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METHODS USE IN EARLY STAGES OF ENGINEERING AND INDUSTRIAL DESIGN – A COMPARATIVE FIELD EXPLORATION

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1. Introduction

In product development, there are major differences between the core convictions in engineering design education in contrast to professional practice. Especially in Germany, education is still dominated by functional understanding of engineering design [Pahl et al. 2007] whereas in industrial practice the influence of integrated positions [Cross 2008 among many others] is growing, which leads to a stronger value and customer orientation [Cagan and Vogel 2002 u.a.]. This makes even more sense having in mind that “effective and successful innovation is increasingly based on a dexterous interlacing of functional-structural and socio-emotional design – under due integration of aesthetics, economy, ecology and ethic.” [Schwaninger 2005]. In order to achieve this claim, industrial design and engineering design need to come much closer concerning their values and possibly even more important concerning their processes and methods. But despite some achievements concerning a product oriented basic understanding, product development methods that are commonly accepted across the design disciplines are still expetional. This is true as well for industrial practice as for academic education.

The following study provides multifaceted empirical data from interviews with engineering and industrial designers about professional product development processes. The study aims to describe differences and consistencies in the use of industrial and engineering design methods. The findings may complement the basis for further research on the integration into broader product development processes.

2. Problem and research questions

In Germany, engineering design education is still mainly based on the German Systematic „Pahl/Beitz Konstruktionslehre“ methodology and the related VDI guidelines. In industrial design education, there is no such common methodology. But there is an overall agreement on the mismatch between engineering and industrial design methodology and thus different processes goals and methods in the disciplines [e. g. Roozenburg and Cross 1991].

The existent discrepancy between academic design methodology and industrial practice in engineering design in Germany has been previously investigated and discussed [cf. e. g. Jänsch 2007]. In contrast to this research insight into engineering design practice, there is no empirical research on the professional practice of industrial design and its differences to academic methodologies or to engineering design practice.

Specific procedures are determined by specific methods in the sense of cognitive and social organizational principles. Depending on the different main goals of the design disciplines (technical solution [e. g. Pahl et al. 2007] versus product experience [e. g. Schifferstein and Hekkert 2008]) there

are different emphases already during methodological education which may influence professional practice of the graduates. Pervasiveness, extent and consistency of (German) methodological education in engineering design lead to the assumption that professional engineering designers apply more of the methods learned than their counterparts in industrial design do.
In order to get insight into consens and differences regarding general proceeding and applied methods in the early stages of the design disciplines, an explorative field study has been accomplished. The study aimed at answering the following main research questions:

- Are there preferred ways of proceeding in the early stages in product development? Are there differences between engineering and industrial design?
- Which methods are used by in professional practice in the early stages of product development? Are there differences between engineering and industrial design?

3. Research methodology

The data has been collected in guided interviews with 35 engineering and 15 industrial designers. The interviews took about 45 minutes each and included questions about typical proceeding in the early creative stages of product development in the professional practice of the participants. There was an emphasis on naming rating specific methods applied in the design process.Most of the participants are employees of small and medium enterprises, five of them work in product development departments of larger companies or research instututions.Most of the participants had more than five years of professional experience.
Qualitative analysis of the data has been accomplished according to the research questions. In order to be able to describe typical ways of proceeding, the frequent use of specific methods as well as connections to specific other methods have been examined and clustered. Additionally, the number of applied methods, the rating of the methods as well as the frequency of naming of the methods as been evaluated statistically in order to be able to compare engineering and industrial design.The single methods have been sorted into deductively prepared categories evaluated statistically for the early stages of analysis, synthesis and evaluation.
The interviews have been conducted and analysed by different researchers in an interdisciplinary research project. In order to ensure reliability, seven interviews have been analysed by two coders. The correlation has been proven by Cohen's $\kappa = 0.84$.

4. Results

4.1 General proceeding in the early stages in engineering and industrial design

The division of the front-end of the design process into the (usually) sequential stages analysis, synthesis and evaluation (with different naming depending on discipline and company) has been proven as helpful for the interviews in both design disciplines Thus, the results are presented according to these three stages.

