THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Design Syntactics: A Functional Approach to Visual Product Form

THEORY, MODELS, AND METHODS

ANDERS WARELL

Engineering and Industrial Design
Product and Production Development
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Cover illustration
The visual form of a product can be described by form entities, which create structure and syntactic functions in our perception of the form. See page 95.

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TO JOHANNA

"Something hidden. Go and find it.
Go and look behind the Ranges –
Something lost behind the Ranges.
Lost and waiting for you. Go!"

RUDYARD KIPLING
The Explorer, 1898

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Anders Warell, Product and Production Development,
Engineering and Industrial Design, Chalmers University of Technology

ABSTRACT

In line with the increasing importance of high quality appearance and aesthetic appeal in the design of consumer products, there is a growing need for enhanced understanding and ability to handle visual product form in industrial product development. In an approach for meeting that need, this thesis concerns the nature and development of visual design aesthetics in product form design. The contributions provide a means for enhanced reasoning about the structure and function of form design. The aim is that the findings will provide support for the specification, analysis, synthesis, and evaluation of visual product form in relation to technical aspects in the area industrial design and engineering design interaction.

In the thesis, theory, models and methods supporting the development of such product aspects are proposed. Based on theoretical elements from a number of fields, including engineering design science, design semiotics, form aesthetics, and visual perception, a 'hybrid' theory for visual design aesthetics is proposed, which links the aesthetic form of the product to functional reasoning.

Through the theoretical framework of *design syntactics*, a descriptive model of the nature and workings of the visual product form is developed. The framework consists of three main conceptual elements; *form functionality*, concerning the purpose and function of visual product form; *form syntactics*, related to the structure and organization of the visual form; and *design formats*, associated with form content and design philosophy from a company perspective.

Based on the modeling framework, methodology support for form design activities in industrial design development is proposed. The three suggested methods include approaches for analysis of technically and aesthetically determined functionality of form, for development of visual form aesthetics in product design, and for the creation of design formats for utilization in operative and strategic design development.

Keywords: design methodology, design syntactics, engineering design, form design development, functionality, industrial design, interdisciplinary design, product form, product semantics, visual design aesthetics

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The outset for the 'post-licentiate' part of the research work was an odd experience during a sleepless night in the desolate base camp of Cerro Aconcagua in the high Andes, December 1999. In the early morning hours, between my gasps for oxygen-deprived air, a sudden notion gave the inspiration to develop what is presented in this thesis. The road traveled since the tent experience has been stimulating, challenging, and exacting, and it now feels immensely satisfying to realize that the end of the road has been reached. Upon finishing the writing of this thesis, my most immediate urge went to attaching a label on the front cover, reading "Warning! This is a Ph.D. thesis. Don't try this at home!" But, as you all can see, I managed to refrain from that…

During the course of work, I have been dependent on many people who have helped me in realizing this goal. I am indebted to, at least, all of you in the following:

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GÖTEBORG, DECEMBER 2001

Anders Warell

LIST OF PUBLICATIONS

This thesis is based on the work contained in the following papers. The papers are printed in their originally published state except for changes in format minor and errata.

Paper A
Warell, A. [1999]: “Artifact Theory for Industrial Design Elements”, *ICSID Design’99 Conference*, Sydney

Paper B
Warell, A., Nåbo, M. [2000]: “A Model for Visual Design Aesthetics Based on Form Entities”, *Proceedings of NordDesign 2000*, Technical University of Denmark, Lyngby

Paper C
Warell, A. [2001]: ”Design Syntactics - A Contribution Towards a Theoretical Framework for Form Design”, *Proceedings of ICED’01, International Conference on Engineering Design*, Glasgow

Paper D
Warell, A., Nåbo, M. [2001]: “Emergent Form Design Development Modeled by Form Entities”, *Bulletin of ADC’01, 5th Asian Design Conference*, Seoul

Paper E
Warell, A., Nåbo, M. [2001]: “Handling Product Identity and Form Development Issues in Design Management Using Design Format Modeling”, accepted to *DMI 2002, the 11th International Forum on Design Management Research and Education Strategies, Resources & Tools for Design Management Leadership*, Northeastern University, June 9-12, 2002, Boston

Paper F
Warell, A., Nåbo, M. [2001]: “Methodology Support for Form Design Development in Industrial Design Engineering”, accepted to *TMCE 2002, the Fourth International Symposium on Tools and Methods of Competitive Engineering*, April 22 - 26, 2002, Wuhan

Co-author statement

All articles are written by Warell. On papers B, D, E, and F, Mats Nåbo, industrial designer and lecturer at Linköping University, is co-author. The role of Nåbo has been that of discussion partner in the research. Nåbo has provided valuable input and reflection to the work on proposed theories and methods, and has contributed to the application of the results in design education.

Additional publications

Additional publications accomplished during the research but not included in the thesis are listed in the following:

Warell, A. [1997]: "On the Role of Industrial Design in a Product Structure", Research Report, Division of Machine Design, Linköping University, LITH-IKP-R-1038, Linköping

Warell, A. [1997]: "Produktsyntes. En metod för systematisk struktur- och formvariation vid konceptutveckling", Division of Machine Design, Linköping University, Report LITH-IKP-R-1079, Linköping University

Warell, A. [1998]: "Treating Industrial Design Issues within Existing Design Procedures", *Proceedings of NordDesign '98*, Royal Institute of Technology, Stockholm

Warell, A. [1999]: "Introducing a Use-Perspective in Product Design Theory and Methodology", *Proceedings of the 1999 ASME Design Engineering Technical Conferences*, Las Vegas

Warell, A. [1999]: "Industrial Design Elements – A Theoretical Foundation for Industrial Design based on a Design Science Perspective", Licentiate Thesis, Linköping University, Linköping

Janhager, J., Persson, S., and Warell, A. [2001]: "Survey on Product Development Methods, Design Competencies, and Communication in Swedish Industry", accepted to *TMCE 2002, the Fourth International Symposium on Tools and Methods of Competitive Engineering,* April 22 - 26, 2002, Wuhan

Pohl J., Warell, A., Krus, P., and Palmberg, O. [2001]: "The Use of Simulation Driven Experiments for the Conceptual Design of a Variable Valve Train", *Proceedings of the 2nd International Conference on Advanced Engineering Design*, Glasgow

CONTENTS

Structure of the thesis

This thesis is organized into nine main sections. For more expedient study of the thesis, an outline of the contents is given in the following.

Section 1 An introduction to the work. This section may be studied by readers who wish to get an insight into the background and context of the work. The incentives for the research are presented, as well as an introduction to the term ‘design’, and a discussion of different approaches to design work in different design fields.

Section 2 The section presents the scope of the research work. Objectives and focus areas are presented, and goals and research questions, which have guided the work, are discussed.

Section 3 This section discusses the scientific approach to the work. A review of schools of scientific research is presented, followed by a discussion of research approaches in design science research. The research method applied in this work is presented, with an emphasis on empirical studies carried out in the research, followed by a review of approaches for verification and validation of design science research.

Section 4 In the theoretical frame of references, the main fields of knowledge which have contributed and influenced the research work are presented. The value and importance of different theory fields in relation to the research presented in this thesis is discussed.

Section 5 A condensed presentation of the results of this research, as presented in full in the appended papers, is found in the contribution section. The constituents of the theoretical framework of design syntactics is presented and discussed, followed by a presentation of methodical approaches developed from the framework. The reader who is primarily interested in the findings of the research may concentrate on studying this section of the work.

Section 6 A short review of the appended papers.

Section 7 In conclusions, the value and novelty of the research is discussed, and an outlook for future research in the area is presented.

Section 8 References used in the work are presented.

Section 9 The six papers are appended in unabridged versions.

GLOSSARY: DEFINITIONS AND TERMS USED IN THE THESIS

*Engineering design**	Design with particular emphasis on the technical aspects of a product, including both analytical and synthetic activities.
Form	Shape (geometry), dimension, surface texture, structure, and configuration.
Form element	A form ‘unit’, a constituent element of a physical, visuo-spatial form. A recursive term.
Gestalt	A discernible whole; an arrangement of parts so that they appear and function as a whole which is more than the sum of the parts [Monö, 1997].
*Industrial design**	Design with particular emphasis on the relation between product and man, e.g., semiotic, ergonomic and aesthetic aspects of the product.
*Product design**	The activities involving the design of products, including the activities of engineering design and industrial design.
*Product**	A system, object or service made to satisfy the needs of a customer.
Function	*see* Product function.
Semantic function	Product function related to the meaning we place, or interpret, into its form. Includes the four functions to describe, to express, to exhort, to identify [Monö, 1997].
Syntactic function	Product function related to the structure and configuration of visual form.
Ergonomic function	Product function that enables or enhances the use of a product with respect to physical or cognitive ergonomics.
Communicative function	Collective term for syntactic and semantic functions.
Form function	Alternative term for Communicative function.

Product semantics	The study of the symbolic qualities of man-made forms in the cognitive and social context of their use and application of knowledge gained to objects of industrial design [Butter and Krippendorff, 1984].
Product function	What a product or an element of a product actively or passively does in order to contribute to a purpose, by delivering an effect. A function is intended or incidental.
Functionality	The combination of all effects, properties, and their behavior, that contribute to making the product useful for its purpose.
Form entity	The active unit of an aesthetic organ. Provides the relational properties of visual form.
Aesthetic organ	A structural design element for the complete realization of a form function. An aesthetic organ is a structure of form entities. Some aesthetic organs consist of only one form entity.
Property	Any characteristic of an object, that belongs to and characterizes it [Hubka and Eder, 1988].
Configuration	A system which is designed by selecting existing elements and arranging them into a product.
Form configuration	A configuration of a set of physical form elements, a relational property of the visuo-spatial form.
Structure	Elements and their relations (functional and spatial).
Artifact	A thing made, or given shape, by man [Karlsson, 1996].
Design (object)	The result of a design process [Andreasen and Mortensen, 1996].
Design (process)	To conceive the idea for some artifact or system and/or to express the idea in an embodiable form [Archer, 1971].
Semantics	The study of the sign’s message (the meaning of the sign) [Monö, 1997].
Semiotics	The study of signs [Monö, 1997].

Syntax	The study of the signs relations to other signs and the way it interacts in compilations of signs [Monö, 1997].
System	A system is separated from the surroundings by a borderline, and has a structure consisting of elements and their relations [Andreasen, 1980].
*Technical system**	A man-made system that is capable of performing a task for a purpose.
User	Any individual who, for a certain purpose, interacts with the product or any realized element (system, part, component, module, feature, etc., manifested in software or as concrete objects) of the product, at any phase of the product life cycle.

* The terms marked by an asterisk are defined according to the nomenclature developed in the ENDREA research program [ENDREA, 2001]. Definitions not referenced were developed during the research for this thesis.

1 INTRODUCTION

The subject of this dissertation is on interaction and communication in design work, with a specific focus on visual aesthetic aspects of the product form. This interaction can be seen from three viewpoints of decreasing abstraction levels; as interaction on the company level, as interaction in the design team, and as interaction on the product design level, between user and product.

On the *company* level, the thesis concerns the issue of understanding and handling product form design issues in the product development process of primarily large industrial companies. Here, interdisciplinary teams develop technically complex new products intended for the global mass market, which are used and appreciated by a wide range of people. These products are equally dependent on technical supremacy and user appeal, regarding as diverging aspects as functionality, aesthetics, semantics, and usability; aspects which are becoming inevitable quality criteria of the product. Global competition and increasing customer demands continually raise the requirements on product appearance and customer appeal. In the product development process, these issues have to be addressed in order to realize a desirable product, which fulfills the needs of the users, as well as societal and market demands. This requires efficient design processes, supported by structured methodological approaches for product design. On this design level, the thesis is on the formalization and externalization of knowledge within the field of aesthetic form design, so that this knowledge becomes visible and usable for other stakeholders in the design process.

On the level of the *design team*, this work regards the interaction between industrial design and engineering design functions during the development of such products. This area of design is increasingly denoted industrial design engineering, since the prime aspects of concern are not only related to the human appreciation of the product, nor the technical workings, but both. The actors working in this field must handle a vast multidisciplinary problem area and the complex situation of sometimes apparently conflicting requirements and diverging needs. They must effectively address these issues in the design of new products, which are well compromised and balanced with respect to interactive-communicative aspects and technical considerations. Thus, the goal has been to develop methods and tools, applicable in everyday design work, which assist designers in the synthesis, analysis, and assessment of new product form in the interdisciplinary product development process.

On the *product level*, which is the emphasis of this research work, the focus is on developing a conceptual framework for reasoning about and understanding aesthetically determined aspects of the product form in relation to technical aspects, which address the needs in the field of industrial design engineering. Based on functional, aesthetic, and semiotic theory, this dissertation presents a framework of models and methods, which integrates technical and aesthetic aspects of the product form. The intention is that the findings presented in this thesis will contribute to enhanced cross-disciplinary understanding of the nature and workings of the visual product form, and that the proposed methods will assist designers and design management in the development of products, which are successful from technical as well as aesthetical points of view.

The products, which are the focus of this research work, are mainly designed and manufactured by large industrial corporations in various branches. These companies are active in branches such as consumer products (mobile telephones, household appliances, audio and video equipment), transportation (automobiles, trucks, buses, trains), and heavy machinery (construction equipment, fork lifts). A selection of such products is found in Figure 1. The thesis does not specifically focus on products that do not include technical engineering content (e.g., mechanics, electronics, or mechatronics) such as kitchenware or furniture. However, some findings may advantageously be used for the development of such products as well.

Figure 1. Examples of types of products focused on in this work.

