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KNOWLEDGE-BASED DESIGN: HOW MUCH SUPPORT IS EXPEDIENT?

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ABSTRACT
The present field study compares different types of CAD models for design, and explores which of two templates – with or without advanced features – is more efficient, and why. Design engineers from a company solved three adaptive design tasks. Design performance, design time, and design process were analyzed. The results of this study show that the usefulness of templates with or without advanced features depends on the complexity of the task. In accordance with the results of the study's CAD models, new guidelines are created.

Keywords: knowledge-based design, advanced feature, CAD Design, templates

1 INTRODUCTION
The high dynamics of the current market involve increased requirements in terms of the function and quality of products. Accordingly, the complexity of design processes is increasing, whereas product development times are decreasing [1].
CAD systems have been used to handle design tasks since 1960 [2]. CAD systems have been continually developed, and will continue to be enhanced in the future: for example, the much-used CAD system CATIA V5 facilitates a parametric associative construction, which leads to adaptive products. It is assumed on the one hand that the time for implementation of new requirements decreases, but on the other hand that the complexity of design increases by using parametric associate CAD systems [3], [4], [5], [6].
Beside the new CAD Systems facilitating adaptive products, companies have initiated many activities in order to support the engineers' work. One possibility for reducing the abovementioned design complexity is to standardize the modeling method and structure of parts [3]. The modeling method is very important for the parametric associative design. It is possible to design adaptive products only by using a good modeling method. Therefore, many companies produce uniform modeling methods for their engineers, which are described in CAD modeling methods guidelines. The guidelines, developed by CAD experts and designers, include experience in relation to the appropriate function, procedures, and reference for the design of parts or assemblies [4], [5], [6], [7].
The second possibility for reducing complexity is standardization of the part's structure, which is realized with uniform structure start models, the basis for the following design. The uniform structure start models include the production steps as fixed structures [4].
Some companies proceed using knowledge-based design in the form of templates. Templates are defined as CATIA V5 CAD models that include the basic geometry of the part or assembly. These CAD models are based on the uniform structure start models and the modeling methods. The aim of the knowledge-based design is to replace the time-consuming new design of parts or assemblies. The part, which is designed using optimized methods, should facilitate rapid design and the part's adaptation to new requirements [8].
They are many possibilities for designing with CATIA V5, and, accordingly, there are many possibilities for designing a template. The key question here is which kind of template really supports the engineers' work – in the long run, many people will be working with the templates!

The aim of this paper is to answer the question of which kind of template – with or without advanced features – is more efficient, and why. This also includes the question of how much technology and prescriptions generate benefits, and when. In addition to technical possibilities, the following study considers human cognitive aspects during design.

Advanced features are prepared, single components of body parts that are used more than once. The engineers do not have to repeatedly design these components each time, but instead obtain the components in form of advanced features stored in a CAD catalogue inventory. Here, the CATIA V5 history tree visualizing all construction steps shows only the important information for the components. The amount of information is less compared with design without advanced features [3], [4], [5].

If we examine this topic from a psychological point of view, the question arises as to what extent the use of advanced features supports the problem-solving process. Advanced features can be considered as a cognitive instrument [9] that shows only the relevant information. The level of information in the history tree is reduced. Given the limitation of cognitive human resources, especially the limitation of working memory, the amount of information is a very important aspect for the problem-solving process. The working memory has a dual function: it is used for storing information on the one hand, and for processing information on the other [10]. Both processes compete for the same resource [11]. The working memory greatly influences the design problem-solving process. People adapt the problem-solving process to the mental resources, if the mental burden to high. They use simplified and incorrect presentation of the problem [12]. The higher the mental burden is the design problem-solving process is less successful and less efficient. The aim should be to relieve the burden on working memory [13], [14]. This can be accomplished by reducing the present amount of information to a minimum that is necessary to solve the task [15], [16]. The design of the advanced features includes exactly this principle: only the necessary information is presented to the engineer. All information about the construction of advanced features is hidden, but this information can be viewed if desired. Engineers also have the option of viewing the information in units. This allows a simultaneous handling of essential cogitations [17], [18]. Furthermore, the reduced level of information gives a unique structure to the part. The understanding of the part is easier, the time necessary to search for information is reduced, and it is easier to classify new elements [19], [20].
However, another aspect needs to be considered when evaluating these advanced features. Engineers who use an advanced feature also need knowledge of the feature. In contrast to design without advanced features, engineers need knowledge about the usage of advanced features, as well as the limits of and guidelines for working with them. If the engineers use the respective advanced features less often, it is conceivable that they would need more time for construction with advanced features than without them. Here, it should be discussed to what extent the usage of advanced features is an advantage. On the one hand, the use of advanced features should facilitate a better overview of the part and it can therefore be assumed that the design time is shorter, owing to shorter analysis time. On the other hand, it is ambiguous to what extent the guidelines for working with advanced features have an influence on the performance. Additionally, the question of the role of the task complexity should be answered.

