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APPLICATION OF METHODS FROM SOCIAL SCIENCES IN DESIGN RESEARCH

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1. Introduction, Aims and Objectives

In many engineering publications on approaches to support design activity, there is little evidence of use of valid empirical data. Proposals often rely on single findings, on assumptions or on experience which are hardly articulated or adequately documented. In the last decade a tradition of empirical design research has developed, using methods from social sciences to investigate design processes and design behaviour. The use of these methods requires their adaptation to the specific problems and demands that are characteristic for the field of design.

This paper delivers some fundamental considerations referring to our own experiences in the field of empirical design research. It focuses on methods for surveys and for observing individual designers and design teams.

2. The Problem

The goals of design research are the formulation and validation of models and theories about the phenomenon of design, as well as the development and validation of knowledge, methods and tools - founded on these theories - to improve the design process. Design research must be scientific in order for the results to have validity in some generic, practical sense. For this, design research has to develop and validate knowledge systematically. This requires a research methodology (for more details see [Blessing & Chakrabarti, 2002]. Sadly, although design is one of the fastest growing areas of research, the status of research into its own research methodology is, with a few exceptions, poor. In effect, little guidance exists as to how to do design research, leaving it to the individual to find a hopefully efficient, effective and rigorous approach. Many different methods can be, and have been, used to address the various issues involved in design research [see e.g. Blessing, 1994, Blessing et. al. 1998, Dwarakanath, 1996]. Design research is extremely varied, showing little coherence in terminology, approach and results, which might be caused by the specific characteristics of design as a research topic.

Unfortunately, many publications do not provide details of their research, such as data collection context and data analysis methods, and validation of the results is rather uncommon. There is little reflection on the applied methods and methodology. Often methods seem to be chosen, because they are popular rather than because of their suitability to answer the research questions. In addition, inconsistencies between aim, data collection method, data analysis method and conclusions can be found. Examples are: conclusions that cannot be drawn on the basis of the way in which and the circumstances under which data has been collected; or a set of methods that is unsuitable for the stated aim. In addition, findings, assumptions and interpretations are often not clearly distinguished. Last but not least, most studies result in correlations between pairs of influencing factors, very few link their findings with success criteria [Blessing et. al. 1998]. As a consequence, the results are often not suitable as a basis for the development of design methods and tool to improve the design process. To make matters worse, many publications on approaches to support design activity, show little evidence of using valid empirical data as a basis, even where this is available. Proposals often rely on single findings, on assumptions or on experiences that are unfortunately hardly articulated and not adequately documented.

This situation has given rise to increasing concerns about the efficiency of design research and the effectiveness of its outcomes. A research methodology is needed, as well as guidance for using and adapting research methods and approaches. Design is a complex activity, involving artefacts, people, tools, processes, organisations and the environment in which this takes place. Each of these aspects belongs to a specific discipline, e.g. engineering science for artefacts, cognitive and social sciences for people and processes, computer science for computer tools, etc. Each discipline has its specific research methods and underlying paradigms and assumptions. The problem is the unfamiliarity of most researchers with many of these methods. As a consequence, these methods are not used correctly, or they are applied to answer questions for which they are unsuitable, resulting in invalid data that cannot be used as a basis for the development of design methods and tools.

In this paper, we will not discuss research methodology (for which we refer to [Blessing & Chakrabarti, 2002], but present our experiences with using methods originating from the social sciences for studying design processes. We highlight the characteristics of design that make the study of design processes such a challenging task and use three case studies to illustrate some of the difficulties and pitfalls of using social science methods. In the last section, the lessons we learnt from these and other studies we undertook are summarised to provide some guidance to other design researchers that intend to use - but are unfamiliar with – such methods.

3. Asymmetry of Design Research in Engineering and Empirical Social Sciences

Social science methods are needed for formulation and verification of hypotheses. Due to a fundamental “asymmetry of knowledge” ([Beckenbach 1993] pp. 41.ff.) and due to different “resources of power” (loc. cit. pp.49.ff.) these methods cannot be transferred without being modified.

