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ADVANCES IN COLLABORATIVE ENGINEERING EDUCATION

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ABSTRACT
This paper describes a project called ProVerStand ("Produktentwicklung über Verteilte Standorte" or product development involving distributed locations) initiated by the Chair and Institute for Engineering Design (ikt), RWTH Aachen University and is participated by universities within the federal state of North Rhine-Westphalia (NRW) in Germany. This paper will show the infrastructure of the cooperation within this project as well as information on license capacities and the current state of utilization. Further the influence and efforts of ProVerStand on curricula within NRW will be presented to give an example of effective and successful collaboration among universities at distributed locations. The paper also includes a perspective of future plans concerning expansion and upcoming projects.

Keywords: Engineering Education; Product Lifecycle Management (PLM); Multidisciplinary curriculum

1 INTRODUCTION
With the need of further decreasing time to market, sustainable processes and facilitating tools, enhancing collaboration across borders and time-zones have to be established in industry. Companies realize the urgent necessity to integrate their knowledge-based data management during the whole product life cycle. PLM is a strategy for handling this issue.
Within chapter 2 the thematic "PLM" will be introduced. The content of the project ProVerStand with its software und hardware is described in chapter 3. The curriculum within ProVerStand will exemplary be illustrated for three universities in chapter 4. Several research ideas will be explained in chapter 5. A summary and an outlook will be given in chapter 6.

2 PLM
High complexity in the matter of product, process and organizational structures in a company is nowadays difficult to handle and mostly a result of historical growth of a product's structure, process and organization. An improvement for handling this complexity can be achieved by controlling the data/information flow in connection with an adjusted product structure as well as organization along the product creation process [1]. A possible strategy to address this topic is the Product Lifecycle Management (PLM).
PLM is defined as a knowledge-based enterprise strategy for all processes and their methods concerning the product development from the product idea up to the recycling phase [2].
Regardless of the above definitions, it is important to emphasize, that PLM is not a term to describe a certain IT-system. PLM is rather a strategy dealing with (the integration of) data and/or information within a company.
By understanding this, appropriate tasks can be derived, which have to be accomplished as part of a PLM strategy. This comprehends for example the management of the product as well as the process data or the control of access authorizations of the system users involved. A tool to accomplish these tasks is the Product Data Management System (PDMS). This tool is preferentially used by several enterprises for the implementation and support of their PLM strategy.

3 PROVERSTAND

3.1 The ProVerStand Initiative

Within the last 5 years more than 40 institutes and professors of 15 universities throughout the federal state of North Rhine-Westphalia (NRW) teamed up to enhance PLM-education. This alliance aims at better preparing the next generation of engineers in a global environment. Therefore it is indispensable to adopt the curricula to modern industrial needs.

Contemporary tools and practice-oriented concepts play a major role in this context. The demand of shorter educational cycles and decreasing monetary resources at most of the universities, force the faculties to break new fields. Thus it is more and more important to provide opportunities for students to enhance their knowledge. An integration of powerful tools enables education along the whole process chain from design, followed by simulation of mechanical behavior, NC-programming up to the management of development data within a PDMS. By providing access to e-learning platforms in order to get advanced qualification, ProVerStand helps the universities more to focus on teaching the fundamentals of engineering and to strengthen research and development. To ensure a competitive education of tomorrow's engineers the students need access to powerful workstations which match the requirements of today's 3D-CAX applications. ProVerStand provides these machines and offers flexible teaching scenarios with multi-room courses to guarantee efficient use of personnel and room capacities and emphasizes the use of new media.

3.2 Software

On the one hand, to better prepare the student for their professional career and on the other hand to decrease the time needed for adjustment on the job after being graduated, university has to care about the right knowledge and use of PLM including the associated systems. In order to do so, ProVerStand provides applications which are widely spread in industry and support the systematic academic approach.

Since the year 1986 Pro/ENGINEER (Pro/E) is utilized in the engineering environment. It was the first fully parametric 3D Computer-Aided-Design-tool (CAD) and remains up to now one of the most-powerful application in its sector. Due to the definite logic within the structure of a three-dimensional model Pro/E supports the anticipating product modeling. In this respect it assists methodical teaching as far as engineering tools are concerned and it also supports a methodical approach in the field of problem solving. Referring to the explicit structure of the CAD-model, Pro/E enables the integration of multiple CAx-tools: multi-body simulations, FEA or NC-machining. The time-consuming familiarization with new user interfaces is reduced to a minimum.

