INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'09
24 - 27 AUGUST 2009, STANFORD UNIVERSITY, STANFORD, CA, USA

EXPERIENCE CONCEPT AS A TOOL FOR FUZZY FRONT-END IN ENGINEERING DESIGN

Jens Krzywinski[1], Christian Wölfel[1] and Frank Drechsel[1]
(1) Technische Universität Dresden, Germany

ABSTRACT
This paper aims to discuss, to what extent industrial design methods are suitable for the use in the frontend of engineering design processes. The main focus is on the conceptual design stage.
Based on a study within transportation design, a definition of experience concepts is suggested, the contained elements are described as well as processes to its development are presented. This experience-oriented concept understanding serves as the basis for applications within the development of mainly technically oriented products such as wheel loader and textile or packaging machines. Further, it is successfully transferred to a workshop program, which has been tested within engineering (design) education since 2007/08. The discussion of the results of these ongoing studies focuses on a general integrated application of experience concepts in engineering design.
Finally, proposals for a self evident integration in education and practice as well as an approach for an collaborative research project of industrial and engineering designers studying methods in early phases are presented.

Keywords: industrial design, conceptualization, experience

1 INTRODUCTION
Since a long time, methodology is an important research topic in engineering design (ED) and also is the researcher community of industrial designers rapidly growing. But in both disciplines a general uncertainty concerning approaches in early phases still exists. “Conceptual design is an important phase of the design process. However [...], design theory and methodology has little to offer to support this crucial activity” in [1].
On the other hand today there is a general agreement on the importance of these early phases in both disciplines. “The degree, to which a product satisfies customers and can be successfully commercialized, depends to a large measure on the quality of the underlying concept” in [2].
Between 2005 and 2008 the authors accomplished a study on concepts in Transportation Design (TD). Some of the results are presented in this paper. Within the study TD processes have been compared to ID processes. This has been expanded to the ED field on the basis of some test studies later on. A number of findings on the concept phase have been derived this research. The results are focusing on a new definition of design concept as an experience-oriented concept, but they also describe concrete content as well as processes which lead to this kind of concepts. “The design concept as experience-oriented concept works as a highly compressed mental starting point for the design. It can be called nucleus (for the design), at the same time it confirms guidelines which lead through the process to the product” in [3]. The experience concept contains three major elements, a comprehensive narrative scenario, a user story and a description of the objects essence. These consistent elements are integrated visualized as one holistic concept.
This compressed form of the concept stands contrary to the comprehensive description, which is developed during conceptualization within ED. In Engineering Design, both Function Analysis and Requirement List, form the results of the first working procedures and serve as the first product-representing model [4]. These extensive descriptions hardly permit free cognitive spaces for development processes concerning the product as a whole. Accordingly they are reduced unconsciously, or are worked on step by step, detail after detail. Taking the cognitive workload into account, it seems unfeasible being able to work at the product as a whole.
In order to avoid such unconscious and rarely reflected losses, the paper suggests an integration of design concepts as tools into the engineering development processes, and presents first practical attempts in this direction.

2 DEVELOPMENT PROCESSES IN INDUSTRIAL AND ENGINEERING DESIGN

2.1 design disciplines in product development

In product development processes are always several disciplines involved (engineering and industrial design, economics etc.). Depending on company, product etc. one of these disciplines can be dominating (e. g. [5], [6]). In almost every case product development processes are also design processes, therefore design disciplines are usually well represented. Although the products of these processes may be quite different, "the processes of their creation are in many ways similar – however within each process the emphasis that is given to particular activities varies greatly between different domains" [6].

Design (-ing), in a very broad sense can be understood as: creative development of new objects or processes [7]. Beside many other things this can be products, machines and plants. Designing is based on competences, skills and above all the (general) knowledge of the designer. A general definition of design which addresses the aspect of knowledge is given by Hatchuel et al.: "Design is a process by which something unknown can intentionally emerge from what is known" [8]. This leads to the description of design processes - either in ID or ED - as a parallel, iterative development of problem and solution space [9].

Both disciplines ID and ED are essential elements of the product development and integrated increasingly. Therefore a strict separation between engineering and industrial design development is no longer possible, but new incorporated theories, methods and tools are rare. First contributions are made by e.g. Cagan and Vogel [10], Press and Cooper [11], Clarkson and Eckert [6] but a broader scientific discourse to this topic is still missing.