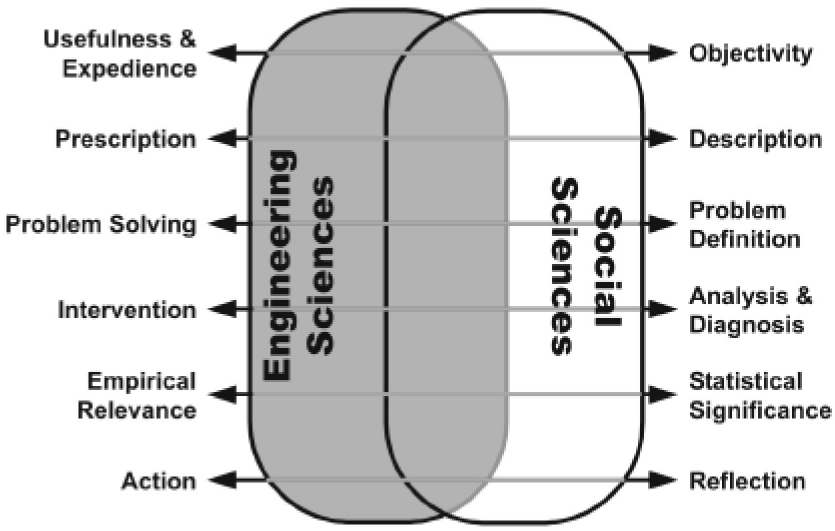

Figure 1. Asymmetry engineering and empirical social sciences

The focus of knowledge in the area of engineering can be categorised as <u>knowledge to solve problems</u>. This knowledge allows the definition of solution spaces and the systematisation of relevant variables, objectives and optimisation criteria in the context of model that is as non-ambiguous as possible (loc. cit.). In contrast, the focus of knowledge in empirical social sciences is on valid <u>diagnosis</u> and <u>analysis</u> of concrete coherences between actions and on a methodically well-funded description of behaviour and social structures. Therefore, knowledge in the area of empirical social sciences is first of all knowledge of reflection with empirical evidence, which is particularly aiming at problem definition (loc. cit.). That implies a general asymmetry of the aims, approaches and methods of research between these both disciplines which are described in Figure 1.Of course, the figure shows the extremes and in most cases real research activity will be positioned somewhere in between, tending more to the one or to the other endpoint.

4. Appropriate Methods for Observation and Analysis of Design Processes

For the empirical analysis of design activity a variety of methods from the social sciences are useful and have to be adapted. This paper focuses on methods for:

- observation of individuals or groups undertaking the activity to be investigated;
- interviewing the individual or group about their activity;
- analysis of the designs and documents generated by the designers.

The analysis can take place in real design practice (field research) or in a laboratory environment (experiments). An overview of units of analysis and methods gives [Atteslander 1995] (Figure 2).

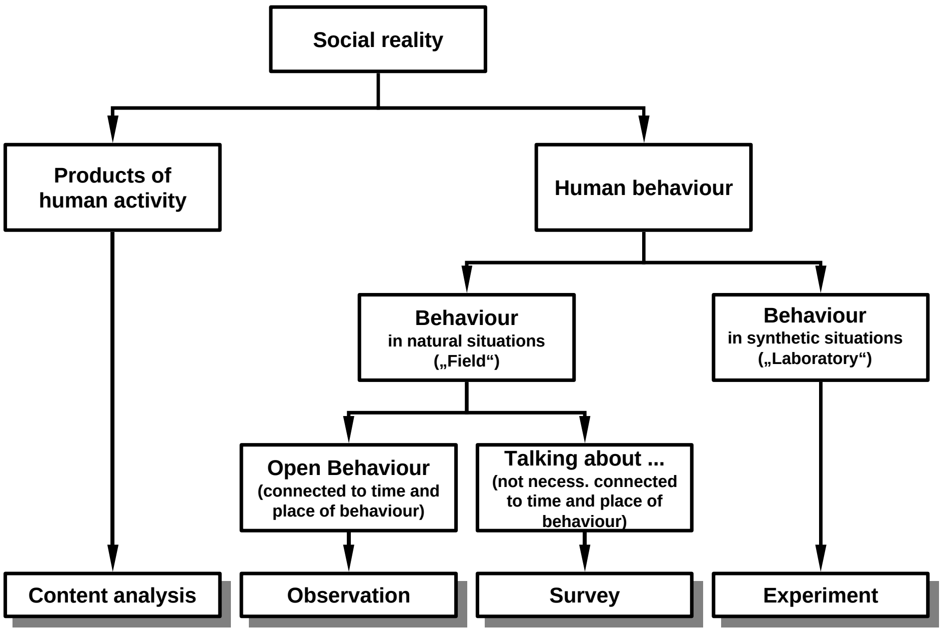

Figure 2. Units of analysis and methods of empirical research in social sciences

The collected data can be categorised as qualitative (e.g. transcriptions of interviews) or quantitative (e.g. number of elaborated solution variants). Appropriate units of analysis for design processes are e.g. [v.d. Weth 2001] basic operations, documents, sub-functions, phases of problem solving, and main design operations.