1.1 INCENTIVES FOR THE RESEARCH WORK

This research work is based on a number of incentives, which have contributed to the initiation, realization and finalization of the project. To a great extent, personal experiences from design work in education and from projects carried out together with industry have contributed to the identification of needs, which have influenced the direction of the work. The incentives are described in the following.

The need for unification of visual form and technical workings

A common view in industrial product development seems to be the idea that the form[1] of the product and its technical workings are separate entities – "form is something, which can be dealt with in the end." This type of thinking often results in products, which are less successful in terms of overall functionality, rendering a product which is difficult to use, expensive to manufacture, and hard to sell. Industrial design work, which is 'added' at the last minute, is usually rather inefficient and does not utilize the full potential of industrial design. Companies, which employ industrial design competence at the right time during product development (often early in the project) increase their chances of achieving a product, which is more appreciated by consumers[2].

A guiding light in this work has been the idea that form and workings are in fact inseparable, and must be consciously treated together. Choosing a technical solution on the basis of the potential capacity for a better trade-off between technical workings and form may result in a 'better' product, which is more appreciated by consumers, resulting in higher sales and increased profits. A beautifully designed link mechanism in a machine may be perceived as an aesthetic experience as much as a classic piece of art, an Italian sports car or a fancy home audio equipment. If a technically functional product can be perceived as aesthetically appealing, cannot an aesthetically appealing product form be regarded 'functional'? The aesthetic aspect of a form is simply yet another viewpoint we can take when appreciating or judging a product, e.g., when we choose between two products, which are technically, or ergonomically, similar. In the same sense as a product has properties and functions related to the technical workings, it seems reasonable to believe that the form of a product has aesthetically determined functions and properties.

The idea that the purpose and characteristics of form and technical workings of products may very well be explained and reasoned about using a common conceptual framework, that they in fact constitute "two sides of the same coin", has been a significant driving force of the work.

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[1] Here, the term 'form' is used in its widest sense, denoting shape, color, surface texture, graphics, etc.

[2] The Swedish Industrial Design Foundation (SVID) provides support to Swedish industry in utilising industrial design competence, with the expressed aim to "increase corporate awareness of the importance of design as a competitive tool and to encourage companies to integrate it more into their business activities" [SVID, 2001]

The need for enhanced interaction between industrial design and engineering design activities

There are multiple reasons for the dualistic view of form and technical content. Due to the specialization of product development in the 20th century, engineers and industrial designers developed into separate competencies. The ability of the engineering designer to create aesthetically appealing product form and gestalt disappeared, and was gradually taken over by the artist working in industry. In Sweden, the term ‘industrial design’ appeared in the 1940s [Brunnström, 1997] as an answer to the need for a competence in product development specifically devoted to product form, while the engineer developed into being more of a specialist on technology and system analysis than on synthesis.

The increasing interest in industrial design as a competitive factor in product design is a natural consequence following a gradually evolving awareness of other subjective product aspects such as ecology, quality, and ergonomics. From schooling, the ‘modern’ version of the industrial designer is characterized by a largely individually performing person, devoted to developing aesthetic product form, identity, and character of the product. The engineering designer, a dedicated team worker from schooling, has taken over many of the ‘soft’ factors of product design, such as competence in product development, product synthesis, product quality, environmentally conscious design, and ergonomics. With the introduction of industrial design engineers, the loop is starting to close, on a higher level of complexity. Now, products are developed to suit the global mass market, for a wide range of users, featuring advanced technology and materials, and requiring highly structured and efficient development processes.

In Swedish industry, the situation in product development regarding engineering design and industrial design interaction is divergent. Some companies have been more successful in this integration process than others. Such companies often have geographically co-located concept development teams, working with common computer platforms, featuring multiple competencies which are working in an interactive, cross-functional manner. Other companies are characterized by more or less isolated industrial design functions. However, among the several drawbacks with such solutions is an industrial design activity with insufficient interaction with other design functions. Differences in working culture and prestige aspects can also amplify the lack of interaction [Persson, 2001]. The interaction between competencies may be enhanced by new knowledge and methods.

The need for a common model of product form

From product design projects carried out in the mechanical engineering program, it appeared to be common that different disciplines misinterpreted each other about their respective goals for the product and the project. A project member taking uninformed decisions regarding some aspect of the product, could result in detrimental effects for the project as a whole. Available competence and expert knowledge in the field which was not efficiently utilized, could result in a poor overall design, offended project members, and project rework loops. One reason for this situation may be that each discipline has their own viewpoint on design, and their own goals for the product to be. An assumption is that goals, which are not externalized and communicated to a sufficient degree, may contribute to a situation where team members did not realize the need for or value of other design competencies.

During later industrial studies, I have observed situations of similar diverging viewpoints in design work. At a design concept meeting at a large industrial corporation, industrial designers presented several styling concepts for the project team, which included engineering designers, ergonomists, marketing, project management, and sub-suppliers. During the presentation, industrial designers were struggling to communicate their intentions about the concepts, regarding the reasons behind specific form solutions. It was also evident that team members did not communicate on the same level about overall solutions or details of the styling concepts. It seemed that the communication suffered from the lack of interdisciplinary understanding of needs and purposes of design solutions.

The conviction about the need for a general model or 'language' for reasoning and understanding the product from multiple perspectives, giving members of the project a common viewpoint regarding product form, has grown stronger during the research and has been a major incentive for the work. The challenge has been to find an appropriate conceptual framework for reasoning about the purpose of aesthetic product form in relation to technical aspects.

The need for holistic methods for form design development

During product design projects at Linköping University, the systematic design procedure of the WDK-school[3] was employed. The design procedure is based on the comprehensive theories for mechanical engineering systems, developed in Europe since the 1960s [Andreasen, 1991a]. As a student working with the systematic design procedure in industrial product development projects, I saw the strength of the structured methodology and the advantages of using it compared to how design work was traditionally carried out in industry. Subsequently, in the role as supervisor of student design projects and master thesis projects, I have at many occasions noted the high quality designs resulting from the use of the procedure. The design concepts developed by comparatively inexperienced design students have

[3] Workshop Design Konstruktion – the WDK-school – is an international society for the science of engineering design. Basic theoretical concepts include the theory of technical systems by Hubka and the domain theory by Andreasen.

often been competitive, and sometimes even superior, to the proposals developed in industry. They have also exhibited novel approaches to solving the problem, resulting in patentable solutions at several occasions. Moreover, using the procedure results in a continuous documentation of the process, which automatically improves the quality of the work, as well as the quality of the designed product concepts.

However, problems with using the methodology arose when other design aspects, such as ergonomics and industrial design, were introduced. The WDK-approach does not include aspects of usability or appearance in the theory or methods of designing. The procedure does not provide any support in the process of finding good design solutions from the perspectives of industrial design or ergonomics. It could, of course, be argued that methods and theory, in fact, exist in both of these fields as well as in other related design fields, such as the QFD-method for product quality and LCA method for environmental product design, and that one cannot demand of the WDK methods to scope all influencing aspects of product design. The ergonomics field provides a great number of approaches, methods and tools for analyzing and optimizing the product from the perspective of human capability and constraints. Industrial design provides methods for the synthesis of product form concepts from the viewpoint of appeal, appearance, and product semantics, although the theoretical elaboration and understanding of the field cannot yet be compared to ergonomics or engineering design science.

However, as illustrated in the previous section, one of the main challenges we are facing in industrial product development is how to achieve a generic approach to product design, in terms of theory about the product and methods for developing a product efficiently. Many methods are available and some are even used, but few provide an interdisciplinary understanding and a common focus. Taking the risk of being biased, it can be claimed that there are few other bodies of theory and methodology, which are as elaborated and as potentially suited for this task as the WDK-school. Few other approaches provide such a powerful method for supporting the generation and development of appropriate solutions during the synthesis process; the very incubator of good design solutions. A method for form design based on the WDK-approach could be very powerful. We have in fact seen examples where WDK, together with other relevant fields of knowledge, has been used as a theoretical platform for developing approaches for form development, as well as for usability [Tjalve, 1979; Markussen, 1995]. Could not theoretical approaches be developed, which tie elements of the fields together?

My experience of the potential of the approach and methods of the WDK-school has been a significant incentive for developing an approach, which can comprise the technical workings of the product and the interactive aspects of its form within a common conceptual framework.

1.2 WHAT IS DESIGN?

The design phenomenon is as old as the human being itself. We were designers long before we knew about it, before we could form words to talk about it, and before we could spell it. The design phenomenon is, in its broadest sense, probably as diverge and multi-faceted as there are people on earth. Everyone is, has at some occasion been, or will in a near future become, a designer; a person who identifies a need or problem, analyzes the problem, and finds a solution to that problem. Anyone who attempts to transform an existing situation into a desired new situation performs an activity we call design [Simon, 1969].

One could say that *designing* in its widest sense is *the creation of a solution to a problem, for certain purposes, with a given set of requirements, and within certain constraints*. It can also be stated that anything which is designed is made for a purpose; it has a function. If any one or several of these features are missing, it is harder to say that it is design. For example, a piece of art such as an oil painting on the wall may have social, decorative and affective functions. But it is not the solution to a specific problem, nor does it have a practical function; it does not deliberately help in making everyday life easier. It was created by an artist working without a prior specification. The strive for a certain feeling or expression made the artist work unconditionally, with few constraints. As an artist, he could have used several materials in reaching that expression. Thus, with the above definition, painting is not designing. When we consider other works of craftsmanship, such as pottery, glassworks or jewelry-making, we come closer to designing. The process is more defined, the considerations and constraints are integral parts of the work towards the goal. Thus, craftwork is closer to designing. In industry, a multitude of constraints in time, cost, and feasibility have to be considered when developing a vacuum cleaner or an oil tanker; it certainly classifies as designing. If we consider a not too unrealistic future scenario, a machine such as an automated computer system may do a lot of problem-solving. Here, however, we are again leaving the nature of designing. The process itself is determined beforehand, the machine does not invent, it only follows a rule-based sequence of steps in finding an optimal solution to a given problem. However, the team of engineers or computer specialists who developed and programmed the computer system may have been inventors as well as designers.

The term *design* and its abbreviations are used in all kinds of senses in literature and everyday language. The purpose of this thesis is not to finally define the term, a task that seems as impossible as inappropriate. Literature abounds with definitions of design. Hubka and Eder [1996] list 21 definitions from various engineering related areas. General definitions of the activity are found, such as “a goal-directed problem-solving activity” [Archer, 1965] and the “professional service of creating and developing concepts and specifications that optimize the function, value and appearance of products and systems for the mutual benefit of both user and consumer” [Ulrich and Eppinger, 1995]. Seen from an engineering design perspective, design may be described as containing the activities of problem solving, product synthesis, product development, and product planning [Andreasen, 1991a]. Included in these activities is the “process of establishing which of several alternative ways (and with what tools) things could be done, which of these are most promising, and how to implement that choice, with continual reviews, additions and corrections to the work” [Hubka and Eder, 1996]. Based on Archer [1971], ENDREA [2001a] proposes the following definition: “to conceive the idea for some artifact or system and/or to express the idea in an embodiable form”, which largely covers the general idea of the concept as used in this thesis.

But design is not only the process of *designing*; the finding a solution to a problem. Design also denotes the outcome of such processes, the *design*; the created object, system, or service. A complementary definition used to denote the designed object is thus needed. Andreasen and Mortensen [1996] define the design objects as “the result of a design process”. A design may be everything from a pattern on a textile, through a clothes-hanger, an office furniture, a flattening iron, an automobile, to a train tunnel, or an airport in-flight control system. It can include any additional systems or services for the selling, servicing or manufacturing of such products or systems. It could even be the laws governing the sales of such systems.

There are many types of design found in product development. A discussion of some of the terms, which are in focus in this work, and how they relate to each other, may be in order.

Product Design

‘Product design’ is a useful, yet difficult-to-define term. Interpretations abound, ranging from the creation of textile, glass, and ceramic handicraft, to the form-giving activities of the industrial designer, and the engineering activities during product development. In the area of product design, where products implies mainly ‘consumer products’ that an individual can buy in a store, product design can be described according to the following: “*the activities involving the design of products, including the activities of engineering design and industrial design*” [ENDREA, 2001a].

The field of product design is thus broad and the activities involved therein are many, including engineering design as well as industrial design. Product design thus includes the activities needed for the development of a product, which in turn can be defined as: “*a system, object or service made to satisfy the needs of a customer*” [ENDREA, 2001a].

In this thesis, the focus is on discrete, physical, and industrially manufactured objects. This implies that a product needs engineering knowledge and skill for its realization. Thus, e.g., an object of handicraft, a book, an internet service, or jet aircraft fuel, are not considered ‘products’ as the term is used here.

Industrial design

Industrial design includes the areas normally treated by industrial designers or persons with similar competence, e.g., aesthetics, semantics, appeal, graphics, product and corporate identity, ergonomics, and visual form conceptualization. A definition proposed by the Swedish Engineering Science Academy reads: "the formulation of properties primarily concerning the usefulness and appearance of products" [IVA, 1988]. Monö [1997] explains industrial design as "the creation of the gestalt of useful products intended for mass production, with the aim of adapting them to Man and his environment". The definition of industrial design used in this thesis scopes the meanings cited above, but aims at being slightly more specific: "*design with particular emphasis on the relation between product and man, e.g., semiotic, ergonomic and aesthetic aspects of the product*" [ENDREA, 2001a].