Because of traditional strong engineering sciences, a weak ID research community and the geographical separation into ID and ED institutions in Germany, a dialog about integration is still very weak [12]. Interestingly, there have been a few older attempts to develop design methods with the intention of integration into engineering design methods. Just as the "methodology for developing and constructing technical systems and products" [13] and "general procedures" [14] can be seen as a compendium (for Germany) of all ED methodological efforts, the VDI Guideline Industrial Design serves the same purpose for ID [15]. All these work hang behind the approaches of the former paragraph. Exceptions are two recent contributions from Uhlmann [16] und Lindemann [17] about structures and content of integrated design processes.

2.2 Old differences between the two designs

From a cognitive view, designing is very similar in its different domains. But, having the recent situation of two separated disciplines in mind, it might be helpful to care about old or still existing differences. Different activities and forms can be found depending on the aims [6], [18], [19] of design. ED and ID, when working - with unequally weighted aims - on the same object, can be differentiated regarding the following aspects:

- The solution is developed from its entirety, inwards to the details in ID (holistic approach) (e. g.[10]), whereas in ED, the overall solution is derived from solutions of sub-tasks. These sub-tasks it selves have been developed from the design problem ([14] and others).
- Aims and solutions are technical functional and objectively assessable in ED [14], [6], [4], contrary to socio-cultural, emotional and subjectively assessable in ID [20], [21].
- In ID usually several possible solutions are on par, whereas in ED usually objective decision criteria and tools are used to filter one optimal solution [6].
- In ED specific knowledge from professional experience and to a lesser extent from education is used as a basis for designing [21], whereas ID primarily bases on knowledge from everyday life and the entire biography [20], [21], [3], [22].

Although industrial design, among other related disciplines, belongs to the engineering designer's most important partners in product development [23], there are still preventable difficulties that hinder an efficient collaboration across the design domains [24], [25]. From an engineer's perspective, industrial design aims might not be plausible and thus complicate the engineering design process [4]. In addition to that, different cultures, tools, terms and work styles hinder or even prevent understanding, acceptance and effective collaboration [24], [25]. In many cases, industrial design

issues are considered being meaningless or bothersome in engineering design processes. This is to some degree caused by traditional engineering design methods, which admit almost no influence to industrial design. The other way round, technical conceptualisation is an essential part especially of the early stages of industrial design process.
There are two major options to address the conflict: this is on the level of aims and contents [Cagan & Vogel] and from a process perspective [lindemann]. The first define value and user's experience as the new goals of product development, the second recommend a network like structure to describe the combination of opportunistic and systematic (linear and iterative) process steps.

2.3 Conceptualization in engineering and industrial design

According to Keinonen [26], "Concepting is a relatively new idea within in product development."
So what would be a description of design concept development processes? Despite a large variety of publications about creative techniques, the process itself remains vague. Within the design process all other phases appear to be investigated much more intensively.
The development of a design concept does not consist of rigidly ordered sequences. Explanations for that can be extracted form psychological work on problem solving (cf. e. g. [7]). Others (e. g. [1]) name abductive reasoning as the key action during concept development. "Innovative abduction is the key mode of reasoning in design and therefore highly characteristic for this activity. But it is not unique to design. In both science and technology, and in daily life, abductive steps are taken in the search for new ideas."
For an application of the experience concept within engineering design it is necessary, to regard the differences between definitions and methods. Thus, three different concept models are described below.

2.3.1 Product development concepts

A development-oriented, economical concept model is based on the complete product development process including marketing and sales activities. "A concept is a description of the form, function, and features of a product and is usually accompanied by a set of specifications, an analysis of competitive products, and an economic justification of the project.[…] The concept development process includes the following activities: identifying customer needs, establishing target specifications, concept generation, concept selection, concept testing, setting final specifications, project planning, economic analysis, benchmarking of competitive products, modeling and prototyping." Furthermore Ullrich & Eppinger [2] recommend a five step method including: (1) clarify the problem, (2) search externally, (3) search internally, (4) explore systematically, and (5) reflect on the solutions and the process.
Looking at these five activities, conceptualization is described rather vague and on an abstract level, which may lead to very different forms of design concepts and can be applied to very different domains. This method offers a systematic concept development, however, these five steps appear to be very general and thus offer only little insight into conceptualization processes.

