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THE ENGINEERING DESIGNER IN THE ROLE OF A DESIGN ANALYST – AN INDUSTRIAL SURVEY

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Abstract

Traditionally, design analysts are solely responsible for all computer-based design analysis (CBDA). CBDA refers to quantitative design analyses utilising computational tools in the engineering design and development of technical solutions. There are currently limited insights into and knowledge of tools and methods needed to facilitate the use of CBDA by engineering designers. In order to gather information on this aspect of CBDA, an industry survey has been performed.

77 persons completed the survey (16% affiliated to NAFEMS) open for twelve weeks during October-December, 2014. Around 35% answered that within their companies CBDA is used by engineering designers, and 28% of those who are not currently doing so expect to do so in the future. Linear static analysis is the most frequent type of analysis performed by engineering designers. The benefits put forward by the respondents in favour of involving engineering designers in CBDA are: it allows early evaluation of concept candidates, shortens lead time, frees resources for the analysis department, and reduces costs. 26% of the respondents answered that there is resistance from the analysis department against allowing engineering designers to perform CBDA, 19% within the engineering design department are also against this involvement and 26% answered that there has been no problem associated with this involvement.

Even though the engineering designer performs CBDA on his/her own, supervision (56%) and quality assurance of the analysis results (59%) is the responsibility of the design analysts. This is also the case regarding the development of tools and methods to be used by the engineering designers as well as instruction and training of the engineering designers.

1. Introduction

During an engineering design project, the traditional process is that when the engineering designer has developed a concept, product architecture or detailed design solution, these are sent to the design analysis department, which performs the actual computer-based design analysis (CBDA). CBDA refers to quantitative design analyses utilising computational tools in engineering design and development of technical solutions. CBDA is here confined to structural analyses using the finite element method (FEM), computational fluid dynamics (CFD), and multi-body system (MBS), also including supportive tools such as knowledge ware and optimisation tools (shape optimisation, topology optimisation and others)—all within mechanical engineering. A CBDA project might have a number of different objectives, such as evaluation of technical solutions or exploring design parameters in order to validate the working principle for a specific solution or optimise the performance of an actual design.

The influence of the lead time of a CBDA task is substantially dependent on the engineering design project from which it originates. One reason for this is that the design analysis department analyses many different products and designs, most often involving a huge variety of analysis problems, and thus makes it necessary to prioritise the CBDA projects with reference to the priority of the engineering design project from which it originates. Low priority indicates that the lead time will be longer than for a product of higher priority. One example is the evaluation of new concepts, in some companies it has a low priority, the lead time for this type of analysis can sometimes be as long as 6 - 12 months [1]. This may well give rise to situations where engineering designers will focus on more urgent problems than designing new concepts, thus increasing the risk that the company will produce less innovative design solutions.

One solution to this problem is to involve the engineering designers to perform CBDA in a controlled form. The considerable development of CAD-CAE systems, their usability and improved integration, makes that feasible. However, engineering designers will never have the same level of knowledge and experience as design analysts, which increases the risk that the design solutions analysed will still be flawed when they arrive on the design analyst's desk for verification, thereby neutralising all positive effects. The question of cost is also important. If engineering designers are allowed to perform CBDA, instructions and training will be required as well as support, supervision, and possible software adaptation, not to mention the larger number of expensive licenses.

The main objective set out for this paper is 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 NAFEMS and 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.

The paper is outlined as follows. The next section presents related works and background information on the topic. The general approach chosen for this investigation, the selection of respondents and the structure of the questionnaire are then reported. This is followed by the presentation of the results from the answers of the respondents to the questionnaire. The paper ends with a discussion of the results and a conclusion on how the results can be used in the future development of CBDA methods and tools for use by an engineering designer.

2. Related work

This survey focuses on what positive effects the industry might gain from letting engineering designers perform CBDA and how it should be implemented for best outcome. Works that touch on this topic are reviewed below.

In the literature, it has been repeatedly recommended that engineering designers should be trained in CBDA and that software companies should adapt software to their specific needs [2; 3]. However, all authors state clearly that the analyses performed by engineering designers should be limited to well formulated, small, routine or basic design analysis tasks [4; 5]. The engineering designers can get help from the so-called “first-pass” tools for exploring some ideas and quickly eliminate non-viable proposals [6; 7], but thorough verification should be left to the analysts [4; 8].

In order to ascertain how widely the approach of letting the engineering designers perform CBDA is used in the industry, surveys were also reviewed. The EASIT[2] survey from 2011 [9]—1094 respondents from 50 different countries—gave a broad perspective on the use of CBDA in industry; the NAFEMS Simulation Capability Survey 2013 [10]—1115 respondents—shows that CBDA is now used in all phases of a development project, with 30% of all analyses done during the conceptual design phase. However, in these surveys, the proportion of design analyses performed by engineering designers is not brought to surface.

In an industrial survey carried out in 2007-2008 [11] within Swedish companies, answers indicated that in some companies there are activities related to this topic; about 30% of the companies let their engineering designers perform analysis. A study on the use of analysis and simulation during design (before production ramp-up) from 2006, the *Simulation-Driven Design Benchmark Report* [12]—270 companies—, made the first large attempt to clarify the companies' attitudes and strategies regarding the use of engineering designers to perform CBDA. The report established that involving the engineering designers to perform analyses was by far a minor issue compared to the other challenges of performing CBDA early. The number of companies involving engineering designers to perform analyses is not mentioned, but 29% of these companies provided easy-to-use software (CAD systems with embedded CAE for example) to their non-experts, giving an indication that around one third of the companies let their engineering designers perform analyses. This is similar to [11] , see above. The companies have also training programs in the form of tutorials, generic and specific examples, and training materials. In a follow-up study from 2013 [13], it was found that 41% of the 488 interviewed organisations captured simulation expertise to make it available to engineering designers and less experienced users; around 45% had expert users mentoring new simulation users; and analyses performed by non-experts were supported by senior management in 26% of these organisations.

