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ENHANCED ENGINEERING DESIGN PRACTICE USING KNOWLEDGE ENABLED ENGINEERING WITH SIMULATION METHODS

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1. Introduction

The objective of this paper is to discuss how Knowledge Enabled Engineering, when combined with simulation methods is a development step for product development processes, engineering design methods and evaluation support systems. The paper opens the discussion on how these approaches, i.e. work methods, simulation support and Knowledge Enabled Engineering (KEE) methods affects best practice in engineering design (ED) by adding synthesis support to the already existing analysis support. In the presented work the authors discuss the actual state of industrial applications, with challenges and opportunities, at Volvo Car Corporation, automotive manufacturer, and Volvo Aero Corporation, jet engine component manufacturer, both operating in Sweden.

1.1 Engineering Design

The company specific product development (PD) process is the process beginning with the perception of a market opportunity and leading to the delivery of the product. The generic view of the mechanical engineering part of the PD process is the engineering design (ED) process, a decision-making process [Hazelrigg 1997] that transforms needs and requirements into verified solutions. Most frequently, limitations in lead time and cost restricts the time available for engineering work. Two areas of technology that are used to enhance engineering work are highlighted here. One area is Knowledge Enabled Engineering, which represents a methodology used to capture and reuse this knowledge in computer aided design systems. The other area is computer simulations where knowledge of properties and behaviour of forthcoming products may be predicted. KEE includes the more traditional term KBE and similar knowledge rich strategies.
Knowledge Based Engineering was developed during the 80's, and gained some industrial acceptance primarily during the 90's within several organisations. One definition of KBE is:

> *"The use of advanced software techniques to reduce lead-time to capture and re-use product and process knowledge in an integrated way"* [Stokes 2001]

The main objective is to reduce lead-time by capturing *product* and *process* knowledge with a *product model* [Andreasen and Hein 1987] as the core of the system. The key concepts are that the logics of the design object (artefact) and the actual design process is described in a way that allows generation of design solutions (i.e. geometries and more). A KEE system is needed which provides a language for defining an engineering design process and a user interface that allows the activation of the design process definition and the subsequent creation of a design [Rosenfeld 1995]. Using KEE, the advantages are quite appealing; lead time for standard work activities can be dramatically decreased in combination with an increased and controllable quality. Standard solutions can be generated, evaluated and reported repeatedly at a low cost for every iteration. Engineers can concentrate on the more intellectual parts of engineering work rather than spending time doing routine work. In this way, the design team can afford to investigate more design alternatives on a more detailed and controlled level than what is possible using interactive approaches.

Simulation technologies are extensively used as an integral part in the design process to increase the number of iterative synthesis-analysis loops and to decrease the total lead-time. Virtual prototyping has proven to give insight and good support in both product development and choice of process parameters. It is less expensive than testing, at the same time mistakes are cheap and can be discovered and addressed earlier. Research in computational engineering has traditionally been focused on efficient numerical solution strategies and more accurate models. The user-friendliness has improved mostly due to effort from software providers this have made simulation tools more available for designers. Anyhow especially the pre-processing in traditional simulation software is time-consuming and demands deep insights in boundary conditions and material modelling, making simulation difficult to use continuously to drive early decision-making processes.

2. Methods

The systems used as examples in this paper are made in close collaboration between researchers from Luleå University of Technology (LTU) and Volvo Aero Corporation (VAC) and Volvo Car Corporation (VCC). The results of this research are now in use in systems used in the product development process at both companies.

3. Combining KEE and simulation for the benefit of Engineering Design

Combining KEE methods and simulation technologies can improve the design evaluation process. Positive effects are the possibility of early standard analysis of design concepts; shorter analysis cycles (i.e. creating the possibility for optimisation and more iteration) and the fact that experienced simulation experts can spend less time on routine tasks that are done by the KEE system users instead. Efforts in combining Finite Element Methods with KEE has been made by [Pinfold & Chapman 2001, Isaksson 2003] where Pinfold et al. propose a rule base method concerning the creation of first geometry of the vehicle structure and then from this a simplified model for mesh generation and then finally the generation of the FE mesh itself. Isaksson proposes a similar approach and emphasises the opportunity given to study a wider set of design variations than what is traditionally possible using most parametric strategies.