The effective use of CAD produces an immense data volume. Handling this data becomes more and more extensive. With an excellent integration of the web-based Product-Data-Management-System (PDMS) Windchill™. in Pro/E this combination is well suited for educational purposes. To access the data, only a web browser and an internet connection is needed.

The application Windchill™ and the "PTC Link Solutions" in particular base upon the parametric designed product models. As example the modul "PTC PartLinks" can be quoted as it supports the development of an individual parts catalog which is referenced to the parametric CAD models and offers the opportunity to generate adequate models within Pro/E by editing parameters in Windchill™.

In order to provide enough license capacity for the universities of the federal state of North Rhine-Westphalia, the ProVerStand initiative negotiated a state license for both tools. The license agreement is valid until March 2011 and provides a number of 10.000 concurrent users for the software Pro/E. To meet the requirements of the participating chairs and institutes, nearly all modules are available. Additional licensing including the CPC-Software Windchill™ guarantees state-wide access to PDMS with a number of 45.000 registered users.

Fundamentals of Pro/E and Windchill™ can be learned using the e-learning tool PTC University (PTCU). This represents a valuable preparation for the exercises within the academic courses. Additionally PTCU with its assessment tool provides advanced qualification concerning the use of applications going further than what can be taught in the timeframe of design courses. It will improve the qualification of prospective engineers especially in international comparison, since this kind of educational offer is not widespread. Because of strong performance differences between universities in the world, it is actually a necessity to offer the students additional qualification. This educational offer can not be accomplished by the staff of the institutes. Thereby e-learning is a suitable alternative, as it

is accessible around-the-clock and does not depend on the actual student location. They can even participate in e-learning during vacation or abroad in case an internet connection is available and they are registered as students in NRW. Besides that the content is available in several languages.
There is also the possibility to create own content and integrate it in the educational plan. It can be of every format, which is able to be presented using Internet, like mpeg, html, shockwave, PDF, PowerPoint, etc. This enables existing learning material to be integrated and managed in PTCU.
Within the project ProVerStand there is a license capacity for 5000 concurrent users for PTCU.

3.3 Hardware

In order to supply the workgroup consisting of over 40 professors within NRW with appropriate collaborative and data warehouse services, a server concept had to be implemented within the RWTH Aachen University. The Chair and Institute for Engineering Design (ikt) and the Center for Computing and Communication (CCC) of RWTH Aachen University therefore combined their competences to operate a server compound fulfilling the requirements of the large number of users which was to be expected. This cooperative operation concept provides the bundled competence of how the servers are operated and how the software is to be used and administered for research and educational purposes.
The hardware for the server compound was chosen in tight cooperation with potential vendors with expertise in the Windchill™ software. As the requirements pay heed to the resources of the ikt as well as the CCC a manageable solution had to be found. Due to the rapid evolution of computer based systems the main focus laid on sustainability and performance. As the systems were installed in 2002 the renewal of the hardware, which held its performance promise up to date, is queued for 2007. The server compound is in extensive use for teaching purposes as well as for research, therefore reliability had to be granted ensuring operations with minimal performance losses in case of a failure.

Requirements

In the year 2001 when sizing for the server compound was performed, the expertise for a Windchill™ System matching the mentioned dimensions were sparse. So requirements were generated from guidelines provided by hardware vendors giving an impression of performance for collaborative systems in general. The key figures for the compound sizing were the total number of users which point directly to the needed storage as well as the number of concurrent users which represent the key performance issue. Other aspects of the sizing concern reliability and online accessibility.
The server compound is to be used within the Resource Compound NRW (RV-NRW) [3] and is therefore available to all universities within the state. It is used for teaching projects between universities and an increasing demand for these services was expected over the years. This is why the number of total users (TU) as well as concurrent users (CU) had to be defined for initial purpose and gradual growth. The TU determine the storage capacity for the assumingly produced data. As hard disk space is easily amended by modern computer technology this requirement has been adapted to the actual needs during the last years. The number of CU on the other hand is the key performance indicator for the server systems within the compound and as servers are far more difficult to scale as hard disks are a certain security surcharge had to be intended by the calculation in the following.
In the federal state of NRW a total number of 452,356 students were enlisted in the winter semester of 1999/2000 [4]. As more actual statistics were not available when sizing was conducted in late 2000 these numbers were used. However the available number of 440,205 students enlisted within the 20 strongest faculties in the winter semester 2000/2001 [5] show that the numbers can be seen as adequate. As the project is of most interest for the faculties of mechanical engineering, information technology and economics, the numbers of 128,285 students [6] enlisted were the major indicator for sizing purposes.
Based on the number of registered students of the universities who committed their support in 2001 for this project, the number of TU is estimated with approximately 45.000 users as shown in Table 1.
To estimate the amount of CU the first semester was taken as calculation basis, because usually the classes are biggest in the first semester and the number of students decreases within the course of study. If calculation CU one has to take in consideration a worst-case scenario for the concurrent accessibility of the ProVerStand server compound. Decisive in this case are compulsory classes such as technical drawing or machine elements within the faculty of mechanical engineering. In the year 1999 55,491 student beginners were enlisted in the first semester, 19,208 of them belonging to the faculties of mechanical engineering, information technology and economics [6]. Taking into

