WORKFLOW INTEGRATION OF COMPUTER AIDED ENGINEERING: AN EDUCATIONAL APPROACH

Reiner Anderl, Orkun Yaman

Technische Universität Darmstadt, Faculty of Mechanical and Process Engineering,
Department of Computer Integrated Design
Petersenstraße 30, 64287 Darmstadt, Germany

yaman@dik.tu-darmstadt.de (Orkun Yaman)

Abstract

The increasing importance and frequent use of computer aided engineering (CAE) methods motivate universities for educational activities in the interdisciplinary field of Computational Engineering (CE). Current approaches in the education of CE focus mainly on the specific topics, which are driven from a domain-centric perspective. Didactic concepts focusing on the stand-alone application fields hinder a holistic understanding of CE. Industrial applications of CE are applied indeed in the product creation process, for which data and processes are to be defined and managed regarding the product lifecycle aspects.
The department of Computer Integrated Design (DiK) of the Faculty of Mechanical and Process Engineering has been involved in the study program "Computational Engineering" from the very beginning. Within this frame a new course "Introduction to CAE-D" has been established in the fall semester 2006 with a scope on the interdisciplinary feature of CE. Understanding of CAE as a process within the product lifecycle plays a crucial role in the syllabus. This contribution presents key points of a new approach towards an educational concept for CE considering the lifecycle aspects. The course aims at describing CAE as a dominating link between the engineering design and analysis, which enables efficient and reliable product verification. Students from different departments are made familiar with the notion of data integrity of CAE within a process chain.

Keywords: Computer Aided Engineering, Computational Engineering, Education, Process/Data Integration, Lifecycle

Presenting Author’s biography

Orkun Yaman. Graduated from the Middle East Technical University (METU) in Ankara with a degree of "Bachelor of Science in Mechanical Engineering", Orkun Yaman obtained his Masters Degree in Mechanical and Process Engineering from the Technische Universität Darmstadt in the field of Numerical Methods in Mechanical Engineering. He has been working since 2004 at the Department of Computer Integrated Design as a research assistant and doctoral student. He is responsible for the CAD/CAE education. His research activities involve data and process integration of computational methods and tools into the product creation process.

ISBN 978-3-901608-32-2

1 Introduction

Engineering applications are becoming more and more complex. Computational Engineering (CE) has been established as a powerful alternative to the theoretical and experimental methods of engineering, where the analysis of complex physical phenomena reaches its limits, for example when an experimental observation turns out to be too costly or too difficult or even impossible.

Computer Aided systems (CA-x) refer to a wide field in engineering. Computer Aided Engineering (CAE) describes here the interdisciplinary area integrating applied mathematics, computer sciences and engineering sciences. CAE builds a main pillar within the methods and tools of CA-x. This contribution attempts to put CAE into the application side. CE is concerned to be on the research front dealing with the development of new methods as well as enhancement of the current application models.

Anderl pointed out a knowledge stream from CE into the engineering fields. Scientific developments in CE become standard technologies of the engineering domain after a maturation period, [1]. Finite Element Analysis (FEA), for example, was introduced formerly as a computational engineering domain. Specialists were required to perform FEA tasks. Nowadays engineers are assumed to have a basic knowledge in the field of FEA. Simplified FEA modules are provided for Computer Aided Design (CAD) systems for earlier analysis of basic design decisions. A knowledge transfer has been occurring from CE to the engineering sciences.

The Department of Computer Integrated Design (DiK) of the Faculty of Mechanical and Process Engineering has been involved in numerous educational activities since the establishment of the interdisciplinary study program "Computational Engineering" (CE). Within this frame a new course "Introduction to CAE/D" has been established in the fall semester 2006 with a scope on the interdisciplinary feature of CE. Understanding of CAE as a process within the product lifecycle plays a crucial role in the syllabus.

The multidisciplinary nature of CAE promotes new didactic approaches in order to seamlessly integrate diverging disciplines for a holistic understanding. This contribution presents key points of a new approach towards an educational concept for CE considering the lifecycle aspects. In the following sections, the theoretical background of the educational concept is presented. Despite the different underlying models, CAE methods show a similar pattern on the application front. Based on the pattern similarity of CAE applications, the educational concept is implemented for numerous courses. The structure of the practical content enables the integration of manifold CAE methods into the CE education. Use of integrated process is emphasized throughout the exercises. Students are confronted very early in their study programs with the important issue of lifecycle management.