Engineering design

Popularly, engineering design is what engineering designers 'normally' do. Professionals within this field can be trained engineers of different disciplines, or other individuals working mainly with engineering aspects of product design. Such aspects may be, e.g., machine elements, solid mechanics, strength of materials, aerodynamics, fluid dynamics, hydraulics, electronics engineering, software engineering, systems engineering, quality engineering, industrial economics, and human factors engineering. Here, engineering design is defined as follows: "*design with particular emphasis on the technical aspects of a product, including both analytical and synthetic activities*" ENDREA [2001a].

Naturally, it is very difficult, and hardly worthwhile, to try to define what activities belong to the domain of industrial design or engineering design, respectively. A gifted industrial designer working in product development may very well partly work with issues of engineering character, which in other situations may be carried out by an engineering designer, and vice versa.

1.3 ADOPTING A HOLISTIC APPROACH TO DESIGNING

By necessity, this research is about design and designing viewed from a Swedish perspective, regarding the needs, objectives and activities of design. By tradition, the term 'design' in Swedish usually denotes a design activity primarily concerned with appearance and aesthetic appeal of products. Thus, when the term design is used, it has denoted objects and activities concerned with, e.g., fashion clothing, textiles, glassworks, silverware, jewelry, and furniture.

In this thesis, that narrow sense of the term is repudiated, and the contemporary view of designing found in English language literature, as discussed in the previous section, is adopted. Hence, it is here acknowledged that designing is an activity performed by many professions in various fields, including architects, mechanical engineers, electrical and computer engineers, marine and aeronautical engineers, and product designers. In the product development field, we find many design professions, of which engineering designers and industrial designers are two of the most common. As designers, they are both engaged in design activities as defined previously. Engineering designers are primarily concerned with the technical workings and material aspects of the product, while industrial designers are commonly more devoted to appearance, usability, and socio-cultural product aspects.

Muller [2001] recognizes two different ways of approaching the design problem usually associated with these professions. Focusing on material utility value, the *engineering-oriented* designer starts by designing the various parts of the product and from them develop a coherent whole, technically and functionally. Visual coherence is not usually under discussion. The *aesthetic-oriented* designer aims at creating a coherent image of the object by searching for a gestalt and then working towards the parts, focusing on social and cultural utility value, Figure 2.

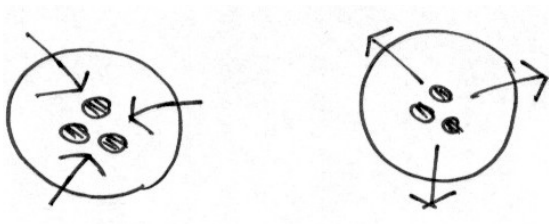

Figure 2. Different ways of approaching the design problem. The aesthetic-oriented designer works from the whole gestalt towards the details (left), while the engineering-oriented designer works from the parts in the creation of a coherent whole (right). Based on Muller [2001].

The different approaches to the design problem result in different perspectives of viewing the product. Different aspects are addressed and focused on, sometimes resulting in diverging opinions and prioritizations made during design. The main difference in reasoning patterns is found in the type of knowledge available in each field. Traditional engineering designer can rely on a scientific knowledge base for predicting technical functionality and behavior of form and material. Industrial designers, on the other hand, largely lack scientific knowledge for creating the socio-cultural function and predicting the perceptual effects of the form. Their reasoning is therefore determined by subjective knowledge, personal views, and values [Muller, 2001].

In this context, however, it must be recognized that the description of Muller illustrates two ends of a *spectrum* of orientations for approaching the design problem. The intention here is not to postulate the actual working approaches of either the engineering designer or the industrial designer. In the real world, we are most likely to find designers of all kinds who approach the problem in different ways, integrating both approaches in actual design work.

An emerging trend in Swedish industry and education suggests that these separate disciplinary viewpoints are no longer sufficient when designing. For efficient product development processes, a common focus and goal when designing is of course essential. An understanding of the whole problem is of prime concern for designing a product, which is successful from the overall technical-aesthetic perspective.

In response to the need for professionals with a holistic view of product design, the field of *industrial design engineering* has emerged as a new domain of design knowledge. In industrial design engineering, the product is viewed as a 'whole' problem, where the socio-cultural function of the product cannot be viewed independently from the material-technical function. In establishing a 'complete' product, the aesthetic point of view cannot be separated from the engineering perspective. The distinction between two kinds of designers thus seems obsolete. In the future of product design, designers with the ability to grasp the holistic approach will be needed to handle the complexity of product development.

2 SCOPE OF THE RESEARCH

2.1 OBJECTIVE OF THE RESEARCH

The purpose of this research work was to develop descriptive theory and models, and prescriptive methodical approaches, in the area of product form design in conceptual product development. 'Product form' means the form of the product from various perspectives. Since this research project[4] has been part of the ENDREA[5] research program, the focus is on the perspectives of aesthetically *and* technically determined aspects of product form. Thus, the purpose of the research has been to:

- increase the understanding of the nature of product form,
- increase the ability to describe visual product form in relation to technical aspects of the product form, and
- provide methods, which support the development of visual product form in relation to technical aspects of the form.

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[4] Under the ENDREA project title "Methods for Conceptual Design in Industrial Design – Engineering Design Interaction"

[5] ENDREA: Acronym for the 'Swedish Engineering Design Research and Education Agenda', a national product development research school partially financed by SSF, the Swedish Foundation for Strategic Research. During the period of 1996-2002, the program was active in the research fields of DTM: Design Theory and Methodology, EM: Engineering Management, and SDP: Simulation and Digital Prototyping. In total, ENDREA engaged around 60 doctoral students at four major institutes of technology in Sweden: Linköping Institute of Technology, Chalmers University of Technology, the Royal Institute of Technology, and Luleå Technical University [ENDREA, 2000].

2.2 FOCUS OF THE WORK

This research project utilizes knowledge from different areas of research and practice. It aims at describing phenomena of different professional knowledge disciplines, and its applications are found within different groups of people, activities, and company functions. Thus, the focus of the research work has not been one, but several. The foci are presented and discussed in the following.

Multidisciplinary focus

The research aims at building bridges between disciplines involved in product design during the early conceptual phases of product development. Primary disciplines of interest have been industrial design and engineering design. Engineering design is a large field, which includes mechanical engineers, electrical engineers, materials specialists, etc., all which may participate in or contribute to the design of a new product. Other disciplines, which may be involved, include ergonomics, marketing, management, and production. Other stakeholders involved may include sub-suppliers, consultants, users, etc. In this thesis, the focus has been on the disciplines which are primarily involved in form design development during the early conceptual stages of the new product development process, and which may be collected under the term ‘industrial design engineers’.

Focus on different perspectives of product form

The main activity of interest is the process of form development in product design. It is acknowledged that product form can be seen from a variety of viewpoints. The mechanical engineering viewpoint of form is often that of machine elements, mechanics, structural solidity, or material sciences. Mechanical engineers thus primarily optimize the form of the product from the perspectives of, e.g., technical transforming functionality or strength, which are associated with the ‘internal’ characteristics of the product. Industrial designers approach product form from the perspective of its ability of aesthetic appeal to an observer, of communicating desired product properties or qualities, of its differentiating and characteristic aesthetic appearance, of expression or semantics. These are part of the ‘communicative’ characteristics of the product. Ergonomists are primarily concerned with product form from the standpoint of anthropometric fit, comfort, reach, tactile or haptic qualities, etc., and try to optimize the product form from those perspectives, aspects which are part of the ‘interactive’ characteristics of the product.

Of course, it is not possible to draw a distinct line between these aspects of product form, since they are all interrelated and interdependent. The categorization is not exhaustive, and only serves to clarify the various viewpoints regarding the form, which may be part of different stakeholders’ mindsets during product development, and which thus have to be deliberately considered during the form design process. The question of this research work is how to deal with these various perspectives of product form, and how to handle them during product development.

Focus on structure and function of visual product form

To be able to handle form development during product design, it is necessary to understand what product form is, how it is constituted, how it can be described, etc. Based on the natural sciences, mechanical engineering designers are provided with theories in, e.g., solid mechanics and fracture mechanics, which describe what happens to a designed part exposed to, e.g., prolonged fluctuating loading. Engineering designers are also provided with CAD tools, which enable them to very accurately assess a certain form from various viewpoints. Ergonomists are equipped with theories from physiology, anatomy and biomechanics, which enable them to determine the effect of a certain product form design on the human anatomy and physiology.

But no theory related to the core of industrial design work is yet available, which has a predictive capacity equal to engineering and human factors sciences. The reason for this is of course that human behavior is unpredictable and stochastic.

No industrial designer can accurately predict the reaction of a certain person to a product form, regarding what it expresses in the eyes of the beholder, or whether the product will be perceived as appealing on the market. We can only come closer to some degree of understanding from empirical studies, carried out in, e.g., the social and behavioral sciences. However, advances in areas related to the industrial design field have lately contributed to the knowledge of form design. Based on linguistic and semiotic theory, product semantics provides us with the viewpoint that product form has representative qualities, and tells us how we interpret signs in forms as messages. The knowledge within this 'semiotic-aesthetic' field is primarily conceptual, and empirical studies are largely lacking. Perception psychology tells us how we perceive abstract forms, how we create visual gestalts, etc., an area which is closer to this research work.

In this work, however, the aim has not been to study aesthetic preferences of product designs. The effort has been to approach the 'formal-aesthetic' perspective of product form, focusing on how the form is constituted and structured, and how it functions 'syntactically' in the product. The approach has been to adopt a functional modeling perspective for describing the structure and workings of product form, based on the WDK-theory, merged with other relevant fields of knowledge.

Focus on form design in product development

Another effort of this work has been to create knowledge, which can be used in product development activities, where visual product form is of prime concern. With the help of the findings, the ability to specify, generate, develop and evaluate form during form synthesis activities will ideally be supported. For form analysis purposes, the intention is to increase the ability to describe and value form proposals. As a generic model for product form, the focus has been on making theory and methods applicable for form design purposes regardless of product type, of the size of the design team, or whether used for educational or professional purposes. The framework should also be applicable regardless type of product development, i.e., equally usable for redesign and new product design. The focus has been on developing descriptive and prescriptive approaches, including theory, models, and methods, for describing and creating well balanced product form from several perspectives.

2.3 GOALS OF THE RESEARCH WORK

The overall goal of the work has been to generate new knowledge in the field of product form design applicable in design work, based on scientific methods in design research. As part of the ENDREA program, the work can be considered belonging to the field of applied sciences, since the research aims both at a theoretical, and a practical, goal [Ropohl, 1969]. In applied sciences, the theoretical goal has no purpose in itself, but serves only as a means for reaching the practical goal. Here, the educational goal as recognized by Hubka and Eder [1996] is included in the practical goal.

Theoretical goal

The theoretical goal of the research is to further develop existing theories relevant to the research objective, as well as to develop new theories or theoretical elements as found necessary. New theories can be both extensions and alterations of existing theories, or hybrid theories, which include elements from several existing theories, or novel theories including new theoretical elements. The creation of new knowledge will contribute to increasing our understanding of the nature of visual product form.

Practical goal

The practical goal of the research work is to provide approaches, methods, or tools, which can be used for the purpose of form design development in industrial product development processes and for educational purposes. In line with the strategic program goals of ENDREA, the overall goal of the work has been to contribute to reduced lead-time, improved quality, increase flexibility in the product development process, and increased performance/cost ratio of manufacturing companies located in Sweden [ENDREA, 2000].

2.4 RESEARCH QUESTIONS OF THE WORK

The incentives described in section 1.1 acted as a starting point for commencing the formulation of research questions. Through the work with the project, research questions have been operatively guiding the research activities [ENDREA, 2001b]. They have also continually been developed and become more precise as a result of the increasing understanding of the field, based on empirical and theoretical studies. In the following, the research questions are shortly introduced and presented in order of increasing 'focus' of the research effort.

As described in the incentives, I have experienced that the practical and theoretical knowledge fields of engineering design and industrial design have been suffering in the respect of having too separate perspectives. In the product development process, common understanding, focus and goals for the work are important for achieving a successful result. Means in that process are theory and models of design. The first question is concerned with the need for a common model of product form design, which increases the ability to overview and handle form design issues from different product perspectives.

Question 1. How are visual form aesthetics related to other product aspects in a descriptive product model?

Several approaches for the development of a product's interactive characteristics are found. These include the human factors view, the semiotic approach, cognitive theory, and the functional point of view. This work is based on a synthesis approach for form design development in primarily the conceptual design stages of the design process. Here, a functional modeling approach seems beneficial as an outset for the generation and development of desired product characteristics, including technical and aesthetic aspects of the product. The task evolved into creating a framework for handling the development of aesthetically determined product aspects using a functional approach. The starting point was the WDK-school, together with relevant knowledge from related fields, as a suitable basis for this work. The research question guiding this part of the work was:

Question 2. How can visual product form be described, explained and communicated in form design work, based on a functional approach?

The third research question concerns methods for form design work. Methodology support is available for industrial design and engineering design purposes, respectively. However, they are based on separate product perspectives and have separate foci. Theory and methods dedicated to the needs of industrial design engineering, which contribute to more efficient product development processes and the design of better products where human appreciation and technical aspects are considered important, would thus be beneficial. These need to be generic in approach in order to apply to specific design problems related to product form design.

Question 3. What is the nature of a tool or method for use in design work, integrating industrial design and engineering activities in early conceptual design?

