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TOWARDS A THEORY OF PRODUCT DESIGN SPECIFICATIONS

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Abstract

The product design specification is an important element in a product development project because it defines the target to be met. One requirement on the product design specification is to articulate and communicate the aspects, which makes the product attractive seen from the users' viewpoint. In the design methodology literature we find guidelines and methods to compile a product design specification. The contributions are based on the common underlying assumption that it is meaningful and the only feasible approach to interpret the result of a need analysis into a set of technical specifications, which express the customers' need and perception of value. In this paper we will scrutinize this assumption. We outline the roles and tasks of the product design specification in order to identify the requirements on a theory of product design specifications and we identify existing theory elements to build such a theory of product design specifications upon.

1 Introduction

In the fuzzy front end of new product development the design team is working in a situation of great uncertainty with respect to creation of a new business, where design problem, solution space, design strategy and required resources are vaguely comprehended. A core design team may be working based on a tentative formulation or weak vision of a product idea, requiring an explorative search for solutions and a preliminary understanding of customers' need and values. A central task of the core design team is to communicate the preliminary idea and understanding of the customers to all persons involved in the product development project. The medium or document to articulate the customers' need and values in a set of specification statements is known as a product design specification (PDS). The task to explore and communicate product idea and understanding of customers is critical to the outcome of the product development project. If the product design specification is wrong or if its content is misunderstood the result could very well be a product failing on the market, and as a consequence no business for the company.

In the design methodology literature we find guidelines for the content of a product design specification, and attempts to contribute to our understanding from researchers proposing methodologies. A typical goal specification approach is found in [Ulrich & Eppinger 1995], where it is stated that the output of the initial concept development activity is a set of carefully constructed customer need-statements, organised in a list with importance weightings for each need. Based on this list the product design specification is established. Specification statements are here seen as a precise description of what the product has to do. They are the translation of the customer needs into technical terms, and each specification statement consists of a metric and a target value for that metric. Thus, the content of the PDS defines the target of the product development project.

Empirical research indicates that early planning and specification is a key success factor in new product development, e.g. [Baxter 1995, Cooper 1993], but unfortunately also that the process of establishing a good PDS does not get much attention in industrial practice, e.g. [Hollins & Pugh 1990, Foxley et al. 2000].

In the literature a number of studies on the success and failure of new products are reported. Baxter [1995] analyses data from [Cooper 1993] and identifies a strong market orientation and early planning and specification as key success factors in new product development. Baxter writes, "*Products which are sharply and well defined in a design specification prior to development were 3.3 times as likely to be successful as those that were not. The message – put lots of effort into getting the product right at the start before beginning the design work.*"

However, it seems that the message is not heard. Hollins & Pugh [1990] write, "*In our research one of the most surprising discoveries (and one of the most depressing) was the woeful inadequacy of the product design specification in companies. The authors anticipated that companies would generally have prepared a fairly complete written PDS before embarking on design. This was found not to be the case. In most companies the PDS was brief, incomplete and based on very little and poorly organized market research.*" This observation is thrown in relief by a surprising result from a recent survey carried out in the UK [Foxley et al. 2000]. In the survey more than 400 small to medium sized manufacturing companies were interviewed about their product development performance. A key area for improvement identified during the interviews is that 44% of the companies need to improve customer focus, competitor analysis, and market research. Thus, the companies actually do not know, how they compete. A similar situation seems to exist in Germany. In a survey carried out in German industry [Grabowski & Geiger 1997] on the situation of product development the companies see customer and market orientation as the most important success factor. However, the companies judge their ability to treat customer and market orientation properly as being weak.

The authors of this paper see these empirical findings as an important motivation for the development of a theory of product design specifications. In this paper we will scrutinize and question the underlying assumption of theory and practice, that it is meaningful and the only feasible approach to interpret the result of a need analysis into a set of technical specifications, which mirror or express the customers' need and perception of value. One may ask what alternative strategies exist for capturing the aim of a product development project, express what is believed to be a good design solution and establish guidance for the project navigation leading to an appropriate product in due time.