2 CAE in Engineering Education

The increasing diffusion of CA-x in engineering and sciences has motivated universities to develop new curricula and enhance the existing courses with new content. Methodical and tool competence in computer simulations plays an important role in the new teaching methods, [2]. Fig. 1 shows the response of universities in education to meet the requirements of the changing landscape in engineering.

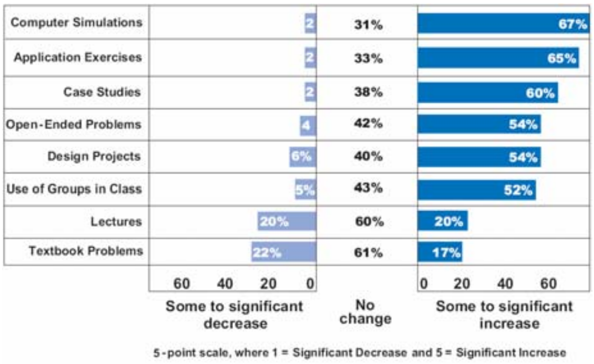

Fig. 1: Faculty's Reports of Changes in Teaching Methods (ABET), [3]

Current approaches to integrate CAE into the engineering study programs follow a domain-centered view. For example, courses about Finite Element Analysis at the TU-Darmstadt are offered by different departments. General methodical aspects are considered rather by the Department of Numerical Methods. Some other departments offer in different applications fields courses about the application of the method in a special topic. In the course contents, the major issue of modeling is described from the view of a particular use-case.

Holistic development of study programs for the engineering education, especially for the interdisciplinary subjects has become recently the focus of concern, [4]. The emerging study program Computational Engineering at the Technische Universität Darmstadt, for example, is a step forward to realize a cross-disciplinary approach to engineering education, Fig. 2. Methods competence in individual disciplines is supported by cross-disciplinary topics.

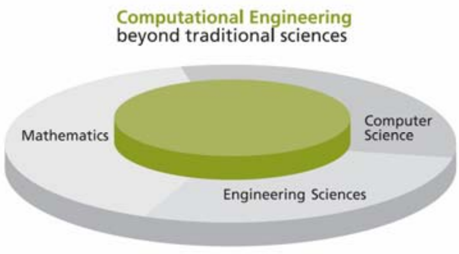

Fig. 2: Constitution of Computational Engineering.

ISBN 978-3-901608-32-2

The new department has been established conjointly by six regular departments: Department of Mathematics, Applied Mechanics, Computer Sciences, Mechanical and Process Engineering, Electrical Engineering and Information Technology, cp. Fig. 2. A cooperate council of participating departments possessing legislative functions has been assembled to organize the education. The council resolves for the Department of CE regulations concerning curriculum and exams. Furthermore it is responsible for the continuous improvement of the curriculum and coordination of course offerings.

The governing philosophy underlying the course offers of DiK within the curriculum of CE is the bridging function of lifecycle approach between the scientific field of CE and industrially applied field of CA-x. The industrial use of CA-x methods and tools takes place in an IT-landscape, for which a detached employment of CA-x is not considerable. Beyond the methodical problems, other application and organization related problems arise due to the process connectivity throughout the different stages of product creation. Product creation includes lifecycle phases of a prospective product from idea to the market. Here data is aimed to be reused; processed and made reproducible.

The missing link "lifecycle approach" supports the holistic view on simulation. The students of CE are made familiar with the notion of data integrity very early in their education. Exercises provide the application of process integration as a focal topic. Domain-centric knowledge clusters in CE methods are interconnected using the integrated product modeling approach of CA-x.

The educational concept presented the next sections does not aim to replace the conventional didactic methods of CE, but would act as an integrating tie between numerous methods and tools in a diverging IT-landscape in CAE.

3 Lifecycle Approach in CE

The course approach is based on three pillars, representing contents from the traditional syllabuses: Understanding of Product Lifecycle, geometrical modeling and computational modeling. The exercises are designed in an order to optimally support the key purpose of understanding the integrated process landscape of engineering.

3.1 Lifecycle Understanding

As a missing link among processes and data of CAE lifecycle approach is presented as a strategic means to exchange and integrate data within the product creation process. The concept of integrated product model is emphasized, in order to give an insight into the subject of product representation, Fig. 3.

