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ANALYSIS OF CAX-INTERDEPENDENCIES FOR AN EFFICIENT BUSINESS-ORIENTED TRAINING

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ABSTRACT
Modern engineering in combination with an effective business can only be managed when there is an efficient way to handle modern tools supporting the product development process. With extended use of Computer Aided Engineering (CAE) there is a demand, to not merely exchange engineering data but also to provide reasonable linking of the single tools. The vast amount of commercial and customized programs and their mostly uncharted interactions can delay the time to market. This necessitates special employee training as a key issue. With training on the job being too late to internalize the basic principles of CAx-education as well as project management issues, the academic teaching concepts have to be analyzed and revised to meet the requirements of today's design processes.

Keywords: academic training, teaching concept, computer aided engineering, data exchange

1 INTRODUCTION
With global markets changing fast the application of computerized support has become an important component of product development (CAx). Tools, like Computer Aided Design (CAD) software, Finite Element Analysis (FEA) and Computational Fluid Dynamics (CFD) support many automation techniques therefore saving time and cost. Shorter time to market processes nowadays are fundamental for performing concurrent or distributed engineering, in order to remain competitive. The enormous amount of different systems both available and used in companies or by their subcontractors makes efficient use of the programs' potentials and the particular data exchange a key issue in speeding up product development.
But with extended program functionality and therefore rising complexity an increased probability of maloperations or misinterpretation of obtained results arises, because only few employees can properly tab the full potential of the tool they are working with. A general problem here is not only insufficient training of users, but also that, in general, software functionalities are badly known and interactions between different tools, concerning data exchange or interdependencies of results are mostly unfamiliar. A lack of CAx-tools' couplings will obstruct the product development process.
As an approach to handle the CAx-tool interoperability a research cluster, with its main aim to improve enterprises' operational structures by providing purposive guidance, has been initiated.
Up to now the employees' CAx- and workflow-training is mainly taking place on the job although this is way too late to impart the required knowledge for an effective business. Hence teaching these skills to future employees has to begin at university and present teaching concepts have to be analyzed and if required adapted.

2 REQUIREMENTS
The approach lined out in the following chapters of this work contains the results of a research cluster analyzing necessary requirements and resultant outcomes enriched with a deduced teaching concept to augment the general educational background for future employees in industry.

2.1 A research cluster for product development workflow
Increasing use of computer-aided tools and therefore the necessity for supportive technologies concerning their correct application is a well known fact. To face this challenge and other potential traps of product development the research cluster FORLFOW [1] funded by the Bavarian Research

Foundation was created. Involving four universities and more than twenty companies the focus of the project is the development of a process and workflow support for planning and controlling the progress of product development processes. In cooperation with partners from the industry, starting with small and medium sized businesses and ranging to automotive companies, all approaches and results are counterchecked in order to reassure their suitability for practical use.

One sub-project especially targets on cross-linking single process steps to a coherent workflow by integration of approved process chains. These linkages were created according to real processes in enterprises and abstracted to ensure a wider applicability (see chapters 3.1 and 3.2). Appropriate end-user support can only be achieved by providing the designer with relevant information taking into account the current design step and numerous other influences. Therefore modeling strategies and simulation guidance have to be developed and, as well as the generated process and product data, have to be linked to the corresponding process steps.

Another particular project involves the required data exchange between each single CAx-tool (see chapter 3.2).

As basic outcome an integration platform for all sub-projects a "Process Navigator" has been developed. It is essential to clarify the needed exigencies not only for academic purposes but also for industrial use to improve design processes and shorten design cycles.

2.2 Industrial requirements

Several interviews have taken place to evolve applicable end-user support as well as strategic approaches to advance and to accelerate the product development itself to match the research results with real situations in enterprises [2], [3] (Figure 1).

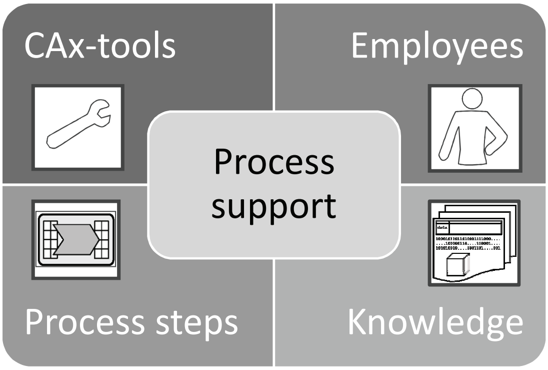

Figure 1: Industrial requirements for process support

The companies' main interests are

- the integration of company specific conditions,
- the consideration of workflow-related requirements and
- the usability for the end-user.