2 Product design specifications in theory and industry

Eekels [2000, 2001] distinguishes in his description of design geography between what is going on in the realm of reality or the material reality on the one hand, and what is going on in the realm of the mind, i.e. during the creation of the design, on the other hand. In the realm of reality there exist people with needs and attitudes. In the realm of the mind the design team

makes an image of the existing need situation, determines purpose and make value judgements. The central element is the design of a means, i.e. the synthesis of a technical solution, which is supposed to satisfy the need or at least to create a new improved situation in the material reality. In this paper we are looking for design activities and documents to be applied by the design team to identify and externalise the team's image of the existing need situation, purpose or goals, and specification statements. Firstly, we identify specification approaches described in the literature and secondly we focus on industrial practice.

It is easy to recognize the importance of a product design specification in a product development project because it defines the target to be met. The PDS has to be established reflecting the need and values of potential customers. The design team applies the PDS to focus synthesis activities on fruitful directions in the solution space, and the PDS is used when selecting a design solution among a number of alternatives. The design solution's fulfilment of the PDS has to be verified. When one of more elements of the PDS, i.e. one or more specification statements, cannot be satisfied, then either the design solution has to be modified or rejected, or the specification statements have to be changed. Due to the importance of the PDS and its many uses in product development, the PDS is taken up again and again in the design methodology literature. However, it is an area where the terminology is not consolidated and agreed upon yet, and where different authors present their contributions in form of guidelines or methods in their own terminology.

In order to proceed we have to describe our focus and choice of terminology:

- We focus upon a company creating products for a consumer market, i.e. a situation where it is a central task for the design team to interpret market and user needs. Thus, we are not considering a business-to-business situation, where the specification is seen as a contract between two parties.
- We focus upon the set of goals to capture and translate the need and values of potential customers into a vision of an attractive product. Thus, we ignore the wider set of goals, which are important for a company in order to decide whether the development, production and marketing of the product will lead to a viable business. According to Andreasen & Hein [1987] this set of goals may be called the business specification.
- We focus upon the early activities of new product development where the design team are working based on a tentative formulation or weak vision of a product idea, and where the purpose of the activities is to provide a basis for deciding whether to pursue a product opportunity or not. A result of this activity is a set of goals for the product to be synthesised, where the goals reflect the need and values of the potential customers. Following the terminology of [Ulrich & Eppinger 1995] the set of goals is formulated as a number of specification statements, and the specification statements are compiled into the product design specification. Alternative names for this set of goals are the specification or requirement list [Pahl & Beitz 1984] and the design specification [Roozenburg & Eekels 1995].

2.1 Product design specifications in the design methodology literature

Based on a study of the design methodology literature we have identified several approaches to define the product related targets for a product development project.

A typical *product specification design approach* is based upon focusing on the product's functions and properties [Pahl & Beitz 1984, Hubka & Eder 1984]. The designer or design team build up an imagination of the purpose and properties of the ideal design solution compared to the properties and qualities delivered by the competitors' products, and a PDS is formulated. Often the product design specification document contains a verbal formulation of the design problem. Different types of "logic" are developed for the formulation of specification statements, like fixed requirement, minimum requirement, demand, and wish.

A second approach is based on *use of a checklist*. Tjalve [1979] has developed a hierarchical checklist, which contains more than 450 factors to be considered by the design team. The checklist is structured according to product life phases. Pugh [1991] has set up a checklist, which contains 32 higher-level classes of factors. According to both Tjalve and Pugh the design team has to see the factors as primary triggers from which the product design specification will evolve based on the design team's insight from a user need definition stage. Mørup [1993] do not develop a written checklist, but a graphical model of the total product life, and he identifies the stakeholders in the product life phases. Mørup proposes the use of scenario technique to capture the quality expectations of the stakeholders.

A third approach is based on *reuse of a product design specification*. Many product development projects take an existing product as a starting point for the development of a new version of the product. If the existing product has been successful on the market it is worthwhile to use the existing product design specification as a basis for establishing a product design specification for the product variant to be developed. In the last decade a lot of research has been carried out with the goal to develop models, which can represent specification statements in a computer system, because a computer representation of a product design specification is well suited for a reuse approach. McKay et al. [2001] propose a data model for the computer-based representation of a product design specification, and state that the model could be used to capture specification statements and could contribute to the integration of requirements with product definition. Schachinger & Johannesson [2000] present a generic object-oriented model that together with a top-down approach, supports specification of product needs and mapping of surrounding factors. The goal is to make the individual engineering designer able to handle and view more information related to concept selection and thereby be able to make more accurate decisions. According to Schachinger & Johannesson the model has been tested in a redesign of an existing product.