Finally, research or reports on general technology development or method development were also investigated. Technology or method development, in the analysis terminology, is the development, verification and validation of specific guidelines, procedures or templates(1)for the analyst or the engineering designer to follow when performing a design analysis task [14, p. 1188]. This can be partially or fully automated. These guidelines define for example what types of meshing are allowed, what loads and boundary conditions are to be considered, what results are to be extracted and evaluated, etc. This allows for engineering designers to make some specific types of analyses while leaving more advanced analyses to the expert. Technology development or method development is present in several companies and is mentioned in [10; 12-14], but only a few papers in this area were found. Moreover, templates are not presented as a way of supporting CBDA. In [15], a methodology has been developed to facilitate the use of topology optimisation by engineering designers. In an industrial application reported in [16], a positive result could be achieved by introducing design analysis and optimisation to the

[1] Pre-developed code that supports or guides the engineering designer in performing design analysis tasks, e.g. from predefined settings available in traditional tools, to developed in-house scripts, and advanced usage of knowledge ware.

engineering designer, all done under the supervision of a design analyst. The result from this work indicates that costs, weight, and lead time can be reduced significantly, as the engineering designer, with a little effort, might be able to evaluate a concept directly without waiting for the analyst to carry out the analysis of the concept. In two other projects [17; 18] it was shown that it was fully possible to secure quality and to configure the CAD system in a way, which confines the use of the software to those approved in advance. These two projects also shows that it is possible to support the engineering designer while performing CBDA by integrating different types of support system, in the actual case by using knowledge based systems (KBS).

3. Approach

The chosen format for this survey is that of an online questionnaire, in order to be able to reach international respondents. The survey contained a maximum of 73 questions (depending on the answers of the respondents); most of the questions were in closed format; in some of the questions, the respondents had the possibility to give additional information. The online survey tool www.quicksearch.se was used.

In order to reach relevant respondents, the following strategy was pursued. An announcement on the home pages of NAFEMS and the Design Society, and an article in NAFEMS's magazine *Benchmark* were published. To be able to reach out to those who are not members of these organisations, postings in different member groups within ASME (15) and LinkedIn (35) networks were made. Finally, a set of companies, mainly selected from an earlier survey on CBDA [11], were chosen and invited to answer the questionnaire through personal invitation. Even though there were different kinds of invitations to this survey, all respondents were handed the same information and all had the same opportunity to answer it. In the questionnaire, there was a possibility for the respondents to give their e-mail address if they were willing to answer additional questions and if they wanted feedback on the results from the survey.

The questionnaire was divided into the following eight sections linked together according to the flow chart, which is presented in Figure 1.

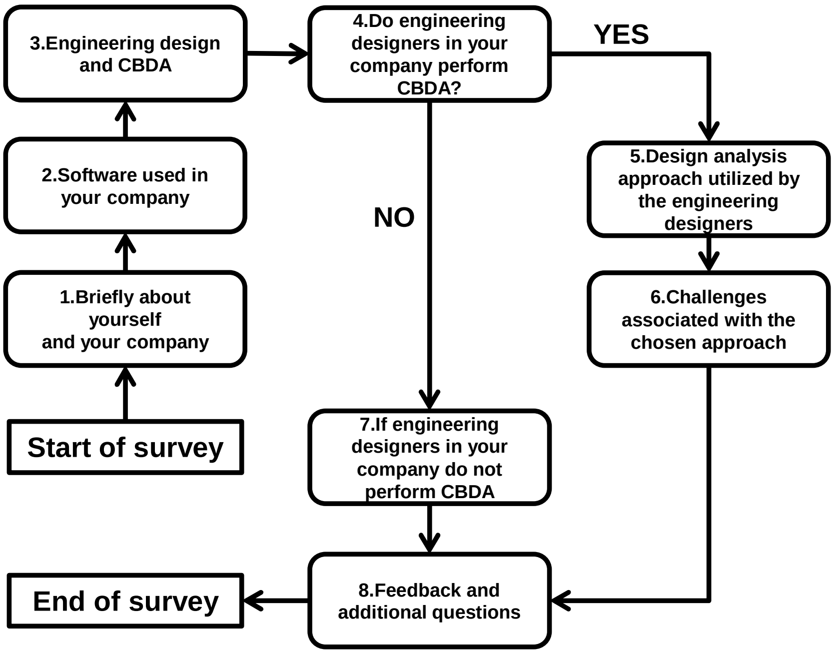

Figure 1: Flow chart of the questionnaire

1. **Personal information and information on the company**

2. **Software used in the company**

3. **Engineering design and CDBA**
   Presence of a formal product development and/or analysis process model in the company, mode of integration between engineering design and design analysis activities, use of CBDA in the different phases of the product development process.

4. **"Do engineering designers in your company perform CBDA?"**
   The question in this section directed the respondents into one of two different tracks depending on their answer.

5. **CBDA approach utilised by the engineering designers**
   Questions about how the analysis is utilised, development of methods, training, and/or support, quality assurance (QA), type of analysis performed and resources allocated for this activity.