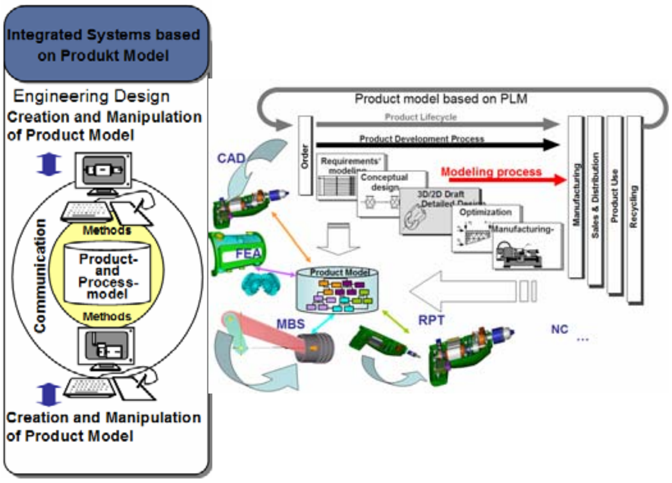

Fig. 3: Product modeling in engineering processes

The course starts with the fundamentals of Product Lifecycle Management (PLM), including hardware (HW) and software (SW) architecture of CAE tools and process management aspects. The purpose of this section is to give the student the notion of thinking and handling in a "process chain" while processing with CA-x-methods, [5][6]. In other words, a holistic approach is presented aiming at avoiding the deficiencies related with the encapsulated use of the methods and tools of CA-x. The methods of CA-x suffer from the interface problem, resulting from incompatible representation architectures of the underlying analysis methods. Potentials of the seamless information flow throughout the lifecycle stages of engineering processes are emphasized in this section.

3.2 Geometrical Modeling

CAE is for the prevalent industrial applications a workflow, which starts with the geometrical modeling of a product or its components. Solid modeling plays a major role as the information container for the product data and the corresponding computational processes. This is particularly essential for the detailed design phase, in which diverse analysis tools use the same master-model geometry, [6]. Consequently, geometrical representation becomes a major role within the CAE processes, Fig. 4.

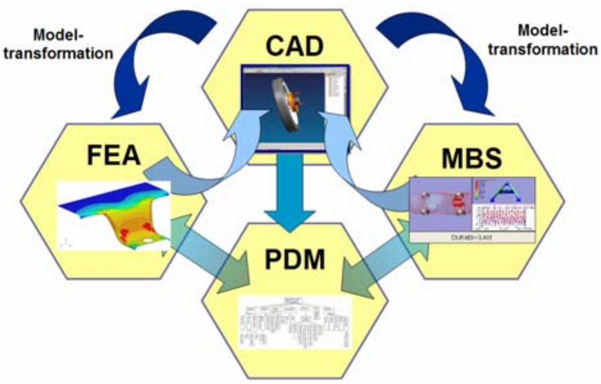

Fig. 4: Product representation in different contents

Students are taught the theory of geometric modeling, geometric representation models and methods and techniques of solid modeling. The focus is set here on the information reuse, information consistency and information redundancy.

3.3 Computational Modeling

A major block is dedicated to the relation of systems modeling, computation and simulation. It is exemplified by the theoretical and practical aspects of FEM in depth. Finally these topics are summarized in terms of other integrated processes, such as CAD-Multi-body Simulation (MBS), CAD- Digital Mock-Up (DMU), and CAD- Rapid Prototyping (RPT), Fig. 5. The relation among different models, among different scales of a product and among different modeling purposes is discussed.

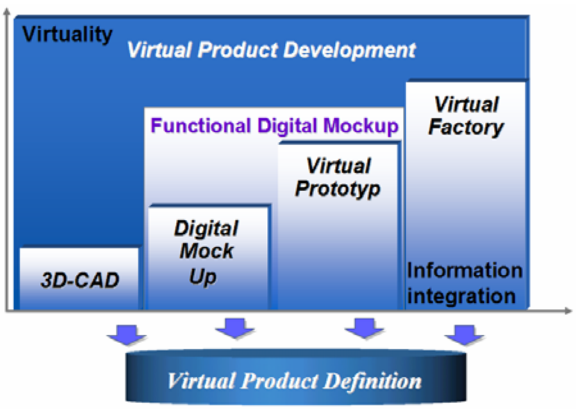

Fig. 5 Models towards virtual product definition

Definitions of "model" in the context of Product Lifecycle Management (PLM), CAE and CAD are distinguished. Consequently, a clear understanding is achieved regarding the computational modeling, especially regarding the engineering design and analysis towards a virtual product definition. Within this context, model transformation is stressed as a major issue in lifecycle, cp. Fig. 4.

Throughout the course, the cooperation of geometrical product definition and computational modeling is described as a chain of processes, which are not necessarily sequential. The objective is stated as a seamless flow of design information in product development. The lifecycle understanding is promoted as a connecting link to overcome the inherent complexity of today's product development processes, particularly CAE processes. Seamless capture, storage and retrieval of design information are introduced as the major challenges of the computer aided design and analysis tools. The next section presents an approach to developing exercises for CE based on a generic schema.

