, however, consists of evaluating the advantages of fully parametric 3D modelling, designing free-form features and generating automatic data for computer-aided manufacturing (CAM). Hence, the use of MCAD systems is becoming increasingly widespread in the planning side of this work. A hybrid use of CAD systems of both sectors could, with the use of PDM systems, prove to be an asset compared to conventional document management systems, in spite of the problems described above.

3.3 Connection to ERP systems

Enterprise resource planning (ERP) systems, such as SAP, Microsoft Dynamics, or Oracle eBusiness Suite form an important part of the IT infrastructure in many business domains today. They typically provide data management functionalities for the following areas:

- Financials (accounting, cash management, billing, ...)
- Human resources (personnel, payroll, time & attendance,...)
- Customer Relationship Management (customer contact, sales, marketing, ...)
- Manufacturing (cost management, process management, quality control, ...)
- Supply Chain Management (purchasing, inventory, supplier scheduling, ...)

Although the functionality of ERP systems can be seen as orthogonal to that of PDM systems, especially the last two points stand in close relation to the engineering data managed by the latter. For this reason, some of the PDM providers have developed so-called *gateways*, that integrate ERP and PDM systems by enforcing the consistency of the data stored in the separate databases.
Applied to the AEC industry such an integration is particularly beneficial for construction companies, since (1) the quantity take-off realized on the basis of the CAD model can be directly linked to the required resources, (2) supply chain management can be realized using CAD information, and (3) the construction progress can be captured in the CAD system for 4D simulation and at the same time in the ERP system for cost management, billing, and so on. So far we did not finish our investigations on PDM-ERP integrations; results on that are presented in future publications.

4 Customization

PDM systems merely offer basic functionalities by way of an out-of-the-box solution. Customizing refers to the amount of implementation required to align the PDM system to the specific needs of a company (Goltz et al., 2003). One essential requisite is to define precisely what is expected of a PDM system in advance. This includes general requirements, such as the number of users or the modules required, on the one hand. Some firms can manage without a project or requirement management, for example. On the other hand, it is essential to make a careful record of which processes are to be displayed within the system, before the corresponding workflows are implemented. It is not uncommon for companies to be unable to give an adequate description of their own processes. According to Arnold (Arnold et al., 2005), the customizing of a PDM system can be divided into the following stages:

- Administrative level
- Logical level
- Functional level

The administrative level deals with the basic settings such as the distribution of users, roles and groups or adjusting the GUI to certain user profiles (command suppression). The logical level, on the other hand, addresses the topics of workflow modelling, adapting the meta-models to different products (specific tags, for instance), the status, diverse regulations, the numerical logic, etc. Graphic tools are not always available for implementation purposes, and it is often necessary to have recourse to script languages. The functional level is taken to mean intervention in the system functions. This makes it possible to realize certain additional functionalities, such as the deep integration of a further CAD system or other programs. To this end, however, it is usually necessary to interfere with the source code of the software, which makes the adjustment work more complicated.

5 Conclusion

Product data management systems are basically able to solve large parts of the data management problem of the AEC industry. They provide powerful features including the revision and preview functionalities for CAD models, highly customizable workflows, and a tight integration with process management solutions and enterprise resource management tools.

However, in the moment there are serious limitations for employing PDM systems for civil engineering projects. The most critical one is that CAD systems used in civil engineering context today store their data in large, monolithic files which results in a granularity that is too coarse with respect to modification tracking, versioning and locking. Mechanical engineering CAD systems that store the parts of a CAD model as individual files and thus provide the required granularity can be used alternatively but lack important features for an efficient application in civil engineering projects.

Other particularities of construction industry such as the individuality of the projects with respect to the “produced” building, the changing composition of project partners, the separation between the engineering and the realization of a building, and the need to dynamically adapt the workflows render the introduction of PDM system additionally difficult.

The future will show whether either AEC CAD providers will change their file storage strategy to a one-file-per-part basis, thus immediately opening their products to the PDM world, or the (IFC) Model Server concept that is based on the fully resolved storage of the entire model within a database will get widely accepted. In any case, the AEC industry will greatly benefit from a profound data management solution.

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