consideration that the software would most heavily be used concurrent within the engineering department by approximately 20% of the students in the first semester, within information technologies and economics by 4% each and up to a maximum of 0.5% of the other faculties a total number of approximately 1500 CU results from the numbers of first semester students, which was used as a key indicator for hardware sizing.
The server compound has to be accessible for teaching and research throughout the year. Even a reliability of 365 days and 24 hours a day is to be strived for, this cannot be achieved by the available resources. Within the educational environment slightly higher latency or short inaccessibility are acceptable in order to reduce cost for men and machines, because in comparison to commercial use no financial losses may accrue. Even reboots can easily be performed within the educational environment if users are informed early enough without risking lessons to fail. However, requirements for consistency and security of data meet industrial standards. A backup is provided as well as firewall technologies. By using two locations a high availability can be achieved even if one location is cut off or fails. The main requirements for the project were:

- Availability throughout the year 24 hours a day with accepted downtime up to one day and short time deadlocks permitted.
- 1,500 concurrent users.
- Automatic backup.
- 0,5 terabytes of storage which has to be easily scalable. This counts for approximately 5 Megabytes of storage per user on a basis of 45.000 total users within a mirrored data scenario.
- Two locations for the overall server compound.

Table 1. Number of enlisted students of the universities initially committed to attend the research group of ProVerStand within the most interesting faculties according to [6]

University	ME	IT	Eco	Total
Uni Bochum	1,284	0	3,533	4,817
FH Dusseldorf	814	0	1,383	2,197
RWTH Aachen	4,859	1,740	2,904	9,503
Uni Siegen	993	0	1,872	2,865
FH Munster	826	0	1,879	2,705
Uni Duisburg	880	50	3,536	4,466
FH Monchengladbach	2,314	0	2,459	4,773
FH Gelsenkirchen	912	357	1,585	2,854
FH Cologne	3,035	1,064	2,766	6,865
FH Dortmund	566	1,296	1,901	3,763
Total (Faculty)	16,483	4,507	23,818	44,808

ME: Mechanical Engineering
IT: Information Technology
Eco: Economics

Server Concept

In order to supply NRW with a PDM Software such as Windchill™l a central server installation pays of for using synergy effects throughout the federal state. The nature of a project entailing collaborative cooperation already implicates a central data pool for the geographic distributed locations [7]. This is contributed by the university spanning collaboration in the ProVerStand project. The schematic architecture of the Windchill™l PDM system uses three tiers to represent the web based service:

- User Interface
- Application Server
- Data Assurance Service

The user interface utilizes a Java capable browser such as the Internet Explorer or Mozilla Firefox as well as Opera among others. The contents are displayed via HTML code and Java Applets. By using

