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Using Templates to Support the Engineering Designer Performing Computer-Based Design Analysis

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ABSTRACT

In their quest for a more efficient and effective utilization of the resources allocated to engineering design projects, and thus to the overall product development project from which the current design task(s) originate, an increasing number of companies allow engineering designers to perform Computer-Based Design Analysis (CBDA) on their own – CBDA is here confined to quantitative analyses using finite element-based structural and thermal analyses, Computational Fluid Dynamics, and Multi-Body Systems. Since all of these tools require a certain level of expertise in order to be successfully utilized in industrial practice, the types of analyses performed by the engineering designers are confined to simple, straightforward ones.

In striving for an increase of the individual engineering designer's possibilities to actively participate in CBDA in industrial practice, an online survey has been carried out and reported in [1]. The main objective set out for this survey was to give an overview of the current situation in the global industry regarding CBDA tasks being performed by engineering designers, what positive effects they might present to the industry and how they should be implemented for best result. Resulting from this survey, one new type of support, Template-Based Design Analysis (TBDA), was singled out as very promising for future development. TBDA is a support to be used in engineering design analyses based on the utilization of the advanced features provided by high-end Computer Aided Design (CAD)/Computer Aided Engineering (CAE) software in supporting and guiding as well as monitoring the design analysis performed by the engineering designer.

Since TBDA is still in its infancy, substantial development needs to be invested in it to make it the full-blown support needed in industrial practice. To be able to contribute to the development of TBDA, it is essential to acquire knowledge about how companies, both national and international, are planning to introduce and utilize TBDA in industrial practice. It is likewise of importance to acquire knowledge of the arguments against an introduction of TBDA.

To that end a new online survey has been carried out, focusing on the introduction and benefits as well as the disadvantages associated with an implementation of TBDA. The survey was sent to 64 recipients, 41 of whom were selected from the previous survey [1] and 23 came from Swedish companies known to the authors to utilize CBDA on a regular basis. The limitation to Swedish companies was due to practical as well as economic reasons, as these companies were also invited to participate in interviews. The main objective set out for these interviews was to get an in-depth view on the outcome of allowing engineering designers performing CBDA/TBDA in industrial practice. An additional objective was to get an indication as to the validity of the responses obtained in the online survey by comparing the

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results from the interviews with the responses given by the companies to the survey

42 of the 64 recipients, from 17 countries, completed the survey. All of the invited Swedish companies completed the survey. However, due to the risks associated with revealing proprietary information during the interviews, only 5 out of the 23 companies were willing to participate in the interviews.

The introduction of TBDA in an industrial setting has resulted in many advantages, such as shorter lead times, opportunities to generate more concept candidates, and increased collaboration between the engineering designers and the design analysts, all of them contributing to more mature technical solutions. Three different automation levels of TBDA have also been identified and accounted for as well as exemplified. In the companies in which TBDA has not been implemented, some of the reasons for not doing so are high costs, company policy, and the lack of knowledge and experience on the part of the engineering designer. This paper presents the results from both the new online survey and from the interviews.

INTRODUCTION

The responsibility for all quantitative Computer-Based Design Analysis (CBDA) performed within the engineering design process, rests traditionally with the engineering design analysis experts, here the design analysts. In the majority of companies, the design analysts are working within a specialized engineering design analysis department. CBDA is the comprehensive term for all quantitative computer-based design analysis activities within engineering design, or simply design, here confined to the utilization of Computer Aided Engineering (CAE) tools such as the Finite Element Method (FEM), Computational Fluid Dynamics (CFD), Multi Body Systems (MBS), and supportive tools such as Knowledge-Based Systems (KBS) and optimization methods/software (shape, topology and others), all within mechanical engineering.

However, there have been recurring efforts towards allowing the engineering designer to perform CBDA. This approach has yielded mixed experiences in the past, but nowadays between 30% and 40% of the companies allows their engineering designers to utilize design analysis tools on a regular basis [1;2]. Introducing design analysis to the engineering designers has often proved to be very effective [3]. This is especially relevant now that 30% of all analyses are performed during the conceptual design phase [4]. To that end, several types of support are available: usage of guidelines, supervision by a design analyst, special training etc.

In a previous online survey [1], the main objective was to give an overview of the current situation in industry regarding CBDA tasks being performed by engineering designers, what positive effects it might present to the industry and how it should be implemented for best result. This has been done by means of a survey addressed to members of engineering associations such as the National Agency for Finite Element Methods and Standards (NAFEMS) and the American Society of Mechanical Engineers (ASME), as well as targeted companies. The main subjects touched upon by the survey are the proportion of companies applying this approach, the type of support used by the engineering designers, the degree of freedom they have, and the challenges associated with this approach. Resulting from this survey, Template-Based Design Analysis (TBDA) was identified as a very promising support for an extended use of CBDA in industrial practice.

TBDA is defined as a pre-developed code that supports or guides those performing design analysis tasks, e.g. from predefined settings available in traditional CAE tools to scripts developed in-house and advanced usage of KBS. TBDA can be used to allow engineering designers to perform certain specific types of analyses while leaving the most advanced analyses to the design analysts.

Generic templates have been used for many years by design analysts, and the normal usage for templates is a form of basic template used e.g. for creating geometry for defining different types of predefined coordinate systems, functionality and license limitations. Ansys, in its latest releases, has introduced a new aid that is described as templates [6]: modules needed for a specific type of analysis can be chosen from different sub-templates to build up an analysis template. In a case study within Ford Motor Company’s North America Engine Engineering Organization, an analysis template to accelerate the initial geometry and analysis generation process has been developed [7], focusing on simplifying and automating task-related analysis connections, boundary conditions and mesh generation. Both in Ansys and in the case from Ford Motor Company, the main focus was on the analysis performed by a design analyst.

The development and use of TBDA for engineering designers is challenging. Engineering designers have generally limited skills in analysis compared to design analysts. Templates for engineering designers might have to be more focused on product type and/or one type of analysis. However, the potential benefits are numerous. The engineering designer can, for example, perform preliminary analyses before sending the design to the design analyst for additional analysis. It allows him/her to develop and simulate more concepts, even “exotic” ones, and also the engineering designer can perform the analyses of new concepts that in some companies have very low priority [8]. The engineering designer can perform analyses on his/her own instead of asking for support, thus freeing resources for more demanding analysis tasks. The templates can be designed so that they ensure the quality of the design analysis process and its results, which is important in a Quality Assurance (QA) perspective.

What is the current position of the industry in this matter? There are very limited insights into and knowledge of the use of templates for engineering designers in industry. Several industrial surveys investigate CBDA performed by engineering designers, e.g. [2;9;10], but TBDA is not touched upon. There is no knowledge of the spreading of TBDA or of the attitude of the industry towards the use of templates in industry. The goal of this paper is to bridge this knowledge gap. In order to remedy the lack of information regarding the use of TBDA by engineering designers, an international survey and a number of interviews have been carried out.

