UNIVERSITY OF ZIELONA GÓRA
FACULTY OF MECHANICAL ENGINEERING
in association with the Design Society

THIRD INTERNATIONAL
SEMINAR AND WORKSHOP
10th - 12th October 2002
Zielona Góra - Łagów
POLAND

ENGINEERING DESIGN IN INTEGRATED PRODUCT DEVELOPMENT
Design Methods that Work

WHY METHODS DON'T WORK AND HOW TO GET THEM TO WORK

H. Birkhofer, H. Kloberdanz, T. Sauer, B. Berger

Darmstadt University of Technology
Department of Product Design and Machine Elements
e-mail: birkhofer@pmd.tu-darmstadt.de

Keywords: Design Methods, Transfer, Education, Designers, Industry

Abstract: *In order to improve the use of methods, the whole field in which methods are applied must be taken into account. There should be a substantial increase in the effectiveness of using methods in design projects, as well as in the support in learning and teaching them. The optimization of methods should follow a holistic approach, which includes influencing factors, such as education, designers, and organization. This paper presents and discusses an experience-based analysis of reasons why methods don't work. Based on the analysis, some approaches for improving the transfer of methods are also presented. The paper closes with an outlook on the research-project "pinngate" at the department of product development and machine elements (pmd) at Darmstadt University of Technology.*

1 INTRODUCTION

In the range of product development a multitude of established and new design methods can be found in literature, method collections or databases. Examples are well known references such as Pahl [10] or Ehrlenspiel [6], who assign design methods to certain design phases of product development or relate them to special access items. Within the Internet the so-called MAP-Tool [9] is an example for a method collection especially arranged for industrial users.

Principally in European countries, Systematic Design has been elaborated since the mid-sixties. The importance of design methods is generally accepted and companies are forced to develop innovative products methodically. Amazingly, it has to be said that methods are not widespread among industries and empirical investigations observing designers in industries often demonstrate a mix of intuitive and experience-based behavior.

Based on a questionaire, Gausemeier [7] proclaims that especially complex methods (e.g. QFD) are not widely distributed. Methods which are easier to apply and aim to increase the efficiency of product development (e.g. Creativity Methods like Brainstorming) are more frequently used. But in truth, the use of these methods is mostly adapted to specific needs and differs considerably from a regular procedure.

The question should be: why do we have this situation after nearly 40 years of design science? And - even more urgent: how can we change this situation? This paper attempts to answer both questions in regard to the transfer of methods in university as well as in industry.

At the department of product development and machine elements (pmd) of the University of Technology in Darmstadt the education of students as well as the training of designers in practice has a long and cultivated tradition. The approaches in education and training as well as experiences are presented here, and it all leads to a holistic approach which should overcome quite a remarkable set of problems.

2 TEACHING DESIGN METHODS AT UNIVERSITY

At university students normally acquire knowledge and methods in lessons and apply this know-how in exercises. Teaching methods for product development is mostly split up between a basic course and an advanced course. While the basic course mainly focuses on teaching well-structured factual knowledge, the advanced course focuses on process-oriented and methodological knowledge.

The reason for this two-step approach is based on the hypothesis that without knowledge students can hardly design properly, and therefore, a solid foundation of knowledge must be built up before they work in design projects.

2.1 Teaching knowledge vs. teaching methods

It is usually so that teaching design methods is more difficult than teaching knowledge. Students normally have a poor practical experience in the field of product design, and therefore, it is difficult for them

1. to design successfully without sufficient knowledge, and
2. to understand and estimate the value and profit of design methods due to a lack of experience with alternative procedures.

A conventional learning process is therefore often interrupted by interpolated questions. Furthermore only examples of methodical design processes, which are easy to follow because of its limited product knowledge, are understood well. However students mostly fail at working on more difficult and complex tasks.

2.2 Specialized approaches for teaching methods

In order to optimize the education, the department of product development and machine elements started to restructure its content and its approach to teaching methods. Five years ago a first project was arranged in teaching machine elements [1], followed two years later by a teaching project in product development. Both projects aim to improve the understanding and the application of methods.