3.1 Examples from auto industry and aero engine industry

Two industrial examples are presented. First it is presented how simulation technology can be organised and tailored to contribute to the engineering design work, and in the second it is presented an example where KEE integrates Finite Element techniques to evaluate the rules.

3.1.1 Simulation support for car design

Combining simulation of mechanical properties with Rule Based techniques has been made for car body design at VCC, with the software DAMIDA and ADRIAN, see Figure 1. The effort to develop simulation tools was earlier concentrated only to the later simulation phases where very high accuracy is the ultimate goal. Some years ago it was realised that considerable gain could be made if the simulation with reasonable accuracy of common assemblies in the car body, such as beams and joints could be made faster and during the actual design activity. The geometrical design at VCC is made by design engineers striving for a design that fulfils numerous, and often, contradictory requirements, such as low weight, high strength and stiffness, joining possibilities, corrosion resistance, and commonality with similar vehicles etcetera. The mechanical requirements are often of similar nature between different cars even though numerical values vary. This makes it possible to reuse the boundary conditions and analysis type from project to project. By standardising the analysis procedures for some often recurrent assemblies, analysis can be made fast and with reasonable accuracy by design engineers without deep experience of engineering analysis. The goal of the software have been their user friendliness and that they should be safe to use, the standard user in this case do not alter the software, but more experienced users can run advanced modes where more user interaction is allowed.