A fourth approach is known as *requirements engineering* [Karlsson & Rosenblad 1998, Kaulio 1995]. The requirements engineering idea is to involve the users during the product development project. When the design team makes their considerations and results visible, users can comment and propose better alternatives seen from their viewpoint. This approach requires access to a suitable number of potential users, which are willing to participate. When users are not immediately available the engineering designers have to make an interpretation of user value and attitude into specification statements.

A fifth approach is based on listening to the *Voice of the customer*, where the *Quality Function Deployment* method (QFD) and analyses of market trends are available tools. QFD [Hauser & Clausing 1988] is a method focusing on matching the customers' statements about an existing product to its properties. A number of customers are asked to comment on an existing product based on their perception of and/or experience with the product, and the design team links the comments to the product's properties and features. The design team compares the product with products from competitors, and identifies areas for improvement. In this way a basis for creating a PDS and for developing a new version of the product is established.

A sixth approach is what we have reason to believe is a common *industrial design approach*, where the designer bases the synthesis activities and considerations on a design brief, and where there is no or very limited use of explicitly formulated specification statements. Instead the designer develops an argumentation for the benefits of the product, to be used in milestone meetings or customer contact.

A seventh approach is based on *integrated product development* [Andreasen & Hein 1987] where the design process is carried through by a team consisting of marketing researches, engineering designers and production specialists. Such an integrated team can make comprehensive evaluations of design alternatives from many viewpoints and often the

traditional PDS document is used together with team-based evaluations. The approach can be seen as a step towards a reflective design practice, where the design team makes the decisions based on a situational understanding [Schön 1983, Gero 1998].

Although we have identified several different approaches available for a design team to establish a product design specification, we observe that most of them share a common underlying assumption, namely that it is meaningful to interpret an understanding of the potential customers' need and perception of value into a set of specification statements in the form of a PDS document *before* actually searching for design solutions.

Based on our literature study we observe that the design methodology literature, not least the textbooks, presents the issue of establishing, formulating and applying a product design specification in a surprisingly uniform way. It is not clear whether the approaches described in the literature can be seen as results of theoretical considerations or they are based on empirical observations or registration of industrial practice. Further, we observe that in this area authors develop their own terminology rather than build upon existing literature.

2.2 Product design specifications in industrial practice

As shown in section 2.1 we observe that there has been carried out theoretical work on goal specifications with respect to the design team's establishment of a product design specification, its content, and its use during synthesis and decision-making activities. However, as stated in the introduction it seems that these results have had very limited impact into industrial practice [Hollins & Pugh 1990, Foxley et al. 2000].

Almefelt et al. [2003] made an empirical study of the management of requirements in an industrial company. Almefelt et al. followed a product development project from early concept phase to industrialisation, a time period from 1996 to 2002, in a Swedish automotive company. The case studied was the development of a passenger car cockpit, which is a major sub-system of a car and has multi-technology content. The research method encompasses a product study, a study of documents and a number of interviews, and both the Swedish car manufacturer and the French system supplier constitute the base for the observations and data collection.

In relation to our work we find a number of important insights from this empirical study:

- During the interviews many of the respondents express an awareness and understanding of the importance of working with specifications, but give advice not to focus too much on fulfilling each specification statement. Almefelt et al. write *"If all requirements specified were complete, set to a reasonable level, correct and well balanced – meaning that internal requirement conflict were resolved – a fundamental emphasis on fulfilling all requirements would consequently lead to a very good product. But, since requirements are often incomplete and conflicting, a strong effort to fulfil them, without having a flexible approach, might lead to sub-optimisation and project stagnation."* Thus, is it a challenge for the design team on the one hand to satisfy the PDS in order to develop a good product, but on the other hand not to allocate resources on impossible subtasks.
- According to Almefelt et al. the product design specification documents have over the years evolved to become rather complete and well-structured documents in the company. However, some criticism and proposal for improvements are stated during the interviews: *"A further step could be to emphasise a set of key issues, approximately ten, in order to provide a shared cognitive map for the development, and to facilitate evaluation activities."* Thus, the design team members have to focus their attention on few important specification statements. Another element of criticism relates to the fact that each sub-system has to have its own specification document, which makes it difficult to obtain an overview. Almefelt et al. write, *"Even though it is explicitly desired, so far there is no over-arching cross-system design prerequisites document clarifying interfaces and*

capturing common, important requirements for interdependent systems and components. Furthermore, there is a lot of back and forth referencing between documents, and the access to referred documents is sometimes limited, at least for the supplier."