6. **Challenges associated with this approach**
   Problems related to letting the engineering designers performing CBDA within the company.

7. **If engineering designers do not perform CBDA**

Respondents were asked whether there are any plans for implementing this activity in the future.

8. **Feedback and additional questions**

4. Results from the survey

The total number of respondents that started the survey was 282, 77 of whom completed it. The respondents came from 71 different countries, three answers(2) came from the same company or organisation and three did not identify the company they belong to. After question 4 the survey was divided into two different tracks, see Figure 1. For sections 5 and 6 the number of respondents was 27 and for section 7 it was 50. Note that the results are sometimes presented in in form of percentage and sometimes in absolute values.

Respondent status and information about the company, section 1.

From Figure 2, the results show that the major part of the respondents were engineering designers (39%) and design analysts (27%) followed by managers (14%) and project leaders (13%).(3) The educational level of the respondents shows that most of them hold a Master's degree or equivalent education (48%) followed by 30% Bachelor's degree or equivalent and 20% holds a PhD degree, Figure 3.

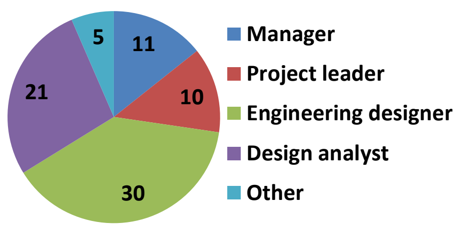

Figure 2: Primary position of the respondents

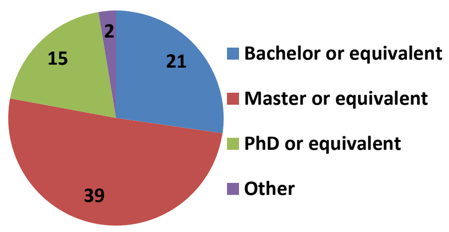

Figure 3: Formal level of education of the respondents

Compared to the Easit[2] survey [9, p. 16], these show similar numbers. In the field of experience of the respondents, it was found, Figure 4, that

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[2] After examination of the respondents' answers, it was possible to discern that they belong to different analysis departments/sections within the same company; the responses have therefore been included in the survey in the same way as the responses from the other respondents.
[3] Some of the professions originally entered by the respondents in the Other category have been assessed as belonging to the main categories (for example: "FEM engineer" or "stress engineer" have been included in the Design analyst category); the presented figures have been corrected accordingly.

67% have held their position for less than 10 years and 12 % have held it for more than 20 years. The results in Figure 5 show how the respondents were invited or how they found the survey. The respondents were invited from NAFEMS (16%), Design Society (4%), ASME (8%), and by personal invitation (21%). Most in the last-mentioned category are personal invitations from the authors of this paper. The last category was Other (52%); most of them came from different groups within LinkedIn. Overall, the respondents were employed in organisations involved in engineering consultancy (35%), manufacturing (45%), or Other (20%), as shown in Figure 6. In the Other category involves resellers, training institutes and academia.

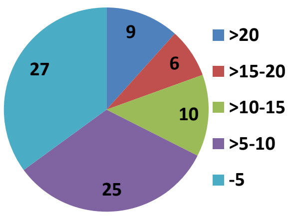

Figure 4: Number of years the respondent has been working in her/his current position

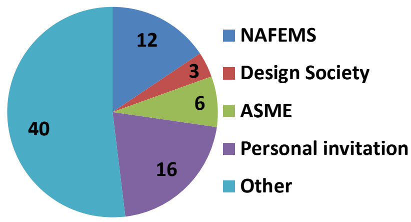

Figure 5: Engineering associations from where the respondent received this questionnaire

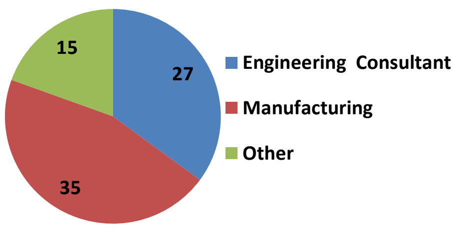

Figure 6: Type of company

The classification of the different industrial branches originates from the software manufacturer Dassault Systèmes [19]; it is similar to the classification used in the NAFEMS Simulation Capability Survey 2013 [10]. Industrial equipment (31%), aerospace and defence (23%), transportation (23%) are branches in which most respondents operate (Figure 7); these also represent branches where design analysis is often used.

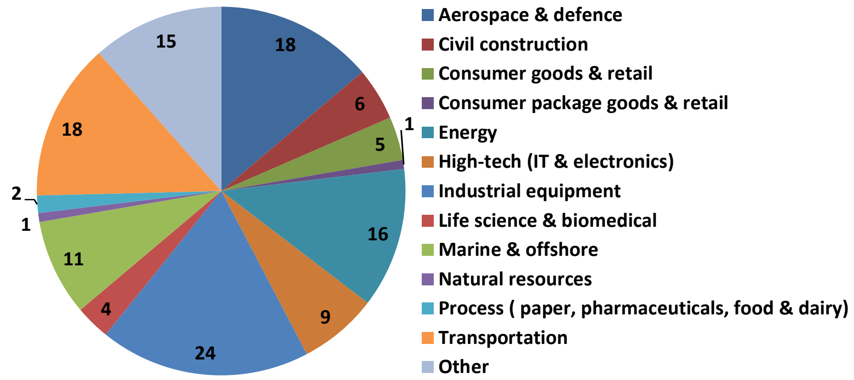

Figure 7: Industrial branch to which the respondent's company belongs

Looking at the number of employees belonging to the category engineering designers (43%), Figure 8, and design analysts (58%), Figure 9, are mainly working within smaller companies that have between 1 to 10 employees. For companies with 11 to 50 and 51 to 100 employees these categories are 22% and 17% respectively. For large companies with more than 101 employees, the numbers are 23% and 8%.