The field of ***company specific conditions*** mainly contains the aspired strategy planning, which actually means that the products' market segment has to be considered. It is a major factor for the whole design process, whether low or higher price products, mass ware or custom-built designs are planned. The choice of a product strategy in combination with the material used and the deduced manufacturing method can determine parts of a process in advance, as the tooling methods for steel like milling are fundamentally different from those used e.g. for polymers. In this context also the enterprise's machine park has to be considered, as e.g. if there is an in-house foundry a filling simulation tools is more essential than milling or turning CAM-programs. Another important point is the integration of internal regulations such as certain machining parameters or special procedures needed for a quality management system or an environmental certification. The use of in-house knowledge has to be stimulated so that the enterprise's core competence can be used effectively [4].

This knowledge ought to be available in all relevant departments of a company: The marketing as well as the sales department should know the important parameters of the product they have to sell. The designers ought to be in contact with them and the financial department to set a certain price level for the product, as that's next to quality and functionality the most import factor for the customers. Therefore there is a need for software, available in all departments, such as a knowledge management system for the employees and for the targeted use of human resources. So next to the hard skills like knowledge of CAD-software and calculation capabilities, soft skills like the ability for interdisciplinary communication and working with people of different divisions become a key principle in employee training (Figure 2).

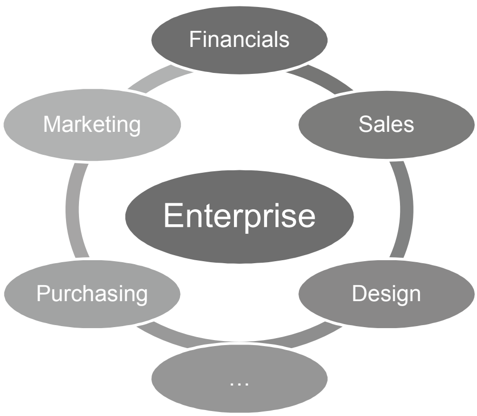

Figure 2: Interdisciplinary communication in enterprises

To guarantee smooth business ***workflow related requirements*** also have to be considered. Implementation of CAx-software into the product development process is essential in order to create a workflow-management not only useful for controlling of business processes but also supportive for development itself. In concordance with preceding decisions the required CAx-tools and generated product data have to be linked properly to corresponding process steps, so that an appropriate machine and personal planning can be done in time to avoid bottlenecks and to exploit the factory's full potential. Therefore also the data exchange processes of in-house software and data delivered by subcontractors and customers have to be optimized. The clarification of interactions of different programs is a key task.
Primarily to accelerate the design process, the support of simultaneous and concurrent engineering is essential, too:

- Simultaneous engineering (SE) involves products' synchronized itemization and linking the appurtenant manufacturing method including their interactions
- Concurrent engineering (CE) marks the parallel and contemporaneous implementation of simultaneous executable working stages [5].

By the consistent application of computer aided tools from the beginning of the design process this methodical approach can support the whole procedure and accelerate it to lead to competitive products.

The last aspect of the enterprises' interest is the ***usability for the end-user***. Concerning the support of employees, the main interest consists of three points:

- practical applicability of the software
- the employees' acceptance of the tools
- usability of the software solutions

Intuitive working should be possible in a sense that the user is informed by, for example, help documents but not patronized, so that he can decide whether or not following these instructions will

help him to achieve the current aims. Therefore it is essential to provide the developer with the right information at the right time so that necessary modifications can be realized effectively and fast.
Nowadays some of these requirements can be achieved by modern software tools including certain functionalities, but the main task lies within the skillfully usage of the employees. To ensure this efficient use of supportive technologies two main aspects of the challenge must be covered. On one hand the CAx-programs must be analyzed their relations identified and a processes must be defined and linked with relevant information. On the other hand students must be trained appropriately in order to apply the technologies available, like the investigated CAx-processes and must be familiar with the idea of creating and using new relations help documents and tool-chains by themselves. This second part can only be achieved with a tailored curriculum.

3 CAX-ANALYSIS

The immense amount of CAx-programs available makes a preliminary analysis of the computer-aided tools necessary in order to conceive a matching teaching plan. To determine the tools' properties a survey was done with fifty-one commercial CAE-programs including CAD-, Simulation, Manufacturing- and CAM-Simulation software [6]. These were analyzed in their basic configuration without additional modules that have to be purchased separately. Figure 3 shows the basic classification of the CAx-tools.