The results from the international survey and the interviews reported in this paper touch upon 1) the implementation of TBDA relative to the engineering designers' alternative CBDA supports used in industry such as guidelines, training, etc.; 2) the usage of TBDA: the different types of templates used (from basic to fully automated), the types of analysis performed by using templates, exemplified with industry cases, the implementation of TBDA into the product development and engineering design processes; 3) issues related to the development and implementation of templates, and the knowledge and training required of the engineering designers; 4) impact of the use of TBDA for engineering designers on development projects, challenges and future developments of TBDA. In the remainder of this paper, the term templates and TBDA are confined to the design analyses performed by the engineering designer, not to those by the design analyst.

METHODOLOGICAL APPROACH

This investigation is composed of an online survey combined with a set of interviews. The online survey made it possible to reach a large number of professionals; especially those active on the global arena, and to get quantitative data from closed questions. The interviews were conducted to get in-depth answers on open questions related to the outcome of allowing engineering designers performing CBDA/TBDA in industrial practice, such as descriptions of templates implemented, related issues, challenges and recommendations.

Survey

The format of the survey was an online survey, in order to be able to reach respondents internationally. The online survey tool www.quicksearch.se was used. The structure of the new survey is shown in Figure 1. After some background information and some questions about the company's CBDA process and its integration with the engineering design process, respondents were asked whether the company authorized the engineering designers to perform CBDA. If so, several questions were asked regarding the kinds of support the company provided to the engineering designers (guidelines, training, templates, etc.). Finally, some questions were directed to the companies not allowing the use of CBDA in general by engineering designers. The new survey contains a maximum of 34 questions. Beside closed questions, there were opportunities for respondents to give comments and supplementary information.

The recruitment of respondents to the previous survey [1] consisted of an open invitation to members of the NAFEMS and Design Society organizations, different member groups within ASME and LinkedIn, and from a set of selected companies known to utilize CBDA. A total of 77 respondents answered the previous survey [1]. 43 of these were willing to answer additional questions, but only 41 left a valid e-mail address. 19 of the 41 completed the new survey. 23 additional recipients, from Swedish companies known to the authors to utilize CBDA on a regular basis, were invited to participate in the interviews. All of these completed the survey. Thus, the total number of respondents who answered the new survey was 42. The survey was open for two months, February to March, 2015.

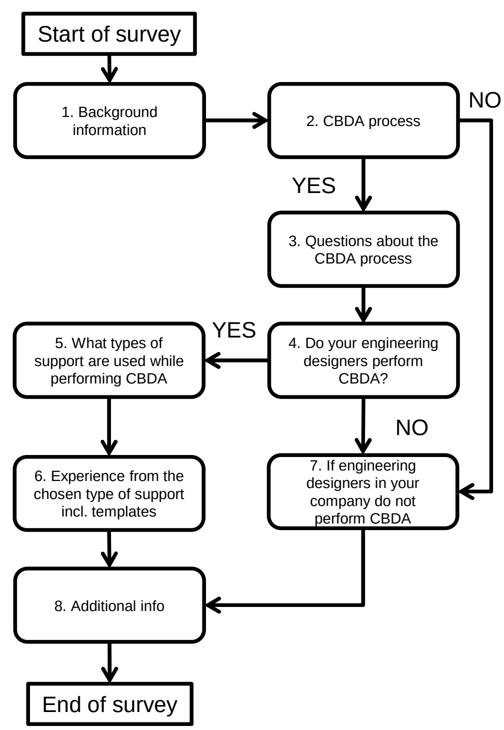

Figure 1. Main structure of the new survey

Interviews – general approach

There were several motives behind the choice of interview technique. Some questions related to TBDA required extensive description and direct interaction for immediate feedback (for example, description of a developed template). Many questions led to confidential information being disclosed in order to allow for a better understanding of the answers. The interviewee could sometimes show some specific documents (design analysis procedures) or ask co-workers for specific information.

Few companies use templates for engineering designers, and the results from the interviews have to be interpreted qualitatively. Each of the companies interviewed gives an account of how they use templates and the impact it has on product development. Nevertheless, these cases can be used to give a picture of the use of TBDA for engineering designers in industry. A similar approach (with 5 interviewed companies) has been reported in [11] to develop a model for the organization, structure and support of design analysis in companies. It can also serve as a basis for reflection both for companies and researchers, e.g. on whether TBDA for engineering designers is an interesting kind of support or not.

The companies accepting to participate in the interviews were sent the complete set of interview questions in advance. An interview lasted for about 1½-2 hours. All interviews were recorded and the notes taken during the interviews were later compared with the recorded interview. The last step was to send the results compiled to the respondents for validation. This approach, based on a combination of a questionnaire and an interview, has already proved successful in the past (see [2;12;13] where a full description of the interview technique is provided). The organization of the reporting of the interview process and results has been based as much as possible on the recommendations of [14] and with reference to [15] and [11].

Topics of the interview

The following topics were included in the interviews. First some questions of general character were asked regarding the company, its personnel and its products together with a focus on the integration of the engineering design process and the design analysis process. The second set of questions was oriented towards the extent of the usage of TBDA and the automation level used within the company. The third set of questions dealt with how and when TBDA should be used and the implementation of TBDA in the company. The fourth set of questions dealt with education/training, documentation and traceability of analyses performed. The fifth set of questions finally, concerned the impact of TBDA on the business, on the development process and on the products developed. The companies were also asked about future plans for TBDA.

Selection of companies for the interviews

As many interview questions were sensitive in nature, and as the interviewee was highly ranked in the hierarchy (head of development or simulation departments), only companies with which the authors had had collaboration and/or which were known to perform CBDA on a regular basis were contacted. Of those contacts, 23 companies were of interest. In 7 of them, engineering designers performed TBDA. In the end, only 5 of them accepted to be interviewed due to the risks of revealing proprietary information previously mentioned; a small number of respondents but significant for the purpose – compare with the investigation reported in [11].

The 7 international respondents from the new survey, who had answered that they use TBDA at different automation levels, were also tentatively approached, but none of them were willing to participate in an interview.

PROFILE OF THE COMPANIES AND RESPONDENTS

The profile of the companies and respondents who participated in the new survey and interviews are detailed below. Note that the figures from the new survey include data obtained directly from the interview participants. Furthermore, note that Figure 2 to Figure 5 include two diagrams. The first diagram represents the profile of all companies and respondents who answered the survey. The second represents the profile of companies and respondents who have implemented TBDA for their engineering designers.

Survey results

One third of the respondents were managers and one third engineering designers, see Figure 2, left. Most of them hold a Master's degree (Figure 3).