5. Problems of Application

The use of methods from the social sciences in empirical design research often has to be done carefully because of following typical characteristics:

- the sample size is low;
- the units of analysis are of high complexity;
- setting up hypotheses is difficult because of a lack of theory;
- the definition of variables is difficult and “pure” influences can hardly be isolated;
- interconnectivity of influences and variables make it difficult to identify and determine causality;
- many variables cannot be observed directly;
- field testing is often impossible, because all cases and participants will be different. Industrial practice does not allow to undertake identical tasks or find identical situations. Moreover, it is

very difficult, if not impossible, to determine with certainty the influencing factors that are different or the same , because the influencing factors have not been established yet;

- normally it is difficult to form control groups consisting of test persons not exposed to the hypothetically influencing variables because of the probably limited motivation of participants when they realise that they do not take part in the “real” experiment;
- pure experiments involving identical pre-tests and post tests is not possible, not even similar tests are possible, because the learning effect will bias the results: a design task cannot be done twice.
- design success as a parameter of high interest is difficult to define, to quantify and therefore to evaluate;
- designers as participants are experts with often limited time resources like or the willingness to give information;
- potential users of technology as units of analysis are often laypersons in the area of technology which may e.g. lead to the problem that they are not able to verbalise details of the way in which they use technology.

These factors have to be considered while designing and undertaking the study, as wells as during, the analysis and interpretation of the results. Most notably, the analysis of the collected data is challenged by these constraints, particularly regarding the significance of the outcomes in relation to their empirical relevance.

6. How to Deal with these Issues: Three cases

Of course, we are not able to deliver a complete and consistent methodology for adapting methods of social sciences to the area of design research. However, in different research projects we gained experience which might be transferable to and valuable for other research projects. Three recent studies and the lessons-we-learnt are discussed in the following sub-sections.

6.1 Study 1: Observation of product users to identify technical requirements

6.1.1 The Task, aims and objectives of the study

Product requirements and expectations from potential users, are important for the development of user-friendly products. Questionnaires are commonly used to determine these requirements. Often these are unsuitable, because users have difficulties describing their problems or fail to notice them at all. Observing volunteers using the products – instead of only asking them – allows non-verbal aspects to be investigated as well. In this way, the researcher receives the information that is, to a large extent, not influenced by the opinion of the users. From these observations, new hypotheses for product requirements can be derived. This approach was used in a research project involving different disciplines in order to develop new household appliances for senior citizens.[1] Senior citizens were involved from the beginning of the project through the establishment of a senior council. [Elsner & Blessing 2002]. From this council all volunteers for the observations were recruited.

6.1.2 Design of the study

An open, non-participative observation was used. This method originates from the social sciences [Bortz & Döring 2002, pp. 262]. In order to find new hypotheses for product requirements, the method was used quantitatively. This means that the actions of the volunteers were observed and documented instead of counting the frequency of specific actions. It was performed using only very few limiting rules for the observers, in order to make neutral recordings of every possible aspect. Immediately following the observation, an evaluation of the collected was done by the same team of observers. Since different disciplines have different focal points, the observers were recruited from the different disciplines involved in the project. The observing team included engineers, industrial designers,

[1] This project called SENTHA is supported by a grant from the Deutsche Forschungsgemeinschaft (DFG)

psychologists and sociologists. Medical doctors and economists could also be valuable contributors, but where not available within the research team.

6.1.3 Procedure of the study

The study was performed in two successive phases: observation and evaluation. In the observation, the volunteers performed tasks and were observed by the expert team, which did not intervene. All observations took place in a lab that was set up to look and feel like a home in order to observe the behaviour in an environment as close to reality as possible. In contrast to the common approach in the social sciences, the volunteers were fully informed about aim and content of the study. This was done to prevent mistakes, that may result from the unfamiliar setting, since these mistakes will not occur during the everyday handling of the products. By doing so the volunteers were expected to show signs of trouble only when the tasks were difficult to perform, giving hints to potential for real improvements. While performing the tasks, the volunteers were asked to comment on everything that came to their mind. This was done to help them and the observers to notice problems earlier and easier. Only one volunteer was active at a time, being observed by all observers together, who were taking notes in a journal of predefined length. Only those actions and comments were recorded that directly related to the study. The focal point lay on emerging problems and unknown ways of handling. The documentation in the journal was done purely descriptive, chronologically and without any comments or judgements.