these standard technologies, the user interface can be reached on nearly all operation systems. This includes open source software which is widely spread within educational communities in Germany. This independence also applies to the application server level which is mostly written in Java code using standards as Java Server Pages, Servlets and Java Beans. For the Data Assurance Service an Oracle database is recommended but alternative databases can also be implemented.
On the physical layer at least two different servers deem necessary. One of them represents the application layer for Windchill™ and the other is a Database Server based on Oracle. This configuration enhances scalability because CPUs can be dedicated on tasks in different systems and do not share workload of the other server processes. Servers are located in the CCC and ikt. These two locations are connected to each other via Gigabit Router. The servers on both locations are represented by one machine although there are indeed several machines involved which will be shown below in more detail.
This architecture is recommended for huge user loads [8] as seen on the ProVerStand server compound, and fulfils the requirements concerning availability and security. The Oracle is located within the CCC, because the bandwidth for the data server is higher here and this is necessary for the backup of the whole storage which is also within the CCC and mirrored to another geographic location in Jülich [6] which is also connected with high bandwidth and relatively nearby but independent. By isolating the Oracle instances security is further enhanced as access is only permitted from dedicated application servers and the ikt itself is not capable of managing this complex storage system itself. This Oracle is not only useable for the ProVerStand server compound but can also be used by local installations of Windchill within the connected universities for deep software research and customizing issues, saving these institutions the effort on implementing their own Oracle instances.
For Windchill, four different machines will be used for one productive and one test application as well as one server for migration and the fourth as cold standby backup to be switched on immediately if the productive server fails. The productive server cold backup is located at the ikt which is also provided with as database mirror. However as we are using cold standby with manual adaptation of network preferences due to economic evaluation, the downtime in the worst case scenario is just about several hours. Both locations are connected via fiber optics and use different transit stations to reach the GWiN (German gigabit science network).
As the license agreement allows the installation on as many servers as needed, it is possible for the ikt and all other institutions of the federal state to implement and operate their own servers as well. This is meaningful for research projects which alter the PDM system in its basic functionalities. The server compound at the RWTH Aachen University can only provide basic functionality and pre defined features of the software but for some institutions more in depth research is necessary. However these institutions can benefit from the central installation of the oracle server which is accessible from throughout NRW on demand.
Another aspect of the ProVerStand-initiative is training which is held at the ikt by the software companies and can also be extended within the research group by its members. The ikt therefore provides the necessary facilities and server resources. Ten test servers are available for customizing projects, demonstration of special functionalities and training issues. Four of the Servers are installed with software of other vendors to demonstrate differences between the PDM systems. Other machines are necessary for the display of CAD files from different vendors.
All parts and the complete topology are shown in Figure 1.

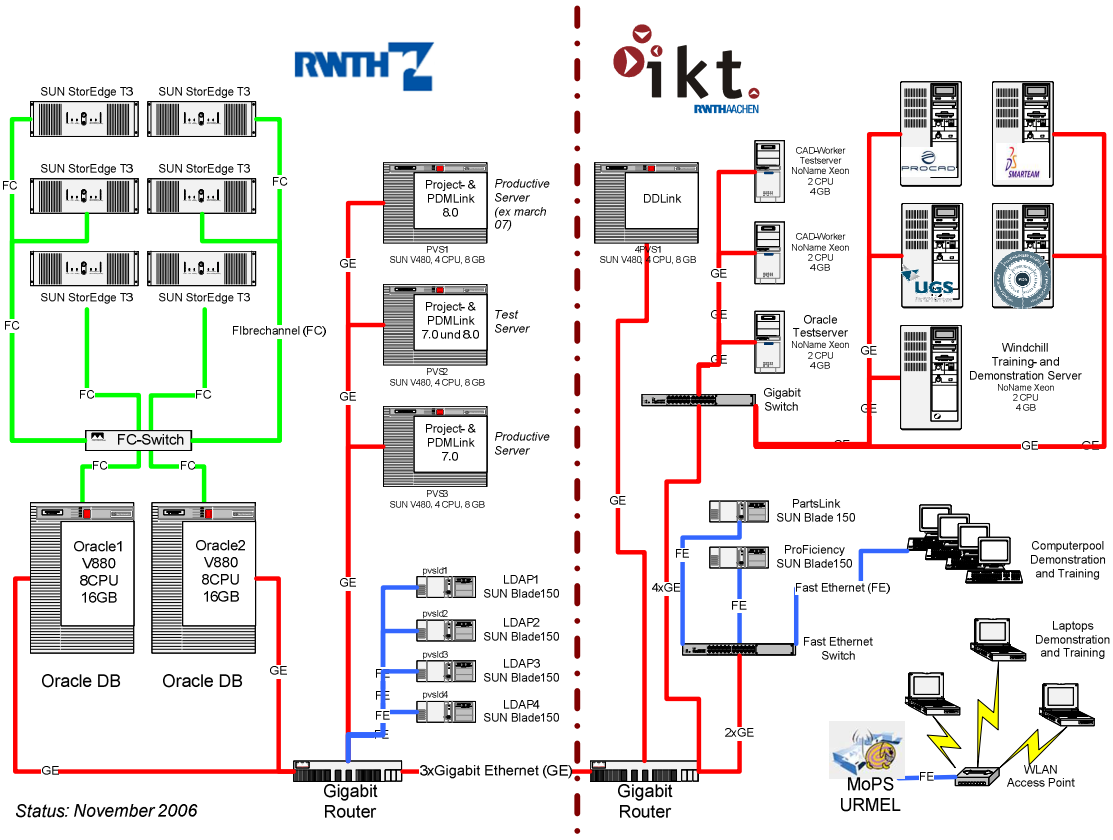

Figure 1. Topology and components of the ProVerStand server compound at the RWTH Aachen University