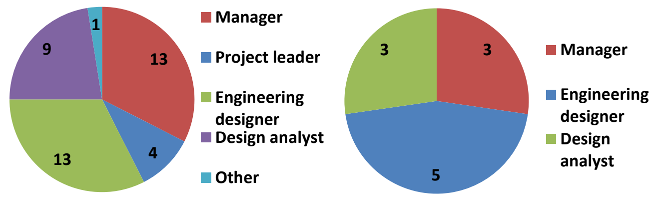

Figure 2. Primary position of the respondent

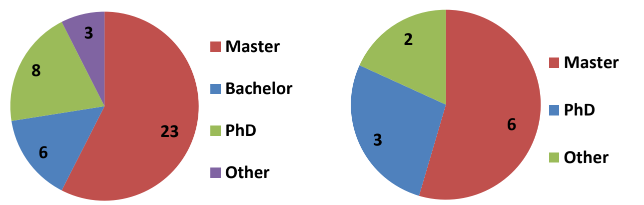

Figure 3. Formal level of education of the respondent

The companies, classified in industrial branches according to [16], are mainly operating within transportation (31%), aerospace and defense (13%), energy (13%) and industrial equipment (11%), see Figure 4, top.

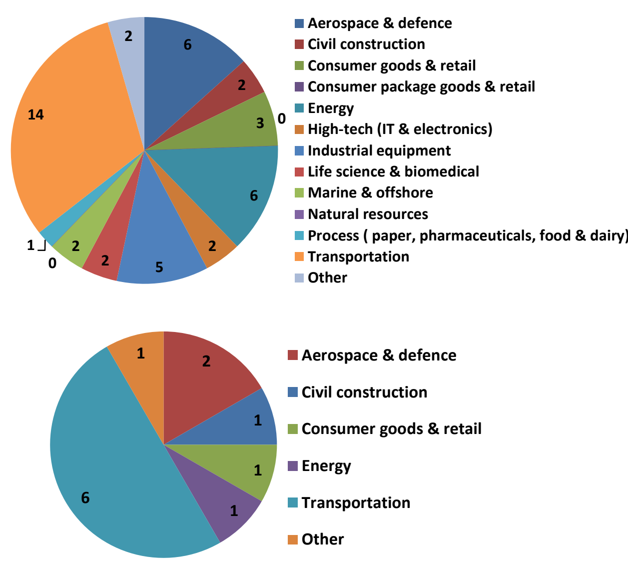

Figure 4. Companies' distribution across industries

The companies which have implemented TBDA are mostly in the automotive industry (Figure 4, bottom). The companies have also been classified according to what they primarily offer: technical systems, complex components (suppliers) or engineering consultancy, as this implies different development activities. A majority of respondents (53%) come from companies developing full technical systems, and 28% are engineering consulting companies (Figure 5, left). Not surprisingly, much fewer consulting companies have implemented TBDA (Figure 5, right).

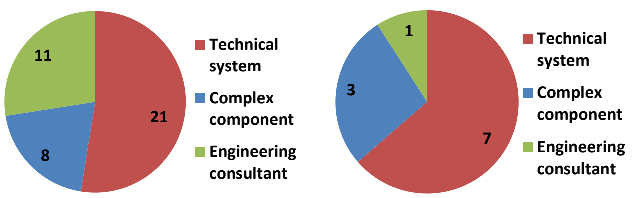

Figure 5. Companies' main activity

Of the 42 companies that answered the survey, 28 (67%) answered that they allow their engineering designers to perform CBDA. Companies that have answered our survey are mostly large companies (>100 engineering designers) followed by small companies (1-10 engineering designers) and midrange companies (11-100 engineering designers). Interestingly, when it comes to the companies that have implemented TBDA, small companies are followed by large and midrange companies, see Figure 6. This indicates that the implementation of TBDA is influenced by the number of engineering designers. In small companies it is expected that the engineering designer handles most, if not all, of the issues associated with his/her role as engineering designer. The need for engineering designers able to perform CBDA on their own is thus more articulated in these companies. In larger companies, the pursuit of increased efficiency is highly prioritized, resulting in the need for engineering designers to take over parts of the design analysis activities. Figure 7 presents the number of design analysts in the responding companies that allow their engineering designers to perform CBDA or TBDA.

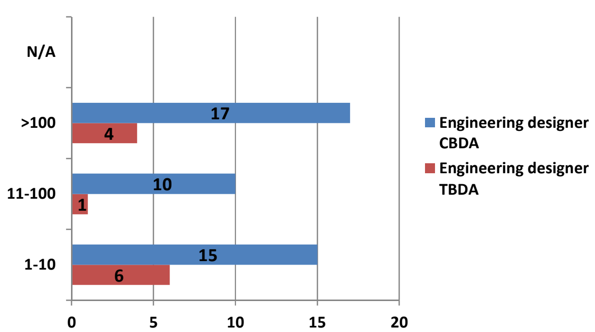

Figure 6. Number of engineering designers in the companies allowing them to perform CBDA/TBDA

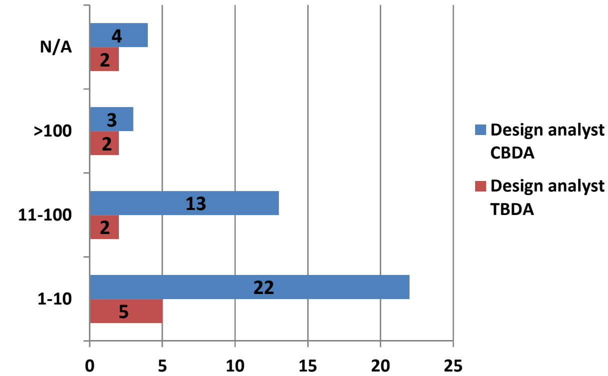

Figure 7. Number of design analysts in the companies allowing their designers to perform CBDA /TBDA

The software used for CBDA is Catia V5, Autodesk and SolidWorks followed by Pro/E, NX, and other. For those who have implemented TBDA, the pattern is almost the same, Catia V5, Autodesk, SolidWorks and Pro/E, see Figure 8. To be able to implement knowledge that is needed for implementing TBDA, integrated solutions are needed, which constrains the companies' choices.

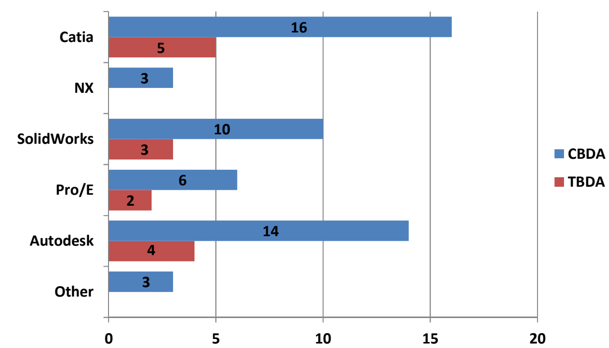

Figure 8. CAD software used in the companies allowing their designers to perform CBDA /TBDA

Interviews

The different companies interviewed have the following profiles (presented in the same fashion as [11]).

