INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN
ICED 05 MELBOURNE, AUGUST 15-18, 2005

An extensive and detailed view of the application of design methods and methodology in industry

BIRKHOFER H., JÄNSCH J., KLOBERDANZ H.

Keywords: design methods, industry, design research, transfer of design methods

1 Introduction

There are many investigations, analyses and evaluations of methodological work in industrial practice [1]. The results of these works are quite similar:

Methodological work is not applied in the desirable breadth in practice from the scientists' point of view, even though necessary prerequisites are met [2]. Even though a lot of young engineers with an education in methodology have entered into practice, scientists claim that they see their methods only hesitantly and sporadically applied.

In contradiction to these statements we notice quite a lot of well-structured work in industry, like project management in Simultaneous Engineering projects as well as the isolated application of complex methods not covered by conventional methodology [4]. For example, many companies have established a quality gate system and apply methods like FMEA and QFD.

The reasons why there seems to be a big gap between the poor application of methodological work in practice and scientists' expectations as to how methodological work should proceed in practice are relatively unknown [3].

2 Objectives

The objective of this paper is to make people realize that a more detailed examination of the use of methods in product development is necessary. Some basic requirements should be mentioned before analyzing such a complex topic as the use of design methods in industry:

1. Design includes the early phases of product development, i.e. the clarification of the task, the conceptual design and the first steps of embodiment design right through to a roughly scaled product model.

2. The terms "design methods" and "design methodology" refer to the set of systematic design methods, published especially by Pahl and Beitz or Ehrlenspiel, and summarized in the German guideline VDI 2221.

3. The investigations and the results refer to German companies.

4. Dealing with the transfer of methods to industry and the acceptance of methods, their efficiency and effectiveness have to be taken into account, as well as the whole design situation including the task, designers, teamwork, company, branch, customer and market. Analyzing a method by itself alone cuts the network of relationships to an isolated view with inadmissible conclusions **Error! Reference source not found.**.

Based on the requisites mentioned above, this paper aims to analyze the use of design methods and the transfer of design methods to the industry, in order to provide a more differentiated view of this issue. Actually, this paper intends to generate a framework for classifying the strengths and weaknesses of design method application in industry, in order to provide insights for substantially improving industrial design, as well as avoiding an unlimited production of undesired methods and tools in design research.

3 Methods

3.1 Empirical studies as a basis of research

Primarily, the assessment of the supply and demand of methodological support in industry is well-founded and backed up by research. This approach is more analytic and differentiated, and covers design methods and methodological work. It is based on long-term design research of almost 20 years and refers to detailed analyses of development processes [5]. The results mentioned in this paper are based on a remarkable number of cooperative projects between companies and the department of Product Development and Machine Elements (pmd). Experiences in this research field were made and elaborated upon in several PhD-theses [6, 7, 8].

3.2 Structuring results in a systematic framework

For a detailed discussion of methodical work in industry the following questions have to be answered:

- Who creates design methods for the industrial work?
- What can design methods accomplish? What might their “real benefit” in an industrial environment be?
- Which features of design methods and methodology support efficiency, encourage acceptance, and motivate people to use them?
- How can design methods be adapted to the requirements of practical use in industry?

Actually, these questions cover the “process-chain” of supply, demand and application of design methods. Obviously, there is an overlap of supply, demand and application, but there is also a lack of congruence between these 3 fields, which is illustrated by the Venn-Diagram (Figure 1).