2.3.2 Engineering design concepts

In engineering, design concepts are technically and functionally determined and emphasize on the constructional structure "A principal solution is an idealized representation (a scheme) of the structure of a system, that defines those characteristics of the system that are essential for its functioning" in [1].
Conceptualization and design in engineering has been deeply regarded by VDI (cf. e. g. [13]). VDI 2222 summarizes the fundamentals of engineering design processes as "splitting the design process into singular steps and their treatment, methods, variation, selection and combination to functioning products" [27]. The function of a product is treated as transformation of input to output. In order to be able to work on the design task, this function is then divided into sub-functions, resulting in a function analysis [14]. Conceptualization, in terms of finding a principal solution, is the crucial step especially in new (original) design processes. In original design processes, the underlying task is usually extraordinary fuzzy. Thus, there has to be paid intense attention to the clarification and definition of the task and the development of the function analysis. Both Function Analysis and Requirements List serve as the first description of the design goal on a high level of abstraction.

2.3.3 industrial design concepts

In industrial design as well as in transportation design, design concepts focus on experiencing, determining the identity and character of the object. The industrial design concept defines the aim of the design process, serving as a nucleus which incorporates "all essence-determining characteristics of the coming product in itself" [16].
According to Jasper Morrison, an industrial design concept can be also described as something which enables the product to be itself. "[…] the concept was to design a camera which had the character of a camera and not to do an exercise in styling and trying to be different." cited in [28].
Experience concepts as ID concepts integrate three core components, a comprehensive narrative scenario, a user story and a description of the objects essence. Usually they combine elements of story boards, character visualizations, mood boards and short texts.

Industrial design concepts are used interpretively, whereas engineering design concepts are applied rather executing. The specific of industrial design concepts and transportation design concepts is described more in detail below.

3 DESIGN CONCEPT DEVELOPMENT IN TRANSPORTATION DESIGN

3.1 Used research methods and procedures

Past studies and observations (cf. [29]) stated that design-concept-based working is of high value – especially in transportation design – while in other design fields comparable procedures are less complex and sophisticated [30]. Therefore students of the Pforzheim University (considered as one of the five internationally recognized universities for transportation design) are selected as major group of probands for the investigation. Due to the rather high expertise level of the test persons and the strong connection between Pforzheim University and the automotive industry, results of this study are quite representative and can be applied to practice, too.
This investigation is a qualitative field study with a rather long observation period (core time 14 days) in the field of Transportation Design. The final research included documentation analysis (n=10) [31] supported by interviews (n=19) and related observation data analysis (n=18) [32], [33] as investigation instruments. Our study differs from the majority of past research projects about early phases of the design process [34], [35], [36], [37] in three substantial points: its duration, its qualitative approach and the absence of restrictive laboratory conditions.
Actions during the design process have been documented for several weeks by the use of open and guided logs. Two aspects have been derived from these data: Use of the design concept and critical actions for the development/change of the same.
Open interviews with different designers about the design concept, the procedure and the biographic background formed an emphasis of the preliminary investigation. The result is a collection of biographic data relevant to design. These designer profiles lead to a first scheme of categories of the connection between design concept and personal episodic memory.

3.2 Results

Design concepts are highly concentrated starting points of the design process. Thus, they can be called nucleus (of the design), while acting as guidelines to the artefact. Based on theoretical preview and empirical data, typical contents can be identified and statements about the completeness of such concepts can be made. The quantity and the density of informational content, as well as the more or less conscious utilization of the concept, depend strongly from the designer. It appears that, the development and use of design concept depend far less by the actual design object.

3.2.1 Existence and function of design concepts

A design concept exists as a key element of the design process in ID and in TD. Such a concept has been traced in 75% of the design projects examined. In each case it exists at least in its basic rather formal (Figure 1) or functional approach. In most cases it is by far more comprehensive (Figure 2) – these are experience concepts. Accordingly, the relevance of a design concept can be confirmed, in particular for the early phases of the design process.

