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A DESIGN RESEARCH METHODOLOGY

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Abstract

The overall aim of engineering design research is to develop knowledge which can improve the chances of producing a successful product. This aim leads to a number of important questions: what is a successful product; how is it produced; and how do we improve the chances of being successful. The paper will address these questions and provide some examples of research results. Based on this, the authors propose a generic design research methodology, ie a set of research methods and their links, that addresses the research questions in a systematic way.

Inhaltsangabe

Das übergeordnete Ziel der Konstruktionsforschung ist das Gewinnen von Erkentnissen, die die Chance erhöhen können, ein erfolgreiches Produkt zu entwickeln. Dieses Ziel wirft einige wichtige Fragen auf: Was ist ein erfolgreiches Produkt? Wie wird es entwickelt?und Wie kann man die Erfolgswahrscheinlichkeit erhöhen? Dieser Beitrag diskutiert diese Fragen und gibt einige Beispiele von Forschungsergebnissen. Darauf basierend wird eine allgemeine Konstruktionsforschungsmethodologie vorgeschlagen, d.h. eine Sammlung von Forschungsmethoden und deren Zusammenhängen, die die Forschungsfragen auf systematische Weise behandelt.

1. Introduction

The overall aim of engineering design research is to develop knowledge which can improve the chances of producing a successful product. This aim raises a number of important questions: (1) What do we mean by a successful product? (2) How is a successful product produced? (3) How do we improve the chances of being successful? To answer each of these questions design research must be carried out. This leads to a further question: What research methodology should be used?

The first question leads to issues such as what criteria should be used to judge success; the second to issues such as what are the influences on success, how do these influences interact and how can they be measured; the third to issues relating to the development and validation of design methods. The question of a research methodology leads to issues of identifying

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research areas and projects within those areas, and selecting specific research methods to address the issues.

Problems in the selection of research areas include the numerous influences and the interconnectivity between the influences. Design involves, among other things, people, products, and organisations. These problems affect and complicate the selection of research methods. A typical characteristic of design research is that it not only aims at understanding the phenomenon of design, but also at using this understanding in order to change the way the design process is carried out. The latter requires more than a theory of what is; it also requires a theory of what would be desirable and how the existing situation could be changed into the desired. To achieve this, methods from a variety of disciplines are needed.

Sections 2 to 5 address the above questions and provide some examples of what criteria have been applied, which research methods have been used and with what results. Each section also discusses the problems that are involved in answering the questions. In section 6 the authors propose a generic design research methodology, ie a set of research methods and their links, that addresses the research questions in a systematic way.

2. Success criteria

In order to determine the factors that contribute to success, it is necessary to define a criterion for success. Two types of criteria are used by design researchers who focus on the factors that influence success. A common criterion used in research in an industrial context is success in the market (sales, profit, return on investment), as used by Cooper [1], and Dwyer & Mellor [2]. In laboratory research a common criterion is the fulfilment of technical requirements (a good design), as used by Fricke [3], and Dylla [4]. Most studies, however, do not use any criterion because they aim at describing a process rather than assessing it. For example, Hales & Wallace [5, 6] tried to identify the factors that influenced the design process of a gasifier test rig in an industrial context.

Which criteria are important for a company depends on the product, market, company image, product image, and company policy. Defining success criteria and their relationship with specific product, market and organisational characteristics, provides a basis for defining company goals. Van Wagenberg [7], for example, showed that the design approach used in a company is related to the characteristics of and the different criteria used by the company; it is important to keep this in mind in the selection and implementation of computer tools.

3. Influences, interrelations and measures

Success criteria enable the identification of the factors that influence success and the way in which they influence success. This in turn helps in identifying the characteristics of successful development processes. This knowledge contributes strongly to the development of effective methods and tools.

The identification of factors influencing the design process is part of descriptive studies. These studies aim at a better understanding of design. Several research methods have been used, many of which were originally developed for use in various other disciplines (such as the use of protocol analysis from psychology research). In these studies a variety of aims resulted in a variety of results, covering many aspects of design. Few studies, however, focus

on the link between success (or quality) of the product and the way the process was executed. In Fig. 1 three different descriptive studies and their results have been summarised.

The main problems in this type of research are:
- the human element,
- the large number of influences,
- the interconnectivity of influences,
- the uniqueness of every design process.