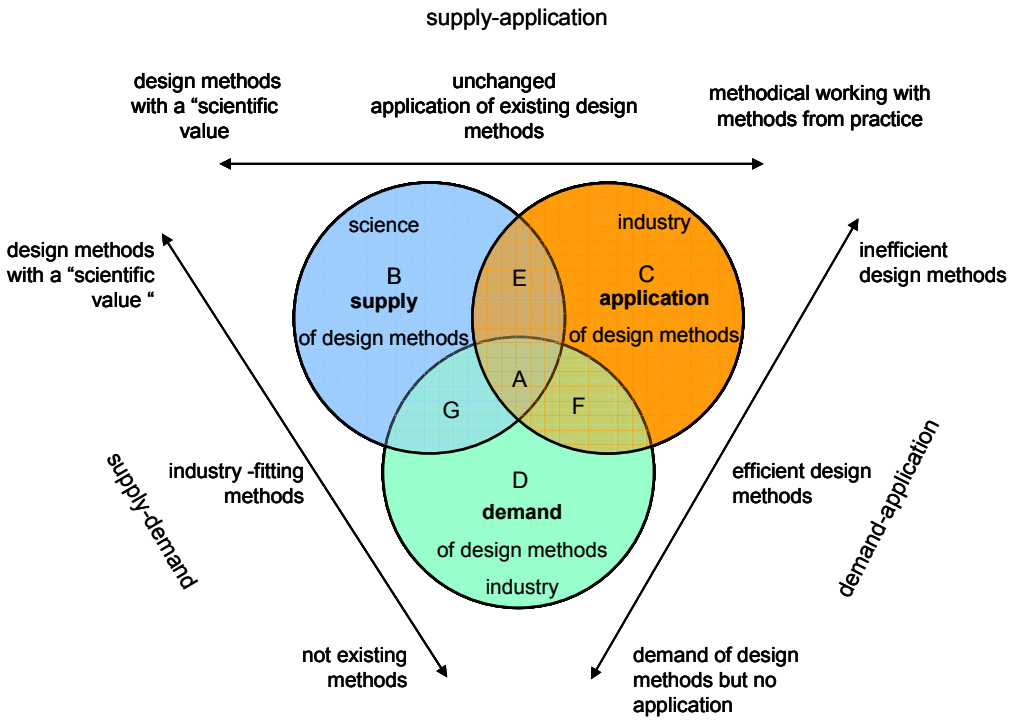

Figure 1. Scheme of supply, demand and application of design methods

Regarding the framework, three fields can be recognized:

- Field B "supply of design methods" contains all design methods summarized in the term "systematic design methods" mentioned above. Field B stands for a purely scientific view of design methods. On the one hand, scientists have found methods in fields A and G, which meet the requirements of industry. However, there are still methods left, which have been invented by scientists but are not used at all. To this type of methods belong the requirement and product specification.

- Field C "application of design methods" covers those design methods actually used by industry.
  In this field, we found almost no methods. Some methods are applied seldom, because it makes sense to structure the product or to get a better understanding of the product. Yet the methods are not user-friendly and do not offer simultaneous documentation for processing the method's results. This is in some part the functional structure. It is hard to integrate this method into the design process and to reuse the results.

- Field D "demand of design methods" comprises design methods, which are explicitly or implicitly demanded by industry.
  This field represents one area with a high potential for research in design. It would be very interesting to analyse this field in more detail, in order to find open fields for design methods. Identifying these fields or problems would make it possible to create methods, which exactly meet the demands of industry. It might also be possible to adapt existing

methods to the actual problems. According to our studies, the type of methods, which might be identified, would be in the field of project management and tool-based methods.

The Venn-diagram in fig 1 contains three scales:

- The "supply-application" scale reaches from the purely scientifically developed design methods to design methods generated by experiences in practice without any perceptible foundation in science.
- The "supply-demand" scale ranges from the purely scientifically developed methods to the complete lack of methods for a special demand.
- The "demand-application" scale reaches from a clear demand without any fulfilments up to the intensive, but inefficient use of methods without any benefit.

The fields and coordinates of the framework in fig. 1 enable one to move on to a more detailed analysis. The three fields should not be seen as individual categories, but as overlapping areas with intersections between them (fig1 EFG).

Intersections can be seen as special fields of research interest.

Field A is the optimal intersection, where science has met the demand of industry and the practitioners can work efficiently with the design methods offered.

Field B is the proverbial "Ivory Tower", where academia invents new methods without any demand from industry and with no perspective for sustainable application by practitioners.

Field C contains design methods, which are implicitly used by designers in industry. Management is not aware of these methods and does not trust in the "experience" of its designers. So, there is no theoretical foundation of these methods.

Field D articulates the demand of industry, but no method is known and design research does not address the topic appropriately.

Field E contains design methods, which are supplied by science and applied by industry in the intended way, but their use is doubtful, because there is no real demand for them.

Field F includes design methods, which are created by industry to improve performance without any support or systematic design research

Field G contains design methods which are provided by science and demanded from industry, but which are not actually applied.