3 SCIENTIFIC METHOD

This thesis claims to present scientific knowledge about design, in the sense of the object of design (artifact theory) and the process of design (design methodology). A scientific research work relies on scientific methods for knowledge creation. In natural and many engineering sciences, research is a rather straightforward process of formulating a hypothesis, establishing a model which describes a phenomenon, carrying out repeatable experiments, observe occurrences and events, and validating the hypothesis. In other sciences, such as social sciences or design sciences, this approach is not always appropriate or even possible. Due to the unpredictable nature of the research object, being humans or human design processes, human behavior or preferences have to be studied using empirical research methods. In the formal sciences, such as mathematics, the empirical research approach is not relevant, but is instead dependent on formal, theoretical, logical coherence. This research work is based on a combination of both empirical and formal approaches for understanding the problem and creating new knowledge, respectively. The methods for knowledge creation are reflected in the epistemological approaches, which have been influential in the development of scientific research. The intention of this chapter is to provide an insight into the philosophy and methods applied in the research of this project, and to put the work into a scientific perspective.

3.1 REVIEW OF SCHOOLS OF PHILOSOPHY IN SCIENTIFIC RESEARCH

A classic problem in philosophy of science is how to distinguish true knowledge from false knowledge. According to *pragmatist* philosophy, thinking and the intellectual activity of humans has evolved as a means in the struggle for survival, and not as an end in itself [Ahlberg, 1927]. A statement is true, not so much because it corresponds to an objective reality, but more because it is acceptable to our current life situation; it has the highest value among other competing theories or hypotheses. To pragmatism, all hypotheses are working hypotheses, and the most convenient competing hypotheses are ‘true’. Having the overall objective of creating something useful, the work in this thesis can be considered as belonging to pragmatism, acknowledging that the theoretical construct has no purpose in itself.

But how is this knowledge derived? The philosophies of *empiricism* and *classic rationalism*, and their more contemporary philosophical derivatives logical positivism and critical rationalism, respectively, represent two principally different approaches in this discussion. According to the empiricist Locke, all our knowledge stems from inner and outer experience, we do not carry with us any innate knowledge. We perceive the world around us, process and categorize those experiences, and construct mental complexes on which we base our understanding of the world. In rationalist philosophy, our knowledge does not stem from experience, but can only be created by our own mental reasoning. We cannot trust our senses; true knowledge can only be achieved through logical reasoning.

Through the philosophies of Kant, both empiricism and rationalism had to be revalued. According to Kantian philosophy, our opinions can be of two kinds; analytic and synthetic. An analytic statement adds nothing to our knowledge, it only develops what we already know. A synthetic statement is acquired by, and provides us with, new knowledge. Our concept of the world is based on the mental models of time and space, concepts which are the basis for our own thinking. This also applies to the law of causality; it is a model for reasoning about cause and effect, which we use to bring order into reality. According to Kant, we will never reach the ‘thing itself’, but only the phenomenon [Ahlberg, 1927].

Logical positivism is a movement which arose in the 1920s and is still one of the dominant schools of thought within the philosophy of science today. According to logical positivism, there are only two sources of knowledge: logical reasoning and empirical experience. Logical knowledge includes mathematics, which may be reduced to formal logic, while empirical knowledge includes physics, biology, psychology, etc. Logical positivism is based on inductive and deductive reasoning, according to Figure 3. From particular empirical observations, inductive reasoning leads to general statements in the form of laws and theories, which can be used to deductively provide explanations or predict behavior in specific cases. Both approaches suffer from drawbacks, especially inductive reasoning, since one single observation is sufficient to falsify the general statement.

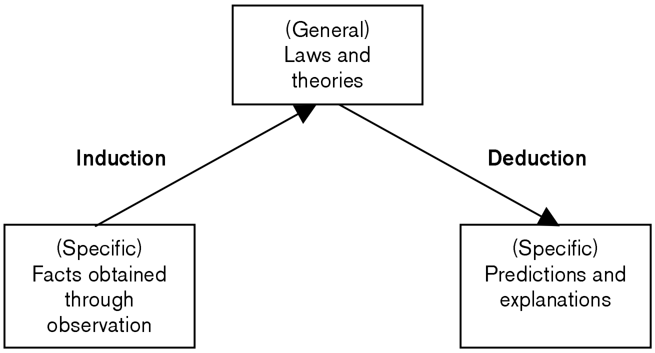

Figure 3. Inductive and deductive reasoning, adapted from Chalmers [1994].

A self-proclaimed '*critical rationalist*' [Stanford, 2001], Popper rejects induction as the complete scientific method. He introduces, as his demarcation criterion to distinguish science from non-science, the principle of falsifiability. According to Popper, for a theory to be scientific, it must be refutable by a conceivable event. Every genuine scientific theory is prohibitive, meaning that it forbids particular events or occurrences. As such, it can be tested and falsified, but never be logically verified. A single counter-instance conclusively falsifies the theory. The more daring the hypothesis, the greater its contribution to science, if not falsified. Methodologically this is a problem: although a scientific law is conclusively falsifiable, it is not conclusively verifiable, and no observation is free from the possibility of error. On the creation of theories, Popper [1959] stresses that there is no ideal pathway to scientific theory, but theory can only be reached through intuition, imagination and speculative hypothesis. In Popper's view, science starts with problems rather than with observations; the scientist only starts making observations when struggling with a problem, and his observations are selectively designed to test the extent to which a given theory functions as a satisfactory solution to a given problem.

The scientific method of modern science is often referred to as 'hypothetic-deductive' method [Elgmork, 1985]. It is related to the critical rationalist method of formal sciences, such as mathematics and logics, but is dependent on observations for testing of hypotheses. The basis for the hypothetic-deductive method is the formulation of hypotheses. The hypotheses are based on prior observations or will determine subsequent observations in order to test the hypotheses. Through deduction, the hypotheses lead to statements and predictions, which are tested by empirical observations. The hypothetic-deductive method is schematically described in Figure 4.

This review of philosophical ideas is not in any way complete. It serves to illustrate that the process of acquiring knowledge by scientific research can generally be described by a number of approaches. Each and every school presented has historically been subject to criticism, and they often represent incommensurable research paradigms. There is thus no rational proof that any particular school should bring about 'better' or 'more true' knowledge.

The prevailing research approach of 'modern science' has naturally been shaped by the development in the epistemological views of each philosophical stream.

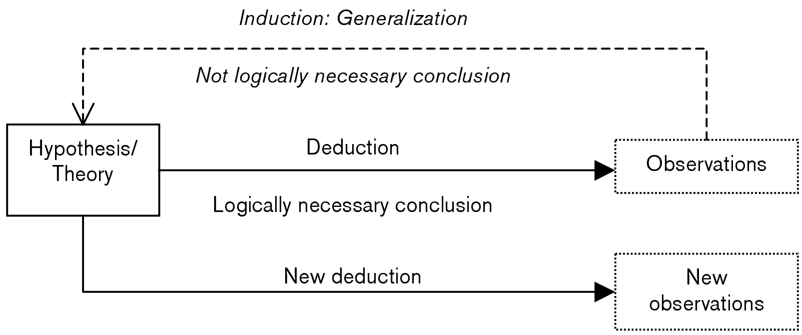

Figure 4. Reasoning scheme for the hypothetic-deductive method, adapted from Elgmork [1985].

3.2 APPROACHES IN DESIGN SCIENCE RESEARCH

Design science is a young research area, which has not yet found its scientific paradigm [Andreasen, 1998a]. Many theories and research approaches still exist side by side; design science is still in its pre-scientific stage [Dixon, 1988]. The situation is not the least indicated by the sometimes confused use of the term 'design research', which in Europe is most commonly interpreted as "(scientific) research into the field of design studies". Other meanings of the term also prevail, such as "knowledge acquisition techniques and methods in design", i.e. signifying tasks in design work. In this thesis, the term is used in the first sense. The differing notions of the term 'research' can be traced to different views on acquired knowledge; whether the knowledge is "new to the world" or merely "new to the individual" [van der Lem, 2001].

The overall aim of engineering design research is to develop knowledge, which can improve the chances of producing a successful product [Blessing et al., 1995]. Stating this, Blessing et al. also recognize that a typical characteristic of design research is that it not only aims at understanding the phenomenon of design, but also at using this understanding in order to change the way the design process is carried out. This requires research methods from a variety of disciplines.

Epistemology of design science

Logically, research in design must be research about the constituent elements of design. Theory areas in design can be structured into research and knowledge about the following [Andreasen, 1998a]:

- the *design process*; the way humans solve problems, decide, organize, plan, document, etc.,
- the *design object*; the artifact to be designed and its nature, and
- the *factors which influence design*; the designer's knowledge, skills, attitude, modeling possibilities, technical means like CAD, management, available information, etc.

The focus of this research project is primarily on the nature of the design object, and secondarily the design process, as discussed in section 2.2. However, the influence of the role of designer in the design process cannot be disregarded, and studies carried out about the design process thus inevitably, at some level, also involve the individual designer or the design team, as well as aspects of structuring and managing the design process.

Heron [1981] proposes an extended epistemology, which includes at least three types of knowledge.

- *Experiential knowledge* gained through direct encounter face-to-face with persons, places or things.
- *Practical knowledge* on 'how to' do something, demonstrated in skill or competence.
- *Propositional knowledge* about something, expressed in statements and theories.

Although stemming from the field of participative social research, Heron's categorization indicates what kind of knowledge can be achieved by research in design, which is largely associated with the study of peoples' actions. Heron notes that the propositional knowledge needs to be rooted in, and derived from, the experiential and practical knowledge of the inquiry subjects. Hence, it can only be arrived at once the other two types of knowledge have been established.

The categorization of Heron is very similar to that of Cross [1995a], who proposes three forms of design research useful in the effort of acquiring knowledge of the above types. Cross's forms of research can be seen as an operationalization of Heron's knowledge types, applied to the field of design research:

- Research *into* design, by various kinds of observation, e.g., protocols;
- Research *for* design, to create tools (especially computer-resident), design methods, forms of modeling;
- Research *through* design, e.g., abstraction from self-observation and other observations during designing, hypothesizing and testing.

This research project has the ultimate goal to contribute with methods, which aid the design work. According to the categorization of Cross [1995a], it thus principally belongs to the second category, research *for* design. The development of methods requires *propositional knowledge* about the design process and the design object, according to Heron. However, the means for achieving this goal involves extending the knowledge about the design process, e.g., concerning how designers work and what methods would be of use. Hence, research *into* design is an important step on the way. Such knowledge requires an understanding of the designer's situation and the products being designed, which can be categorized as *experiential knowledge*. But simply observing design in a phenomenological sense brings only shallow understanding of the needs and problems associated with actual design work. To achieve a more in-depth and comprehensive understanding of designing and its needs, research *through* design is also of outmost importance. This requires personal design experience and participatory research methods such as action research approaches, which generates *practical knowledge*. In this work, the knowledge attained has been gained in the sequential order suggested by Heron [1981], involving a gradual buildup of knowledge through various research activities, largely in the order experiential - practical - propositional knowledge types. The main difference compared to Heron, is that the empirical studies of this work, in accordance with Cross, have been carried out through inquiry type of research on other designers, as well as through participative research efforts. Apart from empirical methods, formal methods have been extensively employed for creating new theoretical knowledge, which will be returned to later.

Scientific methods of design science

While research is any kind of knowledge generating activity into a particular subject, scientific research is characterized by obtaining knowledge following a scientific method [Jensen, 1999]. An accepted scientific method is [Hubka and Eder, 1996]:

1. ask an appropriate question,
2. propose a model and a hypothesis,
3. collect data,
4. analyze the data,
5. formulate an answer,
6. accept the new knowledge, and
7. revert to 1.

This is basically the traditional scientific method found in the engineering sciences, and represents a rather straightforward process of studying a phenomenon based on experimentation and observation. The main criticism of such orthodox scientific methods is the idea that its methods are neither adequate nor appropriate for the study of people (a significant constituent of design activity and the users of the design product), since people are to a considerable degree *self-determining* [Reason, 1994]. Thus, the process of design is *opportunistic*, as noted by Cross [1999]; the path of exploration cannot be predicted in advance, and so the outcome of the process cannot be predicted either. Furthermore, Cross notes that design is also *exploratory*: "the designer sets off in his work to explore, to discover something new, rather than to return with something of the already familiar". It seems quite clear that the normal scientific method is not applicable, at least not to the empirical part of design research involving people, but maybe for the theoretical research about the designed object.

Eder [1990] proposes an approach, which seems to solve some of the problems associated with traditional research. Eder suggests two parallel approaches that can generally describe design research:

- the experimental, empirical way of observing (including self-observation), describing, abstracting, modeling, generalizing, and formulating hypotheses and theories, and
- the speculative, reflective, philosophical way of postulating hypotheses, formulating theories, modeling, and subsequent testing.

These two approaches provide two paths for conducting design research: an *empirically oriented* approach, based on observation and the subsequent production of theoretical statements; and a *theoretically oriented* approach, based on logical reasoning for attaining knowledge, which has similarities with the scientific method of the formal sciences. The two approaches used together also seem more capable of handling the great divergence of the nature of design research, where the design process appears to be well suited for research using empirical methods, and the design object approached by more formal methods. The two approaches cannot be fully separated however, since the 'product and process dualism' of design work cannot be neglected in design research.

It is obvious that the wide scope of design theory, including research about processes, objects, humans, and many other fields, requires a variety of research approaches, methods, and tools. The research methods applied in this project are presented and discussed in the following.

3.3 THE APPLIED RESEARCH METHOD

The scientific method applied in this research project can be described by the hypothetic-deductive method, combined with an abductive method for the creation of hypotheses, based on posed research questions (section 2.4). The abductive method requires the inference of a conclusion from known facts; from premises, which are considered ‘true’ [Roozenburg and Eekels, 1996]. Hypotheses are based on observation and created through inference, using the abductive method of reasoning.