One company is a heavy truck manufacturer. The transportation of goods on heavy trucks along our roads has changed radically over the last 10 years. From previously focusing on reliability and comfort, it has now received a great deal of attention from an environmental point of view. This means that the majority of vehicle components must now be optimized with respect to weight. CAE is important as many different types of simulations are needed. Two of those are optimization and FEM, which have to be used to a greater extent than before. For this to be feasible, the designer's role has become even more important. Within the company there are a number of different departments, all of them with their own design analysis departments which are responsible for all simulations within the department. During the last few years the designers have also been trained to carry out design analysis. There are still important processes around the CAE simulation that have not yet been adopted. Storage of resulting data is one of those. Through the integration of the engineering design and analysis processes, important preparations for the implementation of TBDA have already been started.

A second company manufactures production equipment for food packaging. In recent years, competition has increased and the company is now beginning to explore some different types of options. How to reduce development costs and the cost of the product but at the same time double the capacity of the manufactured product, are two future goals they are looking into. In recent years, their engineering designers have started to use different types of simulation tools. Their engineering designer simulates different design solution candidates by using different tools, for example linear and non-linear analysis, MBS and tolerance analysis. Within the company, there are several computational departments that perform more advanced analyses but also provide support to designers in their simulation work.

The automotive industry, in which the third company operates, faces the same challenges as the heavy truck industry. Demands for less environmental impact and other new regulations also force them to use recycled plastic materials. New lightweight materials or different combinations of them (hybrids) are some of the challenges they are facing. At the same time high quality is important; comfort has to be improved. By introducing design analysis for their engineering designers, they are able to increase the number of simulations performed, which is needed if those new challenges are to be met. The main focus for their engineering designers is to perform linear analysis both at system and part level. If that is to be accomplished, some new type of support for the engineering designers will be needed. TBDA is one of the tools that are being evaluated. The design analysis is organized with a large group of design analysts responsible for all simulation in the company. The latest change made was to locate a few design analysts in the same office as the engineering designers for support and collaboration.

The fourth company is a multinational company that develops, manufactures and distributes products for brake systems on heavy commercial vehicles. The customers are typically manufacturers of heavy trucks, buses and trailers. The design analysis department has a main group that is responsible for all analyses, and there are smaller groups in different departments working in closer contact with the engineering designers. The implementation of TBDA today is still in its first stage. They are planning for a full implementation of TBDA at all of their sites worldwide and for all of their products.

The fifth company is in the defense industry. Most of the products that they manufacture are one-off. Their design analysis department performs most of the analysis work within the company, but the engineering designers are allowed to perform design analysis for the exploration and evaluation of concept candidates. They are only allowed to use linear analysis, though. The company now focuses on implementing a new standard for all engineering designers, and when all processes are updated, there are thoughts of implementing some variant of TBDA.

FORMS OF CBDA SUPPORT FOR ENGINEERING DESIGNERS

Most companies from the survey give their engineering designers some kind of support (only one company allows their designers to perform design analysis without support). Figure **9** represents the use of different types of support along the development lifecycle of a product. The total number of companies using each type of support is also indicated (one company might use one type of support in several development phases). The use of guidelines and supervision by a design analyst are the types of support used most often. All types of support are used in concept and detailed phases. Analyses are less often performed in embodiment design, which can be explained by the fact that design analyses are less needed for the design of the product layout and architecture. Engineering designers are probably less often called on for design analysis during production preparation (advanced analyses for testing and validation) and post-production (analysis of defective products, for example). Other types of support reported are: continuous training during projects (3 companies), collaboration with academic institutions or software vendors (2), experts available for questions (2)—this could be similar to supervision by an analyst—or non-disclosed information. 14 companies in total use templates (7 international respondents and 7 domestic companies). That is the least used form of support.

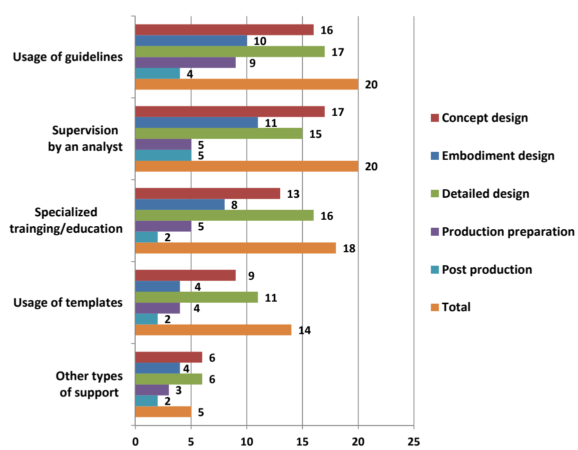

Figure 9. Types of support used during different product development phases

Supervision by an analyst normally refers to an internal source (all the companies using this support) or a senior analyst (55% of the companies). In 30% of the companies an engineering designer is used for supervision. One company has a resource employed 100% for this task, see Figure 10. When using guidelines, 90% answered that guidelines are available to the user in electronic form, 25% in paper form.

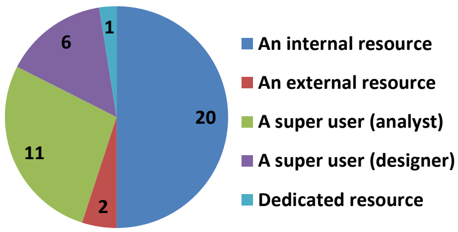

Figure 10. Resources called on for supervision

The resource used for the development of these types of support is reported in Figure 11. The results indicate that this is distributed equally between engineering design and design analysis departments, but when special training or education is needed, external resources (engineering consulting company, academic institution, other) are often hired for this.

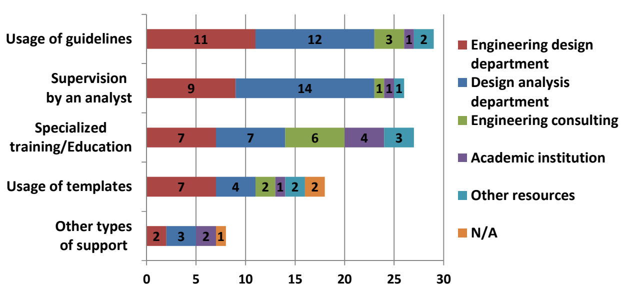

Figure 11. Resources called on for the development of the different types of support

Finally, the respondents were asked how the company and the users value these forms of support (on a 1-5 scale). Note that these ratings are the respondents' appreciation of how highly the company and users value the support. This may not reflect the actual appreciation of the company and users but gives a strong indication of these values. When implementing these different types of support, it is indeed important to find out which type of support has been of most value both for the companies as a whole and for the users. The answers are shown in Figure 12 and Figure 13. These types of support are relatively well accepted by the companies (3.8 in average). The forms of support most appreciated by the companies are the use of other types of support (4.3), supervision by an analyst (4.0), special training (3.8) and guidelines (3.6). The use of templates gets an average of 3.1.

The answers show that the users value all types of support less highly than the company (3.5 on average). This could be an indication that they are not pleased with the fact that they have had some limitations imposed upon them or that they feel supervised, see Figure 13. The average value for other types of support is 4.2, supervision by an analyst 3.9, special training 3.3, guidelines 3.1, and templates 2.8.