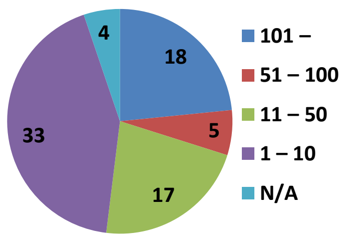

Figure 8: Number of engineering designers employed in your company

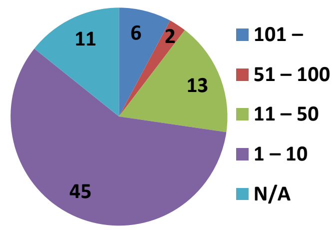

Figure 9: Number of design analysts employed in your company

Software used in the companies, section 2.

The software used for creating geometry is presented in Figure 10. Most frequently used software was: Autodesk (36%) followed by SolidWorks (34%) and Catia (30%). Additional software used was NX (21%), Pro/E, Creo (13%), and other (18%). In the Other category the respondents listed special software used for advanced surface creation and other software not listed as a special category in this survey. Least used software is Solid Edge (8%), DesignModeler (4%) and SpaceClaim (1%).

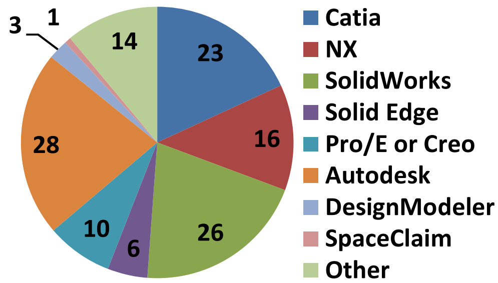

Figure 10: CAD software used in the companies

The type of software used for stand-alone design analysis and optimisation is presented in Figure 11. Structural analysis (73%) is the most common type of analysis, followed by thermal analysis (40%), computational fluid dynamics (39%), and optimisation (27%). The softwares least used are those for multi body simulation (23%), in-house developed software (25%) and other (23%). In the last two categories the respondents listed Matlab, Comsol and MS Excel. All of the top five listed software offer integrated CAE capability, and 60% of the respondents use this kind of software. KBS is also a type of support tool integrated into the most of the software used. There is a low usage of this type of software. Only 10% of the respondents report that they use some type of KBS, and 88% of them use the CAD-integrated KBS.

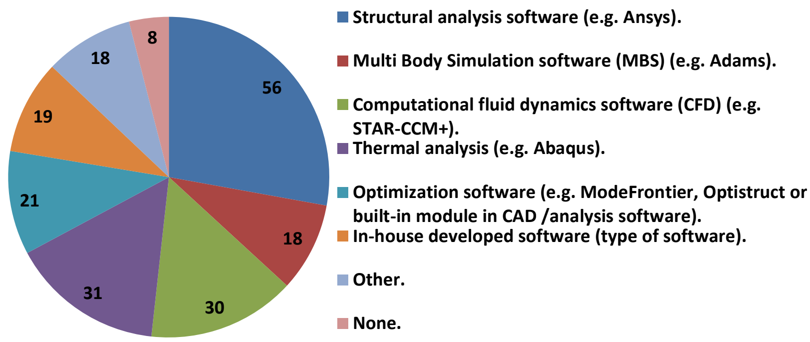

Figure 11: Stand-alone design analysis and optimisation software used for analysing products

Engineering design and CBDA, section 3.

In the literature within engineering design and design analysis, process models for each of the two categories are fairly well described. However, the integration between these two types of processes is much more difficult to find [11; 14]. The majority of the respondents answered that they utilise a formal engineering design process model (44%), see Figure 12, but 27% were using a formal CBDA process model—see Figure 13. When it comes to fully integrated process models, Figure 14, 21% answered that they use an integrated CBDA process models. A large number of respondents (37) answered the question by N/A. This might indicate that they the respondents did not know either whether their company had any integrated process model or that they did not understand the meaning of the concept of integration in the given context.

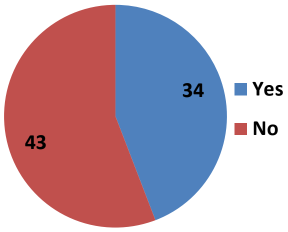

Figure 12: A formal engineering design process model is utilised

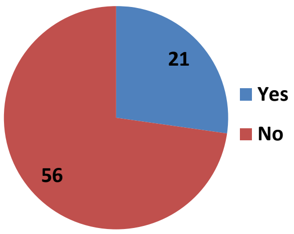

Figure 13: A formal CBDA process model is utilised

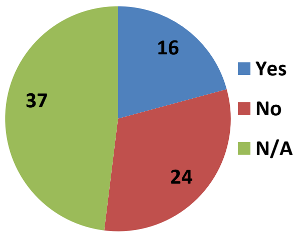

Figure 14: The engineering design process model and the CBDA process model are integrated

Figure 15 shows the percentage of the design analysis activities the companies perform in all the different phases of the product development process.The average results are presented in Figure 16 and compared to the NAFEMS Simulation Capability Survey 2013 [10].The results are quite similar and indicate that the companies that answered the present survey are representative. The relatively large usage of CBDA in the manufacturing phase can be explained by the fact that the manufacturing of production equipment is a part of this phase. In the Other category, respondents have put elements such as analysis for solving problems outside a product development project, failure analysis of returned parts and for analysing deviations, while in [10] the Other category was primarily chosen by respondents who were using the capabilities for methods development or other research activities. By cross-tabulating the data, it could be found that of the 27 respondents who answered that they utilise an integrated process, 10 of them involve their engineering designers to perform design analysis.