The analysis of the data was done by the same team of observers directly after the observation. The aim was to derive general statements and hypotheses from the different observations. Validation was done by consensus of the team members. A consensus does not guarantee validity, since the team can also agree on wrong hypotheses, but it makes it much more likely, that results are valid [Bortz & Döring 2002, p. 335]. Unanimity was desired, but no absolute prerequisite. Differing opinions were noted when they occurred. As far as possible all statements were quantified or at least formulated precisely. From these statements the engineers derived product requirements. Depending on their competence, the other disciplines also took part in the formulation of requirements. All together the analysis included the following four steps:

1. target definition
2. structuring and analysis of the observational data
3. formulation of general statements and hypotheses
4. derivation of at least one product requirement.

6.1.4 What we learnt and what we recommend

The members of the senior council changed very little over time. In the course of the project the volunteers therefore developed a growing familiarity with technical problems. This helped to overcome initial problems, e.g. the focusing on superficial details. The cooperation with familiar people helped to create a routine situation in the lab, promoting a typical behaviour when using the products. Also it helped to overcome the volunteers' fear of failure. Social scientists usually try to avoid familiarity, because the data may not be representative anymore. From an engineer's point of view, however, this seems acceptable, because the advantages outweigh it. Besides, the situation is different between studies undertaken by social scientists and engineers. Social scientists usually evaluate human behaviour in the context of interaction with other humans. This is often influenced by a familiarity with the setting and the observers. Engineers, however, evaluate the interaction between humans and technical devices. This interaction is unlikely to be influenced by the observers (a screw will be hard to turn, no matter if someone is watching or not) unless they directly intervene, e.g. by giving hints.

The approach described above has been useful to discover new or undiscovered behaviour in the use of technical products. From these behaviours new products requirements could be derived. The main criterion for the validity of the results was the interdisciplinary consensus of the participating scientists. In all evaluations this consensus could be reached with only a few exceptions.

6.2 Study 2: Survey on the familiarity with and the use of specific connections and fasteners

6.2.1 The Task, aims and objectives of the study

Selection and optimal design of connections is a difficult design task, which assumes extensive knowledge about the available fasteners and connecting processes, as well as a management of conflicting aims such as manufacturing and assembling requirements as well as, increasingly recycling and disassembling requirements. Only for a fraction of the large variety of connections, the necessary knowledge exists and is published in standards and guidelines. Examples are: bolts, welded and glued connections. The use of disassembly-supporting connections is limited to a few special application areas where connecting functions are of minor relevance and are subjected to small loads. However, potential for a broader use exists. "Disassembly-supporting connections are not used in practice because the connections itself and their properties are not known." The study described here, aimed at the confirmation of this hypothesis by systematic provision, preparation, analysis and interpretation of information. The objectives were to find out:

- to which degree disassembly-supporting connections are known;
- how knowledge of the existence of these connections affects their use;
- what the reasons for selecting connections are and how relevant they are;
- what sources of information are used with the selection.

The aim is not to provide detailed explanations, but rather to describe the existing situation.

6.2.2 Design of the experiment

Up until now, very few data exists on this topic. Because observations are difficult to time-consuming, a survey was selected as the appropriate method to collect the necessary information. A postal survey was chosen, for reasons of time and budget related to the demographic distribution of the people who were to be surveyed. Thus a guarantee of certain equality of the measuring situation is possible by standardisation of questionnaires and the added cover letter. Moreover, the temporal pressure is cancelled on answering the questions and because of the guarantee of anonymity at a postal questioning the likelihood of answering certain questions can be enhanced.

The designer is responsible for the selection, calculation and design of connections in technical products. So the group of designers of the manufacturing industry within Germany was chosen as the population to be asked. Appropriate companies could be found in an industrial company database sorted by industrial sectors. From this frame population a disproportional and stratified sample of 555 enterprises - stratified by industrial sectors - was drawn, to have an adequate number of cases for analysis of sub-sets.