2.2.1 Structured knowledge for methodical use

In machine elements education a fundamental change was made by integrating mechatronic elements and –due to the limited time for teaching- shortening mechanical elements. The increase of the variety of elements forced the restructuring of contents.

If afterwards students are to design even simple mechatronic products, they need an overview of mechatronic elements structured in terms of functionality. Therefore, based on the principles of a system model approach, all machine elements (Fig. 1: Mechanical gears structured in design catalogues) are presented in the paperwork structured in design catalogues [11], [2].

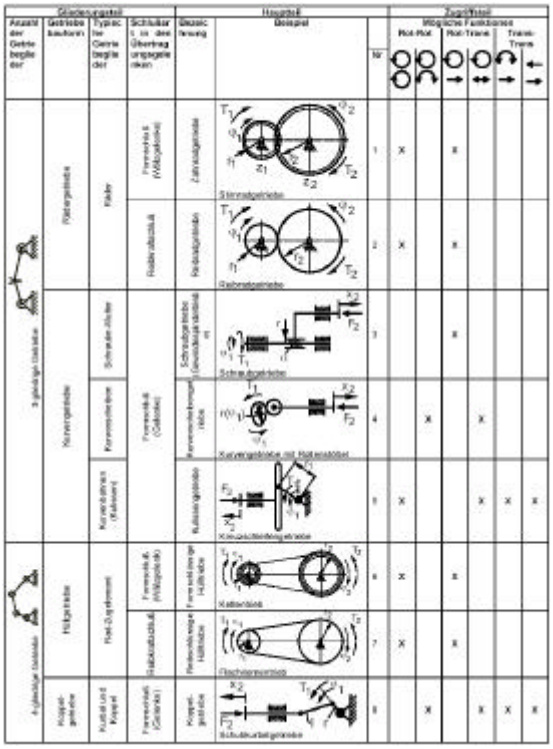

Fig. 1: *Mechanical gears structured in design catalogues*

Finding and evaluating solutions for their special tasks is much easier for students now. This methodically adapted structure and presentation of knowledge is one example which has proven to be a major step in supporting methodical work. It builds up a knowledge base, which can be extended later on by additional courses.

2.2.2 Teaching methods in project work

The machine elements course ends up with a "design-project". Students have six weeks to solve a conceptual design problem in teamwork. The optimal solution of the given problem is not obvious, so that alternative solutions must be created and discussed. This leads the students to real design tasks and problems, and demonstrates how efficient problem solving can be using designmethods.

Working in projects, students also acquire a more profound understanding and basic competence in applying methods. Through making mistakes, changing their problem-solving behaviour and

achieving success, they acquire a kind of heuristic competence almost automatically.

2.2.3 Teaching a method – and its convincing use

The course Product Development in the second phase of one's study at university consists of lectures and exercises, similar to the course in Mechatronic Machine Elements.

All lectures are structured in the same way:

- The first part of a lecture is an example, which motivates the students and helps them to understand the benefits of the specific method.
- After that, an overview about the objectives of the lecture is given.
- An important part consists of definitions in order to build up a common language between teacher and student.
- The contents are divided into "Development Process" and "Design Methods". This supports the understanding that the development process can be created independently from special design methods.
- To explain the contents several simple examples are presented. A design case at the end of the lecture demonstrates the use of the design method while solving a complex design problem and emphasizes its benefit.

2.2.4 Allow students to gain experience independently

Lectures are complemented by exercises, structured similarly to the lecture. The guidance within these exercises is a kind of coaching and students should have enough time to try the application of methods, to correct mistakes and to discuss their problem-solving process. To increase motivation

- all the exercises use the same object (e.g. an inclinometer - a kind of sensor - in the last term)
- the exercises simulate a real developing situation. This forces the students to concretize the given tasks and to find an effective way to solve the problem in time.
- the students work in teams with 4 to 6 members. A member of the department who has experience in real development projects coaches the teams.
- The solutions of the different teams are published in the Internet.
- Phases of reflection at the end of each exercise help to deepen the understanding.