This portfolio helps to identify the critical ranges of design methods, and so provides a systematic presentation of design methods and potential areas for further research. Furthermore, it supports the evaluation of design methods according to their strengths and weaknesses.

3.3 Questioning designers for identifying key-issues

In order to clarify the special questions of this paper and arrange them according to the Venn diagram, partly-structured interviews with practitioners in different fields in industry were set

up. The practitioners were mainly successful designers in German middle-class industries. To obtain a broad and extensive survey, the interview-partners came from companies that produce consumer-products, capital goods and automotive products. Their educational backgrounds and work experience vary from academic education to practical training. Nevertheless, there was an unexpected and general consistency to most aspects concerning the use of design methods in industry.

The central questions of these interviews are:

- With which design methods do you frequently work?
- Which design methods are most useful?
- Can you identify working-steps which do not have/feature a design method?

4 Results

4.1 General statements to the use of design methods in industry

In general, the evaluations of the project, theses and interviews result in the following impressions of the industry according to design methods:

First, one can say that the German middle class industry has a positive attitude toward design methods. If design methods are not applied, it is often due to a lack of knowledge about the design methods and their application, as well as a lack of demand from company management.

Furthermore, we often found that design procedures are greatly based on experience. Designers plan their proceedings mainly according to the structure of the product, to organizational requirements, and to time constraints, such as deadlines and terms of delivery. Questions referring to the way of finding solutions were often answered with terms like “intuition”, “experience” and “feeling”. If designers use design methods, they often apply them afterwards to confirm their feeling.

In addition, a main issue for designers is the use of communication as a kind of “higher” problem-solving method. Many CEO’s require efficient communication between designers. To prevent or solve conflicts they often try to implement methods of conflict management and communication training. Some managers put these methods on an almost equal par with design methods.

4.2 Results from the viewpoint of framework intersections

The following chapter summarizes the research results according to the intersections in the Venn diagram of Figure 2.

- **Total intersection A: Useful and applied design methods supplied by science**

An ideal symbiosis between the supply, demand and application of design methods has been found in area A. Here we find design methods like the requirement list, the systematic evaluation, generating variants and the view on products regarding their functions, processes

and modular structure. Systematic design has its greatest success in industry with methods of systematically defining and analyzing solutions. This phenomenon might be interpreted as a characteristic of human beings, that the sovereignty to create innovations should remain with the designers with all their creativity and experience. Actually, innovation seems to be a behavioral trait of designers and their ambition is related to it. A task definition or a solution analysis as a kind of "lower valued task" is not such an interesting task, and the designers more readily agree to be supported by scientifically based design methods.

- **Supply – application intersection E: Formal applied design methods with no use**

This intersection field remains empty, as no explicit result could be found. Neither the cooperative projects nor the interviews show examples. A reason may be the extreme time pressure in actual design work, which "defends" any application of methods apparently not directed at an expected result. If newcomers from universities try to apply fresh methods in their first design work, they are urged to use more common procedures of the design office.

- **Supply – demand intersection F: Useful and supplied design methods that are not applied**

A main concern of scientists is that existing design methods are able to solve design problems, but they are not applied. There is a lengthy discussion in design science about the benefits of functional decomposition accompanied by claims about the reluctance of patricians to use them. These statements reflect the view of scientists more than the real value of such a design method. Similar to the method "systematic development of solutions", these methods have demonstrably proven their benefit and power – when used by most experienced users! The method "systematic development of solutions" is a good example. It is a method, which has demonstrated its use in many projects, but is not accepted by industry in general.

If designers are indeed hesitant to apply design methods, then it is the fault of the scientists. In creating a method, the scientists often integrate a lot of prerequisites and abstract models, and clutter the method with new or unclear phrases. So, it should not surprise anyone that practitioners do not like functional decomposition since there has been only dissention for nearly 40 years as to what the term "function" means.

- **Demand – application intersection G: Useful applied design method but not offered by systematic design science**

A substantial amount of methods used in design offices comes from outside of systematic design. Especially methods and strategies to structure a design process are commonly needed in design offices. They are often referred to as the company's "culture". These methods range from product- and project planning, project-management, job preparation of serial production, process planning, structured processes with milestones, and design reviews and methods to estimate and calculate costs.