In summary, there are arguments for using templates with advanced features, but also for the work with templates without advanced features. Thus, the following question arises:

Are there any differences between designing with templates with and without advanced features in terms of design performance, design time, and design process, and is this dependent on the task complexity?

2 METHOD

2.1 Sample

The study was conducted with six male engineers, who were assigned to two groups. One alternative for this sample could be the use of students as participants. However, students have no or only limited skills in the use of CATIA-V5. Engineering expertise in CATIA-V5 is the basic qualification for solving the design task, and is therefore an important variable for this study. Consequently, this knowledge gap would be detrimental to the results of the study. The forgoing of a large number of participants in favor of the closer of implementation field is justified [21].

The average age was 33.7 years (SD=5.2), and the average work experience was 6.4 years (SD=7.4). All participants had experience with the CAD system CATIA V5, in addition to engineering experience.
Owing to the low number of participants and trying to control a confounding variable (skill with "CATIA-V5-enginnering"), participants was assigned to parallel groups that were assessed at the beginning of this study by means of a questionnaire (s. 2.3). The groups were then randomly assigned to one or the other of two predetermined conditions (with advanced features or without advanced features).

2.2 Procedure of the explorative study

Before the explorative study began, there was an informative meeting for all participants.
The explorative study included two meeting times, one week apart. During the first meeting, the participants dealt with two adaptation design tasks. The first, complex task included the adaptation of an existing reinforcement of a roof rail. In a second, less complex task, the engineer adapted the trimming of the reinforcement of a roof rail (trimming 1). During the second meeting, the participants performed a third task, which was also a less complex trimming task (trimming 2). The task complexity was defined on the one hand on the basis of expert rating and on the other hand on the basis of the amount of steps in the CATIA history tree. The task complexity increases with rising amount of steps in the CATIA history tree [22]. The participants of the first group solved the first two tasks with the advanced features and the third task without the advanced features. The participants of the second group solved the first two tasks without the advanced features and the third task with the advanced features.
At the start of each experiment, all participants received their task instructions. Afterwards, participants had one hour for solving the first two tasks, and in the second meeting three quarters of an hour to solve the third task. During the experiments, participants were called on to describe their design process while thinking out loud. Additionally, the activity in CATIA V5 and the participants were recorded by video camera. The resulting films were the basis for the assessment of the design process. After solving the design tasks, participants filled out a feedback questionnaire.

2.3 Measurement

Questionnaire for the group formation

During the informative meeting, participants filled out a questionnaire that included questions concerning demographic data, e.g. age, gender, or occupation. Additionally, questions were asked concerning CATIA V5 engineering experience, including the amount and name of the design parts, as well as the time since the last part was designed. Those details were questioned for the different design tasks "new construction," "adaptation construction," and only "checking a construction." Additionally, the hours of working with CATIA V5 in the last year and the hours spent for the different design tasks during the last year were documented. The data regarding the CATIA V5 engineering experience were weighted differently, depending on the relevance for the task. Thereby, a point score was calculated for each person and this was the basis for the formation of the groups.

Feedback questionnaire

After having finished the task, the participants who used the templates with advanced features have had the opportunity to give feedback about their experiences. The participants were asked how easy the use of templates with advanced features was, which aspects were good, and which aspects should be changed. They were also asked to name advantages and disadvantages of the advanced features, as well as the question whether the work with or without advanced features was easier. Additionally, the participants had to state whether they to would like to use advanced features in their future work.

Design performance

The design performance was operationalized with two dimensions: the quantitative mass and the quality of the design product (modeling method). The quantitative mass is defined as the degree of performance of confronted task requirements. The relation between accomplish and necessary performance was calculated. The modeling method has a special role in CAD design. There are different methods for designing a part. Accordingly, different engineers can design the same part using very different methods. As mentioned above, an easy redesign of a part postulates a correct method

constitution of the part [4]. In other words, depending on the modeling method, engineers need more or less time for adapting the part. The actual design process is affected by consistent changes, which are a result of changing general conditions. Accordingly, a modeling method that allows an easy adaptation is more efficient for a company than another method. For measuring the quality of a product, it is necessary to evaluate the possibilities for simplifying and redesigning the product for another frame [4]. Criteria for quality design were derived on the basis of the company-internal modeling method guideline.
The design CAD models of the participants were first analyzed separately to establish the accomplish requirements and modeling method, with the maximum percentage quotation of 100% for each dimension. In a second step, the design performance was calculated by the sum of both the accomplish requirements and modeling method. The maximum percentage quotation that was assigned for the design performance was 200%.