- Almefelt et al. write, *"However, even if the design and organisation of the requirements documents were perfect and the content appeared to be complete, the fact remains that some issues are really difficult to state requirements for. The ability to specify technical requirements is seen as good, while more abstract issues, such as perceived tactile feeling in controls and aesthetic values, are said to be more difficult to capture in a requirement."* Thus, for product properties related to aesthetic values and user feeling it is difficult to formulate specification statements in measurable, technical terms.

If we focus upon the sequence of activities to set up the product design specification and to synthesise a design concept there seems to exist a common understanding in the design methodology literature: Firstly the design team carries out a need analysis to establish the product design specification, and thereafter the design team can close the specification work and fully concentrate on the synthesis of alternative concepts. However, insights from industrial practice show a more complex picture.

Pugh [1991] makes a distinction between a product concept being "static" or "dynamic". In many industries the design team develops a new product based on an existing or predetermined product concept, and Pugh mentions the automotive industry as an example. In this situation the product concept is already there, being "static", and the PDS is written based upon a shared understanding of the concept. In this way the design team can focus their efforts and resources at the subsystem or component level to give the product a competitive advantage through incremental design improvements around the existing product concept. However, if the company identifies a competitive advantage to be reached based on an innovative product or the market is expecting innovative products, then a new product concept has to be developed, i.e. a dynamic concept situation. In this situation the design team has to establish a product design specification and to synthesise product concept solutions.

Andrews [2003] questions the understanding expressed in the design methodology literature that the product design specification comes first. According to Andrews the idea to establish a product design specification first and then synthesise a solution has its roots in Systems Engineering, and it seems that design methodology researchers have adopted this idea without questioning. Andrews [2003] argues that the activity to establish a PDS for a new ship has to be carried out simultaneously with considerations on feasible solutions. Andrews write, *"For this reason the wicked problem demands to be tackled through a dialogue between the requirements generator (the naval staff or ship owner) and the preliminary ship designer. The purpose of the dialogue is to elucidate the best mix of conflicting requirements within what is affordable and achievable, which necessarily has to be done by reference to materially feasible potential solutions."* Thus, the message from Andrews into our situation, where a company develops products for a consumer market, is that the establishment of a product design specification goes hand in hand with the development of the product concept. However, to obtain a dialogue between the design team and a suitable number of potential customers is not an easy task.

We conclude that there seems to exist a remarkable gap between the approaches used in industrial practice and the model proposals of product design specifications found in design methodology literature. Thus, the authors see a challenge to increase the engineering designers' adoption and use of design research results by creating a balanced and productive understanding of product design specifications.

3 Towards a new understanding of product design specifications

In this section we will develop a new understanding of goal specifications in three steps:

- We create a comprehensive model, which shows the influences on and the complexity of the activity to specify.
- We discuss the contents of the product design specification in relation to its tasks and functionality.
- We take a first step to establish a theory of product design specifications.

3.1 A model of the activity to specify goals

Based on our study of the literature we are able to make a number of observations about the nature of the activity to specify, i.e. to identify and establish a set of goals for a product development project. The observations are related to the influences on the activity and to the tasks and roles of the activity's output.

Following Eekels' [2000, 2001] line of thinking the "input" to specifying comes from an understanding of a situation in the realm of material reality. Here we identify at least four different situations:

- Based on a tentative identification of a need situation a core design team may explore the need and values of potential users in more details and develop a vision of a product idea.
- A core design team may identify a market opportunity based on an insight into the products available on the market and the wishes and desires of the customers. A market opportunity may result in the identification of a competitive edge for a new product.
- A client may contact the company asking for a product variant with a well-defined and specific performance. In this situation the product design specification may be established in cooperation between client and company.
- Observations or feedback from customers regarding the use of one the company's existing products may result in an identification of a possibility to develop a new version of the product. In this situation the product idea is well known and the PDS from the existing product may be re-used or modified appropriately by the core design team.