It is obvious that systematic design focuses much more on the innovation and improvement of products than on design processes. Systematic design, seen as a guideline for improving the designer's own problem-solving is perhaps over-interpreted, if these proposals for individual behavior are transferred to a common framework for efficient design procedures.

5 Conclusion

5.1 The potential of successful transfer of design methods in industry

The "offer-demand-application"- framework demonstrates that the successful use of systematic design methods in industry depends on the prerequisites of several stakeholders (Figure 2) and is not only a question of designers being either too academic or too practical.

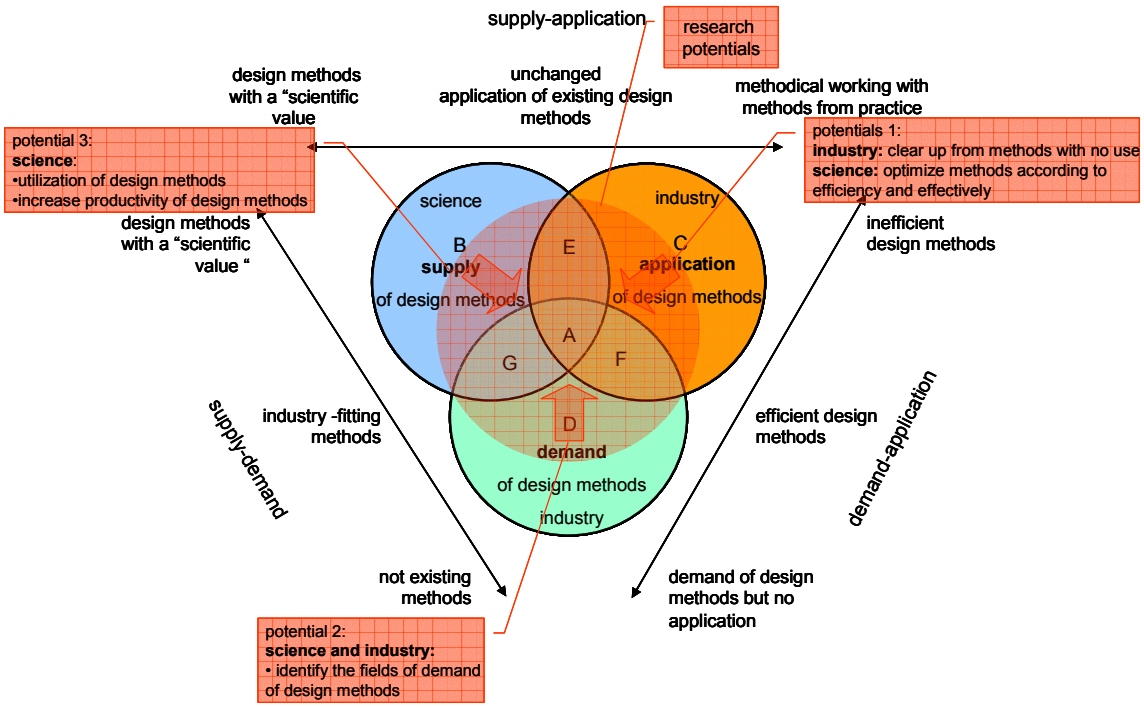

Figure 2. Potentials for design method in industry and science

There are three areas of potential:

1. Some possibilities in industry are to get rid of formal methods, which are not useful, and to be open to applying the design methods that are available. In addition, it would be important to communicate with scientists as to which aspects of a method are useful and which need improving. Another potential for research exists in this field for scientists to optimize methods according to their efficiency and effectiveness. Further potential for science may be also the adaptation of existing design methods to the demands of industry. By analyzing the industry, problems can be identified, which could be solved with new design methods.

2. The potential for science and industry are located in Field D. This field requires a detailed analysis in order to identify demands for design methods.

3. Another possibility for science lies in field B. Here it would be useful to utilize existing design methods in order to make them applicable for industry. It would also be important to adapt existing design methods to the real demands of industry.

In order that the use of design methods is successful, the different perspectives of scientists and industry on methodological work have to be taken into consideration. Scientists are not that deeply aware of the tasks and problems which result from the nature of industry. Accordingly, scientists are very focused on the design methods in themselves and on scientific or educational aspects. This is a matter for a less holistic and differentiated perception of practitioners of the design process. They should not see the design methods as antagonistic to methods used in industry. Scientists and practitioners speak "different languages" and have different backgrounds. Though they have the same goal, practitioners mainly use words like "efficiency" and "results", while scientists use words such as "logically" and "obviously". It lies in the interest of both sides to find some common ground despite their differences.