Figure 1: examples of designs based on design concept focusing on formal aspects, projects done by a student of the Transportation Design Department Pforzheim University

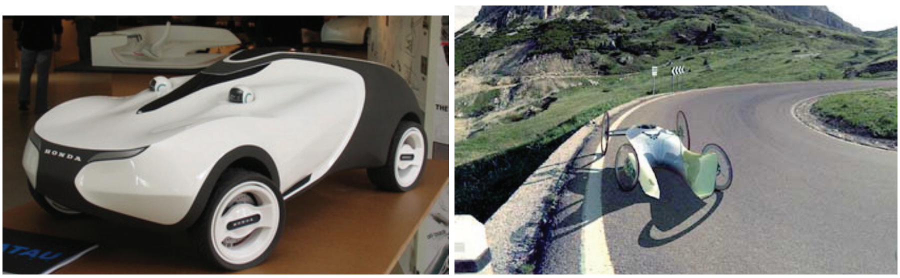

Figure 2: examples of designsbased on holistic design concept, project done by a student of the Transportation Design Department Pforzheim University

The observed design concepts provide a clear aim for the objects to be designed. Design concepts it selves were very subjective. This subjectivity is documented very well in the work of the student Prössler (Figure 3) connecting future luxury with a balloon like travel experience. Or by combing a very powerful tractor with a light, autonomic and flyable cabin (Figure 4).

Figure 3: first sketches and the final design for the Renault upper range project, project done by a student of the Transportation Design Department Pforzheim University

Despite this subjectivity a transfer of experience concepts to other persons and tasks is possible. The result is a personal interpretation and thereby a certain adaptation of the original.
These kinds of experience concepts are generally influenced by the designer's biography, by his world knowledge and socio-cultural background. The use of this knowledge and the biographic imprint are keys to a vivid and individual experience concept.

Figure 4: first sketches and the final design for tractor project, project done by a student of the Transportation Design Department Pforzheim University

Experience concepts are developed by successively compiling three components, namely the development of a comprehensive narrative scenario, a user story and the description of the objects essence. The experience concept develops from the integration of these three elements to a consistent holistic concept.

3.3 Design branches, concept types and designer personalities

In addition to the general statements about the experience concept it is interesting to know, if it is applicable in different design disciplines. It can be confirmed that functions of the experience concepts namely nucleus and guiding principle, were found in Industrial Design and in Transportation Design in similar ways. Due to different tasks, objects and knowledge bases in Industrial and Transportation design, both quantity and quality of substantial concept contents differ. This affects formal considerations as well as ergonomics, among others.

The development of experience concepts in Transportation Design differs significantly from Industrial Design. Transportation Design is characterized by its strong sketching orientation and a broad development of variants. On the other side, the deeper analysis of tasks and crucial problems often takes place only on the basis of rough sketches. In Industrial Design processes the concept phase is supported by a wide range of visual and verbal externalisations but is also characterized by longer episodes of internal, mental processing.

Based on the study generating and extracting concept creation processes can be identified. Both creation types correspond to typical behaviours in the design disciplines. But most promising seems to be a combine of both types, with altering accentuation depending on the specific task.

Typical tools as mood board, mood words, user scenarios and personas can be recommended for a generating and extracting concept creation.

4 CONCEPTS IN INDUSTRIAL DESIGN ENGINEERING (IDE)PROJECTS

The following examples move from TD to IDE and illustrate how engineering and industrial design concepts can supplement each other.

The design of the wheeled loader (Figure 5) was based on an extensive requirement list, which alone would have surely led to a very good technically solution. The inclusion of an experience concept moved the product character stronger into the center. This leads to a perception of the vehicle as a competent cooperator and not as technoid and dangerous. Moreover the experience concept – forcing simplicity – led to an integrated work tool, which perfectly connects crane and bucket. This solution was accepted as a patent in 2008.

Figure 5: Moodboard and final design of a wheel loader, project done by a student of Industrial Design Engineering TU Dresden

The helpful use of visualizations in different phases is represented, on the basis the two following examples. On the one hand it concerns a problem-visualization (Figure 6) out of the first project period – task clarification – and on the other hand a typical mood board (Figure 7), which was compiled during the concept production.