Research in an interplay between formal and empirical approaches

The research process of this project has been characterized by the constant switching between approaches for knowledge acquisition and creation. Real design phenomena have been observed in industry, through empirical studies and supervision of student design projects, and studied in literature. The nature of design products has been studied through literature and object analysis. Hypothetical statements, related to observed phenomena and artifact studies, have been developed using formal theoretical approaches. These have been tested by additional empirical studies of design work in industry, by confronting designers with preliminary findings, and by experimentation with product examples.

In this process, theories and models have been postulated based on a speculative, reflective, and philosophical way of approaching the research problem. The development of research questions has been based on a foundation of empirical observations and theoretical studies and, in a critical-rationalist manner, created with help of imagination and intuition. In the process of falsification, proposed hypotheses have continuously been subject to modification, evolution, and sometimes, even rejection, through the testing against real observations and theoretical studies. Gradually, stronger hypotheses have been developed, which have through observations and educational applications proven useful, and according to pragmatist philosophy, these have been considered temporarily and sufficiently valid for describing observed phenomena.

The overall research approach applied in this work can be illustrated by the model of Jørgensen [1990], which has become more or less de facto in Nordic design research [Jensen, 1999]. Jørgensen takes into account two approaches of research strategy, denoted on problem- and theory-based research, respectively. The left side of the model in Figure 5 shows the problem base created by the researcher during, e.g., empirical studies, while the right side describes the development of theoretical elements into new theories. A research work may thus commence by either analysis or synthesis, but, as noted by Sigurjónsson [1992], most research projects will in practice involve both paradigms in various degrees.

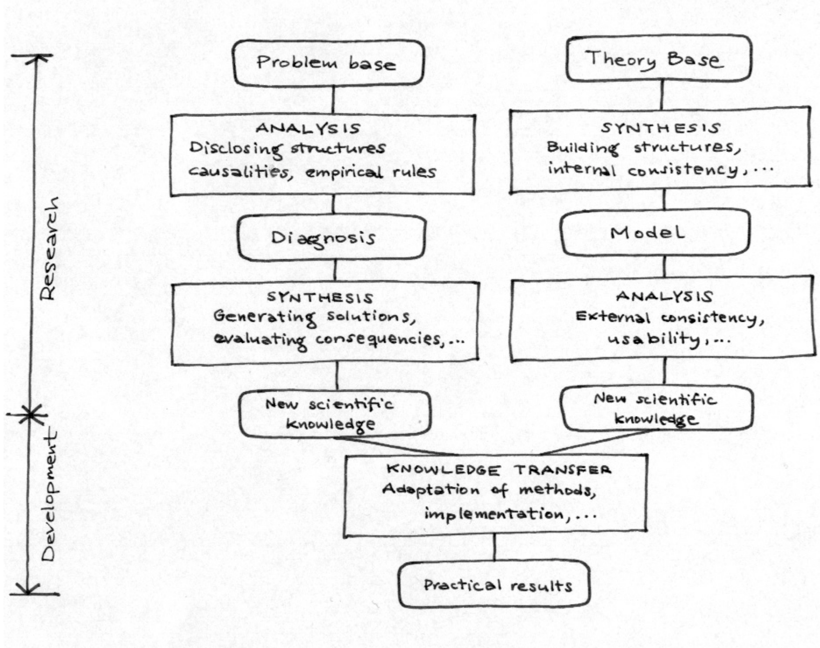

Figure 5. The two approaches of design science research, adapted from Jørgensen [1990].

Another characteristic of the research process is that the two approaches are not independent. The process is not as a straightforward or sequential series of events and activities, resulting in a perfected theory, as the model might seem to suggest. Within each respective 'leg', the synthesis and analysis of models and diagnoses is the result of a cyclic, evolutionary process towards the incremental creation of new scientific knowledge. There is also a constant and ongoing interplay between the empirical and theory-based approaches; as new observations are made and new knowledge is acquired, new theoretical research is required to explain and model the phenomenon.

As discussed in previously, the incentive for this research work was both problem-based (experience from problems encountered during actual design work) and theory-based (insufficiencies of available theories and methods). The research methods applied in the work were thus selected in order to:

1 gain insight into the design activity, including industrial product development processes, interdisciplinary aspects, use of methods, and the need for theory and methods;

2 gain insight into the nature of the design artifact; and

3 develop descriptive theories and prescriptive methods which meet observed needs.

Due to the multidisciplinary nature of the research work, different research methods have been applied in the work. The work can be divided into *empirical* and *theoretical* research activities. The division might give the impression that the empirical studies are 'un-theoretical'; however, this is neither the intention nor the case, as will be shown in the following. Rather, the division serves to differentiate the sources of the acquired knowledge.

Empirical research activities have been employed to gather ‘external’, real-world knowledge of design processes and products, which has served as a basis for developing knowledge of the needs of design work (1). Theoretical activities denote the ‘internal’, formal type of study and development of theoretical constructs, according to the previously presented categorization of Eder [1990]. Theoretical research methods have been employed for the second research objective (2). Finally, both empirical and theoretical research methods have been applied in the development of theory and methods (3), in meeting needs identified in (1) and (2).

During the work, the different research approaches have complemented each other. Obviously, the types of research and the different activities involved in each of them were largely intertwined and overlapping in time, thus fertilizing and inspiring each other during the course of work.

The theoretical activities of this work includes literature surveys for studying state-of-the-art in relevant research areas, and the development of theory, models and methods based on existing theory in applicable areas. Doctoral courses have also been included in this group as a means for acquiring theoretical knowledge. Compared to the wealth of research methods available for carrying out empirical studies, there is no formalized ‘research method’ for theoretical research activities, illustrated by the second research approach suggested by Eder [1990].

Empirical research methods face other difficulties due to the more delicate problems associated with the verification of such research compared to formal research approaches. Therefore, the remainder of this section is devoted to the description of the empirical activities carried out in the project. The research activities, which were applied throughout the different research activities of the work, are shown in an overview in Figure 6.

Empirical research methodology

Empirical research methods have constituted the basis for the problem-based research; research activities aiming at a further understanding of design activities and validation of hypotheses. Empirical research of two major types were employed; *participatory research activities*, including personal involvement in order to research the studied design activity ‘from within’, and *inquiry research activities*, meaning question-based research ‘about’ the design activity.

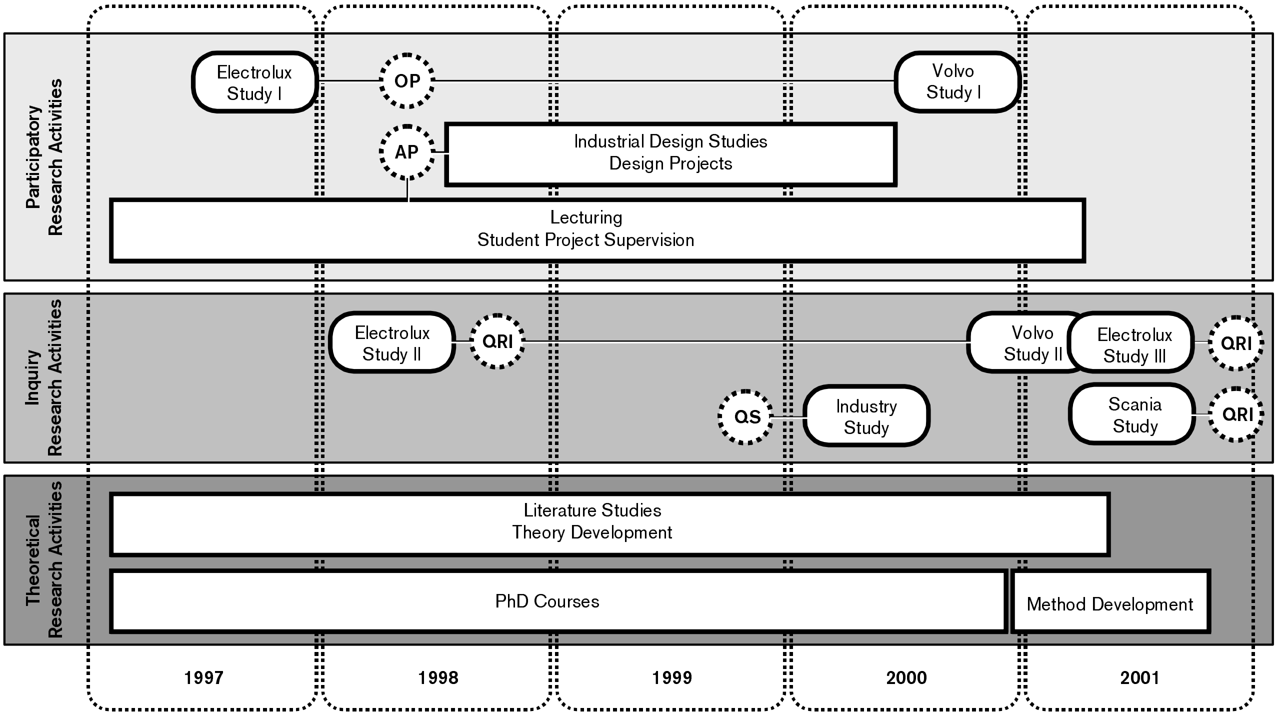

Figure 6. Schematic representation of research activities carried out during the research work, divided into theoretical and empirical research streams. Empirical research activities include participatory and inquiry research studies. Abbreviations signify applied research methods, OP: observing participation, AP: active participation, QRI: qualitative research interview, QS: questionnaire study.

Participatory research activities

Participatory research is used by Reason [1994] to denote a range of action research-oriented approaches, including co-operative inquiry, participatory action research, and action inquiry. The research methods employed during participatory research stream in this project are most closely related to co-operative inquiry, in the sense that the participating researcher is also a co-subject and participates in the researched activity. He reflects on the work, which is being done from a research point of view. The research methods used have included two techniques:

- **Observing participation (OP)** Observing participation is a ‘passive’ participative method [Blessing, 1999], where the researcher takes an observer’s role during the studied design activity, makes observations and takes field notes.

- **Active participation (AP)** Active participation includes the 'active' involvement of the researcher as a co-subject in the design activity. Active participation has been the research approach taken in the role as a supervisor of student design projects, and also as a self-reflecting activity during personal industrial design studies. In the latter process, the practice of design was a significant part of creating models and hypotheses in the research work. The 'active' and 'deliberate' reflection was conditioned by the simultaneous and interactive theoretical research activities regarding the design process, its stages and activities, and about the product.

Lecturing and supervision of master degree level student design projects, and additional university studies in industrial design have also been included in the participatory research activities. Teaching in product development, design methodology, and industrial design courses, has been an integral part of the doctoral studies. The teaching has been fundamental in achieving an understanding of the design process and the use of design methodology in design projects, and in the development and testing of new theories and methodological approaches. It can thus be considered an important part of the participatory research of this work. Supervised projects have been carried out in cooperation with industrial partners, with a large amount of industrial design, ergonomics, and user-product-interaction as central design issues, apart from typical engineering design problems. These projects provided the unique opportunity to implement new ideas and concepts, derived mainly from the theory-based side of the research, directly into an action-type setting in a controlled and planned manner. This proved very useful in testing and evaluating theoretical concepts at an early stage of the research, without the risks associated with industrial implementation.

Another approach towards acquiring more knowledge and experience of design more specifically directed towards the aspects of industrial design in product development included a study period of totally one year at the industrial design program at HDK, the School of Design and Crafts, at Gothenburg University[6]. This experience provided new input in form of design reasoning and reflection from the perspective of industrial design, as well being valuable for the subsequent development of theoretical elements and the introduction of new aspects into the framework of design science. Personal experiences from design work encountered during, as well as before, the work with the research project constitute a substantial part of the knowledge base in this work. Such experiences have been instrumental in forming the vision and intuitive arguments for the research work, and not least in formulating the research questions for the work.

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[6] The studies at HDK included 'traditional' courses in industrial design, including aesthetics, form, color, product semantics, design methodology, modeling, visualization, figure drawing, theory and history, and various applied design projects.

Inquiry research activities

In the inquiry research stream, different forms of 'questioning' techniques were applied. The aim was to gain an understanding of respondents' views about design activities, product development processes, methodology aspects, etc. Two types of methods were used: *qualitative research interviews* (QRI) and *questionnaire surveys* (QS) [Westlander, 2000]. Semi-structured, personal interviews were applied in studies involving only one company at a time, in order get an in-depth understanding about some studied aspect. One study employed printed research questionnaires in order to reach a wide sample of industries.

Empirical research studies carried out in the work

In this section, the studies constituting the empirical knowledge base of the research are described. The activities are of two types, participatory and inquiry research, and have utilized various qualitative research methods, as illustrated in Table 1. The studies are described in chronological order, as presented in the scheme of Figure 6.

Electrolux Study I

In the first study at Electrolux Floor care and Light Appliances, the early conceptual stages of the design process of a new vacuum cleaner were followed from October to December 1997. The study included observing participation at project meetings and design activities. The purpose of study was to learn about the early product development process and study the use of methodology and interaction between team members. The project team included project manager, engineering designers, electrical engineering designer, production engineers, consultant engineers, and industrial designer. During the project, a communication study of type and frequency of interaction between members of the design team, and a product architecture study based on DSM[7] methodology [Eppinger, 1997], was carried out.

Electrolux Study II

An in-depth interview study of the Integrated Product Development Process (IPDP) at Electrolux Floor Care and Light Appliances carried out from January to March, 1998. Five respondents at strategic and operative company levels were interviewed regarding the structure and activities of the IPDP and its correlation to the actual design process at Electrolux.

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[7] DSM is an abbreviation for 'Design Structure Matrix'.