By comparing Figure 12 and Figure 13, we find that the templates were less highly valued by the engineering designer. One explanation, according to the companies interviewed, is that the engineering designers have been trained in basic design analysis to be able to use the analysis software. They have therefore little interest in starting working with TBDA, which constrains their freedom in their analysis work. Another reason is that their workload is too high.

In both cases the use of templates gets the lowest score. This can be explained by the fact that it is a less proven type of support. The companies interviewed were very positive towards TBDA, and no other explanation could be found.

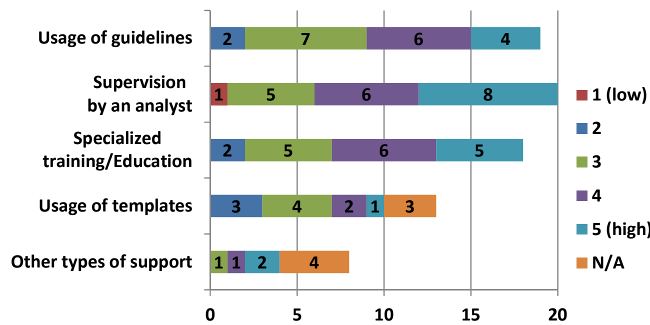

Figure 12. Company's assessment of the value of the different forms of support

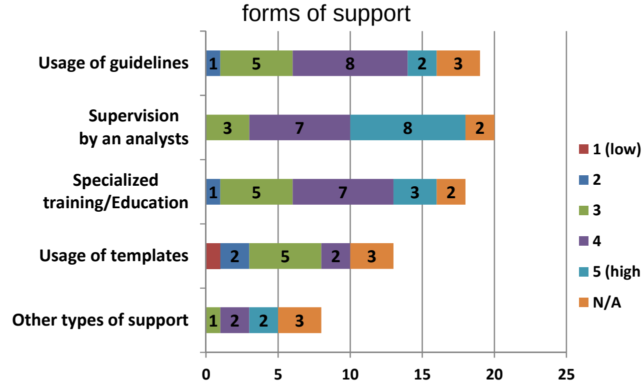

Figure 13. Users' assessment of the value of the different forms of support

USE OF TBDA

A preliminary finding is that the companies interviewed stated that they are in the early stages of their implemention of TBDA. Many of their TBDA projects served to test whether templates helped engineering designers perform design analysis and increase the product quality. It should be noted that most of these projects were performed for real products or parts, and their solutions have been implemented.

In this section, the use of TBDA in industry is described. This covers 1) the different forms of templates used, which can basically be classified according to how much they automate the design analysis task; 2) the types of analysis performed (FEM analysis, CFD analysis, etc.); 3) the position of TBDA in the overall development process of the companies.

Different forms of automation level of TBDA

Templates can be categorized in three different types: basic level, semi-automated level and fully automated level.

In the following sections, these three automation levels are described and exemplified with cases derived from the companies interviewed.

Basic level

At the basic level, the engineering designer has a large amount of freedom to perform design analysis, but some features of the CAE software are locked, in order to ensure a certain quality to the result. Pre-processing activities can be constrained: meshing possibilities may be limited, the number of nodes may be reduced, or the engineering designer may not be able to perform non-linear analysis. Some pre-defined settings might be added, such as warnings when some values are attained. Finally, some equations and rules can be added, such as automatic calculation of weight. The engineering designer, on the other hand, is quite free to work with the geometry of the product, the determination of the load cases etc. The template is always supplied with a set of guidelines explaining the different steps to take to make a correct analysis.

In one of the companies, such a template has been developed for the design and analysis of engine brackets (for more information, see [17]). Many different brackets were not properly analyzed in the past. Safety coefficients were applied instead. The company had decided to improve the development of these brackets with the goals of decreasing weight and cost, which would require a finer analysis of the structural properties of the different brackets. Moreover, the company wanted to leave this task to engineering designers entirely so as not to iterate with an overloaded analysis department. Other demands were that it should be possible to choose a different material, it should be easy to use and guarantee QA aspects, and the product should be fully developed when the engineering designer handed it over for manufacturing. To that end a template was developed.

The template was developed within Catia V5, using the integrated CAD, Finite Element (FE) and KBS capabilities of the software. Predefined settings developed in this template were, for example, the tolerance and order of the elements and a warning when the stress limit reaches the limit for the chosen material. Knowledge Based Engineering (KBE) features connected to the geometrical model are illustrated in Figure 14. A special method, in the form of guidelines, to be used in combination with the basic level approach, was also developed.

The outcome of the project was a weight reduction by 80%. In Figure 15, a newly developed sheet metal bracket is presented, which was developed during 2 months' time. According to the company, this type of development would not have been possible due to the long lead time between each iteration the engineering and analysis departments.

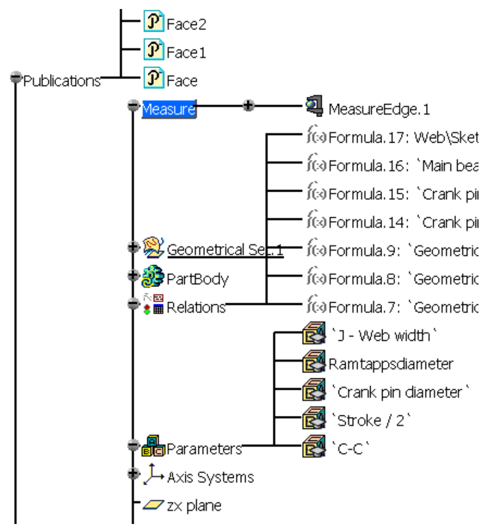

Figure 14. KBE features for TBDA

As this was a pilot project, a design analyst supervised the users when performing TBDA. The project resulted in the development of new guidelines. Templates have not yet been implemented in the daily work, the intention from the management being that, when all support processes have been brought up to date, TBDA is going to be used by the engineering designers or other personnel in the role of design analysts.

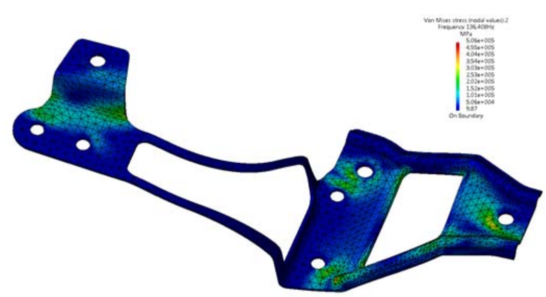

Figure 15. New sheet metal bracket developed with the help of a basic level template

Semi-automated level

In the semi-automated approach, the template interacts with the user, controlling and monitoring part of the process. One case is described below.

A semi-automated level template was developed for the design of a crankshaft and its variants. The crankshaft is the first part of the engine that has to be designed, as the rest of the engine depends on its design and function. A new crankshaft needs to be designed for each new version of the combustion engine, depending on the demands for this new vehicle. A semi-automated level of TBDA was developed for the analysis and optimization of the crankshaft.