5.2 The changing and growing field of influencing parameters in design

Frequently used methods and processes in industry should be used as "best practice" examples in order to identify gaps and missing links in design research. Industry strives for result-oriented processes and operations in general, and in terms of the business objectives time, costs and quality. Their work is shaped by the organizational conditions of business and the aspects of everyday work (Figure 3).

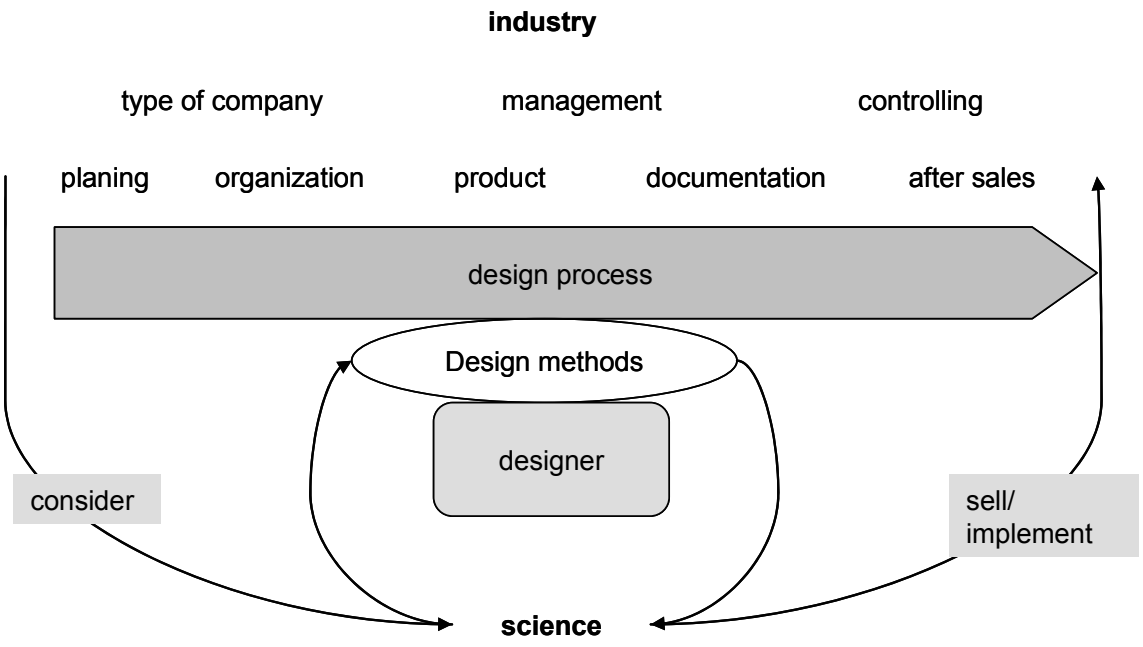

Figure 3. Influence factors for the development of design methods

Industry is strongly result-oriented and aspires to a controllable design process [4]. Thus, industry gives priority to methods that quickly lead to a result which contributes to the progress.

5.3 The "Ten Commandments" of successful transfer

Even if the picture of the "Ten Commandments" may be criticized as unscholarly, we use it here as a catchy guideline for generating or even evaluating current and newly developed methods.

- **Commandment 1: Design is Not Design – Meet the Design Situation!**

Design in industry comprises a huge and manifold area of tasks and duties. In designing products with simple structures, like parts or components, one has to focus on management and organizational tasks, such as establishing a powerful PDM-System or an efficient system to manage variants or to prepare the series production. Designing products with high complexity like cars, airplanes or power plants is a challenge in design and it is important to get a functional and modular overview as a basis for managing suppliers.

However, creating a methodological support for a specific need should not mean creating only several specific solutions that have nothing to do with one another. The current knowledge in design science [15] has to be accepted as a powerful basis for design support in general. It must be a task of scientists to break this knowledge down into specific branches, companies, design tasks and situations. The Special Interest Group "Applied Design Science" of the Design Society [14] will probably see to rules and procedures, which deal with how to efficiently specify generalized design theories to support the design of pistons, as well as of environmental friendly power plants.