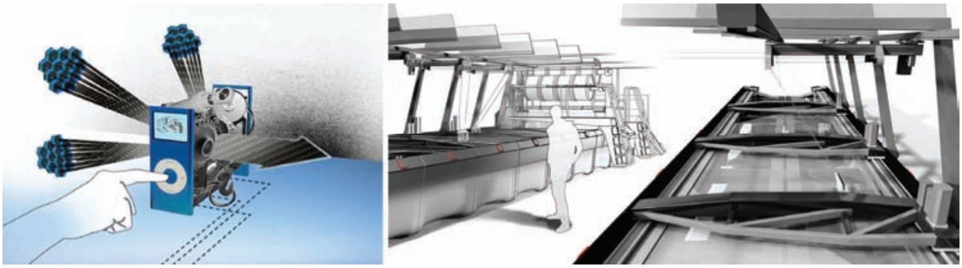

Figure 6: problem visualisation and final design of a multiaxial machine with several weft insertion systems, project done by a student of Industrial Design Engineering TU Dresden

The first case concerns the design for a multi-axial textile machine (Figure 7), which was developed to a modular unitized construction system. With the problem visualization the very complex and heterogeneous real machine was illustrated, and embedded into the ideal of a clearly arranged and easy to operate structure. Thus a clear goal was compiled very early. Being actionable and each time present, the problem visualization was transformed into a experience concept, which found its innovative correspondence in a clearly arranged, clean textile-covered machine (Figure 7).

Figure 7: Mood images for HMI and overall appearance, project done by a student of Industrial Design Engineering TU Dresden

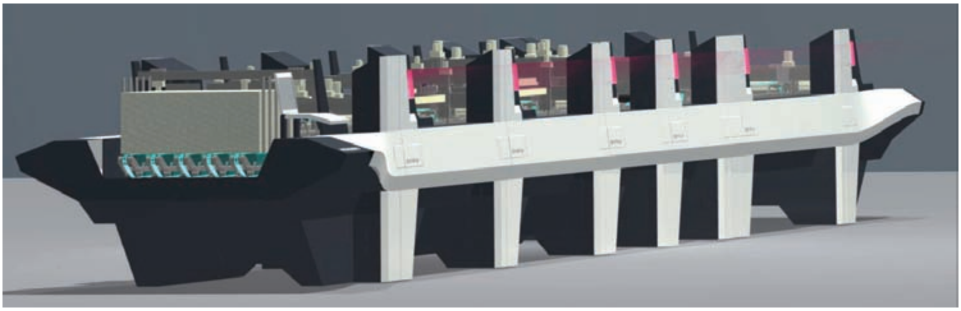

Figure 8: Modular folding machine, project done by a student of Industrial Design Engineering TU Dresden

The second example of a packaging machine (Figure 8) shows descriptive, how an experience concept can be developed separately and used additively for different scopes. The image of the dog sledge was path breaking for the interface concept (Figure 7). A central control stand offers the insight to all essential components as well the foresight to intuitively control the processes actually running. The bridge represents an aligned, modular structure which is technically convincing and aesthetically appealing.

5 APPLICATION OF EXPERIENCE CONCEPTS IN - A WORKSHOP FOR ENGINEERING DESIGN STUDENTS

In paragraph 3 we developed a model of experience concepts from an investigation in TD, we used this in paragraph 4 for IDE projects and will now present its application in a workshop for engineering designers.

Engineering Designers do not have to be educated as industrial designers, in order to be able to apply industrial design methods within the engineering process. To gain additional competences in conceptualization - to support the own and interdisciplinary work - may not burden the essential engineering education. Accordingly, simple theoretical models have to be selected, which are suitable to explain the knowledge and methods used. These models must not contradict, but should integrate to the methodology of ED. They should further more correspond, to ID models commonly accepted.

The example of two four day workshops accomplished with the RWTH Aachen gives an idea of the offered program to students in engineering design. The workshops were in each case made for twelve mechanical engineering students. The production of an experience concept was prepared as a three step method, of scenario building, user story and object essence. In each case the elements were compiled individually, selected and presented within the group. The state of affairs was gathered being available for self reflection and a subsequent treatment. The development of the moodboards was supported by 200 given pictures, from which maximum of five pictures had to be selected and arranged as combination of three (Figure 9).

Figure 9: first mood boards describing the objects essence, done by engineering students

5.1 ID basics and crucial process steps

The first step is to make the essential ID process explainable, for which at least some substantial Industrial Design basics have to be presented. In the workshop program, this takes place via an example-supported presentation. ID activities thereby become more transparent and are practiced within a short project in a second step, which is developing a successor for a blood glucose meter. This happens, supported by individual coaching within four hours. This theoretical and practical input enables the students to set the design processes in context with their own well-known ED procedures. First intrapersonal reflections on differences and similarities of the development processes are the results.

5.2 Guided concept development

The second step is to develop an individual experience concept for a pad saw. This is arranged in three separate working steps, which allow a structured linear operation and guarantee to address all essential holistic aspects of the product. The three steps are: a comprehensive narrative scenario, a user story and the objects essence.