Design time
Design time included attended time for solving the design task. Reading the task instruction was not included.

Design process
The design processes were encoded on the basis of the films, which included the activity in CATIA V5 and the participants, and also what the participants said during they solved the design tasks.
For analyzing the design process, the categories of activities were arranged by a categorize system. Figure 1 illustrates all activities that are possible during the design process. Two independent coders analyzed the design process separately for inter-rater consistency of the coder procedure. The inter-rater consistency was Cohen's $\kappa = 0.64$. The limit of a high inter-rater consistency was accomplished, which is Cohen's $\kappa > 0.60$ [22].

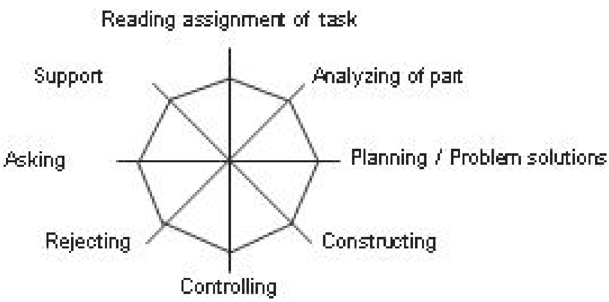

Figure 1: Categorize system

3 RESULTS

3.1 Feedback questionnaire
Participants reported an advantage from using the advanced features: they assumed that the design time is shorter, and that the design of the geometries is faster. However, the engineers remarked that there is a disadvantage with the assumed higher file size and the assumed inferior stability of the CAD models. They reported that the larger the file size, the longer it took to update the product. In regards to the participant's evaluation of these features, the participants' opinion of advanced features is that it is obvious that the advanced features are dependent on the engineers' expertise with CATIA-V5. Participants with CATIA-V5 engineering expertise rated altogether features more positive than those with little CATIA-V5 engineering expertise. In total, five of six engineers would like to use the advanced features in their work context.

3.2 Design performance

Opposite results were found depending on the complexity of the design task: higher performance by templates with advanced features in complex task, but higher performance by templates without advanced features in less complex tasks.

Table 1 shows the results for the three tasks. The design performance was higher for the group that used the advanced features (AF) in solving the complex task. The higher design performance is based on a higher percentage quotation of modeling method. In regards to quantitative mass, two of three participants in both conditions solved the accomplish requirements. In each group, one person did not achieve full percentage quotation (with AF: 58%; without AF: 83%). One engineer with less knowledge of CATIA-V5 from the condition advanced features group was unable to finish the task within the given time. Likewise, another participant with less knowledge of CATIA-V5 from the condition without AF forgot some of the requirements.

An opposite result was found for the less complex tasks. The group that worked without advanced features had a higher design performance. These results were based sometimes on a higher percentage quotation of quantitative mass, and sometimes on a higher percentage quotation of modeling method.

In trimming task 1, the group that used advanced features had a percentage quotation of modeling method of 62.33%, and the group without advanced features had a percentage quotation of 72%. The same tendency was found for the quantitative mass. All participants in the group that worked without advanced features solved the task. One person in the group with the advanced feature conditions was unable to solve all requirements because the time for finishing the task had elapsed.

In trimming task 2, the group that used advanced features had a percentage quotation of 64% of modeling method. The group that solved the task without advanced features had a percentage quotation of 83%. In regards to accomplish requirements, the group that used advanced features had a higher percentage quotation than the group that worked without features. But, all participants, other than one, misunderstood one aspect of the instructions. The participants designed the trim mass to be 48 mm instead of greater than 48 mm, and 40 mm instead of greater than 40 mm. This result is not an aspect which can attribute on the different conditions. Accordingly, it created the assumption that there were no differences between both conditions regarding the achievement of the requirements.

Table 1: Percentage quotation of design performance, modeling method, and given requirements for the three tasks and the two conditions with or without advanced features

	Task 1 complex task		Task 2 Less complex task (trimming task 1)		Task 3 Less complex task (trimming task 2)	
	With AF	Without AF	With AF	Without AF	With AF	Without AF
Design performance	141%	128.66%	145.66%	172%	144.66%	155.66%
Modeling method	55%	34.33%	62.33%	72%	64%	83.33%
Accomplish requirements	86%	94.33%	83.33%	100%	80.66%	72.33%

3.3 Design time

The table 2 shows the design time for the three tasks, and the condition with or without advanced features.