These aspects make it difficult to identify research areas and appropriate subsets that allow scientific investigation, the results of which can be used to develop generic design methods and tools. These characteristics of design require the adaptation of research methods existing in other disciplines.

RESEARCH METHODS			
	Hales / Wallace [5, 6]	Cooper / Dwyer / Mellor [1, 2]	Dylla / Fricke [3, 4]
Aim	Measure influences	Influences on success	Influences on success
Criteria for success	?	Profit Sales	Fulfilment of requirments
Observation	Participant observation	Questionnaire Interview	Thinking aloud video taped
Analysis	Classification	?	Classification
	Industry Team 1 case	Industry Company 200+ cases	Laboratory Individual 15 cases
RESULTS	List of influences and their measures	Success relates to proficiency at early stages	Success relates to methodical, flexible, goal oriented approach

Figure 1 Different descriptive studies: research methods and results

4. Design methods development

The results of descriptive studies can be used in industry as a basis for guidelines or examples. They can also be used to develop methods and tools because they indicate where support is useful or even necessary. However, when the aim of design is to improve the design process, it is not possible to rely upon descriptive studies only, as these studies provide the characteristics of existing, ie often not improved, processes. New approaches and methods have to be developed to support the positive, success-bringing characteristics, to prevent the characteristics that have a negative impact, and to take into account those negative characteristics that cannot be prevented. This is the research area of prescriptive design methodology and of software development.

The most common research method is reasoning based on experience and assumptions. An example of a result is the assumption that searching a wider solution space is likely to improve the quality of the result[2]. Based on this assumption and others, extensive methodical approaches have been proposed by design researchers such as Pahl & Beitz [8], Hubka [9], and Andreasen [10]. The same assumption was also used in developing design support tools such as the Cambridge Materials Selector by Ashby & Cebon [11], and the FuncSION software for synthesising concepts to fulfil intended functions by Chakrabarti [12].

It seems important, not only for the development of methods and tools, but also for their dissemination and acceptance in industry, that the actual design processes are taken into consideration. The main problem is that few methods and tools are explicitly based on descriptive studies. Possible reasons are the recency of descriptive studies in the field of mechanical engineering design, and the fact that most studies do not aim at identifying the factors that influence success. We expect that the increasing number of descriptive studies will give a new push into the development, improvement and implementation of prescriptive methods and approaches.

5. Validation of methods

Once new methods and approaches have been developed, they need to be validated or at least tested and evaluated. The two main issues are: (i) to identify whether the method or approach has the expected effect on the influencing factors; and (ii) to identify whether this indeed contributes to success. Unexpected side-effects may occur.

One research method is to observe and analyse the application of methods and tools by experienced designers, preferably in a realistic (industrial) context. This is the method used, among others, by Hales [5] and Birkhofer [13]. Birkhofer [13], for instance, studied the application of the methodical approach proposed by Pahl & Beitz [8] for the design of textile machinery. Only very few studies, however, involve a comparative analysis. These are studies in which designers using the method (experimental group) are compared with designers not using the method (control group). This would allow more precise statements about the effects of the methods and tools. An example of comparative analysis in a laboratory context is the evaluation of a process-based support system developed by Blessing [14] using a total of eight experienced designers.

The validation of design methods is one of the most difficult research areas. The problems are similar to those mentioned for a descriptive studies and analyses of design processes (section 3). These problems become stronger when control and experimental groups are involved. The success of a method or tool depends not only on the method or tool itself, but also on the context in which it is being used. This context is different for every design. Therefore, it is difficult to generalise the results of an evaluation, until the effects and interrelationships of the different influences are known (the focus of descriptive studies, section 3).

Up until now, the systematic testing of methods and tools has not received much attention in design research, despite its importance for the acceptance of tools in industry. Too many methods and tools do not leave the desks of researchers. Prerequisites for validation are the

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[2] Recent descriptive study by Dylla [4] supports this assumption, provided that the generation of solutions is linked to timely evaluation of the solutions.

development of test methods, and support from industry to obtain results from more realistic evaluations.

6. Research methodology

The previous sections showed that many different methods can be, and have been, used in different areas of design research. The authors propose to piece these research areas together into a generic design research methodology that addresses the research questions in a systematic way (see Figure 2). A simple example will help clarify the methodology. The methods that can be applied in each of the steps were discussed in the previous sections.