The first part of the template dealt with the parameterized transfer of any new design of a crankshaft in the analysis template. The exchange of one crankshaft design for another for each analysis was simplified and secured.

After that, the geometrical instantiation is made, and the semi-automated design analysis can be started. The analysis template (pre- and post-processing) is generated with special settings. The first step is to load a design table with predefined values for the analysis from an Excel table; it is the form of min and max values and the user applied appropriate values for the specific analysis that is to be performed. The predefined values come from the design analysis department, and the values depend on what type of crankshaft is to be optimized. The next step is to adjust the settings for the Design Of Experiments (DOE) optimization, and when this is done the optimization starts. At the same time, a new design table is created where all the results from the optimization are stored. When the optimization has ended, there are around 5-6,000 results to be evaluated. When the results need to be visualized, the engineering designer chooses a suitable configuration among the results, and the calculated result is displayed. In Figure 16, one of these results is shown. The result is evaluated by a small group including the engineering designers, a design analyst and the person responsible for physical testing.

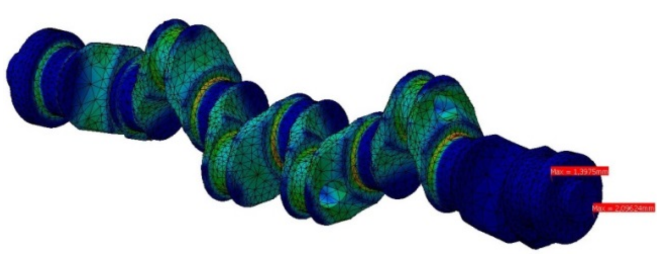

Figure 16. Result of DOE optimization

The company's feedback on this template is that it is very useful, and the knowledge of the product gained has been important. The crankshaft design obtained with the help of TBDA is used for the final product.

Fully automated level

At the fully automated level, the engineering designer has no control over the analysis part. The engineering designer prepares a geometry based on specific constraints, submits it and receives a completely analyzed and optimized design. If there is no satisfactory result, the engineering designer can modify the design and submit a new one. The use of this template, in practice, is limited to products or components that require only minor changes from version to version. The load cases must also be within certain limits. Because the user of the template has limited knowledge of design analysis and cannot affect the analysis, the final design should be inspected by a design analyst. Moreover, the engineering designer might need some support in interpreting the analysis results. To that end, guidelines and supervision by an analyst are available. The development of such templates requires extensive work in order to ensure good quality of the result. The development of the fully automated level approach, in most cases, is developed by an external resource such as an academic institution or a consulting company.

Such a fully automated template was developed in a research project during 2011-2012, in which an existing computer-based design analysis system, previously developed as a part of a research project in Swedish industry and academy, has been utilized as a background case. A full description of the system for which the design system was developed is given in [5]. It should be noted that the outcome of this project was a working, fully automated design system. The purpose was to facilitate the development of lightweight grippers (lifting device), the weight of which should be decreased to make it possible to use standard robots. A new lightweight gripper would be required for each new truck version. A production cell is shown Figure 17. Some possible gripper variants are presented in Figure 18.

Figure 17. The production cell [18]

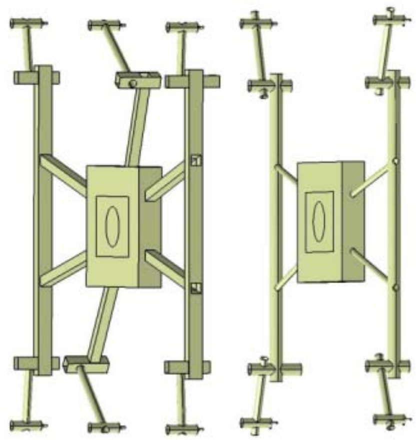

Figure 18. Possible variants of the gripper base

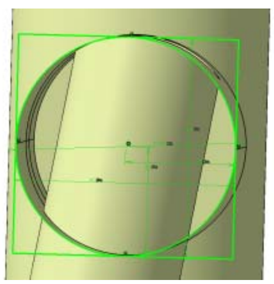

Figure 19. Implementation of the round and rectangular cross sections of the gripper

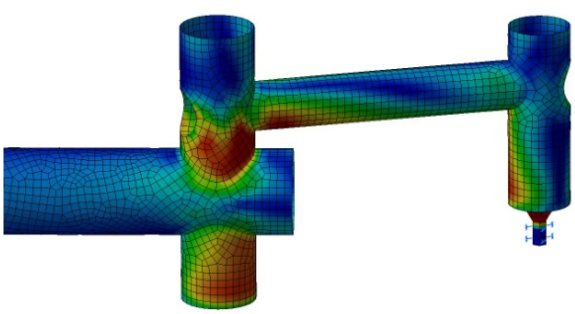

Figure 20. Detailed view of the deformation analysis result for the gripper base

As the production engineers, responsible for the gripper design have limited knowledge and experience of design analysis and limited experience of engineering design, an automated design system was developed for that purpose [18]. The design system is organized around 3 main elements called 1) the reference geometry model—input information about the body-in-white design to be picked up by the gripper; 2) the geometric model— all information about the geometry of the gripper base: the different parts and the rules about their possible configurations (see e.g. Figure 19; and Figure 20); and 3) the analysis model—information necessary to define and perform the structural design analysis: material properties, mesh discretization, boundary conditions and loading.

Types of analysis

Linear static and non-linear analysis is where the TBDA is used most frequently, see Figure 21. Both in linear static and non-linear static analysis it is possible to implement TBDA at many different levels and with different types of limitations and/or quality checks. There were a high number of TBDA systems including optimization. It might be surprising at first, but the extra cost and time of also implementing some optimization together with the development of a template are reasonable.

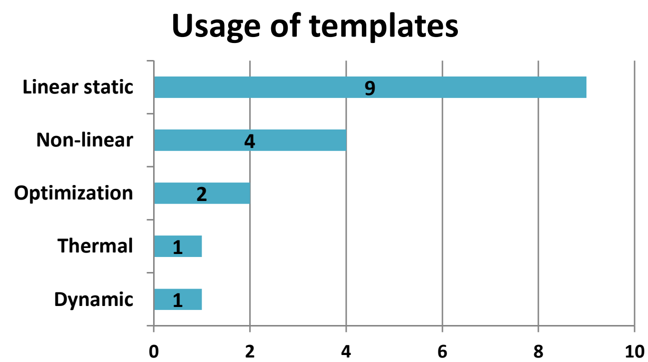

Figure 21. Types of analysis performed with TBDA

The linear static analysis is more often implemented for the basic and semi-automated levels. Logically, the fully automated level is suitable for the implementation of optimization, see Figure 22.One respondents did not use TBDA at any level.

