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IMPROVED APPLICATION OF DESIGN METHODOLOGY: TAKING MAN-INDUCED DISTURBANCES INTO ACCOUNT

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ABSTRACT
To support design engineers and managers in product development, many approaches exist. Their success most generally relies equally on man's knowledge and ingenuity. Likewise, human attributes tend to disturb theoretically well-working approaches. The resulting quality and sustainability of product development processes is thus diminished. Suggestions to improve existing Systematic Engineering Design approaches are given after three approaches have been introduced and analyzed considering specific weaknesses. Interviews with company officials proving the relevance of this examination are summarized. Practical relevance and effectiveness of suggested solutions is demonstrated in a large field study with junior engineers. Suggestions how to improve engineering design education are given.

Keywords: Design education in practice, design methodology in education, design education and industry, creativity in design education

1 INTRODUCTION

Systematic Engineering Design aims at improving the outcome of development processes by providing design engineers and managers with well-structured approaches and methodologies to design products [1]. Theoretically, these approaches ensure a successful development process. Nevertheless, as actors are human beings with given limitations, certain approaches show disturbances related to human influences. This paper examines a choice of approaches and proposes solutions to some disturbances. A bench test with more than 100 test persons underlines the solutions' relevance. The test's results are evaluated to enhance future engineering design education.

2 STATE OF THE ART

Product development as considered by Systematic Engineering Design (SED) is a sequence of actions starting at the original conception through design and leading up to manufacturing. Research on SED has been undertaken within the last 60 years. As research progressed simultaneously in various scientific and cultural backgrounds, several methodologies for SED have been developed. For instance, the Theory of Inventive Problem Solving (TRIZ) is focused on early stages of development [2], [3]. In Japan Quality Function Deployment was developed resulting in the "House of Quality" [1], [2] and in the USA Axiomatic Design was published presenting a method in order to achieve high quality products by axiomatically considering independence and least information content [4]. A more holistic methodology of SED was developed in German speaking countries since the mid-20th century. Joint efforts of several scientists led to the guideline VDI 2221 [5], [6].

2.1 Methodologies in Systematic Engineering Design

Systematic Engineering Design approaches can be divided into Discursive Methods, Methods of Analogy Consideration and Heuristic Methods, as given in Figure 1 [1], [7]. In all methods, humans act with all their deficiencies from irrational behavior. Discursive Methods propose an approach to achieve a solution and do not aim at replacing man's ability of problem solving. Regarding Methods of Analogy Consideration, several approaches can be named, i.e. literature research, lab tests and model experiments. All of them rely on already existing knowledge. The third group, Heuristic

Methods, is made up from a large number of methods, such as all kinds of creativity techniques, e.g. brainstorming or the method of 6-3-5 brainwriting.

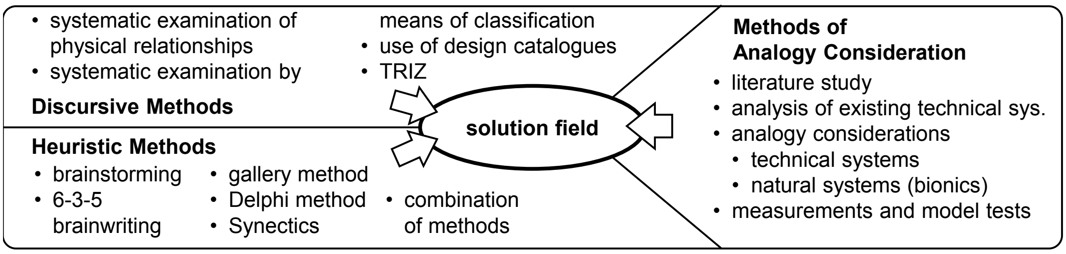

Figure 1. Methods in Systematic Engineering Design

2.2 Man-induced disturbances

According to Dylla, interferences are related to both individual and external influences. Every design engineer's individual problem solving is initially influenced by his individual background, i.e. his personality, knowledge and education and his emotional situation. External influences have to be taken as given in most cases and are always related to settings, task and structure of the organization. They can be kept at bay to a certain extent by well executed project management. Figure 2 shows individual and external influences on SED. [8]