The design time was shorter in favor of the group that used the advanced features in the complex task. The group that worked without advanced features needed less time for solving the less complex tasks.

Table 2: Design time (in min) for the three tasks and the two conditions with or without advanced feature

	Task 1 Complex task		Task 2 Less complex task (trimming task 1)		Task 3 Less complex task (trimming task 2)	
	With AF	Without AF	With AF	Without AF	With AF	Without AF

Design time in minutes	26.0	34.4	17.4	7.3	26.4	12.5

3.4 Design process

The “analysis of the part” category was the longest activity during the design process, independent of the task and the condition. Only one exception can be observed under the condition “trimming task 2” without advanced features, where the engineers needed more time for the design.
In the category analysis of the part by the complex task, the group that used the advanced features needed less time than the other group when solving the complex task. The categories planning / problem solutions, and controlling, also show the same tendency. In contrast, the group needed a little more time for the category reading the assignment of task, design, and support. Table 3 shows the time lag between the two conditions for the activities of the design process depending on the three tasks.
When solving the less complex task, the group that worked without advanced features needed less time for all categories, especially for the analysis of the part, design, and support.

Table 3: Description of the time lag (in min) between the conditions with or without advanced features for the activities of the design process, depending on the three tasks.

	Task 1 Complex task		Task 2 Less complex task (trimming task 1)		Task 3 Less complex task (trimming task 2)	
	With AF	Without AF	With AF	Without AF	With AF	Without AF
Reading assignment of task	0.45	-	0.41	-	1.22	-
Analysis of part	-	21.26	9.30	-	15.50	-
Planning / Problem solutions	-	4.39	2.28	-	4.30	-
Constructing	0.39	-	5.29	-	3.18	-
Controlling	-	2.37	0.53	-	2.33	-
Rejecting	-	0.18	1.18	-	0.06	-
Asking	-	0.08	0.10	-	0.31	-
Support	1.23	-	9.57	-	13.44	-

4 DISCUSSION AND CONCLUSIONS

The current market situation has created shorter product life cycles, shorter product development times, and also increased requirements in relation to the function and quality of the products [1]. Therefore, it is important to use a CAD system that facilitates designing adaptive products. However, with the use of these CAD systems, the complexity during the design process increases. Standardization is one possible way to reduce the complexity, which is realized in uniform modeling methods and uniform structure start models [3]. Some companies have taken a step forward and are using knowledge-based design in the form of templates. Templates are CATIA V5 CAD models that include the basic geometry of the part or assembly, and that are based on the uniform structure start models and the modeling methods [8]. The design of the templates can vary. The aim of this paper is to answer the question which kind of template – with or without advanced features – is more efficient and why. In doing so, the present study considers human cognitive aspects of the design process, and provides an informative basis when technical support is expedient.

In order to answer these questions, engineers had to solve three adaptation design tasks that can be distinguished by the degree of complexity. The design performance and the design time were evaluated. Additionally, by categorizing the activities during the task-solving phase, the design process was analyzed.