Industrial Survey Study

In the spring of 2000, a questionnaire containing 20 multiple-choice questions was mailed to 369 product-developing companies of all sizes in Sweden, resulting in a response from 99 subjects. The questions inquired about included factual information such as company characteristics; functions, tasks and responsibility areas for different competencies; the existence and use of product development procedures, methods, and techniques; and communication frequencies with other stakeholders; also data of a psychological nature such as personal opinions on various aspects of product development work related to methodological issues.

Table 1. Overview of empirical research studies carried out during the research work.

Study	Research method	Number of subjects	Study type	Objective	Deliverable of relevance to this research work
Electrolux Study I	Observing Participation	18 (team size)	Descriptive	Study the conceptual product design activity at Electrolux Floor Care and Light Appliances	Project report, Warell [1998]
Electrolux Study II	Qualitative Research Interview	5	Descriptive	Study the new product development process at Electrolux Floor Care and Light Appliances	Project report, Liedholm and Warell [1998]
Industrial Survey Study	Questionnaire Survey	99	Descriptive	Study the use of product development methods, design competencies, and communication aspects in Swedish industry	Conference paper, Persson, Janhager, and Warell [2001]
Volvo Study I	Observing Participation	20 (team size)	Descriptive	Study the conceptual product design activity at Volvo Car Corporation	Internal report, Persson, Schachinger, and Warell [2000]
Volvo Study II	Qualitative Research Interview	6	Descriptive	Study the conceptual product design activity at Volvo Car Corporation	Conference paper, Persson [2001]
Design Format Study (Electrolux Study III, Scania Study, and Volvo Study II)	Qualitative Research Interview	5	Descriptive, validating, verifying	Study the rationale of the form design process and test developed theoretical models on experienced industrial designers at Scania Commercial Vehicles, Electrolux Home Products, and Volvo Car Corporation	Conference paper, Warell and Nåbo [2001][8]

Volvo Study I

In the first Volvo Car Corporation study carried out during the fall of 2000, the early conceptual design activity in the development of a new car range was followed applying observing participation techniques. The objective was

[8] The article is appended as Paper D in this thesis.

to study interaction between team members, the use of design methodology, and to identify needs for working methods and methodology support. Working project meetings involving project management, project coordinators, engineering designers, industrial design engineer, industrial designers, system and component suppliers, and production engineers.

Volvo Study II

The study, conducted in early 2001, included personal semi-structured interviews with six industrial designers, engineers, and project coordinators involved in the new product development process at Volvo Car Corporation. The issues discussed were related to the previously studied conceptual design project (Volvo Study I). The study aimed at getting a deeper understanding of the interaction between industrial design and engineering design activities during early phases of the conceptual design process. Questions regarded the stages and methods of the design process; specification issues; input from and deliverables of different stakeholders to the process; and communication and collaboration aspects between different stakeholders.

Design Format Study (Electrolux Study III, Scania Study, Volvo Study II)

These studies, carried out during the spring of 2001, were collectively denoted the ‘Design Format Study’. The objectives were to gain a deeper understanding of the form design process of industrial designers, and to validate and verify developed theoretical models. The study contributed to the ongoing development of methodical approaches for form design. The Design Format Study included personal, semi-structured interviews with industrial designers about the rationale of form design development, the emergence of product form during the design process, influencing factors in form design work, and the strategic and operational management of styling design aspects. Designers were also introduced to the developed descriptive and prescriptive theoretical models on form design development. The study overlapped partially with ‘Volvo Study II’, and the studies collectively contributed to the above goals.

3.4 VERIFICATION AND VALIDATION OF DESIGN RESEARCH

The process of validating and evaluating research results in design science is a delicate and often controversial issue. Since the formal scientific approach cannot be straightforwardly applied, likewise, the validation of hypotheses, the ‘correctness’ of theories and models, and the applicability of methods cannot be finally confirmed, but only more or less supported by its ability to describe relevant phenomena or aspects of design objects. According to Buur [1990], it is a major obstacle in design science that it is almost impossible to verify theoretical results empirically. This is a reason why design methodology research has had difficulties in being accepted as a field of science [Buur, 1990; Jakobsen, 1995].

In order to verify the results of design research, we have to discuss what characterizes good design research. To be considered ‘scientific’, design research should according to Andreasen [1994] be characterized by:

- Having a theory base (a system of logically related bits of knowledge valid for a domain)
- Being based on scientific methods

  for definitions, object identification, demarcations
  for creation of concepts
  for modeling
  for proofs
- Being based on considerations about validity and uncertainty

If a research work in the design science area possesses the characteristics stated above, it can hence be claimed that there is an increased probability that the research can be considered scientific, and therefore ‘valid’. The first points have been discussed in the chapter on theoretical basis. In this section, issues of verification and validation of design research will be considered. In section 7, the issues of verification, validation, and novelty value of this work are discussed in further detail.

Verification of design research

Verification of research results is concerned with establishing the truth or accuracy and the predictive and explanatory power of proposed theories, methods, and models. Due to the difficulty in empirical validation of design research, Buur [1990] suggests the concepts of logical verification and verification by acceptance.

By *logical verification*, Buur proposes

- consistency; no internal conflicts between individual elements of the theory,
- completeness; all relevant phenomena can be explained or rejected by the theory (including empirical observations, literature observations, etc.),
- the consistency of the theory with other theories and methods, which have proven their success and applicability, and
- that case-studies and specific design problems can be explained by the theory.

By *verification by acceptance*, Buur suggests that

- claims made by the theory are acceptable to experienced designers, or by a relevant scientific community due to the disagreement of the ability of experienced designers to verify a theory by acceptance, as re-stated by Olesen [1992], and
- that models and methods elaborated from the theory are accepted by experienced designers.

Olesen [1992] adds the aspects of applicability and novelty value as evaluative criteria:

- Applicability; the use of the tools allows the probability for success to increase with repeated use. It may not necessarily lead to success every time of application, but over a period of time, results will be better than if the tools were not used.
- Novelty value; new solutions are presented, or new ways of looking at a problem are introduced.

Buur [1990] argues the view that “the classical verification of design methods demands that their application to the practical design of artifacts is successful”. Buur considers such design experiments unrealistic, due to two factors:

- Since the design process is a stochastic and opportunistic process, it can never be verified whether a new design method or tool implemented in design work in fact increases the chance for success.
- Also, there are many influencing factors that cannot be controlled or taken into account. This makes it virtually impossible to repeat any experiment carried out for purposes of verification.

The contributions made in this thesis are, to a large degree, statements of design theory, models and methods, and their validation may thus be tested by logical verification as suggested by Buur and Olesen. The motivation and argumentative foundation for these theoretical statements is largely found in the empirical studies carried out in the research.

Validation of design research

Validation of research results is concerned with establishing the relevance and meaningfulness of theories, methods, and models. Cross [1995b] suggests, that for validity, design research should be:

- *Purposive*: based on identification of an issue or problem worthy and capable of investigation;
- *Inquisitive*: seeking to acquire new knowledge or new relationships among knowledge elements;
- *Informed*: conducted from an awareness of previous, related research;
- *Methodical*: planned and carried out in an efficient and disciplined manner; and
- *Communicable*: generating and reporting results, which are testable and accessible by others.

Yin [1994] suggests four tests, which are commonly used to establish the quality of any empirical social research. Since a large part of the empirical studies carried out in this work, including participatory and inquiry research activities, constitute types of social research, it is logically assumed in this and other research projects (e.g., Stake [2000]) that these tactics are also applicable as quality criteria in design research. The four quality criteria are:

- *Construct validity*; establishing correct operational measures for the studied concepts. This constitutes a specific problem in qualitative research. In quantitative research, it is a matter of finding a relevant set of measurement criteria. In qualitative research, construct validity is instead determined by the quality of data gathering, such as using multiple sources of evidence, and having draft reports reviewed by key informants.
- *Internal validity*; is concerned with the correctness of causal relationships. In experimental and explanatory research, internal validity is concerned with establishing the causality between events. In qualitative research studies, internal validity is extended to the principle of inference. By dealing with inference as a means for arriving at a conclusion by reasoning from evidence of sound data gathering, the specific problem of internal validity is addressed.
- *External validity*; establishing whether a study's findings can be generalized beyond the domain of the study. A qualitative research study must rely on analytical generalization for generalizing a particular set of results to a broader theory.
- *Reliability*; concerning the trustworthiness of the results. Generally, reliability is closely related to the repeatability of a study, the data collection process and the replication of results. In this research, the studies performed have been indicative since they aimed at suggesting descriptive and prescriptive approaches concerning a specific phenomenon. Thus, the reliability of the studies has to be viewed from the perspective of selecting data gathering methods, research subjects, and research problems of each study.

In section 7.2, the research of this project is evaluated according to relevant criteria of verification and validation illustrated above.

4 THEORETICAL FRAME OF REFERENCES

The purpose of describing a theoretical frame of references is to establish the fields of knowledge, which in some way contribute to the understanding of the present field of study. In this section, relevant contributions of knowledge areas, which have been influential in the research work of this project, are presented and discussed. From the start of the research work, the intention has been to investigate the elements of interaction between the two fields of industrial design and engineering design. Naturally, it is thus not sufficient to study only the one field or the other, but a wider approach towards studying influential elements of both fields is necessary, as well as the incorporation of knowledge from related fields relevant to the research issue.

Since the research task of this work aims at a wide approach to understanding a problem, the focus of the review of contributing areas is on a broad, general understanding of relevant fields, rather than a detailed, profound, in-depth understanding of theoretical aspects of the contributing areas. The goal in establishing a theory base for this work has been to create a system of logically related knowledge areas, valid for a domain. According to Andreasen [1994], the elements of such a theory base could be concepts, information about knowledge (facts), theories, and methodology.

As a natural consequence of the wide knowledge base, the research carried out does not reflect the same depth in all areas. Some theory areas have been considered more important than others, and have thus influenced the work to a greater extent. The distribution of effort invested in different areas is the result of a living research process - although goal-oriented, the work has evolved into new directions in different phases of the work, and some areas have come to the attention and been brought into the research focus in, sometimes, a rather opportunistic manner.

The theoretical frame of reference includes contributing theory areas such as *design science*, which constitutes the work of WDK, including the theory of domains, the theory of technical systems, and integrated product development; *design semiotics*, including product semantics; and *aesthetics*, including form development, structure and constitution of form, and gestalt theory.

4.1 A HOLISTIC PRODUCT PERSPECTIVE

A product can be seen as a trinity of a technical, ergonomic, and a communicative whole, within the limits of an economic/ecological circumference, as seen in Figure 7 [Monö, 1997]. In design work, the whole product must be considered; otherwise the result will be unsatisfactory from one or several perspectives. The technical whole includes the use of technology, the technical functionality, the characteristics and properties of the product, and its production. Ergonomics deals with the human element and its interaction with the product. The mental and physical capabilities of the human body such as biomechanics, cognitive ergonomics, information processing, and anthropometry, belong to the ergonomic whole. The communicative whole refers to the product's ability to communicate with humans, its adjustment to human perception and intellects, and the human and society's relation to the product as a whole.

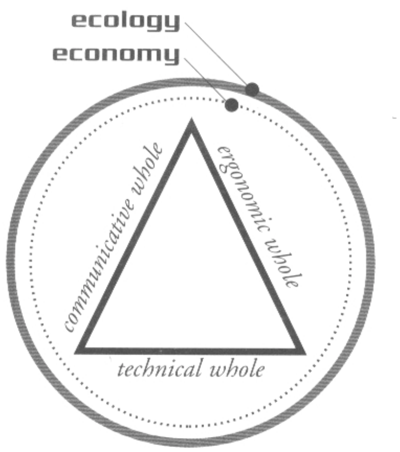


Figure 7. The product can be seen as a trinity of a technical, ergonomic, and a communicative whole, within the limits of an economic/ ecological circumference [Monö, 1997]. Related to the diagram, the focus area of this research work is specifically devoted to the relation between the technical and communicative whole of the product.

This division into three separate views is of course idealistic; in reality it is not possible to separate them since they are fundamentally interrelated. The connection between the technical and ergonomic whole can be regarded as especially strong, as the alternative term for ergonomics, *human factors engineering*, indicates. The same applies to the relation between the ergonomic and communicative whole, which can be seen as constituting an interactive whole of the product. However, the separation into three possible perspectives helps focusing when approaching different aspects of the designed product.

In this research work, the focus is on interaction between industrial design and engineering design. Related to the model of Monö, the aim has been to shed further light onto the relation between the technical and communicative whole of the product.

4.2 DESIGN SCIENCE

Since the beginning of the project, the work has been strongly influenced by the research of the WDK-school. The reason for adopting the WDK-school as one of the theoretical foundations for the work, lies in its well-defined theory-base and the many tools and methods derived from it, which is unequalled by any other theory of mechanical engineering design in terms of its mass of rigorous and scientific reasoning. It thus constitutes a solid foundation for enhanced theoretical construction with the aim of elaborating an enhanced product design theory, which is the objective of this thesis. Elements of the WDK-school that have been most influential include the theory of technical systems and the theory of properties [Hubka and Eder, 1988], the systems and domain theories [Andreasen, 1980], the theory of form design and the model of product synthesis [Tjalve, 1979], and the framework of integrated product development [Andreasen and Hein, 1987].

In this work, certain elements of the WDK-school of specific importance have been further elaborated to serve as the backbone to which elements of other research fields have been added. The most influential contributions of design science are briefly described in the following.