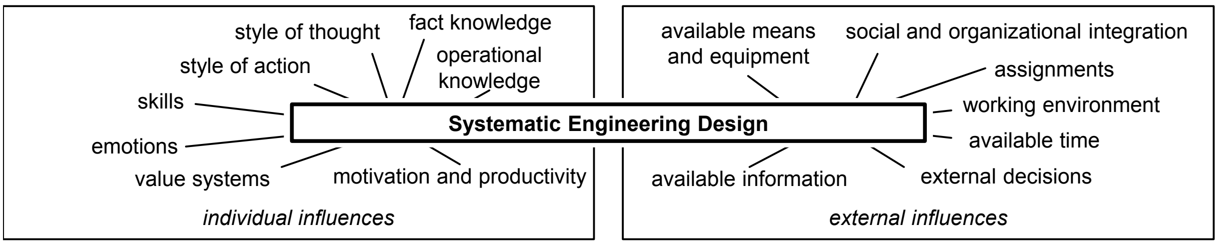

Figure 2. Individual and external influences on SED

2.3 Conclusion

A general aspect of approaches making up SED is that they are put into action by human beings with their given deficiencies [8]. These interfere continuously with the proper execution of the methods.

3 WEAKNESSES IN SYSTEMATIC ENGINEERING DESIGN APPROACHES

For each of the three areas of SED methods, a study will be conducted to identify the weaknesses.

3.1 Discursive Methods – Systematic Combination

To apply this method, functions of the product have to be identified and divided into sub functions. Then, several solutions for each function have to be developed. Solutions are linked to functions, preferably several different solutions to each sub function to form a matrix. Columns hold several solutions to each function. This step is followed by a combination of solutions from top to bottom in order to enable the overall product function. Regarding the systematic combination and its main tool, the morphological matrix, it can be stated primarily that there is the severe risk of excessively producing combinations and potential solutions. Insufficient knowledge and experience could lead to a high number of solutions without any chance for effective use at least if the design engineer executing the design task will have to survey the entirety of the solutions single-handedly. E.g., the task of making up new solutions for a bread roasting device, i.e. a toaster, cannot be fulfilled by combining an open heating thread with water cooling with an open circuit. Without sufficient knowledge of basic laws of physics, such a search for solutions could lead to a rather useless and much too high number of impossible solutions. As indicated in the previous section, applying the method of systematic combination by making up a morphological matrix can produce a large number of dysfunctional solutions in the majority of the cases. The application of this method in a very simple design task with only five sub functions and five sub solutions each could in theory already lead to a maximum of 3125 overall solutions. This simple example shows the method's tendency to produce highly complex overall solutions. This complexity requires a good understanding of the design task on the side of the design engineer, especially if he has to execute the method on his own. The design engineer, presuming sufficient knowledge, needs to be able to keep track of the entirety of solutions. Basically, this ability depends on brain function [9].

3.2 Methods of Analogy Consideration – Analyzing natural systems

The method of analogy consideration is introduced by giving an example considering the aerodynamic values of the trunkfish [7]. Exploring examples for bulky shapes among animals, a design engineer could presume that this animal might be a promising one. Later, modeling this shape in a wind tunnel test, the resulting drag coefficient would prove to be close to the theoretical minimum. The results of this examination could later on be used in the automotive industry while considering low aerodynamic resistance in the development of large cars with low emissions and fuel consumption. While the method of the morphological matrix could even generate solutions almost without any expert knowledge, the method of analogy consideration requires a certain amount of expertise [1], [7]. Without such knowledge, no applicable new knowledge can be obtained. The method of analogy consideration relies on knowledge appropriate for the engineering task. If this knowledge is not available sufficiently, the following problems can occur.

- No initial idea to solve the engineering task
- Results of examinations cannot be transferred
- Development of results will be impossible

Regarding the example of the trunkfish, an individual without proper knowledge of fluid dynamics and flow channel test setups as well as analogy calculation will not be able to deliver relevant results.