4 PROVERSTAND & CURRICULUM

Several universities who joined the ProVerStand initiative started years ago to integrate Product Lifecycle Management (PLM) into their curricula. This means not just to teach how to use Product Data Management Systems but to get a deep understanding of processes and PLM-strategies as they occur in industry. The following chapters show different approaches of implementing PLM in engineering education.

4.1 RWTH Aachen University

The Chair and Institute for Engineering Design has a two-stage strategy concerning teaching in this field. In the first step undergraduate students get in contact with PLM as they attend the course “Technical Drawing and Documentation”. This is an obligatory and essential study module in the education of each mechanical engineering student at RWTH Aachen University. This is a course with a duration of 2 semesters. Starting with the basics of technical drawing and the most common machine elements in the first term of their studies they learn the utilization of CAD and the accompanying need of a serious data management.

Increasing numbers of students each year (1341 students in the current class) lead to enormous administrative expenses. The overall exam consists of 3 different tests. To provide efficient and secure access to each examination document a challenging workflow implementation in the PDMS Windchill™ has been conducted. As first university in the world, the RWTH Aachen has set up a modern identity management system (TIM-Tivoli Identity Manager) [9], allowing each student to activate its personal account for the ProVerStand-server and multiple other online services. These technical preconditions enabled the opportunity to manage the 3rd part of the examination using the Windchill™ module “ProjectLink”. During the whole design process the student saves his CAD-model in the PDMS (ProVerStand-Server). Each data change can be reconstructed due to defined versioning. The demanded design solution is elaborated with the software AutoCAD. Only the last file

checked in into the system will be reviewed. In order to ensure data integrity for each student a complex authorization concept has been set up. Even the whole number of students uses the same platform the single participant only has access (view and write) to his own files.
Due to judicial reasons hard copies of the drawings had to be submitted in the last term. So far this proceeding has a trial run character until the digital signature has been introduced.
It is planned in the near future to use 3D CAD tool for this course. With the help of an efficient workflow an automatic pre review can be conducted in order to optimize the human effort by the review.
The second stage of PLM-education at the ikt takes place within graduate courses. Equipped with the essential methods and basics, we go a step further in teaching and integrate practical training on projects into the curriculum. On the one hand the students are generating complex parts using parametric 3D-CAD systems on the other hand increase collaboration in this courses using PDMS. The labor "Practical Applications of Computer-Aided Engineering Tools" (in German "Labor Rechnerunterstütztes Konstruieren") is held over the winter semester in six sessions and is obligatory for each student who specializes on "Product Engineering". The aim of this course is to provide the student with basic knowledge of applying modern CAX-Tools. This is achieved by working through a design project from the first sketches on to the generation of a fabrication drawing and demonstrating the effective use of each tool, as well as their limitations and common mistakes on the way. The stringency of the working example, which results in interchanging data, also allows covering topics such as CA-Process-Chains and Construction Data Management. After discussing the fundamentals in each session the students get to work with programs such as Pro/ENGINEER under guidance. Treated subjects include: Parametric solid modeling, planning solid models, 3D-assemblies and automated draft-generation. To mention just two courses integrating industry projects and dealing with divers steps of the product lifecycle: AKL and KvMG.
The course „Collaborative Product Development“ deals with the procedures and problems of today’s product development processes. The first part covers aspects and difficulties of product development due to the size of today’s companies and the interweaving to their partners. The second part covers the solutions provided by modern PDM-systems as well as the problems of the implementation of PDM-systems (Product Data Management systems) in companies. In the tutorials the students will learn to work with the PDMS such as Windchill, Teamcenter, ProFile and SmarTeam by working on a project.
The lecture “Collaborative Product Development” covers the following topics:

- Development of processes and tools of product development
- Problems of the historical developments
- Idealized standard processes of product development
- Working with a modern PDM-system
- Interchange of information between project partners
- Implementation of PDM-systems in companies