- **Commandment 2: The Times Have Changed - Deal with Current Design Tasks!**

When systematic design appeared in the mid-nineteen-sixties, it was carried out without using computers in an organizational hierarchy, and most companies had an extremely high percentage of in-house produced parts. Nowadays, in the age of globalization, designers are linked by e-mail, video and data transfer worldwide. The in-house produced parts of the car producers comprises about 30% and design "mutates" to the management of in-house and outside suppliers of services. Often creativity is no longer dedicated to creating innovative products, but to creating efficient processes, which meet the goals of time, cost and quality. These days, designers are active worldwide and not only in design. As project-managers, designers are responsible for product and project success from the first customer request over delivering the product to services and After Sales Management.

Design tasks have grown and changed dramatically in the past, and there is no doubt that they will change in the future. Developing design methods the way it was done in the 1970's may be of scientific interest, but does not meet most current needs.

- **Commandment 3: Focus on Methods for Best Processes, Too!**

The management of the design department needs methods; however, systematic design hardly provides methods to support management processes such as task planning and controlling. The following methods may support the developing management: Task structuring, risk management, decisions support, strategic planning tools, and tools for the coordination of market, product and company strategy. Furthermore, existing methods do not have features to integrate them in the company's context. So, the potential of the actual design methods is to integrate the features of management and supply them to industry.

- **Commandment 4: Don't Forget Organization!**

The integration of design methods in the organization of a company also plays a crucial role. If design methods do not conform to work flows and project management concepts, it is almost not possible to apply them properly. Also, the design methods need to be demanded by the project leader. If nobody requires design methods and searches for a sensible application,

there is almost no chance to work with them. Therefore, the leadership of a company has to be familiar with design methods in order to bring them into play in the right places.

- **Commandment 5: Methods Have to Have a Processable Result**

The result of each method used in design has to be a final document. These documents must contain processable data and should provide a simple record of the design process. It does not help to make printed documents or photographs of the results; the important point is the processing of these data. This is what will make design methods more attractive to industry. If documented results that are processable are provided, it makes it much more attractive for particle work.

- **Commandment 6: Users Use Methods – Meet the Designers!**

Additionally, the people who bring the design methods into play have a decisive role. A person in a position of authority is necessary, who introduces the design methods in the design department [9]. The designers have trust in this person and the methodical work.

Moreover, methodology is an individual working technique for different tasks. So, there should be different methods for project management, leadership, design teams, etc. But the basis of the methods should be the same. Thus, the way of thinking of the managers and designers and project leaders will be harmonious. This is also the basis for good and efficient communication between them.

- **Commandment 7: Teach Theory – But Train Methods!**

The imparting of methodical working is fundamentally different than that of factual knowledge; it implies a change of behavior. It is essential to inspire motivation and understanding for design methods. Lectures and seminars alone do not help in this [11]. It is more important to start a reflection process for each designer. Every single designer has to rethink his own acting and thinking processes.

It is plain to see that designers with no methodological background adapt their actions to the guidelines of design methods without knowing them. This phenomenon confirms that design methods from a human perspective. This phenomenon is found especially in the area of complex products.

Generally, one can say for the teaching of design methods: There is a need for good examples and advice, for sufficient experiences in practice within the education, and the designers have to learn self-reflection.

- **Commandment 8: Design is Difficult Enough - Keep Design Methods Simple**

The requirements which industry formulates for design methods are the following: they have to be simple and pragmatic. They have to be applicable with simple tools which are always available, and they should not be time-consuming. The expense of the design methods has to reasonable to the benefit. Still a positive experience in practice is indispensable.

- **Commandment 9: The Need for Software-Tools**

The invention of pure methods does not provide designers with enough support; their application has also to be considered [13]. The creator of methods has to know how designers work with methods and what their demands for a profitable application are. Therefore, methods also require a tool or an add-on to support the practical application. (See also

commandment 5). It is not believed that software is a cure-all for every problem occurring in design. But software can substantially reduce the effort for iterative and formal tasks.