3.3 Heuristic Methods – Method of 6-3-5 brainwriting

The method's name is derived from the method's original procedure (6 participants, 3 ideas each, 5 times exchange and further development of the solution in that group). It aims at the exploration of synergy effects by combining different human resources [10], without being forced to consider group dynamics or even force participants into problem solving processes. The method requires a rather homogenous hierarchy within the group, whereas different professional backgrounds have proved to be helpful [7], [10]. Place and time should pose no stress to any of the participants. Regarding the procedure of the method of 6-3-5 brainwriting, several differences between this method and the two others presented here become apparent: it relies on human creativity and thinking itself more than on generating new data, information or knowledge. It uses each design engineer's distinct problem solving capacity and does not rely on structured and systematical consideration of all possible solutions. Most heuristic methods only focus on two aspects, the individual and the social background view [11], [12]. The latter focuses on the outcome of the creative process. The creative process most often takes place outside work situations, as ideas often come up in situations other than meetings and situations destined for problem solving. The creative setting is proposed to be a distant and quiet room. Besides that, available time and independence of the individuals solving problems with this method could also interfere with the method. Originally, 6-3-5 brainwriting offers 5 minutes to fulfill the task. This strict limit could interfere with the individual need for more time as well as the rule to use defined form sheets to develop solutions.

4 POSSIBLE SOLUTIONS TO THE WEAKNESSES

Chapter 3 introduces human interference in SED processes leading to limited success of these methods. In most cases, methods attempt to respond to human deficiencies yet do not succeed in it. As a result, design engineers as well as managers often refrain from using SED methods, due to the fact that frequently methods are inefficient or improperly designed for easy use. If these methods could be enhanced in a way by which human interference no longer interrupts their proper execution or at least if that interference could be reduced, their application would be eased. Overall, this would increase the efficiency of development processes and in thus grant engineering companies more success.

4.1 Discursive Methods – Systematic Combination

As shown in chapter 3, principal weaknesses of the morphological matrix can be seen in man's limited short term memory capacity and the large amount of information generated when using this method. A possible way to improve this would be to apply more expert knowledge and spend more time on the preparation before executing the method. Using a separate matrix to determine incompatibility would also help. More so, integrating experts and independent partners in order to provide the in-depth expert knowledge especially needed in large-scale projects will improve the application of this method. In addition to larger expert knowledge provided by specialists outside the distinct development process, they also offer a higher level of abstract thinking abilities than design engineers within the project. Some settings should be provided: If the strategy of the company is merely organized by specific functions of the products, with every department of the company only concentrating on one function of the product, it is not very likely to have design engineers with a general view of the product. A company's structure which is rather focused on the product itself could lead to an inferior application of the method of systematic combination, as in this case it could prove difficult to have highly skilled experts for single but repeating functions of the company products.

4.2 Methods of Analogy Consideration – Analyzing natural systems

To be able to analyze natural systems by considering analogy, the applying design engineer needs to have sufficient knowledge in the examined field. In this case, one difficulty could be to determine if there is sufficient knowledge, or how it can be obtained while applying the method. Likewise, the success of obtaining the desired knowledge cannot be granted in most cases. One possible reaction to this problem could be to combine this method with other methods such as research in literature or analyzing related patents. Additionally, this method could be improved by providing a more structured and guided approach. This will be undertaken in ongoing research at RWTH Aachen University.

4.3 Heuristic Methods – Method of 6-3-5 brainwriting

In chapter 3, several weaknesses of this method have been defined. Most obvious, this method on the one hand requires a relaxed situation, supporting creativity, but on the other hand it is rigid in structure and procedure. This is contradictory. To resolve this, the method could be at first optimized by relieving this rigid structure to some extent. Softening the structure will have to be done considering the fact that stress generally leads to better results in some cases. This leads to a proposal of rethinking the strict limit in time as applied in this method. The rigid, sequential order could be rethought for the purpose of having several distinct steps, separated in some steps at some time and therefore enabling the problem solver to reconsider his solution. In contrast to that, by still keeping short limited periods of time for some steps, human ability to deliver abstract and condensed evolutions of good solutions could be triggered. This will be possible as men and especially design engineers are able to precisely focus on the essential under stress. Doing so, this heuristic method would change focus from creativity to intuition. Intuition is seen to be of a much higher value also to scientific and engineering tasks [13].