4.1.1 Analysis

In engineering design, first steps in the project depend on whether the client delivers concrete requirement specification or just vague goal settings for the product. In the first case the requirements are analyzed to meet the criteria for feasibility, complexity and costs etc. and then transferred to a functional specification. The second case is connected with an extensive development stage, where product features and requirements are defined. After an iterative process of client's feedback and corrections the functional specification can be established.
In industrial design, analysis also starts with either a given (functional) requirements list from the client or other departments or just a rough description of the product to be designed. In contrast to engineering design, all specifications related to product experience usually have to be developed by the designers themselves. This is due to the the fact that given requirements have been defined by non-designers or engineering designers.

A general way of dealing with functional specifications could not be determined. In industrial design, conversation with clients and creating a common mode of communication makes up much of the analysis stage. This then allows the cooperative set-up of requirements related to product experience. In many cases, organized workshops and meetings are used for the development of objectives. In comparison to engineering design, market analysis is frequently performed by designers and shows approaches to orientation and differentiation from competitors. This difference is due to the fact that the interviewed industrial designers are mainly engaged with new product developments, while the most of the engineering designers in this study develop variations and adaptions of existing products on the basis of concrete given requirements. In the case of new product development, market analysis (with appropriate focus) is indispensable in engineering design as well.

4.1.2 Synthesis

In the synthesis stage, proposals for overall solutions are worked out in different variants in both disciplines. Thereby several industrial designers often work on an identical task at the same time, which is particularly in the day-to-day business of design studios a strategy for generating different design proposals. Identified requirements of the analysis phase are regarded as boundary conditions by a few designers, as the starting point in terms of a design concept more by others. Explicitly formulated industrial design concepts (product character etc.), are seldom generated explicitly. The design of variants begins almost exclusively in the form of freehand sketches. According to the project character and complexity, these sketches will be further developed to renderings and other illustrations. In addition to the vast continuation in CAD models, some industrial designers in medical and transportation industry still use physical models in the design phase. The designer's access to earlier drafts is possible, but is rarely used systematically.

The synthesis phase of engineering design can either the parallel development of different variants or a basic variant has been defined already in the analysis stage, ususally due to pressure of time. In addition, the demands of the performance and accordingly the requirement specification can restrict the variant opportunities as well. Thus, about a quarter of the engineering designers in this study do not generate variants. However, if variants are developed, earlier solutions are checked frequently in engineering design. Previous solutions are documented to varying degrees. For the selection of a variant, the generated variants are drawn as paper sketches or saved as CAD layouts with rough dimensions. Partial tables or documents with specifications are produced. In order to develop variants different types of approaches and tools are used. Discussions and brainstormings with colleagues and business partners are central. Market analysis, patent researches and researches of papers from conferences were named several times. Specific systematic engineering methods such as the morphological box, Failure Modes and Effects Analysis (FMEA) or specific simulations have only been used sporadically.

4.1.3 Evaluation

In the industrial design process a two-stage evaluation is common: while in a first internal presentation and discussion five or more variants usually reduced to three, these then are often presented to the external customer or decision makers within the company. These will be included in the selection of the preferred variant or make the choice themselves. If this external presentation and evaluation does not take place, usually there will be a further internal discussion instead. Criteria in addition to the design quality are manufacturability, market potential and, if available, guidelines of the specifications. Usually the chief executive meets the final decision, because he takes the responsibility for the results. In the construction department developed variants are usually presented to a panel of project leader, (involved) engineers, sales professionals and managers.

The evaluation stage in engineering design also aims at evaluating and reducing larger numbers of design variants before the presentation to clients or principals. Criteria are feasibility, cost, time, market potential, production opportunities, assembly and failure-proneness. Surprisingly, known specific systematic methods of the engineering design methodology are applied sparsely again. The participants explained this with pressure of time vs. necessary effort as well as disbelief in the impact of these methods rather than lack of knowledge. Instead, free or moderated discussions are used to evaluate design variants.