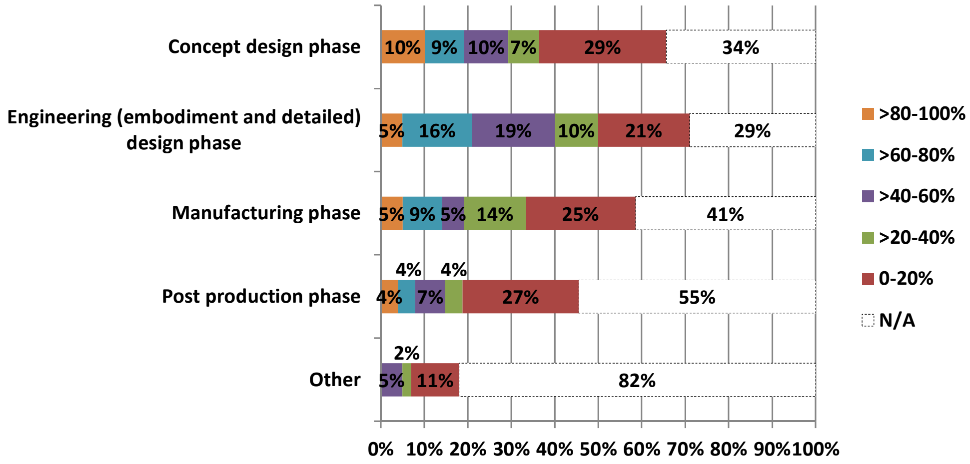

Figure 15: Distribution of the analyses performed over all development phases (read: 10% of the companies spent 80 to 100% of their analysis capabilities in the conceptual design phase)

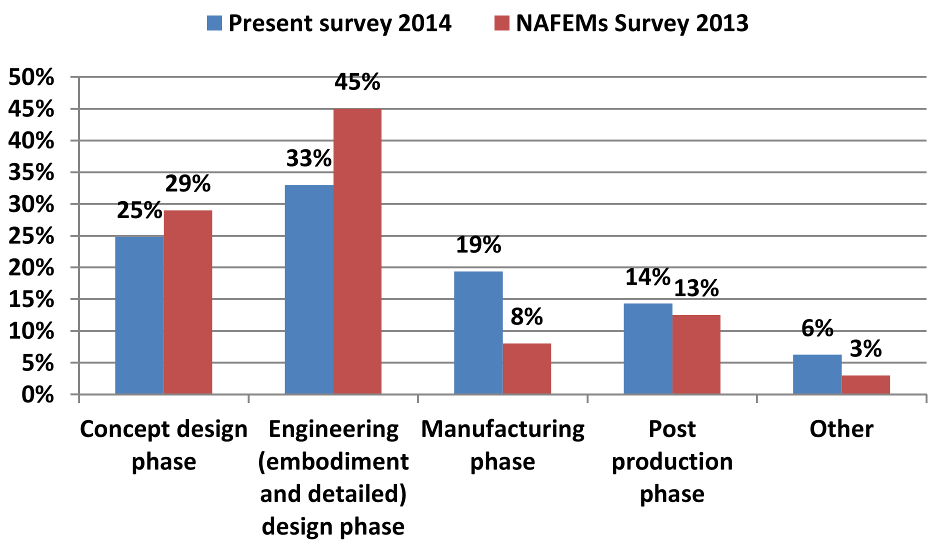

Figure 16: Comparison of the present survey with the NAFEMS Simulation Capability Survey 2013 [10]

Do engineering designers in your company perform CBDA? section 4

To that question, 35% answered that their engineering designers perform design analysis (Figure 17). This is similar to the figure from the Aberdeen reports [12; 13], mentioned in the Related Work section. From those that answered no (65%), the reasons for which the engineering designers do not perform CBDA were that they do not have any projects that are suitable for this activity, or it is a policy within the company that all design analysis should be performed by an analyst. These respondents were further asked whether they planned to implement such an approach in the future. These results are reported section 7.

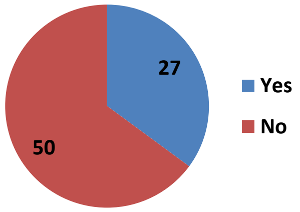

Figure 17: Do engineering designers in your company perform CBDA?

CBDA approach utilised by the engineering designers, section 5

The respondents were asked to assess the value of the advantages obtained by letting engineering designers perform CBDA on a 5-point rating scale. The results are presented in Figure 18. The average score for each advantage is as follows: to allow early evaluation of concept candidates (4.0), frees resources for the analysis department (3.9), shortens lead time (3.6), to facilitate an evaluation of additional concept candidates (3.5), to facilitate a more extensive generation of concept candidates (3.3), economical reasons (2.6) and to limit the use of engineering consulting companies (2.4).