2.3 Experiences in teaching design methods

The measures mentioned above for improving the success in teaching methods considerably increase the success of lectures and exercises. The number of students increases from year to year (at the moment 160 students) although students are allowed to choose other lectures. The rating of the lecture by students is quite good, too.

However, one has first to recognize, that this kind of well prepared lecturing and intensive coaching requires a huge effort in elaborating paperwork and PowerPoint-slides and in running the course. It is the quality of the staff and the manpower needed for preparing and running the course that are responsible for these good results.

A second point must be mentioned here. Educating students in the manner described above is not sufficient to ensure that they will use design methods in their later career. Even in later courses or project work at university students normally try to solve design problems conventionally: with intuition and experience. Although methodical knowledge is expected to be fully alert, most students find it difficult and time-consuming to use design methods. Sustainable methodical work seems too demanding for more sophisticated ways of teaching.

3 TRAINING DESIGN METHODS IN INDUSTRY

In order to transfer design methods into practice and to support the application of methods in product development, the pmd department has realized workshops for practicians in industry for more than 10 years. The teaching concepts and the content differ significantly from the courses for students at university. Unlike students, industrial designers have a lot of product specific knowledge, but lack a detailed knowledge of design methods. They are accustomed to their own style of problem solving and are often unwilling to accept new problem-solving procedures.

3.1 Designers are not students

To better understand why designers do not often use design methods in their daily work, a more detailed look at their work situation is necessary.

In design work one will find a lot of specific restrictions, a lack of resources, and above all, high time pressure. Everybody is expecting an immediate reaction to problems and designers are constantly pressed for fast solutions. Therefore designers are obviously forced to react spontaneously to these requirements.

In addition, designers are frequently forced to decide and to act immediately depending on the actual situation and based on their own experience. Therefore they do not like strictly defined design processes with their inflexibility and rigidness.

Furthermore, designers as human beings are exposed to a high emotional pressure and one cannot expect them to always make completely rational decisions. Therefore barriers often arise preventing designers consciously or unconsciously from using design methods.

Forced by the requirements of their daily work, designers are interested in key-turn tools and hints which are ready to use immediately. They are interested in a problem-oriented way of learning "on the job", applicating the methods directly in their daily work. This also implies that a trainer without a comparable depth of product knowledge normally fails in teaching methods because of his lack of understanding in the actual design problem.

The special situation in design departments obviously needs a special way of teaching design methods, which is unlike the university approach.

3.2 Specialized approaches for training methods in industry

3.2.1 The role of the project group

In order to analyse the reasons why design methods are only used sporadically in practice, the departement of pmd founded in 1995 a group of researchers called the "Project Group". This group has accomplished many co-operation projects with different industrial partners in the past. Normally the project teams consisted of three to eight members both from industry and university. The designers of the industrial partners contributed the special product and process knowledge, whereas the members of the department distinguished their role as trainers and coaches for methodical design work.

The objective of the project group is not to work on new methods, but to ensure the successful transfer of methods in industry and to investigate and overcome certain barriers for a successful transfer.

3.2.2 The Transfer-Workshop approach – training on the job

A first approach to overcoming the barriers in the transfer of methods into industry is the "Transfer-Workshop". Transfer-Workshops are a consequent development of standard seminars adjusted to the specific situation of designers in practice.

Conventional seminars cannot normally be adapted to the specific tasks and needs of the participants due to the heterogeneity of the audience. Therefore the main objective of such seminars, the transfer of methods, is hindered by the effort needed for understanding the more or less convincing examples often very removed from the designer's background.

In contrast to seminars, the training in Transfer-Workshops takes up a specific problem of the involved designers, mostly a current developing task. The participants work independently on the problem, coached by the trainer.

This kind of teaching fulfills the requirements of designers in practice much more than normal seminars. The designers are able to train the learned methods while solving a concrete problem in their field of expertise. No transfer from product examples removed from one's own branch or product family is needed and designers can see how methods work in their own field of expertise.