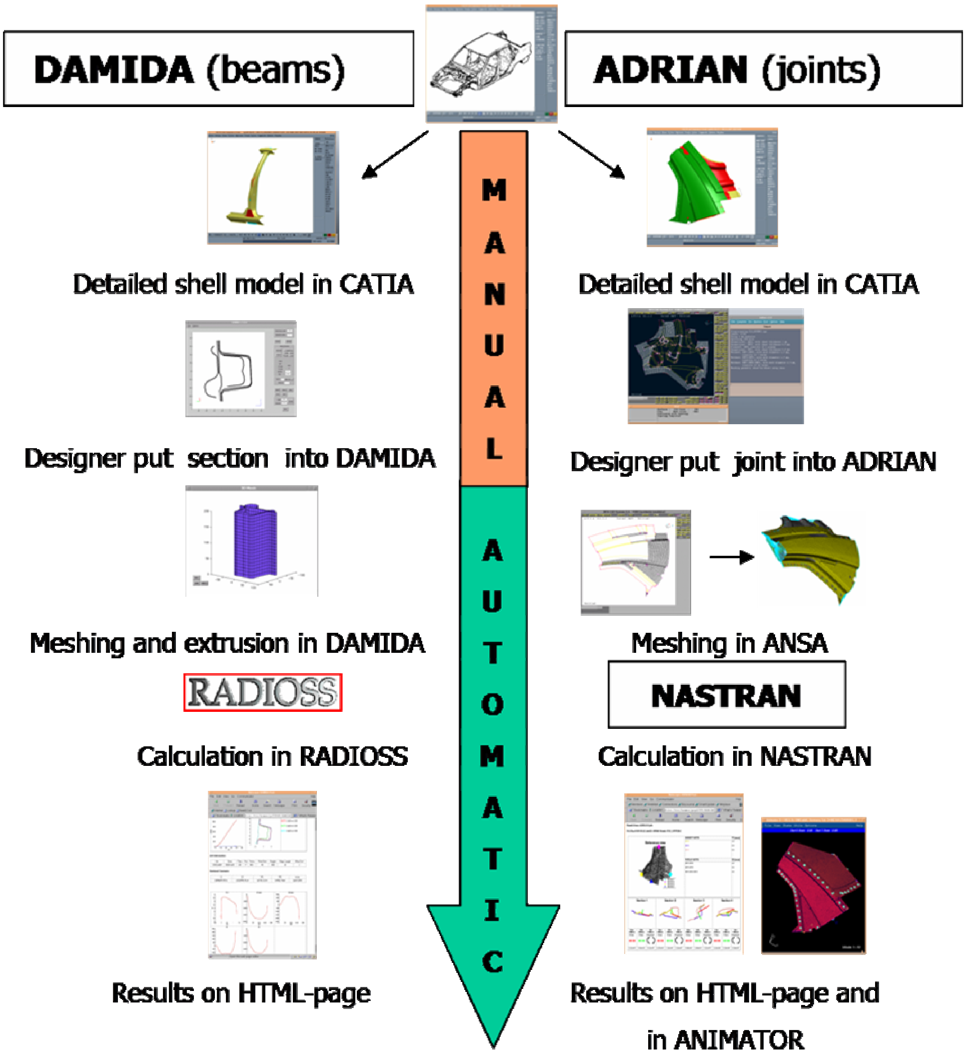

Figure 1. DAMIDA and ADRIAN implementation at VCC

This software consists of a main program with scripts that starts and manages commercial software already used within the company. In this way licence costs are minimised. Furthermore by using the software already in standard use, it is easier to gain acceptance and confidence within the company. The software used in DAMIDA and ADRIAN are seen in Figure 1. CATIA is the CAD software used at VCC, meshing is done internally in DAMIDA in the beam case and in the commercial ANSA software in the case of ADRIAN for joints. The non-linear analysis for beams the beams in DAMIDA is done with Radioss, a FEM program for explicit analysis. The linear analysis for the joints in ADRIAN is done in Nastran, a FEM program for implicit linear analysis. The results are presented both on a webpage and for ADRIAN also in the post processor ANIMATOR. Maintenance of the software is important because the commercial software used changes version regularly.
ADRIAN and DAMIDA changes the way the development is being done, the effect of a design change can be seen within hours and days instead of weeks and months. Simulation can be made more in parallel because more people are able to simulate than before.

3.1.2 Simulation support for jet engine component design

Volvo Aero has a jet engine component specialisation strategy, which enables engineering design systems can be tailored to generate and evaluate conceptual product models in a repetitive manner and with a short lead time. The conceptual models need to be represented as 3D CAD models, including manufacturing and materials information and evaluation of the structural response require analysis using Finite Element Analysis.

In a product development situation, the lead time and quality of preparing analysis models for numerical evaluation require a significant effort. Using KEE technology, the lead time for tedious analysis model generation can be nearly eliminated and thus allows more concepts to be studied. KEE supported by simulation technology thus allows more design iterations which contributes to an improved engineering design process.