Commandment 10: Motto: Get On With Design Methods and Talk About the Experiences

The last point is to introduce design methods in industry. The design methods have to be put on the market and sold with all their potentials and features. It helps none to develop design methods and then not bring them to their place of application and use. This is the request for science to be more involved in industry and demonstrate the benefits and potential for applying design methods. There is a huge demand for efficient methodical work, especially in current design with all its complexity and time pressure. Let science and research do the right thing at the right time!

6 Key conclusion

This paper provides a practical foundation to identify important research fields for science and industry. It supplies a basis for better communication and cooperation between them. The central aim is to move industry and science closer together in order that they support each other.

Hence, scientists should not claim to implement design methods in a scientific way. Rather, they should make scientific considerations about making design methods more accessible, motivating and adaptable to industry. Therefore, the task of the scientists should be to translate their results into teachable and usable methods and methodology. The adaptation of design methods for industrial use must be carefully planned and prepared.

References

[1] Grabowski H., Geiger K. (Hg.): Neue Wege zur Produktentwicklung. Stuttgart u.a.: Raabe Verlag, 1997

[2] G. Pahl, W. Beitz, Engineering Design, Springer, London, 1995

[3] Birkhofer, H. There is nothing as practical as a good theory - An attempt to deal with the gap between design research and design practice In: Proceedings of the International Design Conference - DESIGN 2004, Dubrovnik, Croatia, May 2004.

[4] Stig Ottosson, Udo Lindemann (Hg.), Collaborative Product Development Considerations, in Human behaviour in design, Springer, 2003

[5] Badke-Schaub, P., Frankenberger E., Management Kritischer Situationen. Produktentwicklung erfolgreich gestalten. Berlin, Springer 2004

[6] Frankenberger, E., Arbeitsteilige Produktentwicklung – Empirische Untersuchung und Empfehlungen zur Gruppenarbeit in der Konstruktion, Düsseldorf, VDI-Verlag, 1997.

[7] Schneider, B., Methodeneinsatz in der der Produktentwicklungspraxis, Düsseldorf, VDI-Verlag, 2001.

[8] Heidemann, B., Trennende Verknüpfung – Ein Prozessmodell als Quelle für Produktideen, Düsseldorf, VDI-Verlag, 2001.

[9] Birkhofer H, Kloberdanz H, Sauer T, Berger B, “Why methods don’t work and how to get them to work”, Engineering Design in Integrated Product Development. Design Methods that work. Ryszard Rohatynski, Julian Jakubowski (Ed.): Proceedings of the 3rd Internat. Seminar and Workshop. 10.-12.10.2002. Zielona Gora, Lagow, Poland. S.29 – 36.

[10] Lüdcke, R., Effizienzverbesserung durch gezielte Führung in der Produktentwicklungspraxis: von der Beobachtung zum Reflexionskonzept, Düsseldorf, VDI-Verlag, 2003.

[11] Hutterer, P., Eris, O., Jung, M., Leifer, L., Lindemann, U., Mabogunje, A., "What do designers really need? – an Explorative Experiment Before Developing Teaching Tools and Methods," proceedings of the Cognition and Exploratory Learning in the Digital Age Conference, Lisbon, Portugal, 2004.

[12] Lindemann, U., „Human behaviour in Design“, Springer, Berlin, 2003.

[13] Blessing, L.T.M., A process-based approach to computer-supported engineering design, PhD-thesis University of Twente, Enschede, the Netherlands, published Cambridge, April 1994.

[14] Hosnedl, S., Vaněk,V. a Borusíková, I.: Design Science for Engineering Design Practice. International Conference on Engineering Design – ICED 01. Glasgow, Scottish Exhibition and Conference Center, Velká Británie: Institution of Mechanical Engineers - IMechE, London, 19.-25.8.2001. Vol 3, s. 363-370. ISBN 1 86058 1.

[15] Vladimir Hubka, W. E. Eder. Theory of Technical Systems in The Curriculum of Engineering Schools. WDK 26, Proc. International Conference on Engineering Design, Iced 99, Munich, F.R. Germany, August 1999

Prof. Dr.-Ing. Dr. h. c. Herbert Birkhofer
Darmstadt University of Technology
Department: product development and machine elements (pmd)
Magdalenenstrasse 4
D-64283 Darmstadt
Germany
Phone: +49 (0) 6151 – 16 2155
Fax: +49 (0) 6151 – 16 3355
E-mail: birkhofer@pmd.tu-darmstadt.de