On the one hand, Transfer-Workshops have a high potential to optimize the transfer of design methods. On the other hand, they demand high expenditure from the coaches. In addition there is the risk that the solution of a concrete problem is more important for the involved designers than learning something about design methods.

Besides this, the benefit of the used methods is often played down after the first application. It takes a remarkable amount of a designer's self-criticism, to admit, that methodical work is a better problem solving procedure than one's own familiar procedure.

Finally, one should be aware that Transfer Workshops require an experienced and highly motivated trainer. Learning methods by self-study is not supported at all by this approach.

3.3 Experiences in training design methods

To coach designers in the use of methods is one goal of the project group. To observe and analyze the procedures designers use while designing is another one.

During the project work an empirical investigation was carried out [12], in which the use of methods was evaluated. One part of the investigation analyzed how the methodical know-how increases during the projects. An initial sobering result was that only 32% of the involved designers from the co-operation partners had learned something about the used methods (Table 1: Correlation of knowledge and attitude).

Table 1: *Correlation of knowledge and attitude*

		Attitude positive	Attitude negative	
Methodology-Know-How increases	Yes	64%	12%	32%
	No	36%	88%	68%
		39%	61%	

If the attitude of the co-operation partners towards the methods is regarded, an interesting correlation can be conceived. Designers with a positive attitude (39% of the designers) learned significantly more of the used methods (64%) than designers with a negative or neutral attitude (12%). Obviously there is a strong correlation between the attitude of designers towards methods and the knowledge they actually acquire.

But why is there such a large number of designers who refuse the design methods (61%)? In the following chapter a set of deficits of the use of methods in industry is pointed out.

3.3.1 Designers think in objects and not in models

Using design methods properly is not only a question of the knowledge of methods but also a question of knowledge of the theory behind them. It appears clearly that designers are mostly lacking knowledge of functional decomposition, of basic principles for developing systematics, of principles of structuring and recombination, or of the area of physical effects as a basis for product innovation.

To work methodically a clear concept of product modelling is necessary, a linguistic consciousness and the ability of abstraction, which is the ability to recognise the important and urgent aspects and to concentrate on them first.

Without a doubt in regard to these requirements, there is a lack of education even in universities. It is no wonder that most designers, who did not study at university are not able to handle methods effictively, to fit new methods into their knowledge-space, or even to adapt it.

3.3.2 Methods must fit the situation

Another problem arises when methods well-learned in courses or picked up subconsciously are not used due to misunderstanding the situation the designer is actually in. If he does not properly assess the situation and estimate his "degree of freedom" in terms of working methodically, he will neither be able to select the suitable method nor use it successfully.

In heavily problem-loaded situations even well-trained practicians sometimes fail to detect possibilities for the successful use of a design method. Especially under high time pressure, designers often try to proceed as they did in the past to avoid mistakes and time losses. Hurry on as fast as you can! The only goal is to get a draft, a sketch for presenting it on time.

3.3.3 The first solution is the best

A large barrier in the application of design methods is the conscious refusal of them for obvious reasons. Frequently for most designers the first idea seems to be the most charming one. Problems accompanying a more complex solution are either not visible or consciously neglected.

Furthermore, if there are no competing ideas, designers do not have to fear criticism by developing a solution that is not a global optimum. And if the solution later fails or causes severe problems, one can find a lot of excuses and reasons "why not...".

3.3.4 Poorly presented methods are poorly used

The description of design methods often varies concerning the kind and volume. Similar methods or facts are described using various terms and in different sequences. Thus, the search for methods designers in industry is really complicated.

Moreover design methods are mostly described to impart knowledge, not competence. Authors of methods normally neglect the fact that creating a method like FMEA or QfD is one task, but it is quite another and rather challenging task to transfer methods into practice sustainably. Neither abstract descriptions of design methods nor highly formalized procedures with a step-by-step approach will support designers substantially to use methods successfully. Didactical elements such as application-oriented explanations, hints, aids and assessments are seldom pointed out separately.
This focus of most method-descriptions has to be diagnosed as a fact, as the main target group for paper-based method descriptions in books is the scientific community – and not the designers. The needs of designers are often considered less.