4.2 FH Düsseldorf

Windchill™ as well as Pro/E are significant components in education at the University of Applied Sciences Düsseldorf, faculty of Mechanical Engineering and Process Engineering. In the summer semesters the plan for the next ring project in the winter semester is conducted. Within this time frame the software is used by 6 professors and other faculty at FH Düsseldorf.
The goal is to establish a task definition, which scope and form represents all main courses in the program study at the University of Applied Sciences Düsseldorf. Furthermore a time period, in which subtask could be solved, is compiled.
From October 2005 there were 74 students, who participated in the course “Ring Project Computer Integrated Communication”. A team consisted of 6 to 7 students and passed through all phases of product development and production using computer aided methods in the frame of engineering workflow concepts.
An existing assembly (flange bearing unit) was made available to the students and served as a basis. The casting housing had to be redesigned and manufactured for the smaller number of pieces.

4.3 FH Dortmund

At the University of Applied Sciences in Dortmund the main focus concerning the ProVerStand activity laid on the preparation for the wide application in the courses dealing with CAx. Few problems occurred in the usage of Windchill™ version 7 in combination with Pro/E, which could not be solved despite the support of PTC. Therefore a local server as a test system was established with Windchill™ version 8.

The Cam laboratory had local character and was not linked with the other laboratories in the faculty of Mechanical Engineering or external institutes. Within the frame of a restructuring the CAX-environment in the faculty, 4 computer laboratories were merged. After the completion of this reorganization, Windchill™ was applied into the CAX-courses as a general product data basis. The ProVerStand-Server in Aachen is used thereby. Besides Pro/E, Catia V5 is also used within the labors. Therefore the integration of Catia V5 in Windchill™ is of importance.

There were two diploma thesis related to Windchill™ recently. One of the theses was conducted at ThyssenKrupp Automotive in Bochum. Because this company uses the CAD-tool Catia as well, the ProVerStand-Server in Aachen could not be used until the Catia Workgroup-Manager had been installed. Before, several parts of the CAD model were converted into Pro/E Wildfire and then checked in to the ProVerStand-Server.

The partner for the second diploma thesis was the company Vaillant in Remscheid. The design data at Vaillant was created using CAD-tool Pro/E Wildfire and was stored as well as managed using Intralink. A concept was acquired and realized for the new development to answer the question, how the design cooperation with the suppliers should be developed. The ProVerStand-Server was used for this thesis. The result was introduced at a panel presentation of PTC.

5 PROVERSTAND & RESEARCH

Two research proposals in the thematic of PLM/PDM were submitted to the DFG. These were new proposals to raise funding for research projects in cooperation with other institutes.

In cooperation with the Laboratory of Machine Tools and Production Engineering (WZL) and the Information Systems Institute at RWTH Aachen University a proposal with the theme “Development of a Diagnostic Software for Continuous Evaluation of PLM-supported Systems” was submitted to DFG. The usage of this diagnose tool is of serious importance in a company with high product variety. The evaluation of the PLM-supported systems using key figures should continuously capture the efficiency and predict the benefit (or disadvantage) of the planned change. Thereby the boundary conditions, which are coming from company extern and company neutral, should be considered as evaluation parameters.

The second proposal has the theme “Development of a Reference Product Data model for Mechanical Engineering”. This is also a result of research cooperations with the WZL. The objective is to establish a reference product data model, which is focused on a certain industry sector, integrated over the life cycle and system neutral, for mechanical engineering. This serves as a basis for the derivation of a company specific data model. The resulting reference product data model and the developed implementation method enable the evaluation of existing PLM-supported systems in the companies and for the identification of measures concerning a higher integration of data.

6 SUMMARY AND OUTLOOK

The use of 3D CAD will be established in the undergraduate courses in winter term of 2007. With a number of 1400 students in a single course the infrastructural needs for the CAx tools are enormous. ProVerStand elaborated a coherent concept which is supposed to be fully realized in spring 2007.

The next step will be the integration of the digital signature in the examination process. In addition with a revision using functionalities of ProFiciency, this will allow an automated certification modality.

An international expansion of the course „Collaborative Product Development“ is planned to take place in 2007. In advance there will be a multidisciplinary project between at least 4 chairs as a test run. This project features the integration of industrial, manufacturing, electrical and mechanical engineers. The international project with partner universities emphasizes collaboration across time zones and languages.

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