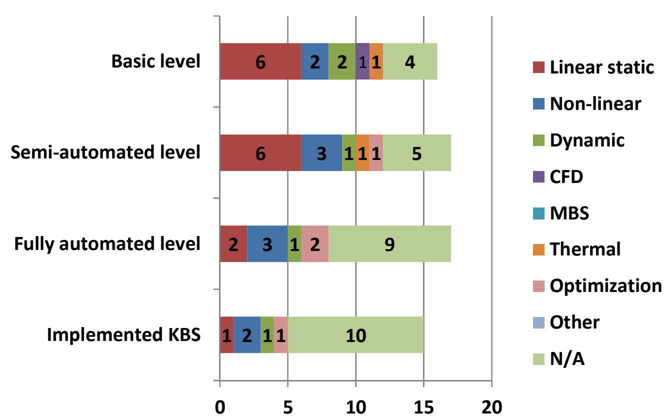

Figure 22. Types of analysis for different levels of TBDA

Role of TBDA in the overall development process

TBDA is naturally tightly connected with design analysis activities. Together with the TBDA, most often guidelines and support from an analyst are used as extra support. The guidelines help the engineering designer to set up the boundary conditions and other product related properties as it can contain information from, for example, physical testing.

Most of the companies that answered that they use TBDA have done so in the form of pilot projects. In some of those it has been done with a real product developed to be used as a commercial product; there are companies that use a basic level approach on a daily basis. TBDA is useful and valuable to use in some types of analysis but not in all. E.g. linear and non-linear analysis and optimization are suitable for TBDA.

The most valuable outcome of the pilot project with TBDA is enhanced concept generation and a higher technical knowledge of the product. It is also clear that the respondent companies are planning on full implementation of TBDA where possible. To be able to take full advantage of TBDA there are some processes around TBDA that have to be taken care of before the implementation of TBDA. In some of the respondent companies, there are still questions to be solved by the management, and one question is how to save the data generated.

Therefore, it is currently not easy to get a clear picture of TBDA and its role in the product development process. Some companies answer that they have a fully integrated design and analysis process, other ones that the product development process has been updated to also include design analysis and its process. TBDA could easily be made part of it. From the QA aspect, all results obtained from the TBDA are discussed with the design analyst and/or with the person responsible at the department, and the results are then finally approved.

DEVELOPMENT AND IMPLEMENTATION OF TBDA

The development of the templates, in some cases, has been done by academic institutions in direct collaboration with engineers at the target company, or with the help of an external source or resources inside the company. When an external consultant is used, the development time may vary depending on the workload at that time. If the company chooses to develop the TBDA within the company, there are many factors that have to be accounted for, one of them being that a dedicated project with its own budget and personnel must be created. It is also interesting to notice that, for most companies interviewed, there is a dedicated person or group at the company level that is responsible for both the TBDA implementation and the training/education provided to their engineering designers. This group also discusses with the design analysis department and/or the person responsible for that department in what project or for which product TBDA is to be used. The main reason for the decision to implement TBDA is to shorten lead time, to achieve better technical understanding of the product and to minimize the iteration time between the engineering designers and the design analysis departments. One important factor is the total cost of developing TBDA. Licenses, adaptation of software, implementation of TBDA and any education/training of engineers are all factors that must be taken into account when evaluating the benefits of TBDA obtained.

Engineering designers performed CBDA prior to the TBDA implementation. As this usage was more of an activity for interested engineering designers and the company had little control of it, decisions have been made to ensure that there is a company standard for the usage and implementation of TBDA. Furthermore, TBDA is valuable when companies do development work on different sites. Instead of sending information in text documents, it is very easy for the developer of TBDA to update the TBDA with new information. Many of the international companies use some sort of Product Data Management (PDM) or Product Lifecycle Management (PLM) system where the templates, input and output can be stored. Another aspect to have in mind when developing and implementing TBDA is the time. Not all companies have the resources needed for this type of enhancement. In some of the companies, a few persons have been working on this for a long time, improved the functionality during the usage and gained experience. In other companies they have chosen to enlist the help of an academic institution.

The implementation of support tools like TBDA requires good planning. As TBDA is implemented as a help for the engineering designers while performing design analysis, it is important that “such computer support should be cooperative, subordinate, flexible and useful” [19]. It is important to have this in mind when it is developed and implemented.

Training and knowledge pre-requisites for the engineering designer

Some of the engineering designers that have been using CBDA and now have used TBDA have been part of an internal training program. Such programs are traditionally connected with the generation of geometrical features, but there is also a basic course within the CAD-integrated FE software. There is a wish from the companies that the engineering designers who are going to use TBDA should have to pass the basic course for the integrated FE software. Some of the companies are now in the process of developing a new type of education/training that is directly connected with TBDA and design analysis. To raise the knowledge of these matters within the field of mechanical engineering in general, education/training for a wider circle of staff is also part of the program. Both internal and external resources are used for the education and training programs and there is also collaboration with universities within this field. The pre-requisites to be allowed to perform TBDA are at the same level as for an engineering designer. In most companies, a 3-5 year university program within the area of mechanical engineering is necessary.

IMPACT OF THE USE OF TBDA

For the engineering designer

In the companies interviewed, several engineering designers were already familiar with design analysis, and the introduction of TBDA was actually not appreciated by all engineering designers, as TBDA entailed limitations in their use of design analysis. However, after the introduction of TBDA, engineering designers in general are pleased with the functionality and the outcomes. The survey answers confirm this statement (Figure 23). Some of them have raised their skills both in general design but also in design analysis with the result that the technical knowledge of the product has become higher and thus generated products with a higher product quality.

For the design analyst

Traditionally, during development, the engineering designers send geometrical models to the design analysis department for evaluation against the mechanical properties. One recurring problem has been that the models have not always been mature or adapted for analysis. By introducing CBDA and TBDA, the design analysts have noticed a clear increase of competence in the technical knowledge (see Figure 23). Consequently, the models to be analyzed have generally been at a higher state of maturity, without any demands for modification by the calculation engineer. Moreover, the engineering designers understand better the possibilities and limitations of design analysis and make a more efficient use of the analyses. But as the engineering designers now have a better technical knowledge, a more technical discussion between them can take place. For example, it is now possible to have a deeper discussion about boundary conditions, materials and other technical analysis features than before.

Contrary to what was hypothesized at the beginning of this study, the total number of iterations between the engineering designer and the design analyst has increased. But as a result of higher training in design analysis, more valuable analysis tasks are ordered, resulting in products with better quality.

It is interesting that the design analysts in the companies interviewed are now pushing for an extended implementation of CBDA, especially TBDA. A few years ago, the opposite was true.

For the company

While the overall rating of the use of templates is not higher than that of the other types of support (Figure 12), the overall result is that the companies interviewed are pleased with this type of support for the engineering designers, and further development and implementation are planned in most of those companies.

In the companies that have information and experience of TBDA, it is clear that by introducing TBDA, some benefits have been reached. Most importantly, it is now possible to make more concept candidates and to perform more extensive evaluations of the concepts. A higher understanding of the product is another result. As knowledge about the product rises, the quality of the product also increases. In different pilot projects it was reported that the outcome was so satisfying that it resulted in less physical testing and reduced the total cost for the product. All the companies participating in the survey have experienced improvements in both lead times and quality of the design (Figure 23). The time saved through the help of TBDA was used by the companies interviewed to extend the time for concept generations.