Speaking of designers as a homogenous class of people is a further oversimplification. We have to recognize the huge variety of designers from the beginner to the expert, from a technical drawer to the design manager for complex power plants, from the

aircraft specialist to the expert for designing cutting tools. It should not be at all expected that all these designers a single method description presented in a chapter of a book in the same way.

3.3.5 Good products are designed without the use of methods

We must also be aware that many good products exist or were designed without any explicit use of methods. Further empirical research with conventionally and methodically working designers [8] did not provide convincing results, that designers working methodically design substantially better.

Even extensively trained and experienced methodological designers may not recognize the value of design methods, because they are not depending on them and succeed without them, using their self-made toolbox. And not being convinced of the value of methods is a killer-argument for applying a method by themselves, as well as in a design team. Could a formal application of methods cause anything else besides trouble and criticism?

3.3.6 Too many methods and too few tools

Besides the problematic description of design methods there is a severe lack of useful tools. In practice designers use powerful CAD-systems for modeling complex parts, components and products and simulation tools for calculating strength, stresses and dynamic behavior.

In contrast there exist only a few software tools for supporting the early phases of product development. Management of requirements, functional modeling or combination of working principles is supported only by some tools, which are mainly designed for individual use and specific problems. Due to their inflexibility they produce isolated results, which cannot be transfered to other tools or databases. There is no known tool supporting the early phases, whose results, for example, can be transferred to a CAD-system! In addition most of these tools are not intended for teamwork and they are often completely useless or even obstructive in dynamic meetings.

3.3.7 A sobering summary

Teaching and learning strongly depends on the specific situation the designer is working in and on its individuality. Furthermore various barriers increase difficulties in training methodical design. Experiences show that the wide-spread use of design methods cannot be achieved by isolated and uniform lessons and training. Rather integrated concepts are needed which teach students at university as well as practicians in industry, and which take into account the specific situation of a design task and its environment. These concepts also have to include powerful tools supporting the application of design methods.

4 A HOLISTIC APPROACH

4.1 Embedding the use of methods in the industrial organization

Education and training of designers alone cannot guarantee the use of methods in their daily work. Experiences show that product development projects are not necessarily carried out methodically after designers have visited a seminar or training course, even if the course was convincing and considered to be successful. In addition to the skills of the designers, the use of design methods is strongly dependant on the situation and environment of the company. One can see that there are three major influences at work here:

- Organizational embodiment of methodical work in the company, e.g. in a development guideline.
- Attitude of the management and the way they look at methodical work
- Atmosphere of the company is beneficial for innovations and promoting project- and teamwork.

Regarding product development as one of the most important processes of the company, which is done best in project manner, is the prerequisite for working methodically. Defining this development process based on methodical principals prepares the organizational anchoring of development methods best. By doing so, the whole process is structured into defined sub-processes and milestones, which are linked to partial results that can be verified.

On the other hand these demanded results correlate to design methods. For example clarification of the task and release of the requirement list, as well as conceptual design and release of concepts can be established. In this way planning far enough ahead and efficient budgeting capacities emphasize the early phases of the development process. Also the achieved results, e.g. requirements list and concepts, become very important since far-reaching decisions will be made based on them. Moreover, former sketches and drafts will become important documents in the development process.

By defining the development process the application of design methods can also be explicitly demanded. For example QFD can be defined as permission for starting the development process or FMEA for the start-up of production.

But even prescribing application of methods by law is no guarantee that designers attach great impor-

tance to them. It may be that designers use methods but only superficially and formally and without profiting much from them. In order to firmly establish design methods the support of the management is also needed. Executive personnel has to show that they take methodical development seriously by reviewing the results of defined processes and according methods. The management can further underline their intention of establishing design methods by linking up releases of development budgets with results of these. Management and executive personnel can further prove their positive attitude towards methodical development by supporting the project manager e.g. by moderating large design meetings. They can cultivate stimulating project and teamwork by participating in meetings, thereby emphasizing the importance and the objectives of a development project.