Substantial content of narrative scenarios is a description of the product and user environment, as comprehensive as possible. Those scenarios comprise various aspects of time, environment, user groups, emotions as well as economic or legal issues. The user story consists of a detailed routine of 24 h day of a prototypical user (or persona) and diverse employment settings of the product. The goal is to produce a comprehensive and detailed description of experiencing the product. The description of the objects essence is done by a linguistic and visual characterization of the product, which goes far beyond quantifiable product data. Hereby the use of moodboards and moodwords turned out to be very helpful.

Completely open problem situations can be avoided, with this structured procedure. Instead of this, separate work packages are created, which supplement each other and can partly compensate deficiencies. These three components can be analyzed, completed and examined for compatibility iteratively. By reaching a solid level for each of them, the next step is there integration to the experience concept.

5.3 experience concept application within individual design studies

The developed experience where put into practice within the next step – developing first product ideas, sketches and models. This step is particular important as individual tests of comprehension and usability of ID methods and tools in forthcoming projects. The application is guided by an industrial design lecturer and also organized as an iterative more step approach. In order to ensure learning success, regular interventions of the development paths for visualization and reflection about goal procedure and product are substantial. This avoids risks like: caring about technical constraints, which do not correspond to the initial problem, which are time-consuming or were a handful of respectable solutions exists. This guidance helps to pursue the goal of a holistic product development.

6 INTERPRETATION AND CONCLUSIONS

6.1 Successes and Difficulties

To give Engineering Design novices a fundamental understanding of Industrial Design, appears amazingly easy. Even so a statement to there independent application is still pending. In particular the common prejudice, that ID is caring only for the outside shape of an object and followed a creative, unordered and indefinable process could be eliminated.

During the workshop explicitly the meaning of the product experiencing by the user was stressed as a core element. The acceptance of several equally possible solutions was strengthened and a process containing single methods for concept development was established. Additionally fundamental drawing skills and visualization techniques could be obtained.

The following feedback underlines the high satisfaction of the participating engineering students:

- [The course was] “Particularly helpfully: The tools for a systematic procedure to the experience concept represent a marvellous manual, which can be applied to a multiplicity of practice cases.”

- “The workshop opened a completely different perspective to me. I looked at technical problems from a very different side, compared to that one I studied before. I’m very grateful for experiencing this.”
- “I found the general approach to the information identification very helpful. [it was surprising,] that one can collect so much information around a product, which one hardly knows before”
- [For me it was substantial, that] “Many different solutions can fulfill the same task, although the setting seemed to be clear. And that I took a step on the industrial designer’s side of product development.”

Difficulties in particular, occurred during evaluating the quality of a concept, and within the next process steps when product geometry had to be found. First, is a logical consequence of the greenness in handling experiencing concepts, and can easily improved through a more frequent or general use of concepts. The second leads to an excessive styling to emphasize the character. This may result from a missing sensitization in shape and graphic and can not be attained within a few days. In practice this problem can be mastered by working in a team together with an industrial designer. Unchecked is however, whether the developed concepts are stabile enough for long-term projects as well.

6.2 Further knowledge transfer of ID methods and tools

The available investigations supply sufficient approaches for a continuation and an advancement of the program. Thereby we would like to emphasis a pool of small, concrete activities to introduce ID processes and tools to students and graduates of engineering sciences, aiming for more sensibility about ID attitudes and goals.

The attraction of this adjustment lies in the possibility to reach a multiplicity of future engineering designers comparably easy. But therefore necessarily substantial elements of the design process have to be prepared, likewise the experience design concept. We see clarifying the task and developing first principals as the next important topics. This offer would supplement perfectly by a similar program introducing basic ED processes to ID on an interdisciplinary projects basis. Comparable programs exists e.g. at Stanford University, Carnegie-Mellon University and MIT.

Making this possible, the next generation of engineers and designers could work together more easily and far more productive, than that seemed possible so far.

6.3 Possible next research steps

With the available approach for introducing experience concepts within engineering design education, a theoretically justified and empirically based model for this process section is presented. However there is still no up-to-date scientific theory for an integration of ID and ED which is international accepted. Also on the level of concrete tools it lacks explicit problem solution tools for early design phases, just like visualization and reflection tools during the process. In each case a multiplicity of approaches exist however there is little valid, empirical data. How the transfer of supplementing specific contents takes place in both directions would be a collective research topic for ED and ID.