5 FIELD STUDY AND INTERVIEWS

To prove the solutions proposed previously, interviews were held with officials of leading engineering and manufacturing companies. In the first section of this chapter a short introduction on the scope of the interviews and the background of the companies is given. Second, the field study analyzing the relationship between individual engineers' backgrounds is introduced and third its relevance as quoted by the interviewees is shown. Along with this a conclusion from the results of the study is provided.

5.1 Scope of the interviews

Five engineering companies with products ranging from household appliances over laser machine tools up to large scale plant engineering participated in the interviews. All interviewees are engineers in leading positions, in general responsible for the research and development department. The interviews were held in guided but open style. Every interviewee was confronted with the same questions, though the interview left space for personal comments and individual answers.

5.2 Field study

In order to validate this paper's approach, a field study was undertaken with 116 junior engineers. All of them attended higher semester engineering classes at RWTH Aachen University. Every single test person had to perform a five part design task. First, the students had to assess the given product, a set of gear wheels with treadles for a common bicycle by abstracting the product into basic modules and functions. Next, improvements to the product based on a set of given deficiencies had to be developed and sketched in a principle solution. Third, one part of the product had to be drafted using CAD and be subsequently put together with other provided parts to make up a digital assembly of the bike parts. All test persons were divided into four groups, each with a different time to complete the five tasks. This was done to determine the effect of very short time available compared to largely sufficient time. Therefore, the group with the shortest time given had 30 minutes to complete the five tasks, while the one with largely sufficient time could use 65 minutes. In between these two extremes, two other groups had 40 and 52 minutes, in order to be able to determine tendencies within the whole scope of test persons. The evaluation was done by examining the test persons' results on the one hand and on the other hand by interpreting the entries the test persons made in interviews along the test. These interviews inquired the background of the test persons along with the personal, emotional and stress impression after every single task. Additionally, the test persons' spatial perception was measured with a specific test. The consideration of the test persons' individual background aims at creating an insight into these backgrounds' relationships with the individual performance, as well generating possibilities of enhancing task design and concepts along with methods provided for problem solving. Three relationships will now be preliminarily introduced, whereas suggestions for improving tasks and given methods in engineering processes are subject to current research. The field study led to a total of 12 assumptions. Due to limited space in this paper, the most appealing will be discussed. First assumption in question was whether the individually perceived temporal demand in the tasks corresponds to the quality of the individual results. This assumption showed a variable outcome, as to be seen in Figure 3. Considering the correspondence in tasks demanding manual execution, the product assessment and improvement using principle solutions, a clear correspondence can be stated (Figure 3 1st left), while tasks with execution using a computer do not show a clear correspondence (Figure 3 2nd left). For the second assumption (subjective frustration decreasing with more time given), a peculiar observation has to be stated: While the outcome for manually executed tasks does not show that more time leads to less frustration (Figure 3 1st right), tasks executed with the help of CAD do at least show a tendency for this assumption (Figure 3 2nd right).