Example:

Criteria (section 2):	A reduction in time-to-market is identified as a criterion for success.
Description I (section 3):	A descriptive study, involving observation and analysis, shows that insufficient problem definition relates to high percentages of time spent on modifications, as per VDI 2210 [15].
Prescription (section 4):	Based on the outcome of the descriptive study, a method or tool is developed to support problem definition, with the implicit assumption that this contributes to a reduction of the time-to-market.
Description II (section 5):	The method is applied and a descriptive study is executed to validate the method. This includes two tests. The first test is whether problem definition is supported (a comparison with Prescription). The second test is whether less time was spent on modifications, and whether this, in turn reduced the time-to-market (a comparison with Description I). There might be reasons as to why the second test fails, such as side-effects of the method.

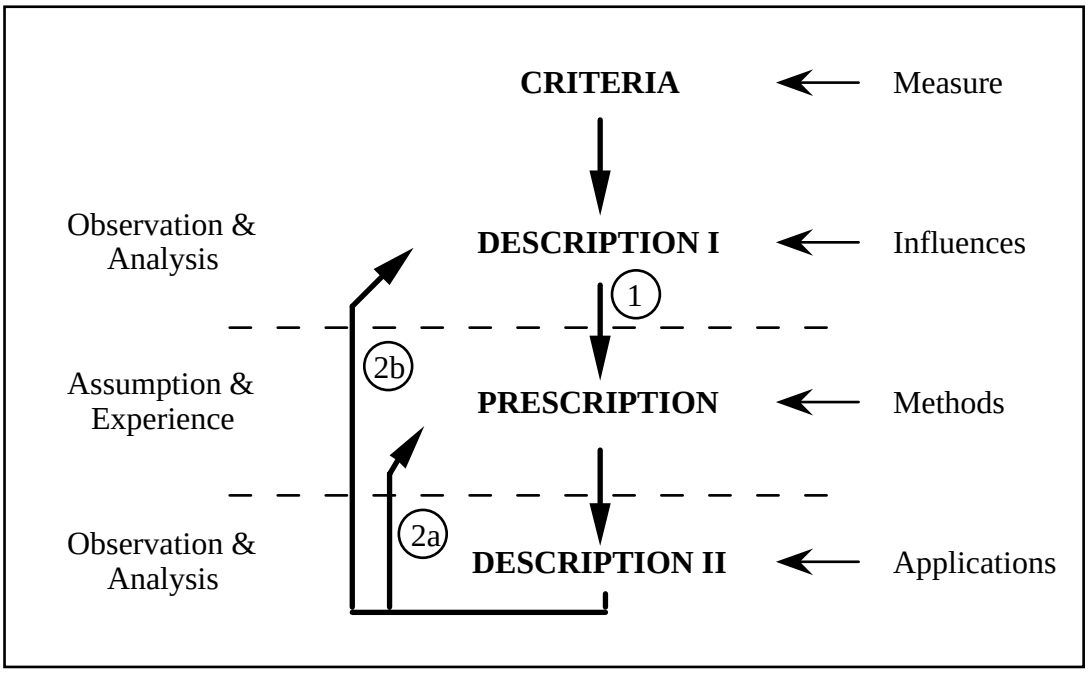

Figure 2 Design research methodology, and missing links

As the example shows, descriptive studies may reveal a chain of causes and effects, connecting influencing factors with the criterion. Methods developed in the Prescription step can directly address one or more influencing factors in this chain, which are then expected to affect the rest of the chain. The Description II step should test all causal links between the influencing factors addressed by the method and the success criteria.

7. Conclusions

As the previous sections showed, most of the steps in this methodology have been addressed in design research, in various areas, using many different methods. The proposed methodology reveals some key issues that need to be addressed:

- The identification of subsets within each research area that can be investigated scientifically, and that will provide information for the development of practical design methods;
- The establishment of a link (link "1" in Figure 1) between the results of descriptive studies (Description I) and the development of design methods (Prescription);
- The validation of developed methods through the establishment of links between Description II and Prescription (link "2a" in Figure 1), and between Description II and Description I (link"2b" in Figure 1).
- The development of new and the adaptation of existing research methods from various other disciplines for each of the steps in the methodology, in collaboration with researchers from disciplines such as computer science, sociology, psychology and management studies.

It is hoped that the collaboration between the research areas and the related disciplines will contribute to the improvement of design methods and tools, and that these, in turn, will improve the chances of producing a successful product.

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