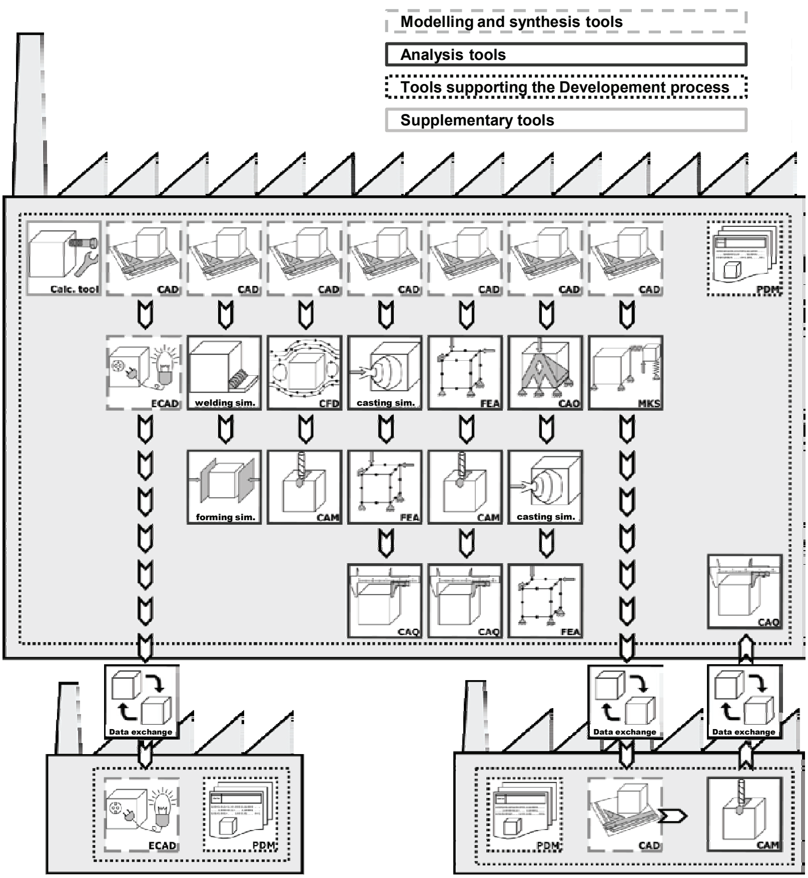

Figure 3: CAx-tools necessary for design processes

3.1 Functionalities and the interactions of the CAx-tools

In order to analyze the tools they were divided into two major classes: Syntheses and analysis tools. The former are used to generate the product's characteristics, the latter are to check its properties [7]. Generative tools are e.g. CAD (Computer-Aided Design) and CAO (Computer-Aided Optimization) tools, whereas analyzing tools can represent software like FEA (Finite Element Analysis) and CAM (Computer-Aided Manufacturing) (Figure 4).

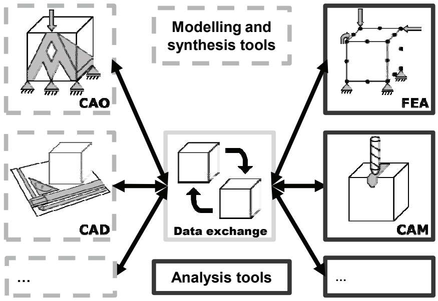

Figure 4: Classification of CAx-tools: synthesis and analysis programs

Basic and advanced functionalities of CAx-tools were examined in cooperation with the industrial partners of the research cluster and the results, together with university in-house experience, are rounded up and linked to the corresponding programs using the ICROS-Method (Intelligent CROss-linked Simulations) as an integral concept to provide an integrated development process [8]. Main goal is to fulfill the aspired product properties as far as possible by appropriately composed CAx-processes in order to make an economical business possible. The origins of ICROS were based on the interdependencies of computer aided strength determinations and manufacturing simulations like the combination of injection-molding- and finite-element-simulation for fiber-reinforced polymers [9]. Within the complexity of innovative design tasks and the capabilities of modern CAx-tools it is inevitable to integrate best-use-strategies for programs to keep the designer informed about interdependencies of analysis results and preceding design steps or reworking expenses that may be caused by relations not considered. This can be realized by e.g. methodic provision of design guidelines during the part synthesis or best-practice documents for the deployment and evaluation of simulation methods. Generally the required input data, respectively correct interpretation of the obtained output data is a key issue (Figure 5).