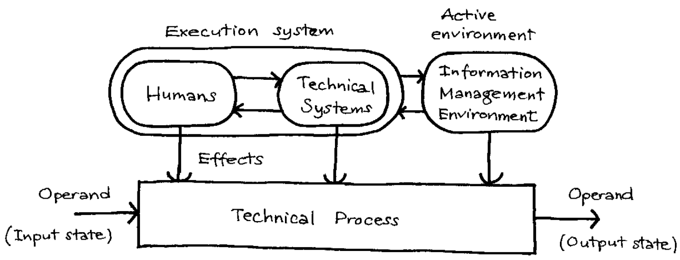


Figure 8. A general model of a transformation system, including technical process and technical system, after Hubka and Eder [1992].

The *theory of technical systems* [Hubka and Eder, 1988] is a descriptive theory of the designed artifact, the machine system. The technical system is seen has having functions of different types that deliver the effects (actions of material, energy or information character) that are necessary for driving the desired technical process, Figure 8. In the technical process, an operand (of material, energy or information character) is transformed from an input state to the desired output state. The technical process is controlled by humans, and affected by an active environment. Technical systems can be described on four system levels; as a process structure on the highest level, a function structure, an organ structure, and a component structure on the lowest level.

A characteristic of the technical systems theory is that only functions associated with, or supporting, the transformation of the operand are considered. The human is reduced to an effect-delivering element of the transformation system. Functions associated with the interaction between human and technical system are thus not acknowledged. For a theory considering only the activity of the machine this is adequate. However, the lack of consideration of the human element as a user results in a design process where the machine is designed only to fulfill technical considerations. This 'shortcoming' of the theory of technical systems is elaborated in section 5.4.

In the *theory of properties*, Hubka and Eder [1988] classify the properties of a technical system and relates them to each other. In their classification, e.g., ergonomic and aesthetic properties relate to issues of industrial design importance. The *basic properties* constitute a special class of properties – they are the only properties that can be directly manipulated by the designer. All other properties depend on the characteristics given to the elementary design properties. Control of the characteristic properties during product design is thus essential in order to achieve the desired functionality. In Figure 9, Tjalve [1979] organizes the properties according to the life of the product.

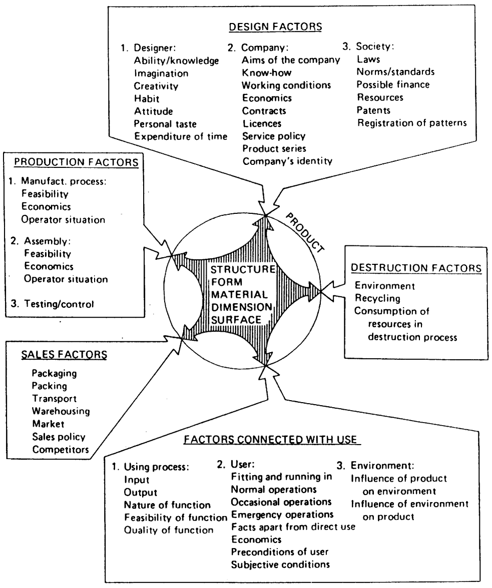


Figure 9. Properties related to the life cycle of the product [Tjalve, 1979].

The basic properties include *structure* (for the product as a whole), *form*, *material*, *dimension*, and *surface* [Tjalve, 1979]. Hubka and Eder [1988] add tolerances and manufacturing method to this class (which they denote elementary design properties), but as suggested by Mørup [1993], it could be argued that these are dependent on the other and thus superfluous as basic properties. According to Roozenburg and Eekels [1995], there are only two basic design properties – *form* (geometrical form), and *material* (physio-chemical form). In this work, the basic properties as defined by Tjalve are adopted. The basic design properties are interrelated in a complex manner (e.g., form is directly dependent on shape, arrangement of parts, and overall structure). All other properties of the product (such as strength, corrosion resistance, price, quality, appearance) are derived from the basic design properties, and are also interrelated, which is the reason why designing products and mechanical systems is such a complex task [Hubka and Eder, 1988].

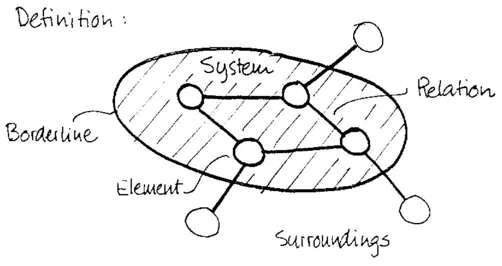


Figure 10. The system definition [Andreasen, 1980].

According to *systems theory,* a technical system can be a sub-system of another technical system at a higher hierarchical level. This is called the recursive systems hierarchy. Figure 10 defines a system according to Andreasen [1980]; a *system is separated from the surroundings by a borderline, and has a structure consisting of elements and their relations.* This system definition is referred to as a "set based system theory"[Jensen, 1999]; consisting of sets of elements and relations between these elements.

According to Andreasen and Mortensen [1996], a system (any artifact or product) can be described in two different ways: by an external description explaining the constitution of the system by way of *design characteristics* ('what it *is*', or '*how* it is'), and by internal description, i.e. the behavior of the system described by *design properties*, including functions ('what it *does*', and '*how* it does it'). This taxonomy is illustrated in Figure 11. Design characteristics, i.e. the design attributes defining the design, are the only characteristics that can be determined directly by the designer [Mortensen, 1995]. They are thus identical to the basic properties of Tjalve [1979]. For this work, it is important to acknowledge that a system can have both a constitutive and behavioral description. Related to system theory, the constitution of visual product form is elaborated in section 5.5.

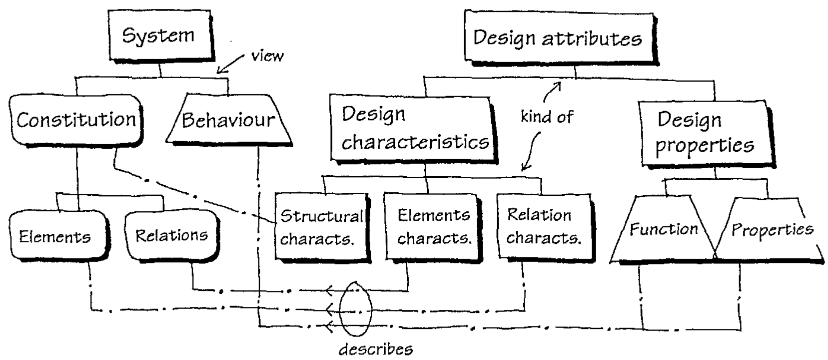


Figure 11. System and design attribute taxonomy [Andreasen and Mortensen, 1996].

In the *theory of domains*, Andreasen [1980] refines the theory of technical systems by Hubka and Eder [1988] and models the four systems structures as distinct kinds of systems and calls them domains. Each domain can be modeled with different degrees of abstraction and completeness, which each represent principally different, but necessary, ways of describing a product in a complete and sufficient manner. The four domains are:

1. *The process system*, describing the transformation that takes place in the machine.
2. *The function system*, describing the effects the machine is to create.
3. *The organ system*, describing the function carriers, which create the effects.
4. *The parts system*, describing the way in which the organs are realized.

Within each domain, work progresses from a simple, incomplete and abstract, to a detailed and concrete, representation of the technical system, as the design evolves, Figure 12. During design work, the designer also jumps back and forth between domains in the gradual detailing and concretization of the product [Buur, 1990]. In this work, the domain theory is used as a foundation for attributing functional (behavioral) properties to visual form design. In section 5.4, the function and organ concepts are elaborated and related to visual product form. Since the theoretical models presented in this work are related to the concepts of the domain theory, its entities are described in the following.

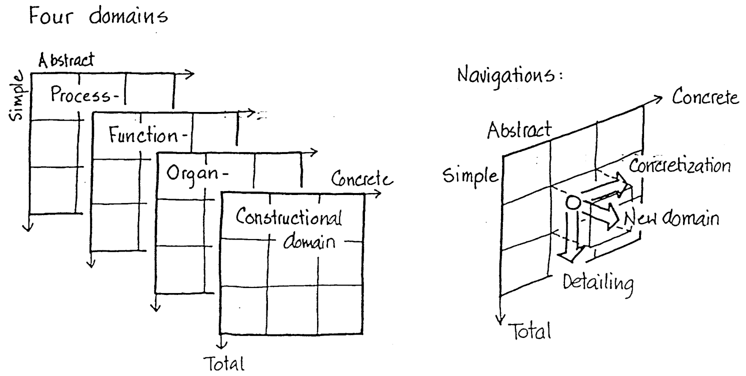


Figure 12. Design involves gradually adding information in four domains, after Andreasen [1992].

Starting from the first domain, the *process system* describes the operation states a machine is going through during the transformation (change of state) of its operands (energy, material, and information) in a technical process.

When viewed upon as a *function system*, the task of a machine is to produce the desired effects (output) which are necessary for carrying out the appropriate transformation of the operand, which is the focus of the process system as described above.

In the product, functions are realized by an *organ system*. Organs are also known as ‘function carriers’ or ‘functional units’ [Hubka and Eder, 1988], and are the (non-physical) ‘active units’ that produce the functions, which the machine is to create [Andreasen, 1992]. A definition of organ provided by Jensen [1999] reads: “*An organ is a structural design element for the complete realization of a given function. An organ is a structure of wirk elements. Some organs consist of only one wirk element*”. The wirk element concept is close to the concept of ‘functional surfaces’ introduced by Tjalve [1979]. With functional surfaces as one of the main building blocks of the theory of form design, Tjalve established the link between the design of parts, organs and their function from an effect-delivering, mechanical design viewpoint. Functional surfaces are described as *the ‘active’ surfaces of parts, where functional effects are delivered to the surroundings*.

Finally, the *part system* materializes the organs in the form of parts, components and constructional elements in a product. The part system is the only *real* (physical) manifestation of the entities of the domain theory, as all other domains are models describing the part system (to-be) from different viewpoints. One part – defined as ”*a non-decomposable element of an artifact*” - will often contribute to the realization of several organs, and one organ will normally need several machine parts for its realization [Andreasen, 1992].

The *chromosome model* is a genetic structure derived from the theory of domains. Proposed by Ferreirinha et al. [1990], the chromosome model can be used for representing relationships between entities in different domains, such as one organ implementing a function and one component realizing several organs, and for managing generic data in a computer-based design system. In line with the new theory of domains, Mortensen [1999] has proposed a revised chromosome model, constituted by three domains: technology, organ, and part.

Based on the chromosome model, Jensen [1999] introduced an organ-based behavior-structure mapping consisting of two domains, as shown in Figure 13. Here, the organ domain consists of hierarchically related structures of organisms, organs, and wirk elements, and the part domain consists of structures of assemblies, parts, and form elements. The relation between the organ and part domains is that the wirk elements are allocated on parts. An important implication is that behavior (function) is created by the organ domain only, while the part structure is a strictly physical realization, a view, which is adopted in this work. The chromosome model is not explicitly used in this work, but it has important implications as a model for relating function to parts of the product. Contributions to the organ theory related to visual product form are elaborated in section 5.4.

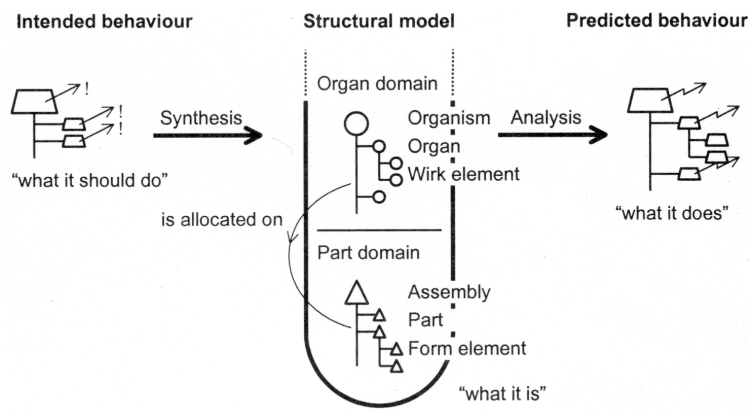


Figure 13. The organ based behavior/structure mapping of Jensen [1999].

The model of Jensen can be seen as a hybrid of the 'new' theory of domains, which features some significant changes to the original version presented above. According to the modified theory, it is recognized that "*strictly speaking, there does not exist a function structure of a machine system, but one may label the organs to be designed by their functional expressions and show the structure of these organs*" [Andreasen, 1998b]. The function domain is thus missing in the new theory of domains, and is instead considered a class of organ behavior, see Figure 14.

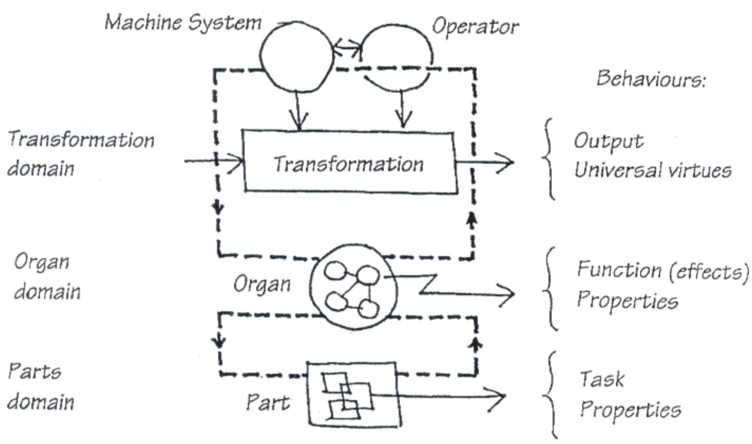


Figure 14. The 'new' theory of domains [Andreasen, 1998c].