4.2 Method use in the design domains

The interviews provided in total 701 namings of methods in the sense of cognitive and social organizational principles. These have been sorted into the deductively prepared category system and evaluated statistically. These categories allow a synoptic view on methods use in engineering and industrial design. The different frequeny of naming of the methods in the design disciplines has been evaluated using the Mann Whitney U test.

On average, the industrial designers among the participants used more methods in the analysis and evaluation stages, whereas in the synthesis stage is no no statistically significant difference (cf. Table 1).

Table 1. Method use in the early stages of product development

stage	industrial designers (n=15) M ± SD	engineering designers (n=35) M ± SD	Z	*p*	
analysis	7.27± 2.82	4.60± 1.96	-3.106	.002	•
synthesis	6.73± 3.08	5.51± 2.37	-1.535	.125	
evaluation	3.87± 1.96	2.26± 1.70	-2.653	.008	•
total	17.87± 5.19	12.37± 3.91	-3.439	.001	•

4.2.1 Analysis

Among the 270 namings in the analysis stage there are more than 50 different methods. Most of them are systematic methods for structuring requirements and development goals. Industrial designers rely on expert dialogues and individual experience to the same extent, whereas engineering designers don't (numbers and statistical evaluation shown in Tables 2 and 3). In both design disciplines, access to prepared information, visualization, systematic tests play a minor role. According to the participants of the study, checklists etc. are applied only rarely in professional practice due to necessary effort or limited flexibility. However, few of the participants reported on the intention to develop or apply company-specific checklists in the near future.

Narrative methods are used only by some of the industrial designers but then rather for communication purposes. While teamwork plays a role for less than half of the engineering designers, it does for about 80% of the industrial designers. Some of the companies organize expensive workshops abroad the working environment in order to support the analysis of the industrial design task.

4.2.2 Synthesis

In the synthesis stage, the total number of 294 method namings is just slightly above the analysis stage. The average of engineering and industrial designers' method naming was similar (6.7 vs. 5.5).

According to the answers given by the participants (cf. Tables 4 and 5), visualization is one of the most important method in the synthesis stage. Though count and elaboration level of the visualisations are not the same in any case, unsurprisingly industrial designers apply this method more often than engineering designers do.

Access to former projects, computer aided modelling and team work is used by the majority of both design disciplines. Just below one third of the industrial designers use physical models in the synthesis stage, whereas this method does play almost no role in engineering design. The industrial designers explained not only the support given by physical models for developing solutions but also for communicating and enforcing them.

It has to be noted that just slightly more than half of the industrial designers name experience and intuition in this stage, which is less than in the analysis stage. In reverse, engineering designers rely on experience and intuition more often in the synthesis stage (one third of the participants) than in the analysis stage.Thus, the difference between engineering and industrial designers is no more statistically significant for the use of experience and intuition as a method for generating solutions. Particularily in industrial design, different individual designers are engaged with the task in order to gain different design proposals (53 %). Some of the industrial design departments in larger companies purposefully mandate external design offices to increase the diversity of the design solutions.

Table 2. Categorised evaluation of methods in the analysis stage

method category	industrial designers (n=15)	engineering designers (n=35)	Z	*p*
inquiry				
— analysis	7 (47%)	6 (17%)	-2.159	.031•
— expert dialogues	12 (80%)	14 (40%)	-2.568	.010•
— information access	5 (33%)	15 (43%)	-.624	.533
— other	1 (7%)	3 (9%)	-.225	.822
concretion				
— structuring	14 (93%)	32 (91%)	-.225	.822
— narration	3 (20%)	0 (0%)	-2.701	.007•
— reflection	1 (7%)	5 (14%)	-.752	.452
— visualization	5 (33%)	6 (17%)	-1.254	.210
— specific tests	5 (33%)	14 (40%)	-.441	.660
— other	0 (0%)	8 (23%)	-2.000	.046•
experience and intuition	12 (80%)	8 (23%)	-3.742	.000•
team work	12 (80%)	15 (43%)	-2.391	.017•
total	109 M=7,3	161 M=4,6	-3.106	.002•