In addition the management can offer designers methodical training and coaching. Furthermore it is up to the executive personnel and management to set up an atmosphere that promotes teamwork and is conducive to innovation. They can further the designers' creativity and new and revolutionary ideas by assessing and rewarding development results.

4.2 Improving the transfer of methods

Obviously a holistic approach for the transfer of methods is needed, considering all the influence factors. This approach is aimed at eliminating deficits concerning the surroundings of the designer, the designer himself as an individual as well as a team member, the availability and quality of design knowledge, supporting tools and the sustainable transfer.

4.2.1 The Pinngate-approach

Such a holistic approach was generated within the project "thekey" [3] and developed as the "Pinngate" approach in the pmd-department at Darmstadt (Fig. 2: The Pinngate-system).

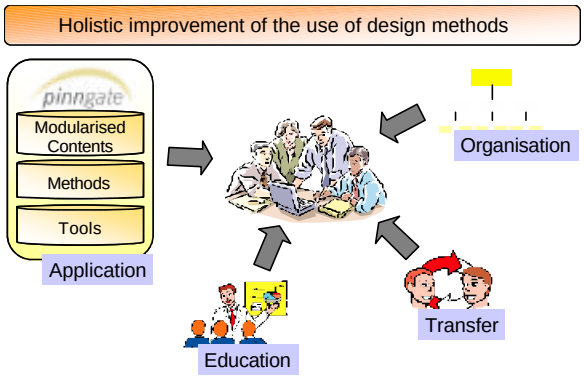

Fig.2: *The Pinngate-system*

The designer is placed in the center of this approach. All suggested improvements are intended first of all to fit to his/her individual situation, his/her special background education and his/her task specific needs.

The aim of "Pinngate" is to build up learning and training systems. Flexibility, individuality, adaptability and up-to-date available information are the main goals of the Pinngate-system.

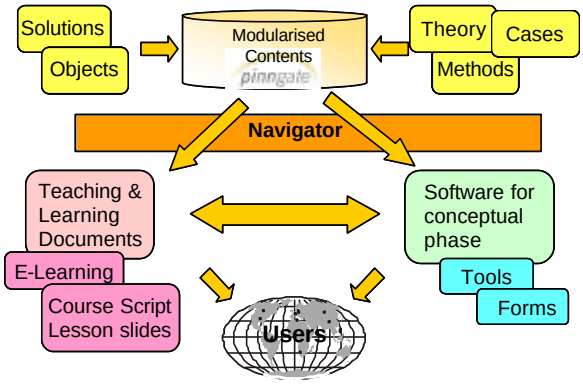

Fig. 3: *Sub-systems and contents of the Pinngate-system*

4.2.2 Flexibility and individuality define the Pinngate- structure

As the first part of the Pinngate-system, a knowledge pool for the designer is provided, including theory of product development, design methods, exemplary cases and a collection of described solutions and objects for different design tasks.

The contents of product development knowledge have to be available in a broad range and rank high in quality. On the same note, individuality in presenting and nearly complete flexibility in use and arrangement of contents has the highest priority. To achieve these demands, the contents of the knowledge pool are structured in a highly modularized way, so they can be adapted to individual needs and specific design problems. Especially the design methods are described in a standardized and structured way, using a Process Oriented Method Model.

As the second part of the Pinngate-system, teaching and learning documents are provided for designers and students. The teaching and learning documents can be derived from the modularized contents of the knowledge pool. Therefore a so-called "configurator" arranges single content-parts up to a coherent document for one or several themes. This enables the configurator to consider different aspects of special target groups and to choose a suitable kind of presentation, such as a script, a slide presentation or even an E-learning environment.

A third part of the Pinngate-system provides software tools especially for the conceptual phase,

which should be applied by designers in practice when they are using design methods.
Product designers in practice are confronted by a huge amount of restrictions and requirements in their product development process. Corresponding to the company they often have to consider special working rules or normative regulations. Furthermore they have to use certain design methods and are required to document the working steps and results.