During the specifying activity it is a central task for the core design team to communicate the product idea or vision and understanding of the potential customers or client's need and perception of value to all persons involved in the product development project. Thus, the "output" or result of specifying has to have a form and content which makes this communication adequate. From the literature study we observe that the satisfaction of a need and perception of value is carried by both the product's technical, measurable properties and the less tangible properties like tactile feeling of controls and aesthetic values.

The members of the product development team use the output of the specifying activity in different activities:

- To control synthesis activities, i.e. point to directions in the solution space leading to attractive design solutions.
- To evaluate design alternatives in order to decide with which alternative to continue.
- To navigate through solution and activity space, i.e. to synthesise an attractive and feasible solution within the resources and time allocated to the project.
- To act in the project milestones as a contract between the management and the design team developing the product [Andreasen & Hein 1987].

And last, but not least, the product development team may break down the content of the product design specification into specifications for sub-systems.

In figure 1 we show a phenomenon model showing the nature of the activity to specify with its influences, tasks and roles. We observe that the activity is quite complex having many influences and several roles and functions during a product development project. Thus, we

conclude that is seems to be a bit naïve to expect that a PDS document in the traditional form of a structured set of specification statements is an appropriate and productive solution to all the expectations concerning the output of the specifying activity.

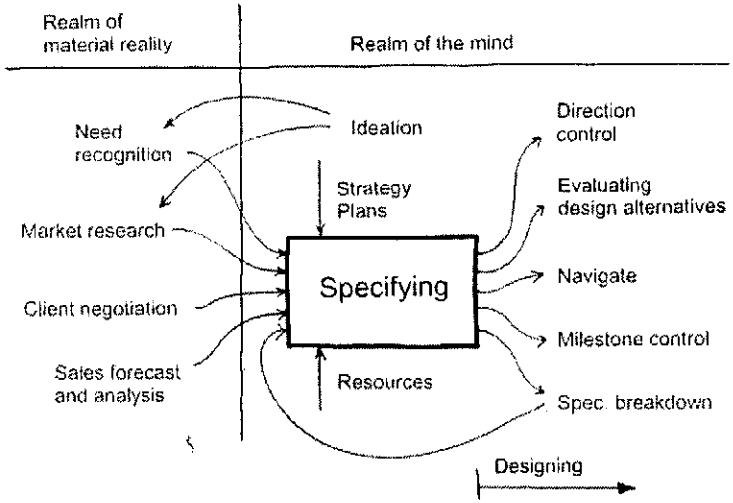

Figure 1 A comprehensive model of specifying showing pre- and after activities, which are setting functional requirements on the product design specification.

3.2 The contents of the product design specification

In this section we will discuss the contents of the product design specification document in relation to the tasks and functionality identified in the previous sub-section of this paper.

Articulation and transfer of product idea

The core design team has to articulate and communicate the product idea and understanding of the users' need and values to all the members of the product development team. The literature study and our model of the specifying activity have shown that the PDS document in form of a structured set of specification statements is not suitable for this task.

A product idea is better captured in a design brief or a verbal problem formulation, and according to [Pugh 1991] a short list of unique selling points or competitive criteria, focuses the product development team's attention on the competitive edge of the product.

Specification statements consisting of a metric and a target value for that metric are well suited to capture product properties related to performance, but it is difficult to express an understanding of user needs, wishes, and perception of value in relation to desire, use and own the product in a set of specification statements. Here the authors believe that application of user characters and scenarios is a more productive way to reach consensus and common understanding within the product development team.

Articulation and selection of the attractive product

When the product development team develops a product for the market the team has to have insight into the need and values of the potential users and customers. During the process the team is again and again confronted with the problem of selecting a design solution from a

number of alternatives, i.e. to answer the question "what is the best solution?" The insight to answer this question might be carried by the PDS, the design brief, and the team members' insight with need situation and solution space. The users' reaction on design alternatives might be exploited if it is possible to identify a suitable number of potential users and involve them in the decision-making activity.
When a product development project is initiated based on a client-company relationship the client and company in cooperation agree upon what shall be delivered and what set of specification statements shall be fulfilled. The product design specification takes a special form for going into a formal contract between client and company.