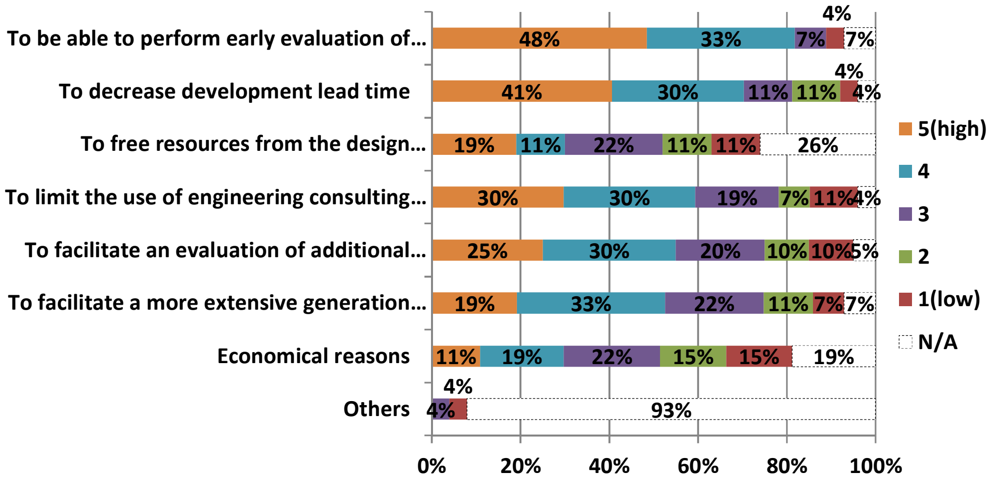

Figure 18: The advantages obtained by letting engineering designers perform CBDA

The companies that allow the engineering designers to perform CBDA have a plan for supporting and training their engineering designers. Supervision by a design analyst (56%) and special training (48%) is the support that is used most frequently, see Figure 19. Even though the engineering designers receive support while performing CBDA, it is important to secure the quality of the analysis performed. Most of the companies have some sort of quality assurance approach: control by a design analyst (59%), followed by specialised guidelines (37%), see Figure 20.

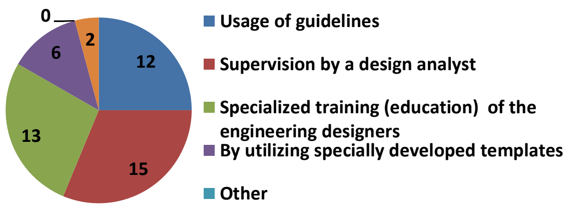

Figure 19: Types of CBDA supports for the engineering designers

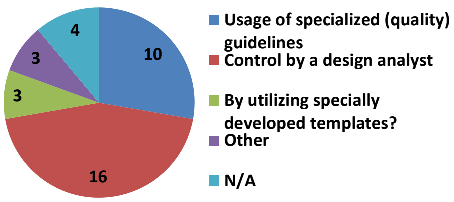

Figure 20: Quality assurance for the results of CBDA performed by the engineering designers

Figure 21 delivers an interesting result. The development of the CBDA approach is mainly done within the company, and it is done in cooperation between the engineering design and design analysis department.

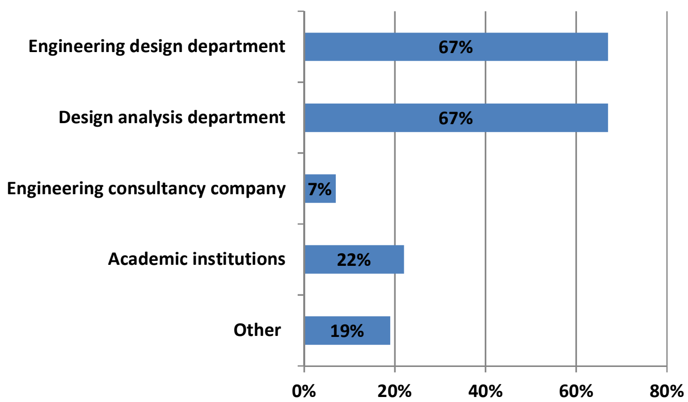

Figure 21: Responsibility for developing the CBDA support(s) for the engineering designer

67% answered that they only deliver a basic level of support during the analysis activity for their engineering designers, while 41% answered that they utilise a semi-automatic level of support, Figure 22. Among the different targeted analysis types for which a CBDA support for engineering designers has been developed, linear static (85%) is the most frequent one, followed by non-linear analysis (52%). CFD (41%), thermal (37%), dynamic (37%), and optimisation (33%) also have CBDA support for engineering designers, see Figure 23.

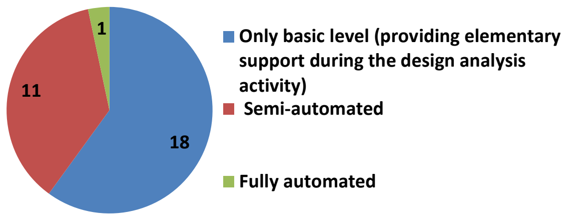

Figure 22: Automation level built into the CBDA support for engineering designers

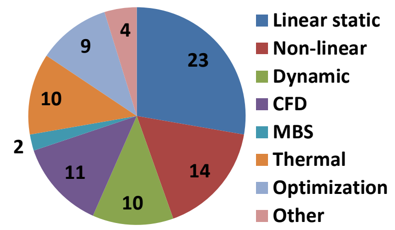

Figure 23: Usually targeted types of design analyses with CBDA support for engineering designers

Validation and verification (V&V) is used for the CBDA approach supports in all cases. Verification is the assessment of the accuracy of the computational model of the design solution, and the validation is the assessment of the accuracy of the simulation results by comparison to data from reality by experiments (by means of prototypes) or physical measurements in working environments. Most frequently used is physical testing and comparison with field data (67%), which corresponds well with the findings in [11], followed by reviews by an expert (56%) or by using different resources within the company (41%). Only 15% answered that they use external resources for the V&V, see Figure 24. Two respondents answered that they do not use any V&V (category Other). It is interesting to note that there seems to be increased engagement in verification from other resources in the company and thus not relying on analyst individual responsibility as found to be the case in about 44% of the companies interviewed in [11].