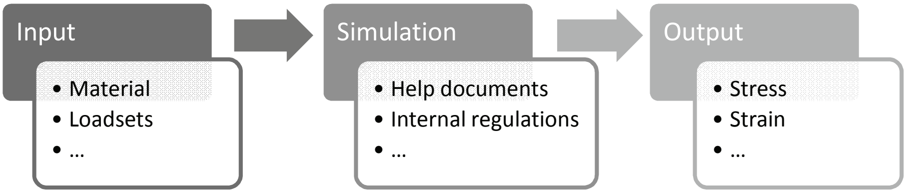

Figure 5: Required input data / generated output data of simulations

As practical example of CAx-tools' logical combination, Figure 6 shows details of the design process of topology optimized parts [10], [11]. Beginning with generative tools (CAO and CAD) followed by alternating analysis and synthesis steps, each considering the data of the respectively previous; Using ICROS this process can be transformed into a coherent CAx-chain linked with all information necessary. Necessary iterations have to be taken if the product doesn't fulfill the desired performance. Because of its abstract character this process and the generated product and process data can be reused for similar future design tasks, saving time and therefore cost. Furthermore a standard process is created, helping to avoid mistakes or which can be used train new employees or even students.

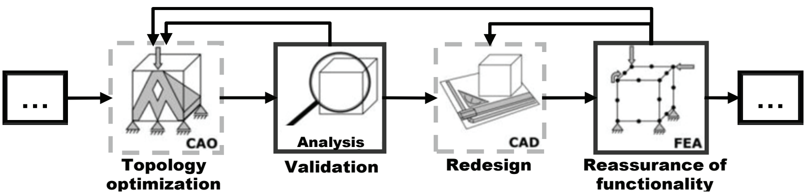

Figure 6: Part of a CAx-chain for topology optimization considering iterations

Properly applied data exchange processes are a basic precondition for properly linked tools, which makes analyzing this topic a key matter.

3.2 Data exchange processes

With CAE-methods widely affordable and accessible the need of data exchange has been a key task of organisations for international standards [12]. This is due to the problem that not all CAD-suites have integrated simulation modules that meet the needed standards or due to tasks carried out in distributed environment [13].
When practicing data exchange in a company the developers should rely on either native files or standardized formats in order to avoid a multitude of models. Several standardized formats for the exchange of engineering data and product model data have been developed. They commit themselves to providing an interface standard based on the two main aspect of interface definition:

- Exact definition of the information and properties that can be transferred
- Precise formulation of rules on how the information has to be exchanged

As part of the research work done in the cluster a pool of standard formats used for companywide data management was to be defined. Several other research projects like PDTNet [14] or GENIAL [15] have done so before, defining STEP as main standard format suitable for their tasks. Part of the project was to determine whether this is appropriate for industrial application, especially concerning SMBs.

In order to do so, the industrial partners of the project were asked to state their data management behaviour and the problems they encounter when especially CAD-models were exchanged. This was done with a form containing questions both on the software and the formats used. The results were counterchecked with experts. Main goal of this survey was to determine the influences on the data exchange behaviour of the companies in order to determine the best available data format for each single task, e.g. transferring geometry from mechanical CAD (MCAD) to FEA for a static strength test.
The results of this survey showed, that each industrial partner had to deal with at least three data formats for 3D and two for 2D data exchange. This correlates with other studies [16]. Formats mainly used were STEP (AP203/214) [17], IGES, and ACIS for three-dimensional an STEP, IGES and DWG for two-dimensional data. Issues identified were mainly the availability of data formats and the loss of parameters and additional information like material properties or parametric constraints.
As part of the research undertaken the availability and suitability of standardized data formats was analyzed. The results obtained showed that data format choice cannot be generalized but is a result of the available CAx-tools as well as of the knowledge of the designer, the purpose of the data exchange and for example external or legal regulations that have to be met [18]. So it is necessary for the designer to have an overview of these influences when entering the company already.

4 TEACHING CONCEPT

In general, students should learn how to apply the above mentioned supportive technologies, their dependencies and interactions and their background from scratch and in continuing industry oriented hands-on training. In order to address both the needs of industry and the results obtained in the research described above, an appropriate teaching concept, based on the current curriculum of a degree program at the University of Bayreuth can be deduced. The courses for the Bachelor of Engineering Science (BE) and the Master program Automotive Components Engineering and Mechatronics (ACEM) [19] partially provide the necessary foundation on which the proposed concept is based.