Navigation during the product development project
The skilled designer is not only goal-oriented; he/she also understands the process for reaching the goal [Asimow 1962], and Asimow uses the term "to navigate". Thus, the product development team *navigates* through the solution space to synthesise an attractive design solution within the resources and time allocated. The navigation criteria are related to the design solution being attractive, the tractability of the product development project, and not least the consequences during the product life cycle.
For the product development team to navigate the well-structured PDS is necessary, but not sufficient. It has to be supplemented with or has to contain a set of specification statements related to the product life cycle, and a set of business specifications. A design brief or a verbal problem formulation is not sufficient, because the scope of these documents is often limited to a narrow focus of user need or problem situation in the realm of material reality. The design team's insight is not sufficient to navigate through the project, because the insight and responsibility of the team does not cover the total product life cycle and maybe not a comprehensive business insight.

Break down and maintaining argumentation
During the product development project the team gradually determines the characteristics of the product in a sequence of design steps. In this process the sub-systems of the product have to be designed, and therefore the relevant specification elements of the PDS have to be broken down to specifications for sub-systems. The empirical study of the Swedish car manufacturer shows that in order to ensure a proper break down and to maintain the argumentation a traditional paper-based PDS is not adequate. So here we have to rely on pragmatic solutions and wait for more clear tools to be developed.

3.3 A theory of product design specifications

Our study of the literature has shown that there seems not yet to exist a theory of product design specifications:

- There does not exist a comprehensive model showing the structure of a formal specification document, an explanation of the designer's knowledge or mindset necessary for applying the document for specific purposes, and an articulated set of methods.
- There does not exist a comprehensive and productive terminology based on which researchers can develop theoretical contributions and which can be applied in product development practice.

However, we have identified theory elements, which can contribute to the building of a theory of product design specifications. We make an outline of theory elements in this section.

Contributions from decision-making theory
As we have seen a decision during a product development project may contain several aspects to be considered by the design team: A good product? A feasible solution? A tractable project? A good business? Acceptable consequences for all stakeholders? And the definition of a good product may lead to questions like: Value for the user? Social and aesthetic

acceptance? Excitement and experience present? Thus, it takes a lot of insight related to the product itself, the product's relational properties [Mortensen 1999], to the business, and to product life aspects [Olesen 1992]. The decision-making activities during the product development project are complex, and have critical impact on the result obtained.
We could ask what the design methodology offers on decision-making to the design team working in industrial practice. In textbooks, e.g. [Pahl & Beitz 1984] and [Roozenburg & Eekels 1995], we find rather simple and straightforward methods and decision rules, and in articles, e.g. [Yeo et al. 2004] and [Rajabally et al. 2002], we find methods based on advanced mathematics. On the positive side the contributions offer a terminology and a set of decision methods to structure decision-making activities emphasising the importance of all criteria, all alternatives to the same level of detail, and consequences. Thus, the decision becomes visible and can be object to a deliberation between the design team members. On the negative side a clear-cut, structured approach forces to simplification, not to the overview of the complex totality of interwoven factors and aspects of a decision.

Break down of product design specifications
During the product development project the design team has to break down the product design specification to specification statements for each subsystem of the product in order to ensure that the subsystems being synthesised contribute in a proper way to the product.
When the product structure is well known, e.g. in the automotive industry, it is relatively simple to break down the specifications for the overall product to specifications related to single functionalities (door opening and closing), to components (the door), or to parts (the window glass of the door). The existence of a known break down pattern is a condition for the QFD-method, and a condition for making proper specification statements for components.
It is an interesting observation that the nature of a specified property may shift when we follow a break down pattern. Ulrich & Ellison [1997] write, "*For example, assume that ride quality is an extremely important customer requirement for landing gear. Ride quality is a function of most of the components of the landing gear. This ride-quality function is quite complex, and can only be partially made explicit, and only by using many parameters and highly non-linear, non-monotonic mathematical relationships. The evaluation of ride quality requires extensive simulation and several prototypes. As a result, it is impossible to decompose ride quality into performance requirements for each of the components of the landing gear. For example, there is no way to say what the ride quality of a support linkage is, without knowing what the tires and shock absorber parameters are.*"
In spite of the importance of breaking down specifications very little is found in the literature. The authors are aware of contributions from Zangemeister [1971], Ulrich & Ellison [1997], Svendsen [1994], Svendsen & Hansen [1993], and Hansen [1995].