Table 3. Methods in the analysis stage (only most frequent and statistically significant)

method	industrial designers (n=15)	engineering designers (n=35)	Z	*p*
market analysis	6 (40%)	5 (14%)	-1,991	,046•
competitor analysis	2 (13%)	2 (6%)	-,901	,368
target group analysis	3 (20%)	0 (0%)	-2,701	,007•
customer interview	11 (73%)	14 (40%)	-2,139	,032•
access to previous projects	5 (33%)	11 (31%)	-,131	,896
functional specification doc.	7 (47%)	20 (57%)	-,674	,500
customer req. specification	10 (67%)	11 (31%)	-2,290	,022•
requirements list	1 (7%)	3 (9%)	-,225	,822
mind map	3 (20%)	1 (3%)	-2,027	,043•
mood board	5 (33%)	0 (0%)	-3,564	,000•
checklist	4 (27%)	9 (26%)	-,070	,944
economical factors	0 (0%)	6 (17%)	-1,692	,091
personal experience	10 (67%)	7 (20%)	-3,160	,002•
team discussion	8 (53%)	10 (29%)	-1,655	,098
instructions	5 (33%)	12 (34%)	-,064	,949
workshop	6 (40%)	0 (0%)	-3,949	,000•
brainstorming	5 (33%)	4 (11%)	-1,829	,067
total	109 M=7,3	161 M=4,6	-3,106	,002•

Table 4. categorised evaluation of methods in the synthesis stage

method category	industrial designers (n=15)	engineering designers (n=35)	Z	*p*
inquiry & data management				
— analysis	6 (40%)	16 (46%)	-.369	.712
— expert dialoque	1 (7%)	1 (3%)	-.624	.533
— information access	2 (13%)	11 (31%)	-1.323	.186
— data management	9 (60%)	27 (77%)	-1.225	.221
rational methods				
— systematization	2 (13%)	4 (11%)	-.188	.851
— visualization	13 (87%)	20 (57%)	-1.999	.046•
— modelling	9 (60%)	23 (66%)	-.382	.703
— simulation	0 (0%)	6 (17%)	-1.692	.091
— specific tests	4 (27%)	9 (26%)	-.070	.944
— other	7 (47%)	5 (14%)	-2.432	.015•
experience and intuition	8 (53%)	11 (31%)	-1.448	.148
team work	11 (73%)	24 (69%)	-.333	.739
total	101 M=6,7	193 M=5,5	-1.535	.125

Table 5. methods in the synthesis stage (only most frequent and statistically significant)

method	industrial designers (n=15)	engineering designers (n=35)	Z	*p*
no variants	0 (0%)	9 (26%)	-2,147	,032•
market research	2 (13%)	8 (23%)	-,764	,445
access to previous projects	9 (60%)	21 (60%)	,000	1,000
visualization	4 (27%)	11 (31%)	-,333	,739
freehand sketches	12 (80%)	17 (49%)	-2,043	,041•
physical models	4 (27%)	2 (6%)	-2,068	,039•
CAD models	6 (40%)	21 (60%)	-1,287	,198
personal experience	5 (33%)	8 (23%)	-,766	,444
team discussion	8 (53%)	16 (46%)	-,489	,625
presentation	3 (20%)	2 (6%)	-1,528	,127
brainstorming	7 (47%)	8 (23%)	-1,667	,096
total	101 M=6,7	193 M=5,5	-1,535	,125

4.2.3 Evaluation

The participants of the study named less methods for the evaluation stage (137 in total). Again, the difference between industrial designers (M=3.9) and engineering designers (M=2.3) is statistically significant.

The small number of method catecories (cf. Table 6) is reasoned by the kind of tasks but also by the smaller number of method naming in the evaluation stage (Table 7).

In industrial design, almost every participant named some kind of team work for the evaluation of design proposals, which is statistically significantly more than in engineering design (still about two third of the participants). Again in industrial design, evaluation is often accomplished during presentations (67%) and decisions are made in dialoque with clients (47%). This is rather unusual in engineering design (11%, 14%). In both disciplines, team discussion is important in the evaluation stage. In industrial design, decisions are often made by the leader (40%) which again is rather unusual in engineering design (9%).