3.4 Computational Modeling in "Process Chains"

The rather abstract knowledge, explained above, is exemplified during the exercises, which are offered in form of practice hours parallel to the lectures. A well defined didactic concept is applied to intensify the learning effect in a short time. A web based tutorial environment, which is developed by DiK, is employed to implement this didactic approach [7]. Requirements of the concept for a methodically sound CAE education have been set particularly in a Bachelor thesis [8]. They are based on the common content and methods of cross-domain, domain-specific as well as tool-specific properties.

The didactic concept is developed based on the analysis of integrated CAE processes regarding the content and flow of data. The reference processes for numerous CAE use-cases had been documented already in frames of a research project. As a result of this analysis, a common pattern for computational modeling, particularly for CAE applications, is identified, Fig. 6.

Both the contents and procedures of diverse disciplines in CAE are comparable with regard to cross-domain as well as domain specific fields. For example, the commonalities in theory and applied techniques related with meshing in FEA and Computational Fluid Dynamics (CFD) would yield advantages in terms of didactic as well as technological realization of the educational content. Another example could be the domain-independent application of FEA for both structure mechanics and thermal analysis. In the former case, the topic of meshing can be used to some extend for both applications fields. In the latter case, the method of FEA can be completely transformed into another field, by only changing the discipline specific data, such as thermal loads instead of mechanical loads.

Students profit from the similar structure and content. Furthermore, they perceive CAE as a whole. On the other hand, the preparation of new tutorials on the same structure and by means of existing content contributes to the quality of education as well. Consequently, the integration of CAE into the education is supported by means of commonalities of methods and tools.

3.4.1 Composition of Topics

The topics of the practical content are composed of two parts. One of them is independent of the application itself. Considering meshing e.g., the theory of meshing is independent of the specific application SW employed to create mesh and, once implemented, can be used by all CAE methods that requires a computational mesh. However, the application-dependent part is devoted to a specific topic, e.g. CFD meshing.

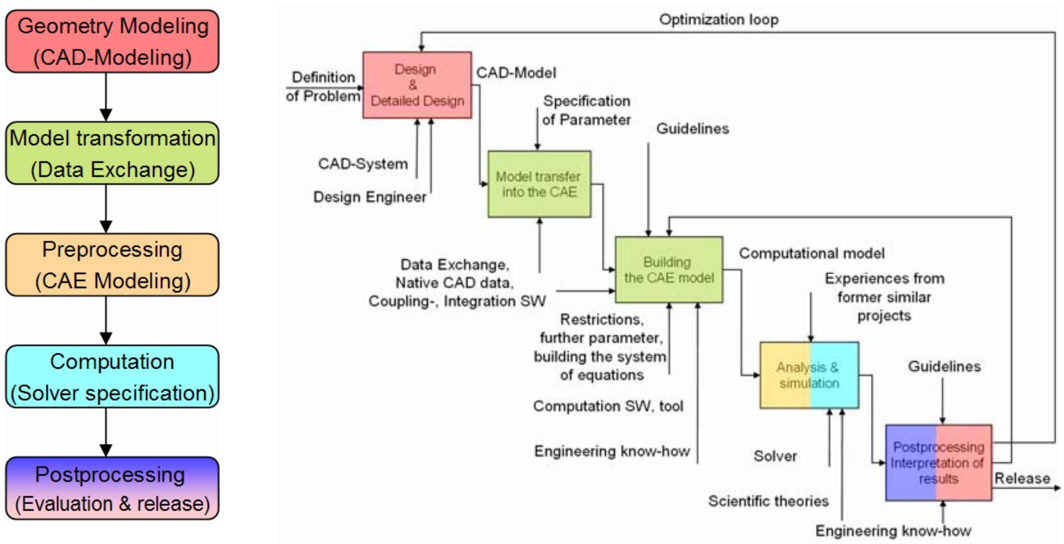

Fig. 6: Common base for the didactic concept

A further differentiation can be made between different SW for FEA. The topic of meshing is then concretized by using a specific High-End CAE-Software. The same theory content of meshing serves also for another Preprocessor. Only the application specific instructions should be added to the content pool in order to prepare the exercises.