Navigation theory
The consequences of choosing an unproven design concept may be unpredictable. Designers speak about "wicket concepts" or "hidden mines in the concept", which may lead to a much higher amount of design work than anticipated during concept selection or even closure of the product development project.
As mentioned earlier Asimow [1962] introduces the term "to navigate" during the design process. In relation to the design team's navigation Asimow introduces two navigational criteria: the tractability of the design process and the cost of producing the design, and formulates the hypothesis that in the earlier phases of the design process tractability is the more important selection criterion, whereas in the later detail design phase the cost of producing the design is the predominant criterion.

A specification theory?

Above we have shown how specifying is interwoven in other important aspects of designing. It means that a theory of specifying or better "a theory of how to capture, articulate and communicate attributes of the wanted product so that the design process leads to such a product" has to share concepts with other theories.

One dimension of such a theory could be a cognitive theory, explaining or modelling how humans apply value statements for identifying emerging structural solutions. We have not yet worked in this direction in our literature search.

Another dimension of such a theory could be a "model-based theory", for instance illustrated in an entity/relation-model, showing the relations between user value statements, a property specification, a structural element of a design carrying this property, a model of the actual structural element, and the modelling result (i.e. a prediction of the element's behaviour with respect to the property). Such an entity/relation-model might also be expanded to show the elements of a product design specification document, like design brief, verbal problem formulation, business specification statements, product specification statements, etc.

The goal of the specifying activity is to set the target and to guide the design team to a good solution, but this solution is only a part of the product development project result. Therefore, an entity/relation-model has to include specifications for business, specifications for the product seen as a system element, and several types of product life properties, e.g. environmental effects, costs related to various product life phases, and quality.

In this paper we refrain from proposing an entity/relation-model, but it is our intention to follow up the research work presented in this paper by elaborations of such models as a basis for a theory of product design specifications.

4 Conclusions

The authors see a challenge to explore the schism between the guidelines and methods to compile a product design specification found in the design methodology literature and the very different picture, which appears when industrial practice is studied empirically.

In this paper we have developed a phenomenon model of the activity to specify based on a study of the literature. The model shows that specifying is a complex activity, which has many influences and several roles and functions during a product development project. Specifying is setting functional requirements on the product design specification, and we have argued for the PDS to be seen as a composed document, where a set of specification statements is only one element. A set of specification statements each consisting of a metric and a target value for that metric is well suited to capture product properties related to performance, but it is difficult to express user needs, wishes, and perception of value in relation to desire, use and own the product in this way. Thus, other elements of the PDS may be a design brief, a verbal problem formulation, a list of unique selling points, user characters and scenarios, and navigational criteria.

Since a theory of product design specifications does not exist yet, we have outlined requirements for such a theory and identified existing theory elements to build such a theory of product design specifications upon. We will follow up this research work by proposing models contributing to a theory of product design specifications.

References

Almefelt, L., Andersson, F. et al., "Exploring requirements management in the automotive industry", Proceedings of 14th International Conference on Engineering Design, eds. A. Folkeson, K. Gralén, M. Norell & U. Sellgren, Design Society, 2003, executive summary pp. 63 - 64, and paper (CDROM) *pp. 1-14.*

Andreasen, M.M. & Hein, L., "Integrated product development", IFS (Publications) Ltd/Springer-Verlag, 1987.