Only 6% of the engineering designers refer to requirements lists in the evaluation stage, which is significantly more often the case in industrial design (27%). The difference might be influenced by the designers' common constellation as contractors.
Similar to the preceding stage, experience and intuition play a role for evaluation in both design disciplines.

Table 6. Categorised evaluation of methods in the evaluation stage

method category	industrial designers (n=15)	engineering designers (n=35)	Z	*p*
rational methods				
— structuring	8 (53%)	17 (49%)	-.306	.760
— assessment	5 (33%)	12 (34%)	-.064	.949
experience and intuition	7 (47%)	10 (29%)	-1.225	.220
team work	14 (93%)	23 (66%)	-2.020	.043•
total	58 M=3,9	79 M=2,3	-2.653	.008•

Table 7. Methods in the evaluation stage (only most frequent and statistically significant)

Methode	Designer (n=15)	Konstrukteure (n=35)	Z	*p*
requirements reconciliation	4 (27%)	4 (11%)	-1,333	,182
— requirements list	0 (0%)	1 (3%)	-,655	,513
— functional specification doc.	2 (13%)	2 (6%)	-,901	,368
— customer req. specification	3 (20%)	1 (3%)	-2,027	,043•
tally sheets	3 (20%)	0 (0%)	-2,701	,007•
personal experience	4 (27%)	8 (23%)	-,286	,775
intuition	3 (20%)	6 (17%)	-,239	,811
team diskussion	7 (47%)	22 (63%)	-1,052	,293
customer conversation	7 (47%)	5 (14%)	-2,432	,015•
presentation	10 (67%)	4 (11%)	-3,946	,000•
leader decision	6 (40%)	3 (9%)	-2,624	,009•
total	58 M=3,9	79 M=2,3	-2,653	,008•

5. Discussion

The main finding of this study is that despite differences in academic methodologies and process models, the general proceeding in the early stages of product development is roughly the same in engineering and industrial design. As could be expected, the content of the sequential stages analysis, synthesis and evaluation differ in detail. The strong differences suggested by the educational models of the design disciplines could not be found in professional practice. The specific design concept in industrial design which focuses on product experience disappears in the swift succession between analysis and synthesis stage. Similarily, specific systematic methods of engineering design are used only sparsely in professional practice. Grown individual experience and implicit knowledge seem to compensate the reduced use of explicit methods.
Differences between professional practice of engineering and industrial designers result from different general goals (technology and function vs. product experience) and typical project forms. Whereas the engineering designers in this study are much often involved in variant and adaption development and thus have predecessors and successors in mind, industrial designers are rather involved in new product development. Additionally, industrial designers usually have to report to clients or principals that have different educational and professional background. It can be assumed that this difference is found in professional practice of the design disciplines beyond the sample of this study. As one example, the more extensive use of requirements lists in industrial design may be affected by the more usual

involvement as contractors as well as the necessity of making agreements with people from other backgrounds. Especially when clients and contractors change often (e. g. in order to get diverse and innovative design proposals), a common understanding as well as agreemenet on development goals must be worked out.
The methods named in the study have been rated by the participants on the basis of an ordinal scale. Unsurprsingly, the methods applied in professional practice have largely been rated as “important” or “very important”. Professionals have the opportunity to use the methods they are convinced of, only then they are willing to put necessary effort into the application within given time frames.
Some attention has to be given to the limitations of the study design. The sample size is rather small (n=50). The extent and depth of the guided interviews allowed valuable insights into professional practice of the designers. However, the results can not be taken for valid for the whole population of professional designers. Based on this study, a semi-standardized survey could be accomplished in order to poll a larger and thus representative sample.
The comparison of general proceeding and method use in the early stages of industrial and engineering design processes helps to abandon existing reservations and prejustices by allowing a better understanding the differences in industrial practice. This will not only allow the design disciplines to understand each other better. Another step in the development of integrated front-ends of product development processes from the professional perspectives rather than solely academic ones seems very promising.

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