Further, the sustainability of the current approach stays unproved. Therefore a control investigation to acquired and automated processes would be helpful. Continued, a next research step could aim at the recording and evaluation of experiencing, using the predecessor product. This would be an invaluable input for the definition of a forthcoming experiencing concept. This kind of experience recording or forecast could be consulted secondly, for the examination of the concept at the finished product.

REFERENCES

[1] Roozenburg N., On the pattern of reasoning in innovative design, *Design Studies*, vol. 14, 1. 1993, pp. 4–18.

[2] Ulrich K.T., and Eppinger S.D., *Product design and development*. 3rd ed., 2003: McGraw-Hill. Boston Mass.

[3] Krzywinski J., and Bongard K., Core Design Ideas (CDI) as Nucleus for Individual, Innovative Design Solutions, in *Emerging Trends in Design*, IASDR, Ed., 2007, Hong Kong.

[4] Brezing A.N., *Planung innovativer Produkte unter Nutzung von Design- und Ingenieurdienstleistungen*, 2006: Shaker. Aachen.

[5] Graf M., and Hartmann-Menzel C., Phaenotype and Genotype, in *Questions & Hypotheses Learning Conference*, Design Research Network, Ed., 2008, Berlin.

[6] Eckert C., and Clarkson J., The Reality of Design, in *Design process improvement: A review of current practice*, J. Clarkson, and C. Eckert, Eds., 2005: Springer, London, pp. 1–33.

[7] Dörner D., *Die Logik des Mißlingens: Strategisches Denken in komplexen Situationen*, 2002: Rowohlt. Reinbek bei Hamburg.

[8] Hatchuel A., and Weil B., A New Approach of Innovative Design: An Introduction to C-K Theory, in *Proceedings of the 14th International Conference on Engineering Design ICED03*, A. Folkeson, K. Gralen, M. Norell, and U. Sellgren, Eds., 2003, Stockholm.

[9] Dorst K., and Cross N., Creativity in the design process: co-evolution of problem–solution, *Design Studies*. 2001.

[10] Press M., and Cooper R., *The design experience: The role of design and designers in the twenty-first century,* 2003: Ashgate. Aldershot.

[11] Cagan J., and Vogel C.M., *Creating breakthrough products: Innovation from product planning to program approval*, 2002: Financial Times Prentice Hall. Upper Saddle River, NJ.

[12] J. Reese, Ed., *Der Ingenieur und seine Designer: Entwurf technischer Produkte im Spannungsfeld zwischen Konstruktion und Design*, 2005: Springer. Berlin.

[13] VDI 2221, VDI Verein Deutscher Ingenieure, *Methodik zum Entwickeln und Konstruieren technischer Systeme und Produkte*, 1993: VDI Verein Deutscher Ingenieure. Düsseldorf.

[14] G. Pahl, W. Beitz, L. Blessing, J. Feldhusen, K.-H. Grote, and K. Wallace, Eds., *Engineering Design: A Systematic Approach,* 2007: Springer-Verlag London Limited. London.

[15] VDI 2424, VDI Verein Deutscher Ingenieure, *Industrial Design; Grundlagen, Begriffe, Wirkungsweisen*, 1986: VDE/VDI-Gesellschaft Mikroelektronik., Mikro- und Feinwerktechnik.

[16] Uhlmann J., *Die Vorgehensplanung Designprozess für Objekte der Technik: Mit Erläuterungen am Entwurf eines Ultraleichtflugzeuges,* 2005: TUDpress. Dresden.

[17] Lindemann U., *Methodische Entwicklung technischer Produkte,* 2007: Springer. Berlin.

[18] Visser W., *The Cognitive Artifacts of Designing*, 2006: Lawrence Erlbaum Associates. Mahwah, New Jersey.

[19] Visser W., Design: one, but in different forms, *Design Studies*, 1. 2009.

[20] Strickfaden M., *(In)tangibles: Sociocultural references in the design process milieu*, Doctoral Thesis, 2006, Napier University.

[21] Wölfel C., How Industrial Design Knowledge Differs from Engineering Design Knowledge, in *New Perspectives in Design Education*, A. Clarke, M. Evatt, P. Hoghart, J. Lloveras, and L. Pons, Eds., 2008: Institution of Engineering Designers; The Design Society, Barcelona, pp. 222–227.