Andrews, D., "Marine design – Requirements elucidation rather than requirements engineering", Proceedings of IMDC 2003, ed. A.D. Papanikolaou, National Technical Univeristy of Athens, School of Naval Architecture & Marine Engineering, 2003, Vol. 1, pp. 3 – 19.
Asimow, M., "Introduction to Design", Prentice-Hall, Inc., Englewood, N.J., 1962.
Baxter, M., "Product design – A practical guide to systematic methods of new product development",Chapman & Hall, 1995.
Cooper, R.G., "Winning at new products", Addison Wesley Publishing Co., Boston, 1993.
Eekels, J., "On the fundamentals of engineering design science: The geography of engineering design science", Part 1/2, Journal of Engineering design, vol. 11, no. 4, 2000, pp 377-397 and vol. 12, no. 3, 2001, pp 255-281.
Foxley, D.M., Blessing, L.S. et al., "Closing Report. Partnership for profitable product improvement: P3I", Sector challenge project number 328, The Royal Academy of Engineering, 2000.
Gero, J.S., "Towards a model of designing which includes its situatedness", Proceedings of the workshop Universal design theory, eds. H. Grabowski, S. Rude & G. Grein, Shaker Verlag, Aachen 1998.
Grabowski, H. & Geiger, K. (eds.), "Neue Wege zur Produktentwicklung", RAABE, Bonn, 1997.
Hansen, C.T., "An approach to simultaneous synthesis and optimization of composite mechanical systems", Journal of Engineering Design, Vol. 6, No. 3, 1995, pp. 249 – 266.
Hauser, J.R. & Clausing, D., "The house of quality", Harvard Business Review, May-June 1988.
Hollins, B. & Pugh, S., "Successful Product Design", Butterworth & Co. Ltd, 1990.
Hubka, V. & Eder, W.E., "Theory of Technical Systems" Springer-Verlag, New York, 1984.
Karlsson M.A. & Rosenblad E., "Evaluating functional clothing in climatic chambers tests vs. in field tests: A comparison of quantitative and qualitative methods in product development", Ergonomics, *Vol.41, No. 10, p. 1399-1420, 1998.*
Kaulio, M.A. "Requirements Engineering: An analysis of design principles, approaches, and methods for user involvement in product design", thesis, Chalmers University of Technology, Sweden, 1995.
McKay, A., de Pennington, A. & Baxter, J., "Requirements management: a representation scheme for product specifications" Computer-Aided Design, Vol.33, 2001, pp. 511 – 520.
Mortensen, N.H., "Design modelling in a Designer's Workbench – Contribution to a Design language", thesis, Department of Control and Engineering Design, Technical University of Denmark, 1999.
Mørup, M., "Total life models – an important tool in design for quality", Proceedings of ICED 93, ed. N.F.M. Roozenburg, Heurista, Zürich, 1993, pp. 849 – 856.
Olesen, J., "Concurrent Development in Manufacturing – based on dispositional mechanisms", thesis, Institute of Engineering Design, Technical University of Denmark, 1992.
Pahl, G. & Beitz, W.,"Engineering design", The Design Council & Springer-Verlag, 1984.
Pugh, S.,"Total design – Integrated methods for successful product engineering", Addison-Wesley, 1991.
Rajabally E., Sen P. & Whittle S., "A Methodology for Model Dependability Assessment.", Proc. Engineering Design Conference 2002, ed. T.M.M. Shahin, Professional Engineering Publishing Limited, London, 2002, pp.291-300.
Roozenburg, N.F.M. & Eekels, J., "Product Design: Fundamentals and Methods", John Wiley & Sons,1995.
Schachinger, P. & Johannesson, H.L., "Computer modelling of design specifications", J. Eng. Design, 2000, Vol. 11, No. 4, pp. 317-329.
Schön, D.A., The reflective practicioner", Basic Books, New York, 1983.
Svendsen, K.-H., "Discrete optimization of composite machine systems – a contribution to a designer's workbench", thesis, Institute for Engineering Design, Technical University of Denmark, (in Danish), 1994.
Svendsen, K.-H. & Hansen, C.T., "Decompostion of mechanical systems and breakdown of specifications", Proceedings of ICED 93, ed. N.F.M. Roozenburg, Heurista, Zürich, 1993, pp. 119 –126.
Tjalve, E., "A short introduction to industrial design", Newnes-Butterworth, London, 1979.
Ulrich, K.T. & Eppinger, S.D., "Product Design and Development" McGraw-Hill Inc. 1995.
Ulrich, K.T. & Ellison, D.J., "Customer requirements and the design-selection decision", working paper, Department of Operations and Information Management, The Wharton School, University of Pennsylvania, July 25, 1997.
Yeo, S.H., Mak, M.W. & Balon, S.A.P., "Analysis of decision-making methodologies for desirability score of conceptual design", J. Eng. Design, Vol. 15, No. 2, 2004, pp. 195-208.
Zangemeister, C., "Nutzwertanalyse in der systemtechnik", Wittenmannsche Buchhandlung, Zippel-Druck Herbert Zippel KG, Berlin, 1971.