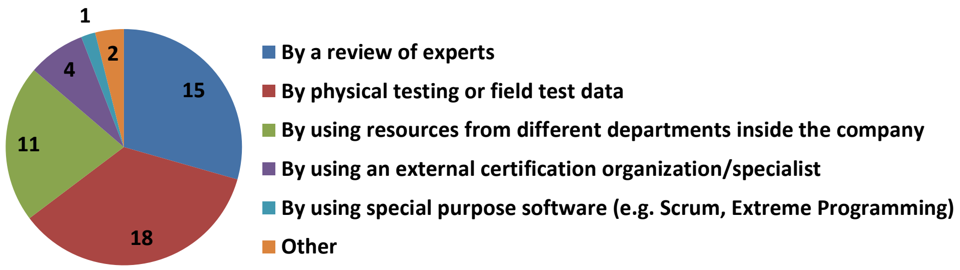

Figure 24: Verification and validation of the results of CBDA performed by the engineering designers

Built-in support for the interpretation of the results is used by 44%, see Figure 25. For this activity, special guidelines and/or instructions (67%) or post-processing calculations on established results based on applied rules (58%) are utilised, see Figure 26.

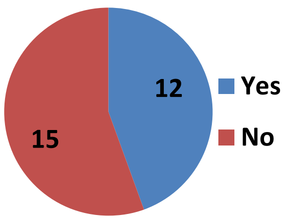

Figure 25: Built-in support (during or after post-processing) for the interpretation of the results of CBDA performed by the engineering designer

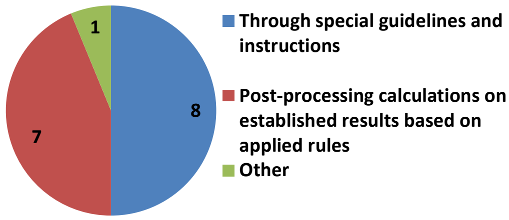

Figure 26: Interpretation of the results of CBDA performed by the engineering designer

How the companies divide their activities between engineering designers and design analysts usually depends on what type of design analysis is to be performed. The complexity of the design analysis task (78%) and the type of design analysis (67%) are the factors considered for the allocation of the design analysis activities, see Figure 27.

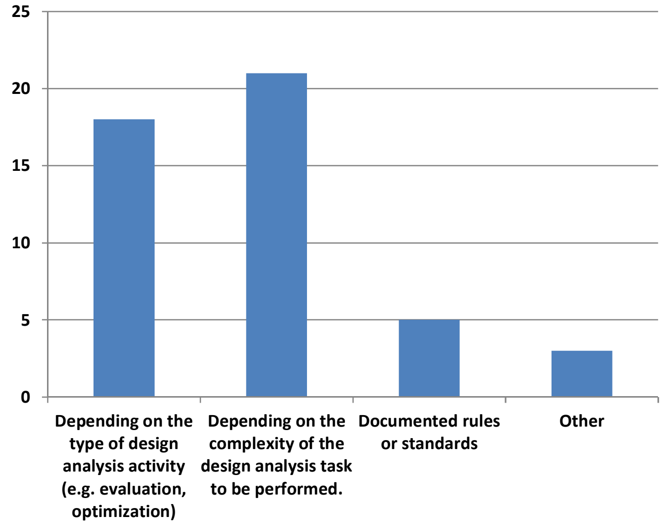

Figure 27: Grounds for allocating design analysis activities between the engineering designers and the design analysts

From this survey it is obvious that the design analysts have an important impact on the CBDA supports for the engineering designers. When preparing the engineering designers for the use of design analysis, 74%, compared with 61% from the Aberdeen Group report from 2013 [13], answered that support from the design analysts is most frequently used, and 33% of the respondents answered that special training had been developed for this purpose, see Figure 28.

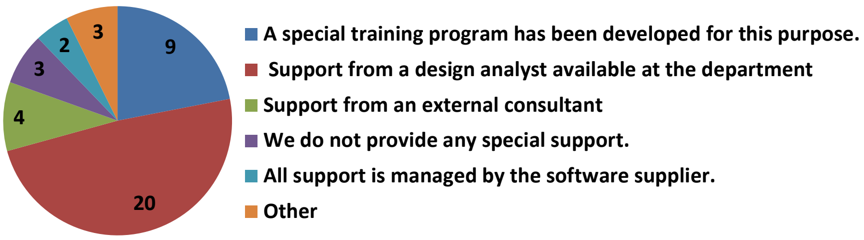

Figure 28: Preparations for the engineering designers to perform design analysis on their own

In Figure 29 the results show that physical testing and/or advanced simulation by a design analyst is the most common approach for validating the result from CBDA performed by engineering designers (76%).