Other degree programs, like the integrated product development courses of the University of Karlsruhe [20] have also been successful over the years and almost every technical faculty is offering the needed education, but usually it is only part of specialization during master courses. While this is appropriate to fulfill the need of enterprises for such specialists it still leaves behind the necessity for the employer to teach the general understanding for all the sectors not covered in the specialization and teach them the benefits of this in a way they are willing to use and share information [21]. Avoiding this is the aim of the proposed concept. From a pedagogical point of view the courses are focused on giving the students access to all documents used by instructors via E-publishing and to make software and hardware, needed for education, available on an extensive level. This, together with a combination of tutorials on one hand and challenging tasks done by unsupervised student groups will strengthen the students' capabilities in the fields of collaboration and problem-solving [22].

4.1 Requirements of the concept

The required contents of a degree program that meets the needs of innovative engineering enterprises can be divided into three key areas: multidomain foundations of engineering science, supportive computer aided technologies and collaborative crossdomain communication and management.

The multidomain basics must consist of the traditional engineering skills of machine elements, electric and electronic components, and mechanics but has to be enriched with basic information technology, computer science and methodological foundations of applied computer methods such as the finite element analysis. Both classic engineering skills and the efficient use of supportive computer aided technologies have to be taught in undergrad courses. They have to be combined with needed soft-skills like communication, entrepreneurship and concepts like distributed development.

Engineering skills like mechanics and the properties of machine elements are over pronounced in most degree courses with much emphasis on details of every machine element and several classes on technical drawings. To create enough space for the additional skills needed this has to be condensed. Cooperation with industrial partners and feedback of former students has shown that special knowledge concerning the individual products of a company must always be provided by the employer at his needs. This is accepted by the employers, while the extension of the knowledge of soft skills and computer aided engineering is often interminable and expensive and should be avoided. The following explanations state a curriculum that can eliminate, or at least reduce, these costly needs. They are focused on mechanical engineering but crossdomain applications are a vital part.

4.2 Proposal of a basic curriculum for a CAx-centered degree

Duration of three years to earn a bachelor and another two years for a master's degree is sufficient. Figure 7 shows the modules necessary for a bachelor´s degree. Just in the first year of studies the students are provided with a two week practical course of CAD-application to provide them with knowledge about basic design modules and basic design concepts. This, together with the basic knowledge of machine elements, machining methods and mechanics, is deepened with a lab-training in which a group of four students has to work out a technical product according to a basic development process yet including concepts of design for machinability, design to cost and encouraging concurrent and simultaneous engineering. As a basic product for example a small single cylinder four-stroke engine can be assumed. The amount of parts that need to be constructed is manageable, very complex parts can be provided by the chair. At the end of the lab course students are able to produce a CAD model, derived technical drawing, strength tests, a manufacturing concept and basic cost assumption for every part and therefore for the whole product.

During the main study period of the bachelor several methodological foundations have to be built up. This results in lectures of finite element theory and practical training with several integrated and stand alone simulation programs as well as deepened education in machining-methods and -simulation. This leads to a need for hands-on training with the opportunity for the students to gain experience in collaborative working with several software components, if possible, enriched with an introduction to PDM-and PLM-Systems at least on a theoretical basis.