The results show that the usefulness of templates with advanced features depends on the task complexity. The use of templates with advanced features can be recommended only for solving complex tasks. The study has shown that the design performance was higher and the design time was shorter. Thus, the use of templates with advanced features under the condition "complex task" is more efficient than the use of templates without advanced features. Looking at the design process, we can find one explanation for these results. The biggest time lag between both conditions – with or without advanced features – is in the analysis of part category. This category is the longest activity during the design process independent of the task and conditions, with only one exception, and under some circumstances takes over 50% of the total design time. Here, it may be concluded that reducing the time of the category can reduce the total design time dramatically.
But why is the time of the "analysis of part" category reduced under the condition templates with advanced features? One answer can be found in human cognitions. The design process alone is described as a complex task, owing to the amount of information involved. Additionally, using the CAD system is a further mental exposure [2]. Limited capacity of working memory is the bottleneck of design activity [10]. On the one hand, the knowledge for the design solving has to be remembered, while on the other the design problem has to be solved [13]. One alternative is to reduce the necessity of the required information [15], [24]. However, information has to be presented in a manner that is adapted to the human cognition skills [13]. Advanced features that present only relevant information of the part fulfill these requirements [17]. The engineers profit by using an appropriate information structure. In contrast to templates without advanced features, templates with advanced features show only the necessary information. Intermediate steps, which normally are present in the history tree, are hidden. Therefore, the amount of information is reduced, and the separate parts are better identified. These facts can result in the assumption that advanced features are also cognitive facilities. Cognitive facilities are characterized by their support to unload the cognitive resource of the users, in this case characterized by the reduction of the amount of information [16]. As a result of the more efficient information structure, the organization and design of the information in the CAD system is stronger, and hence allows for easier information processing. The result is a higher design performance and a shorter design time, and, accordingly, there is evidence of a human adaptive cognitive systems design.
The results of the study also show that the time for constructing is a little longer for using the advanced features than for using templates without advanced features. This confirms the assumption that the use of templates with advanced features necessitates basic knowledge about their use. However, when considering learning potential in the advanced features, it can be assumed that the time for constructing will be shorter for those who have more experience with using the advanced features. In summary, the use of templates with advanced features has by now shown advantages in terms of the design performance and design time of complex tasks. Besides, it could be expected that this tendency increases with increasing experience using advanced features.
In contrast, solving less complex tasks using the templates with advanced features is not recommended. In terms of design performance, design time, and design process, the results of the present study have shown that there are no advantages to be gained in using advanced features. One reason for these results can be found in the task complexity. The less complex tasks are characterized by a lesser amount of information in the history tree. The part information can be found partly in the sketcher. The advantage of a better information structure by using the advanced features has less influence. Additionally, engineers need knowledge to use advanced features. Although engineers do not have to design a new component of the part, they need more time for design, especially for constructing time, analysis, and support. This is a sign that the engineers quickly understand the design of the part, but have problems with using the advanced features. It may be concluded that the use of templates with advanced features is not efficient for less complex tasks.

In summary, using advanced features is dependent on the task complexity. The use of advanced features is recommended if the task is a complex problem-solving task that includes a lot of information presented in a history tree.

The results are based on an explorative study – one that had only a limited number of participants – and therefore must be taken as a limited generalization. Thus, the postulated hypothesis presented will need to be verified in a second empirical study, which will include a statistical evaluation. Therefore, a second empirical study with a greater number of participants is planned. Additionally, it is planned to validate a further new aspect of the template design.

Nevertheless, the results give an initial impression of ergonomic guidelines for CAD systems, especially for advanced features.
1.) In order to achieve a better understanding of advanced features, clear terms, including current user knowledge, should be chosen. In particular, confusing terms such as unknown short cuts should be avoided. As a result of the present study, the terms of the components of features are not yet appropriate for the user knowledge. In other words, some of the used terms were unknown and confusing the participants by using the features. This should be avoided in future; the terms of the components of advanced features have to be better geared to the term standards of the user or the company guidelines.
2.) Additionally, it is important to consider other aspects such as pre-adjustments of the templates before using the advanced features. In the current CATIA-V5 CAD system, we should have the choice of presenting or not presenting necessary information, e.g. points and planes. Engineers should have information that provides a better understanding of the part construction. In the current advanced features, the standard of the uniform modeling methods has not yet been completely implemented. Consequently, having lost the chance to gain orientation through important information, engineers needed more effort to change the current advanced features version than when using models without advanced features. This is most evident in the results of trimming task 1 and 2. Accordingly, an ideal information design for hiding and showing should be presented along the lines of the standard of modeling method in the future advanced features.

However, one further aspect should not be forgotten: ergonomic guidelines are only one aspect that optimizes the use of CAD systems, and, consequently, the efficiency of design performance. In particular, the results of a questionnaire have shown that the acceptance of using new techniques, such as advanced features, depends on CATIA-V5 engineering expertise, especially given that engineers with limited CATIA-V5 expertise have assessed the feature as inferior. In contrast, participants with CATIA-V5 engineering expertise were quickly able to handle the new technique. In other words, the acceptance of and skill for handling new techniques depend on existing knowledge. Therefore, it is important that all engineers take part in a training course for CATIA-V5. This course, and practicing the CAD system, is the basis for developing an appropriate mental model of the system.
In a secondary step, engineers need an advanced training course in order to learn the characteristics of these advanced features. The analysis of the design process has shown which situation was most difficult for most participants. Therefore, training in using advanced features in the design process with different contexts and other examples is advised.

Finally, it must be asserted that the use of technical possibilities is not always efficient. Therefore, it is very important to consider not only the technical possibilities, but also the people that use these technical possibilities, and the tasks for which the technical possibilities will be used. Under these aspects, we can recommend the use of templates with advanced feature for complex tasks. The use of these templates with advanced features can support the engineers to meet the new requirements of the current market.

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