Some difficulties arose from selection of the group of respondents by creating the questionnaire, because they mostly dispose only of limited resources, as e.g. time, and are often not able to give information for secrecy purposes. The difficulties consisted on the one hand of the limitation of the number of questions on simultaneous gaining a maximum yield of information and on the other hand of the interest-waking, clear, occupational group-specific formulation of short questions with possibly a lot of precise defaulted answers to increase the motivation and to minimise the editing effort. Therefore elaborate pre-tests comprising costly inquiries and pre-questionings were executed among engineers to get consistent and complete defaulted answers on the mainly closed questions. The questions and answers had to be formulated in a way that they possibly did not lead to collisions with the respondents obligation to maintain secrecy.

6.2.3 Procedure of the study

The questionnaire was sent with a cover letter to the random-based sample of enterprises. Two weeks after shipping the questionnaires a first reminder postcard was posted to all respondents which contains acknowledgements in case the questionnaire was already sent back or a reminder one more time of the survey. At the end of four weeks another reminder added with a substitute questionnaire was sent to the respondents which had not answered yet. All these letters were directed to the respective department of design.

6.2.4 What we learnt and what we recommend

If the amount of returned analysable questionnaires is taken as a degree of successful operation of the described approach, the survey with its rate of return of 38% can be assessed as a success. It appeared that meticulous preparation of questioning in particular consideration of the specific conditions of the target group clearly can raise the answer and information readiness as well as the quality of answers. Creation of questions and the related default answers took place not only in exclusive consideration of the research aim, but also with strong involvement of concerns of the potential respondents. To deduce consequences for further research in the field of disassembly-supporting connections and for further spreading of these connections in practice not only significant correlations but also clear indications to possible correlations could be considered.
These recommendations may appear trivially to the experienced researcher but might support the inexperienced to avoid so-called beginners' mistakes in this field.

6.3 Study 3: Observation and identification of individual design heuristics

6.3.1 The Task, aims and objectives of the study

Within the study "Applicability of Design Methodology in Early Phases of the Product Development Process"[2] [Bender et. al. 2001b]

- influences of a Design Methodology Education (DME) and
- influences of individual design heuristics and procedures on design performance as well as
- effective strategies for acquisition and proceduralisation of methodological design faculty

have been investigated in a longitudinal approach involving observation and analysis of the development of individual design styles and strategies by following the progress of engineering design students with and without DME.

6.3.2 Design of experiment

Within this longitudinal approach a design of experiment has been developed which determined the effectiveness and efficiency of DME using qualitative and quantitative *variables of test results,* like design quality and design time , as well as *procedural variables,* such as basic design operations and their order. Three test groups of engineering design students were distinguished with respect to predetermined stages of their studies:

A1 without explicit DME, having finished their exams for the undergraduate course of "Engineering Design" (after the 4th semester);
A2 with recent DME, having attended the graduate "Design Methodology" lectures (after the 6th semester);
A3 with advanced DME, having attended the above lecture and taken part in the graduate "Engineering Design Project" (after the 7th semester or later).

Each of the students of these groups was confronted with two design tasks:

- one out of three different conceptual design tasks, consisting of a verbal description of a design problem without any visualisation;
- one out of three different embodiment design tasks, comprising a verbal description, a sketch of the principle solution (i.e. the working structure), design specifications and technical data..

Both the conceptual and the embodiment design tasks had been chosen out of common areas of basic engineering design and were characterised by very similar requirements and constraints. The homogeneity of all tasks had been validated by design experts using a verified instrument for systematic analysis of design problems and tasks [Schroda 2000]. The A1-group was used as "base-line" of design capability before the intervening variable, i.e. the different levels of DME, were applied. At the A2 and A3-stage the students of the test group with explicit DME were tested against a control group of students in the same stage of their engineering studies, but without any explicit DME.

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[2] This project is supported by a grant from the Deutsche Forschungsgemeinschaft (DFG)

6.3.3 Procedure of the study

A total of 74 test persons participated in this study, of whom 21 took part in more than one stage of the study as "genuine longitudinal test persons". This lead to 107 evaluable cases. The test took place with up to 60 participants working parallel on the design tasks. For elaborating the conceptual design task the test persons had one hour, the embodiment design task had to be finished within 3.5 hours. Objective procedural variables of design activity were observed using photo-documentation, self-protocols and different pencil colours according to different test periods. Mental representation of design activity, like the intended strategy, and the retrospectively recognised (recapitulated) strategy of each participant were investigated by using a sorting card technique and questionnaire. In addition, individual qualification and professional characteristics, as well as individual heuristic competence [Stäudel 1988] were investigated using questionnaires too. For analysis and categorisation of the individual procedures appropriate empirical research methods like process matrices, transition matrices and a specific portfolio-diagram, identifying four different types of design procedure, were applied (for further details see [Bender et. al. 2001b]).