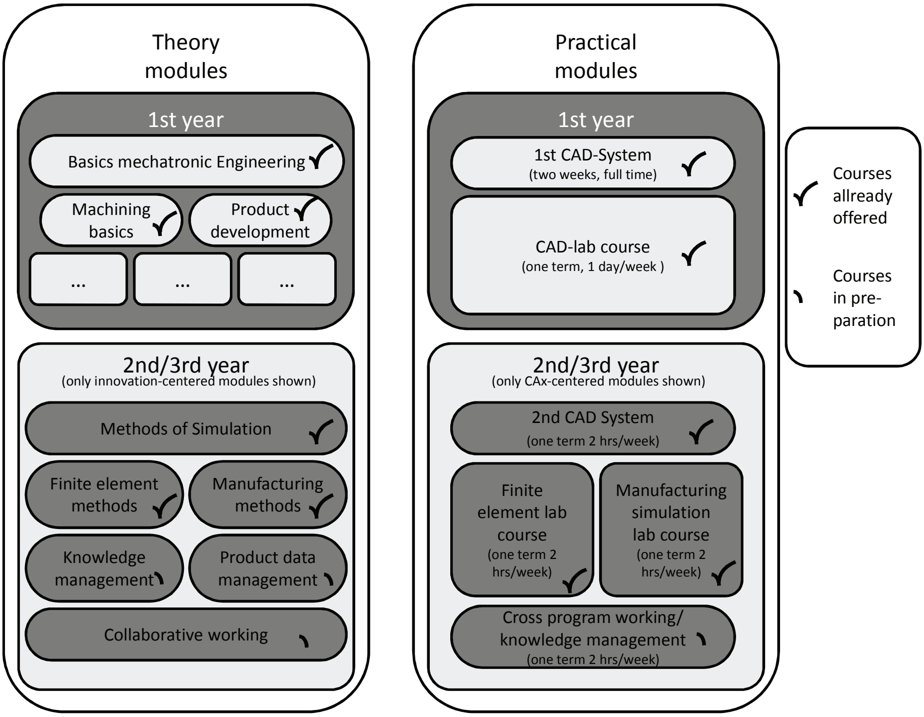

Figure 7: Modules proposed for a CAx-centered degree course; only modules relevant to supportive technologies shown

The problems of cross-program-working can be shown by working with a combination of CAD-Systems, basic integrated manufacturing- and FE-modules as well as stand-alone simulation software. Together with this practical training the possibilities and effects of knowledge management can be displayed. As main result a student should be capable of simulating and reassuring the manufacturing process of a part as well as doing static and dynamic strength tests taking into consideration the effects manufacturing has on the parts' mechanical properties. The coordination, evaluation and documentation of these steps are emphasized with a focus on cross domain and cross program working. As an outcome the finished bachelor students will be able to handle at least two CAD-suites with the most common modules, two stand alone simulation suites and have a basic understanding of several other supportive technologies (Life Cycle Costing-Software, Knowledge Management-Software). This together with soft skills acquired in practical courses and the basic methodologies imparted widely meets the industrial requirements.
As contents for an optional master this curriculum can be extended with a deepened knowledge of any branch mentioned above, together with introductions to Production Planning Systems (PPS) and Workflow Management Systems (WFMS).

4.3 Challenges inherent to this concept

There are three main challenges a university is confronted with when implementing this concept. The one which is easiest to tackle is the cost for software licensing for CAE-tools. The department of engineering design and CAD has calculated an average cost of 150 € per student and semester at about 100 students per year. This must be seen under the condition that many software suites are available to universities at low cost and with lots of license options mostly on a price per faculty basis. So generally the cost per student and term will not increase with a higher number of students but eventually decrease. The cost calculation includes three major CAD-suites, four simulation suites and other supportive programs like MatLab©.

The major parts of investment that has to be done to use this concept are the remaining two challenges meaning the provision of teaching personnel and establishing the necessary IT-infrastructure. While teaching small groups of students at one time can keep the investments for computing and networking hardware low, more tutors and assistants are needed due to the higher number of groups. Smaller groups will also have a positive effect because communication with the lecturers is improved. With large groups the amount of needed lecturers is kept small but hardware costs increase. Nonetheless Industry relevant state of the art education which includes live usage of PDM- and PLM-Software can only be managed when there is an infrastructure equivalent to that available in modern companies.
This dilemma can only be solved by cooperation with industrial partners who are willing to support the universities. Only the broadening of networks like PACE [23] and the individual support by potential future employers can both help colleges and universities to emphasize modern computer aided engineering in education and give the industry the employees of the future.

SUMMARY

The needs of innovative engineering companies and service providers for young professionals capable of doing and coordinating cross-domain and distributed development can only be tackled if these former students have enough knowledge not only about the foundations of engineering but are also well trained in all supportive technologies available to the innovative company. Academic research led to a method that can enable students to use CAx-tools to a high extend and in an early stage of development. This together with extensive training in using and interpreting results of simulations will decrease iterations in the development process. The training the students should receive, as proposed in the teaching concept, will ensure use and reuse of acquired knowledge to support process steps beginning with the creation of a CAD-model to data exchange with simulation software and finally machining and assembly simulations.

OUTLOOK

The teaching concept proposed in chapter 4 today is only available to few students having chosen special focal points within their courses. In order to make it obligatory for more students these essential qualifications ought to be in the basic curriculum of every faculty of engineering sciences.
Therefore it will be necessary to match the teaching plans of universities. Furthermore a wider range of industrial partners has to be included to fit the results with practical requirements, so that necessary adjustments can be integrated. This information can also be counterchecked with the experiences of alumni working in enterprises. Students having skills as proposed in the teaching concept could be even more appealing employees to their future entrepreneur.

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