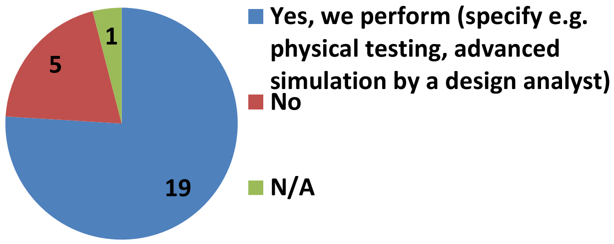

Figure 29: Measures taken to control the results obtained from the CBDA performed by the engineering designers

Challenges associated with the chosen approach, section 6

Implementing CBDA is not an easy task. There is always some problem that has to be solved, Figure 30. The most frequent problems are hardware and software issues (30%), resistance from the design analysis department (26%), and resistance from the engineering designers (19%). 26% answered that they have not met with any problems. Two respondents also answered that KBS is something not many coompanies understand or do not know how to use.

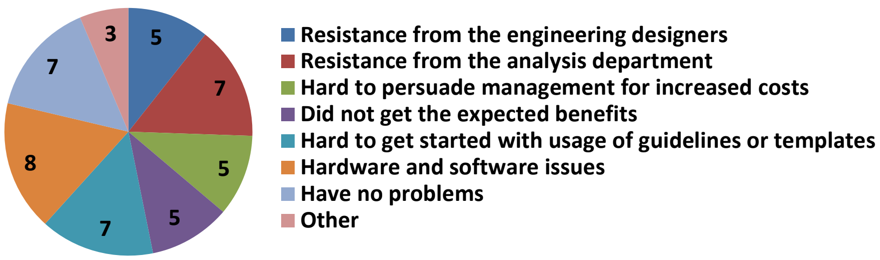

Figure 30: Experienced problems when developing and using the CBDA supports for the engineering designers

Companies without CBDA support for their engineering designers, section 7

For those who answered that their engineering designers do not perform design analysis (65%, see Figure 17), 28% have future plans to implement CBDA for their engineering designers, see Figure 31. They will implement CBDA for their engineering designer as they see an advantage in: higher productivity, shorter lead-time and cost savings. Some of the arguments put forward by the respondents who do not plan to implement CBDA support for their engineering designers, were that, among other things: the engineering designers did not possess enough knowledge about CBDA, management did not see any benefits, it was not required for the company's projects or the projects were to small, or the workload of their engineering designers was already too high.

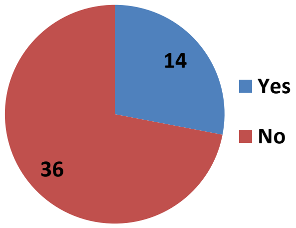

Figure 31: Future plans to implement CDBA supports for the engineering designers

Feedback and additional questions, section 8

The questionnaire ended with some questions requesting feedback from the respondents on the questions in the survey, whether they wanted to be sent the results and whether they were willing to answer additional questions. 62% answered that they wanted direct feedback on the results of the survey, and a surprisingly high percentage (54%) answered that they were willing to answer additional questions.

5. Discussion and future work

About the survey approach

The number of respondents can be considered as quite low (77), given the call for participation was made through many different channels (most responses came from LinkedIn and their member groups.) However, the respondents were members of NAFEMS, belonged to professional analysis groups, or were personally invited, so the respondents can be considered as knowledgeable in the field of inquiry. Moreover, among those who have responded, 77% came from the industrial equipment (31%), aerospace and defence (23%) and transportation (23%) sectors, which have extensive use of design and design analysis. Also, for the questions asked in other surveys, such as the NAFEMS Simulation Capability Survey 2013 [10] and the Aberdeen reports [12; 13] the answers had similar rates (see Sections 1 and 3). The answers can therefore be considered as sensible and reliable.

About the survey results

First and foremost, this survey establishes that 53% of the companies have introduced or plan to introduce CBDA for their engineering designers, a very high number. The results from the survey show that there are possible savings in lead time, opportunities to generate additional concepts and lower costs. It is also interesting to see that, in some of the groups where the survey was posted, there are discussions in progress regarding this subject, and the majority of the respondents are willing to answer additional questions. This shows the broad attention this subject has attracted from the community.

At the same time, relatively few academic works have been published on the subjects. There are several challenges to address, such as cultural changes (resistance from the engineers and analysts), need for training… Regarding education, it might also be necessary to ensure that design analysis is given sufficient attention in engineering design education programs. Training of engineering designers pointed out as a main challenge in the NAFEMS FENet survey of 2005 [20], see also [21].

One specific aspect that also requires further investigation is the potential benefits from the use of templates. Templates present the possibility to control quality in the work of the engineering designers without the constant involvement of expert analysts, but developing them requires resources. This and other related challenges are therefore to be taken up in a follow-up survey, to be released in late January 2015. It will be addressed to the respondents of this survey who accepted to answer further questions as well as new invited companies.

Raw data from the present survey are available upon request.

Future work

The survey revealed many interesting answers as presented in this paper but there are still questions that need to be further investigated. For example, the reasons behind the large resistance to the use of CBDA (26% of the design analysts and 19% of the engineering designers) need to be investigated. In the follow-up survey mentioned above, focus is set on getting fine-grained knowledge about the subject of letting the engineering designers perform CBDA, mainly in terms of gained collaboration, cost savings, shorter lead times and on the types of support required in the different product development phases (especially templates). Of those 54% that answered that they are willing to answer additional questions, 56% answered that they do not let their engineering designers perform CBDA; it might be interesting to see if this number has changed between the two surveys and, if so, what the reasons behind it might be. The survey will also be complemented by personal interviews in targeted companies.

6. Acknowledgments

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