In combination with TBDA, guidelines and some sort of super user (senior engineer or analyst) are used. By introducing TBDA, the companies have found out that there are some other things that have to be improved, among others, the use of PDM/PLM systems. As the usage of TBDA and analysis in general increases, a large amount of digital information needs to be stored, and strategic decisions have to be made on whether it is necessary to save all information.

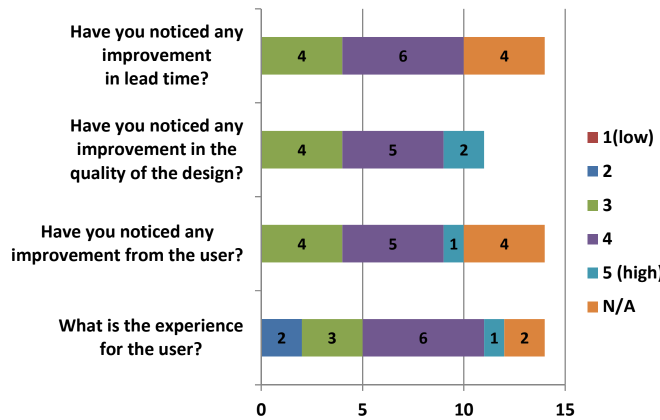

Figure 23. Experienced improvements through TBDA

Costs

The information received from the companies indicates that although they can predict the product cost, they do not yet have a clear picture of the total costs for developing and implementing TBDA. As was mentioned before, all companies are in an early stage and conducting some pilot projects for evaluation. If and when the companies decide to implement TBDA for full usage, one vital factor is the cost of licenses. When implementing TBDA, advanced features must be used and the license costs for these functionalities are rather high. Some companies experience such license problems; it is hard to understand what type of license is needed depending on what type of automation level is used. Moreover, investment in an introduction and/or specially developed training program for the users might be needed.

Next step

All of the companies that have provided information about TBDA are very clear that the implementation is going to continue. Some pilot projects have been finished and there are some ongoing projects that have to be evaluated. The highest priority is to cut the lead time for the whole product, but there is also a demand for lighter products and increased product quality. The main issue now is to review the results from the pilot projects and to review all the processes involved and to adapt them for the full implementation of TBDA.

New CAD/CAE methods that are more suited for TBDA and some other processes that are affected by the TBDA have to be developed to fully support the implementation of TBDA. To be able to handle this new challenge, changes have to be made also at the organization level.

Companies that have not implemented CBDA

Some companies do not plan to implement CBDA, and therefore nor TBDA, for their engineering designers. According to [1], 45% of the companies do not plan for their engineering designers to perform design analysis in the near future. However, in the new survey, 38% answered that it has not been implemented yet (Figure 24), which could mean that they are considering it or have started to think about it. The main reasons for not implementing it are described in Figure 24. One of the main arguments is that the cost is deemed too high, the respondents stating that the return-on-investment was too low. In some companies, it is company policy that the design analysis department performs and has the responsibility for all design analysis activities within the company. Also legal requirements or other standards may prevent the companies from delegating design analysis to engineering designers. Companies also argue that the engineering designer's work should focus on designing new products and that he/she lacks pre-requisites in mathematics and material engineering.

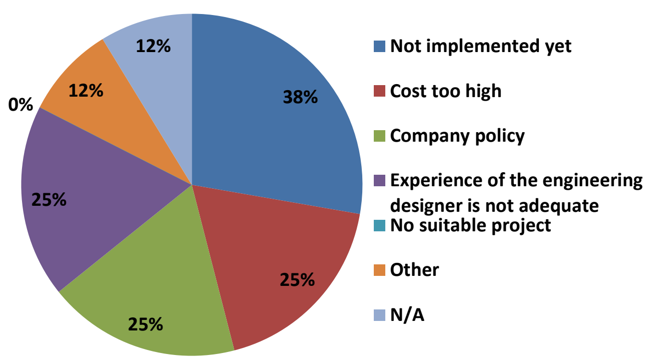

Figure 24. Justifications for not introducing CBDA

A practical difficulty that may also limit the development of TBDA is that it requires software that has the features needed for TBDA. Basic level templates require advanced design analysis tools. For semi-automated and automated templates, KBS and other systems might be required. The company might need to update their current solutions or change their CAD/CAE systems, which is a strategic question.

CONCLUSIONS

The positive outcomes that have been experienced by companies using TBDA are:

- The engineering designer has gained better technical understanding of the products.
- Fewer physical tests are required, which means economical savings.
- The engineering designers have increased their understanding of design analysis.
- The design analysis department is positive to the implementation of TBDA and wants it as soon as possible.
- The number of iterations between the engineering and analysis departments has increased, but as a result of the engineering designer's higher knowledge within design analysis there are better analyses and better products.
- The analysis department does not have to prepare the analysis models before analysis to the same extent as before the introduction.
- Some companies plan to implement TBDA as soon as possible.
- There has been an increase in the number of concept candidates generated.
- The overall product quality has improved.
- The company is introducing new methods to ensure that all analyses are performed according to the same standard.
- A new standard for education/training to be offered to their engineering designers is being developed.
- The answers obtained during the interviews were well correlated to the answers previously given in the online surveys by each of the interviewed companies. This indicates that this is probably also the case for the answers obtained from those companies only responding to the online survey.

Both the companies and the users have given the usage of templates the lowest score among the CBDA types of support for engineering designers (Figure 12 and Figure 13). This can be explained by the fact that it is a less proven type of support. The tools used within KBS, e.g. design table, formulas, Visual Basic and parameters, are dependent on integrated processes and some experience on the part of the user. Still, the companies interviewed were very positive towards TBDA. A definitive explanation to this paradox could not be found.

An interesting topic for further research is to develop TBDA systems that can be used across different development phases (for example both concept and detailed design phases). Even if optimization is integrated in several templates, focus has been on design analysis. From the survey, there are indications that there is a need for further development towards more synthesis aspects, that is systems that would take into account both design synthesis and analysis, enlarging the TBDA concept to template based design synthesis and analysis.

Another issue is integration with PDM/PLM. If PDM/PLM is used, the effects of using TBDA reach even further. As TBDA is a type of template, changes to the template can be made directly within the PDM/PLM system, and all users will then have updated templates available directly, independently of their location. There are problematic areas which need further attention. For example, it is necessary to develop new methods that include all sub-processes, e.g. how to create geometry suitable for the analysis model and how to store generated data in the PDM/PLM system.

The interview and the new survey answers, as well as the cases presented in this paper can be used by other companies (and by researchers) as decision support for whether TBDA for engineering designers makes sense for their business, and as guidelines if they want to implement TBDA. TBDA for engineering designers is not developed enough for anyone to make validated statements about the pre-requisites for adoption of the approach and conditions of success. Nevertheless information from the interviews shows that the implementation will continue.

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