[22] Uhlmann J., and Schulze E.-E., Investigations into the Data Basis of Design Knowledge in Industrial Design Engineering, in *Proceedings of the DESIGN 2008: 10th International Design Conference*, D. Marjanović, M. Štorga, N. Pavković, and N. Bojčetić, Eds., 2008: University of Zagreb, Dubrovnik, pp. 865–876.

[23] Jonas W., Design als systemische Intervention: für ein neues (altes) "postheroisches" Designverständnis, in *17. designwissenschaftliches Kolloquium "Objekt und Prozeß"*, 1995, Halle/S.

[24] Rittel, Horst W. J., On the Planning Crisis: Systems Analysis of the 'First and Second Generations', *Bedriftsøkonomen*, 8. 1972, pp. 390–396.

[25] Kranke G., *Technisches Design: Integration von Design in die universitäre Ausbildung von Ingenieuren*. 2008: Hut. München.

[26] T. Keinonen, and T. Roope, Eds., *Product Concept Design: A Review of the Conceptual Design of Products in Industry*, 2006: Springer. Goldaming.
[27] VDI 2222, VDI Verein Deutscher Ingenieure, *Konstruktionsmethodik – Methodisches Entwickeln von Lösungsprinzipien*, 1997: VDI-Gesellschaft Entwicklung Konstruktion Vertrieb.
[28] G. Bulthaup, Ed., *Perspectives: [taste, pace, style, values, love]*, 2004: Hoffmann und Campe. Hamburg.
[29] Uhlmann J., *Terra incognita. Technisches Design: feuilletonistische Beschreibung eines Forschungsfeldes unter dem Focus moderner Informationstechnologien*, 2002. Dresden.
[30] Krzywinski J., *Erkundungsuntersuchung zu Designkonzepten*, master thesis, 2004, TU Dresden.
[31] P. Mayring, and M. Gläser-Zikuda, Eds., *Die Praxis der qualitativen Inhaltsanalyse*, 2005: Beltz. Weinheim.
[32] Gläser J., and Laudel G., *Experteninterviews und qualitative Inhaltsanalyse als Instrumente rekonstruierender Untersuchungen*, 2006: VS Verl. für Sozialwiss. Wiesbaden.
[33] Bortz J., and Döring N., *Forschungsmethoden und Evaluation: Für Human- und Sozialwissenschaftler*, 2006: Springer. Berlin.
[34] Restrepo J., and Christiaans H., Problem Structuring and Information Access in Design, The *Journal of Design Research*, 2. 2004, Available at http://research.it.uts.edu.au/creative/design/ papers/25RestrepoDTRS6.pdf.
[35] Cross N., Design Research: a disciplined conversation, *Design Issues: history, theory, criticism*, vol. 15, 2. 1999, pp. 5–10.
[36] N. Cross, H. Christiaans, and K. Dorst, Eds., *Analysing design activity: [proceedings of the Second Delft Workshop on Research in Design Thinking, held in Delft in September 1994]*, 1996: Wiley. Chichester.
[37] Candy L., and Edmonds E., Creative design of the Lotus bicycle, *Design Studies*, vol. 17, 1. 1996, pp. 71–90.

Jens Krzywinski
TU Dresden
Center of Industrial Design Engineering
Chair of Engineering Design
01062 Dresden
Germany

Tel: Int +49 351 463 357 50
Fax: Int +49 0351 463 357 53
Email: jens.krzywinski@tu-dresden.de
URL: www.tu-dresden.de/design
Blog: www.technischesdesign.org/blog

Jens Krzywinski and Christian Wölfel are design researcher and lecturer at the Technische Universität Dresden, Germany. They both studied Industrial Design Engineering and Industrial Design at Technische Universität Dresden, Dresden and were visiting students the Burg Giebichenstein University of Arts and Design in Halle, Germany. They have been a research associate at the Center for Industrial Design, Technische Universität Dresden, since 2004 and 2005.
There research interests concern design processes and methods, with a focus on knowledge in early stages and on concepts used and developed during the design process.

Researcher associate Frank Drechsel is a PhD student at the Technische Universität Dresden. As a scholarship holder of the Stiftung Industrieforschung his work centers on the collaboration between engineering and industrial design. The development process of industrial goods in small and medium-sized enterprises is of particular interest.