In contrast to this, product developers should have the best possible flexibility and freedom in planning and organizing their development procedure and in applying design methods to support their creativity and problem-solving ability.

To satisfy all these different demands, specially suited design method tools should support product developers. A design method tool is defined as software, specially developed for certain design methods, such as evaluating a method or morphological box.

The main aim of such design method tools is to close the gap in a defined product development process, including the documentation and flexibility and individuality in usage.

Most importantly, the intended method tools should be applied by designers in practice when they are using design methods.

5 SUMMARY

The proper use of methods is not only a question of having access to a description of methods. Successful methodical design depends on a variety of influential factors, such as the design task, the individual designer, the basic theoretical knowledge behind the method, and the company with its organization and culture.

Experienced trainers with a wealth of task and product specific knowledge and open minded designers, keen to improve their design behavior are key-factors in the successful transfer of methods.

As these design trainers are rare, one approach for a widespread and intensive use of methods is to adapt specific faculties of a designer by powerful software tools, based on a well-defined modularization concept of contents as it is done in the Pinngate approach. This requires a holistic approach with a customized focus on designers and their individual needs. A nearly unlimited flexibility and adaptability of methods is needed to obtain an individual method toolbox.

Nevertheless the role of a trainer remains an important one. It is similar to Internet-based teaching and learning systems: there is a large change for improving the transfer of knowledge and faculties with powerful tools, but the most convincing approach seems to be that of "learning from the experts".

6 REFERENCES

[1] A. Albers, H. Birkhofer, *Teaching Machine Elements at Universities – towards internationally harmonised concepts in view of industrial needs*, WDK 26, Proceedings 12th ICED99, Munich, 1999, Vol.2, p1043-1046

[2] H. Birkhofer, *Skript zur Vorlesung Maschinenelemente*, Shaker-Verlag, 2001

[3] H. Birkhofer, U. Lindemann, M. Meier, *Product Development as a Structured and Interactive Network of Knowledge – A Revolutionary Approach*, WDK 28, Proceedings ICED 01, Glasgow, 2001, p457-464

[4] H. Birkhofer, H. Kloberdanz, B. Berger, T. Sauer, *Cleaning up Design Methods – Describing Methods Completely and Standardized*, Proceedings of the 7th International Design Conferenc, Dubrovnik, 2002

[5] H. Birkhofer, B. Berger, S. Walter, *Modularisation of knowledge – a new approach in the field of product innovation*, Proceedings of the 7th International Design Conferenc, Dubrovnik, 2002

[6] K. Ehrlenspiel, *Integrierte Produktentwicklung*, Hanser, 1995

[7] J. Gausemeier, *Kurzbericht über die Untersuchung „Neue Wege zur Produktentwicklung"*, Berliner Kreis, Wissenschaftliches Forum für die Produktentwicklung e.V. (Hg.), Eigenverlag, Karlsruhe, 1997

[8] J. Günther, *Individuelle Einflüsse auf den Konstruktionsprozess: Eine empirische Untersuchung unter besonderer Berücksichtigung von Konstrukteuren aus der Praxis, Reihe Konstruktionstechnik München, Vol. 30, Shaker Verlag, Achen, 1998*

[9] MAP-Tool, Vom Markt zum Markt, Forschungs-Verbundprojekt des Landes Baden Württemberg, www.uni.karlsruhe.de/~map

[10] G. Pahl, W. Beitz, *Engineering Design*, Springer, London, 1996

[11] K. Roth, *Konstruieren mit Konstruktionskatalogen (Band 2)*, Springer, Berlin, 1994

[12] M. Schneider, *Methodeneinsatz in der Produktentwicklungs-Praxis*, Fortschritt-Berichte VDI, Nr. 346, 2001

[13] M.Schneider, T.Sauer, B.Birkhofer, *Results and Conclusions of the Evaluation of Successful Co-Operation Projects Among Industry and University*, WDK 28, Proceedings ICED 01, Glasgow, 2001, p35-42