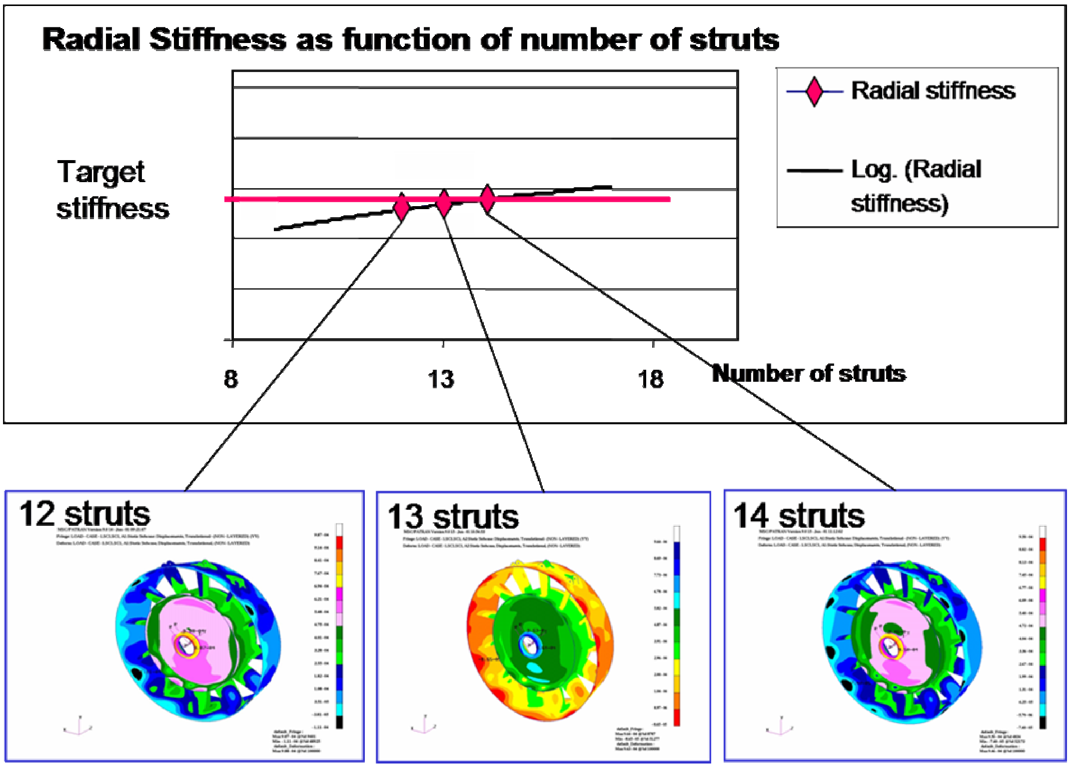

Figure 2. FEA supported alternative design evaluations

Using this system, a conceptual engineering design study for a jet engine component was conducted. The conducted design study required Finite Element simulation for evaluation and enabled concepts with significant configuration differences to be generated and evaluated [Isaksson, 2003], Figure 2. The lead time for each design iteration was reduced by at least 90%, taking iterations from weeks down to hours.

One challenge for successful deployment of simulation supported KEE, in this case, lies in the technical contradiction of model generality and flexibility verses strict model quality and control of the associated simulation models. Another challenge resides in the fact that a significant part of conceptual design now takes place as a design systems development effort rather than the actual product development work.

3.2 Challenges and opportunities

In the new work environment, as presented in the examples, challenges and opportunities appear. *First*, there are technically oriented challenges. It is technically possible to already at an early stage of design define product models with a high level of detail due if making use of pre-existing know-how. It is still technically challenging to define generative models that capture the wider design space that automatically can be automated using simulation tools. This is due to that the simulation techniques impose additional modelling restraints on the design model. Examples of areas undergoing rapid technical development are

- Distribution and collaboration technologies
- Integration of design and simulation techniques
- Knowledge acquisition and maintenance support

In these areas there are many up-coming vendor solutions but few standards and tool independent and neutral solutions.
Secondly, there are methodological challenges. The main shift is that all logical product solutions and their combination must be defined upfront and coded into a computer application. This requires a systems development- and maintenance work which is traditionally separated from interactive engineering work. Often, the Knowledge models can be developed to be "good enough" for 80% of the expected work up-front of a project. Once entering the product development work an additional 20% of systems development/up-dating is needed due to additional situation dependent requirements. A challenge is to define and develop these engineering systems so that users still have the necessary control and not become "black boxes". It is then crucial to have an efficient up-dating and re-design methodology, since such work tend to be carried out in a severely restrained time frame. There is a need to develop simulation models adapted to the actual stage of design and available information. By doing this the combined KEE and simulation environment will become a design support system rather than a design verification system.
Third, there are cultural and social challenges. The new generation of engineering support systems increasingly integrates techniques, methods and experiences from disciplines that are normally represented among different users, such as CAD, PDM and Simulation users. Although it is a technical reality that the systems mergers, new roles and situations appear amongst the users. Challenges are found in that new roles are defined, such as "Knowledge Engineers". More work is spent by users into actually defining the design systems compared to "simply" using a pre-existing tool from a vendor.

4. Conclusion

Systems that combine synthesis and analysis continue to be developed and increasingly deployed. As the analysis phase can be supported by simulation, the entire design - evaluation loop can be supported allowing iterative design. The presented industrial applications show a direction going towards bridging simulation and Engineering Design and combining the result into design support systems applications, based on product models containing both process and product information.
The challenges of introducing these systems can be seen on three different levels;

- Technically oriented challenges
- Methodological challenges
- Cultural and social challenges

The challenge of introducing simulation technology together with KEE in Engineering Design is rather on the methodological level than on the strict technical level. Best practice is yet to be seen, and a new way of work is the probable result of introducing simulation supported KEE in industry.

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