6.3.4 What we learnt and what we recommend

The biggest problem of this study was the lack of availability of appropriate participants for the longitudinal approach. It was impossible to find test persons who took part in all three stages of the study. therefore we could not maintain the genuine longitudinal design.. As a further result, the sample-size was rather small, in particular in the A3-stage (N=5). As a consequence and from a rigorous statistical point of view, much of what we observed could not be proven and therefore had to be neglected. However, we applied some strategies to use these "weak" results for further analysis and interpretation and even to ensure validity:

- The homogeneity of the test and control groups was tested by a survey of qualifications and professional background;
- Analysis methods appropriate for small samples were used [Bortz & Lienert 1998], in particular non-parametric statistics, like e.g. dichotomisation of data distributions and the application of rank order coefficients;
- The same variables were observed and analysed using different methods ("multi-method-approach"). In particular quantitative methods were extended with qualitative methods. As a consequence, it was e.g. possible to verify slightly insignificant statistical results using case studies.

7. General Recommendations for Appropriate Application

As a conclusion from these experiences we feel able to give some general recommendations for the appropriate application of social sciences' empirical methods in the area of design research. These are in particular:

- First of all, one has to learn from others who have applied those methods by reading their books and papers!
- If there is a lack of theory a hypothesis-driven approach is not the most appropriate approach. The formulation of research questions directly or based on exploratory research might be more suitable. Interdisciplinary teams might be very helpful in finding hypotheses and explanations because of the availability and combination of a large number of theories.
- To deal with the asymmetry of empirical relevance on the one hand and statistical significance on the other, extend the quantitative approach to data collection and analysis by qualitative methods. It can e.g. be helpful to explicitly aim at answering the question: "What may I conclude from this result *with a certain likelihood* and therefore have to *take into account* for real design practice?", rather than "What will *definitely happen* within design practice as a conclusion of my results?".
- Give detailed descriptions of the set-up of the study, your analysis and interpretation methods and make all assumptions explicit to ensure that the study can be understood and the results traced.

- Look at the target group! Who are the potential test persons? Which direct or indirect benefits can they expect from taking part? In particular experts from industry, who are under severe time-pressure, have to be convinced of the research objectives before taking part.
- When working with laypersons as participants, well informed volunteers might be less influenced by the experimental set up of the study and therefore act more realistically. The potential loss of representativity might be counterbalanced by a more natural behaviour.
- Choose a "multi-method-approach" to increase validity, when possible combining qualitative and quantitative approaches.
- Increase the validity of the results by using the appropriate analysis methods, in particular when dealing with small sample sizes and strong interconnectivity of variables. Dichotomisation of statistical populations and the application of non-parametric statistics are some promising approaches here.
- Increase the validity of the study by applying fundamental rules of test design and test analysis [Lienert & Raatz 1994]. To ensure homogeneity and inherent consistency of design tasks (not only) for laboratory studies. the taxonomy developed by Schroda and Rückert [Schroda 2000] might be very helpful.
- Establish causality between design success (e.g. in terms of design quality) and co-varying characteristics that have been gathered retrospectively, based on co-variation, time period and the exclusion of spuriousness (for details see [Baumgärtner & Blessing 2001]).
- Use valid methods for evaluating design success resp. design quality following a systematic evaluation process to rank the designs, and estimate and document evaluation uncertainties

8. Conclusion

The application of methods from social sciences is a common strategy in empirical design research. Thereby a fundamental asymmetry between these disciplines has to be considered.
As in engineering design practice, in empirical research the conceptual stage is of major importance. A deliberate formulation of objectives, questions and hypotheses, a sophisticated design of experiment, the choice, adaptation and application of appropriate methods for observation, documentation, analysis and interpretation of data and results are the basis of research success. Any effort taken in this phase will be rewarded when defending the results of research. Many faults due to careless conceptualisation of an empirical study can hardly be amended at the end.
To increase validity and comparability, a systematic and deliberate adaptation of methods from social sciences to objectives and topics of design research is necessary [Blessing et. al. 1998]. Some basic approaches to an appropriate and valid application of methods have been applied in three empirical research projects. No consistent methodology but some fundamental recommendations can be delivered for this area of research.

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