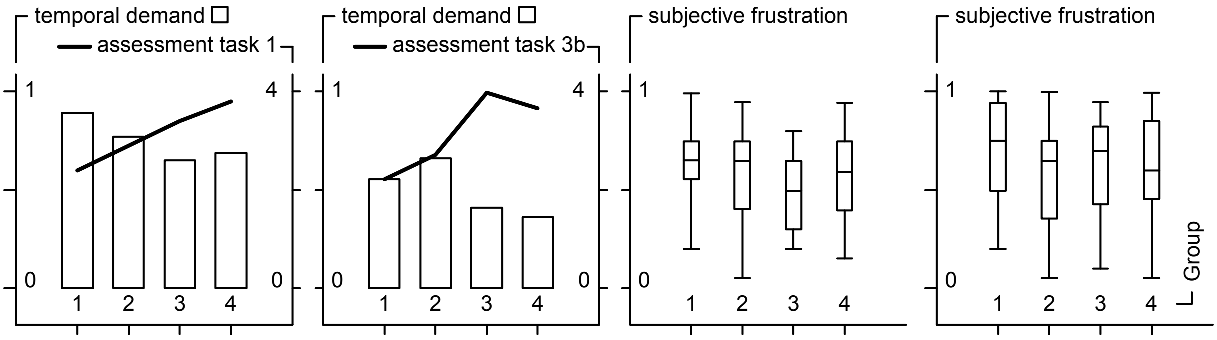

Figure 3. Results of field study

The third assumption considers the influence of spatial perception of the test persons, implying that better spatial perception generally leads to better results in the given engineering task. This can preliminarily be stated as true, even though precise statistical dependencies still remain to be analyzed. The results for the third assumption are given in Figure 4.

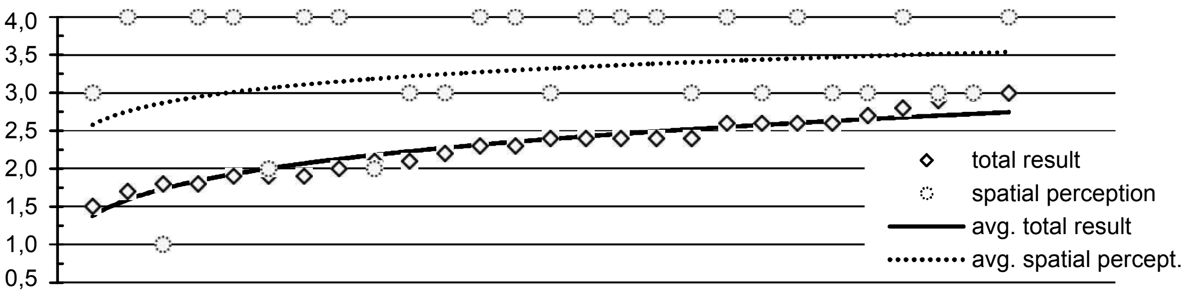

Figure 4. Correlation of students' spatial perception and actual results

5.3 Confirmation of the study's relevance and interpretation of field study results

All interviewees agreed on the significance of the matter discussed in this paper. They quoted strong efforts to improve the application of SED and also noted the effect of human interference in the successful execution of various approaches. Different single reactions were proposed by interviewees to improve SED process outputs. All interviewees agreed that personal and usually neglected social matters are by far more important especially in engineering employment situations than commonly regarded. The field study shows that considering the personal background of the executing engineer is crucial to the success of engineering processes. Curricula taught directly prior to the study had to be applied by the test persons. Occured difficulties with the application of these methods helped to set up an improved way to teach these methods in the future. E.g. methods of product and function structure developing have been simplified and more clearly defined. Equally, methods for principle solution sketches can now be more easily accessed by future students, as more easily applicable rules have been established and will be taught furtheron. Last, the education of CAD application techniques will consider difficulties the test persons faced, such as sequence of design steps and relations of parts.

6 CONCLUSION AND OUTLOOK

This paper aims at showing the relevance of considering the impact of human action in SED processes. Three of these approaches have been examined in order to show the relevance of this concept. An approach from the field of Discursive Methods, the method of the morphological matrix, was examined to determine weaknesses and then propose solutions to them. Here, the realization of man's limitations is the first step to improve the application of the method. Second, from the field of Analogy Consideration the method of considering analogy in natural systems was investigated. The same manner of examination was also applied. As a principal improvement, a better consideration of the initial situation of the design engineer was proposed. Third, from the field of Heuristic Methods, the method 6-3-5 brainwriting was examined, especially focusing on creativity as the source of the results. Here, improving the situation for a better development of the acting design engineers' creativity was conceived as an answer to the weaknesses determined. Next, the examination, the development of solutions and a short overview of the validation of the investigated subject were given, showing the relevance for this kind of research as unanimously stated by all interviewees. Next, a field study was done with junior engineers, proving the strong correspondence of human background to engineering processes' outcomes. This study is embedded in a research field at RWTH Aachen University aiming at the improved application of SED by both design engineers and managers in industry and at better education of students in SED methods.

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