3.4.2 Outline of topics

The similar reference procedure of CAE processes is reflected in the outline of the exercises for different CAE methods. Fig. 6 - leftFig. 7 shows the highest level of the outline, which is designed for a generic CAE process –right on the same figure. Each topic, e.g. preprocessing, has been structured according to Fig. 7. Here a higher level topic is composed of subtopics, e.g. Material properties as higher level, composite materials, a lover level, and further subjects, learning units that are divided into an application dependent and application independent parts. Application independent unit is the theoretical background. For example, the subject of material properties is presented for FEA. Material properties can also be used to same extend or fully for kinematical analysis. Application depended contents are the most dynamical one. This part can be updated, for example for each new release of software, if changes occurred.

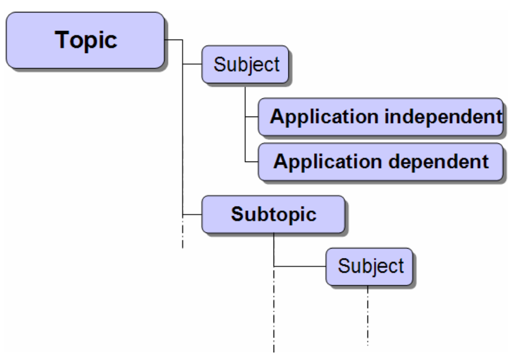

Fig. 7: Structure of the outline

3.5 Lifecycle approach

The lifecycle of computational data and processes are experienced by students in exercises, which are subsequently built upon each other. They build first the solid model of a product by using CAD modeling techniques. This model is then transformed into a geometric representation for computation. Hereby integrated computation processes are experienced firstly, e.g. analysis packages of 3D-CAD tools based on proprietary data models. In the next stage, coupled approach, which is based on neutral exchange formats, such as STEP, is employed. In the next step, preprocessing, the computational model is defined. It is simulated then for different load cases. Similar to the former step, also here integrated and coupled solvers are employed and data exchange problematic is emphasized again. Same solid model serves as the source geometric representation for different domains. Throughout all these steps, data reuse, data consistency, modeling regarding the upcoming processes and data integrity are considered as modeling principals, [9][10].

4 Conclusion

The complexity of modern products has promoted the CAE tools and methods as indispensable media to verify functional requirements, which are increasingly multidisciplinary in nature. The diffusion of CAE into the engineering sciences requires on the educational counterpart support with appropriate didactic approaches. Stand-alone learning of methods and tools of CAE hinders the holistic understanding of modeling regarding the lifecycle of data and processes. The new established course "Introduction to CAE/D", which is offered by the Department of DiK within its participation in the emerging department of "Computational Engineering" emphasize a lifecycle understanding combined with the method and tools of conventional CAE education.

This contribution presents key points of a new approach towards an educational concept for CE considering the lifecycle aspects.

5 References

[1] Reiner Anderl, Orkun Yaman: *PACE: Backbone of Educational Activities in Computational Engineering at TU-Darmstadt.* Accepted for publication, PACE Annual Forum, 23-27 July. Darmstadt. 2007

[2] C. Werner Dankwort, Roland Weidlich, Birgit Guenther, Joerg E. Blaurock: *Engineers' CAx Education—it's not only CAD.* Computer-Aided Design, Vol.36, pp. 1439–1450. 2004.

[3] Lisa R. Lattuca, Patrick T. Terenzini, J. Fredricks Volkwein: *Engineering Change: A Study of the Impact of EC2000.* Center for the Study of Higher Education. The Pennsylvania State University. ABET Publication, 2000.

[4] PITAC Report: *Computational Science: Ensuring America's Competitiveness.* President's Information Technology Advisory Committee. June 2005.

[5] Reiner Anderl: *Introduction to CAE/D. Lecture Notes.* Department of Computer Integrated Design (DiK), TU-Darmstadt, 2007.

[6] Reiner Anderl: *PDT-A Product Data Management: CAD-Systems und CA-x Processes. Lecture Notes.* Department of Computer Integrated Design (DiK), TU-Darmstadt, 2005.

[7] Reiner Anderl, Jürgen Rambo, Daniel Spiess: *Beyond CAST -A new Approach to Create, Present and Manage Online Tutorial Content.* PACE Annual Meeting. Toluca, Mexiko. 2005.

[8] Oliver Weitzmann: *Entwicklung eines Konzeptes für den effektiven Einsatz der Prozesskette CAD-FEM in die Lehre.* B.Sc.-Thesis. Department of Computer Integrated Design (DiK), TU-Darmstadt, 2006.

[9] Introduction to CAE/D: Course URL http://cadcae.iim.maschinenbau.tu-darmstadt.de/, last visited 30.06.2007.

[10] Advanced CA-x: Tutorial URL http://fem.iim.maschinenbau.tu-darmstadt.de/, last visited 30.06.2007.