The *framework of integrated product development* [Andreasen and Hein, 1987] describes the product development process as composed of activities on four levels, see Figure 15:

- *Problem solving*, i.e. activities associated with creating solutions with specific aims in mind. The five phases of general problem solving include the formulation of the problem, the decision on criteria, the search for solutions, the evaluation of solutions, and the carry-out phase [Jones, 1970].
- *Product synthesis*, i.e. the activity of creating a specific product from the formulation of a task. The product synthesis process is described by Tjalve [1979].
- *Integrated product development*, i.e. the activity of creating a product-based commercial activity on the basis of a recognized need or a contract from a customer. The activities of marketing, design, and production, are all carried out in parallel in the integrated product development process.
- *Product planning*, i.e. the activities of implementing and coordinating strategies for the product, market, and technology, within a range of products, which cover the needs of the market and yield the necessary profits.

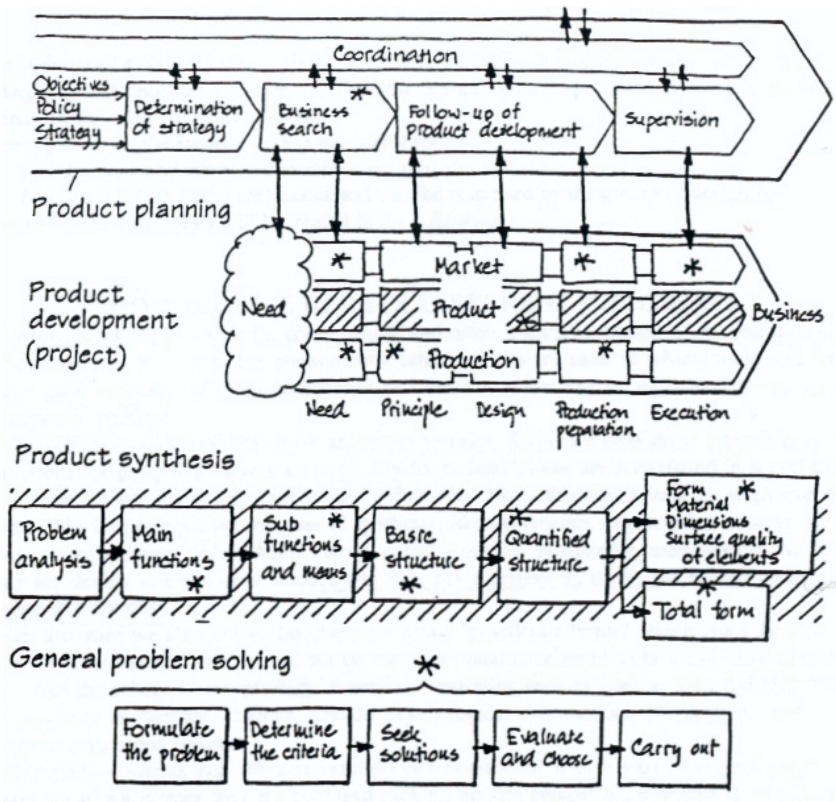


Figure 15. The framework of integrated product development [Andreasen, 1991].

In the *theory of form design*, Tjalve [1979] proposes systematic methods for form design, structure variation, and form variation, based on the concept of functional surfaces; surfaces that have an active function during use, Figure 16. Thus, the theory provides central concepts for the relation between organs and functions of the domain theory.

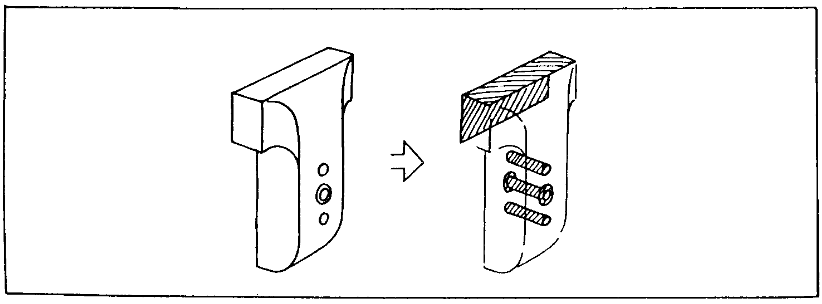


Figure 16. Functional surfaces of the sliding jaws of a vice [Tjalve, 1979].

The methods for form design constitute the core of the *model of product synthesis*. The product synthesis, seen in Figure 15 as part the framework of integrated product development, takes the starting point in the formulation of the desired function and the list of desired properties. The process of form design is signified by a gradual determination of the product form, starting from basic structures, the elaboration of quantified structures, to the definition of the total form of the product. Tjalve also introduces the concept of form elements, which are basic shapes of relatively simple geometrical form, making up the outer form of the product.

The concept of *quality* is important to consider in relation to product appearance, since both aspects are results of the user's interaction with the product. Mørup [1993] defines product quality as: "*the customer's experience (or perception) of how well the totality of product properties of a product satisfies his stated or implied needs*". This implies that quality is not *within* the product; it is perceived when the user experiences the properties of the product, including product functions, according to Figure 17. Furthermore, Mørup introduces a quality concept which takes internal and external stakeholders into account: *Q-quality* is the user's or customer's qualitative perception of the product, expressed in, e.g., verbal subjective statements, while *q-quality* is the evaluation of the internal stakeholders experience of the product, met in, e.g., production and packaging activities.

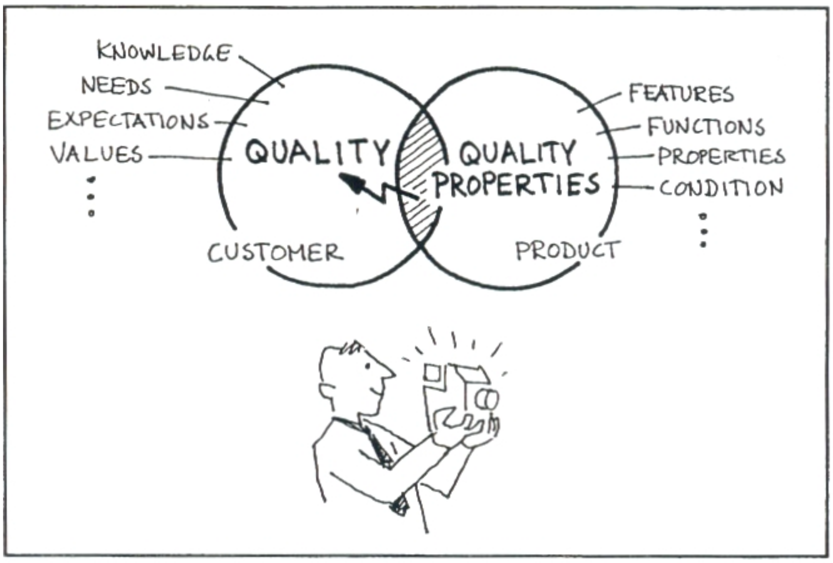


Figure 17. Quality is experienced by the customer when he interacts with the product. The experience is elicited by quality properties within the product [Mørup, 1993].

Mørup notes that "the quality Q has no simple relations to the embodiment of the product or its components". Related to the domain theory, Q is associated with the organ level as a special class of properties of the product, the quality properties. These are especially important to customers as they contribute to the customer's perception of functionality, i.e., "*what* the product does" in customer terms. It seems reasonable to suppose that, apart from technical functionality, the appearance of the product is also an important aspect of the consumer's perception of quality. Poor looks of a product, carried by, e.g., material or surface properties of the product, can certainly contribute to decreasing satisfaction from the customer's perspective.

Discussion of the contribution from design science

The review of influential elements of design science has several implications. As a coherent theoretical framework of the design process and artifact theory, it provides a foundation for the development of new theoretical elements specifically considering aspects of form design. The elements of the integrated product development are adopted as a valid description of the general design process. It states that several product aspects must be developed concurrently, which suits the needs of this work. The domain theory is adopted as a fitting model of the product, which allows for further development. Although there are ongoing discussions on parts of the design science theory, it is nevertheless acknowledged as the most complete, and thus most suitable framework, on which to base further work.

However, aesthetic product form design is not explicitly treated in design science, except for the contribution by Tjalve [1979]. Neither is the human as a user or perceiver of the product, with exception for Mørup [1993] and Markussen [1995], with emphases on quality and interaction design, respectively. It is thus necessary to identify other relevant fields of knowledge, which contribute with such aspects, and which are suitable to be included in a framework for product form design. These are reviewed in the following.

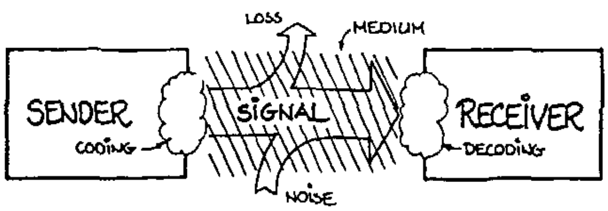
4.3 COMMUNICATION THEORY

One important task of industrial design is the design of the human-product interface, it being the most important factor for effective use of the product. The interface may be seen as the 'arena' for communication of messages between the designer and the user; a successful design communicates the intentions of the designer and effectively aids in the use and handling of the product. It is thus advisable to investigate the factors, which influence the information carrying capacity of the human-product interface.

Communication theory treats the process of communication between product and user. A successful design communicates the intentions of the designer and effectively aids in the use and handling of the product. The characteristics of user-product communication are treated by several authors, including Tjalve [1979], Buur and Andreasen [1989], Monö [1997], Vihma [1995], and Muller [2001]. Two models of importance to this work are illustrated in the following.

The *general communication process* in Figure 17 [Buur and Andreasen, 1989] models the communication process when transferring information from a sender (the designer) to a receiver (the model user). The intended information is coded by the designer in the form of the product, and is decoded by the user during use of the product. The information is transferred in the form of a signal[9] by use of a medium of some sort (e.g., talking, writing, or a cardboard model). The 'medium' is what Karlsson [1996] refers to as a 'mediating object'. During the transition of the signal, noise (distortions) may be added, or loss of information may occur, rendering the information received by the user different from the information intended by the designer.

Figure 17 The general communication process [Buur and Andreasen, 1989].



If the receiver of the information is the user of the finalized product, it becomes apparent that the 'code'[10] of the product must be consciously incorporated into the design of the user-product interface, in order to convey the appropriate message (the information intended by the designer) via the expressed properties of the product. Monö [1997] presents an extended communication model that includes signal messaging from the designer's *intentions* to the user's *interpretations*, illustrated in Figure 18.

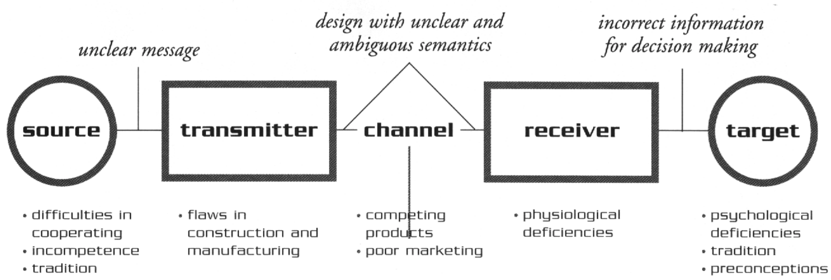


Figure 18. Monö's model of communication of design messages, with potential factors of disturbance [Monö, 1997].

According to Monö's model, the coding is done by the designer (the *source*), giving form to, e.g., controls and graphics of the use-interfaces of the product (the *transmitter*, medium, or mediating object), with the intended purpose in mind. The signals are conveyed by the design (the formal aesthetics) of the product or by elements of the product's form. The decoding of the message is performed by the user (the *receiver*) during use of the product, as he interprets the message (*target*). Ideally, the conveyed message is identical with the information intended by the designer. However, a familiar and frequently observed situation is that the use and operation of the product are unclear due to design deficiencies, resulting in low product functionality, apart from frustration and confusion on behalf of the user.

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9 The term 'signal', as used here, is defined as being of data character during transmission, and of information character before coding by designer, and after decoding by the user. Thus, signal content becomes interpretable information only after being decoded by the user.

10 One conventionalised meaning of 'code' is "*a system of signals, figures, or symbols, with arbitrary, conventionalised meaning, used for communication*" [Funk and Wagnall, 1964] (from [Monö, 1985], translated from Swedish). Monö [1997] defines 'code' as a "*system of rules for the interpretation of signs/signals*". Monö continues the reasoning by saying that "*semantically speaking, the technology is a technical code which gives rules for reading the semantic functions of the product sign, for being able to understand the design's message*".

Discussion of the contribution from communication theory

Related to product design, communication theory treats the communication of design messages from the product side to the user side. From the perspective of design science, it can thus be seen as a process where information, as an operand, is transformed (signaled) from one state to the other in the mind of a perceiver. From the semiotic viewpoint (discussed in section 4.5), the message is carried by signs, and the design objective can be viewed as a semantic problem. The signs are carried by the form of the product, and hence, we have a connection to visual aesthetics, discussed in section 4.6. The communication process is thus a central area when discussing product form. Monö's model is adopted in this work, as it provides a more detailed picture of the noise factors, which can affect the communication process.

4.4 DESIGN MANAGEMENT

In design management literature, industrial design is often discussed from the viewpoints of company and product identity, the importance of design for product branding, and how design work should be planned and used to increase a company's competitiveness on the market. Product design is often treated from the viewpoint of differentiation of the company and its products. Identity is a powerful means for strengthening the company (brand) recognition (*identification*), for differentiating the company and its offerings from those of competitors (*distinctness*, *uniqueness*), for creating coherence across different markets and product categories and over time (*consistency*), and for building a strong brand equity base [Karjalainen, 2001]. Figure 19 illustrates the main aspects of company identity.

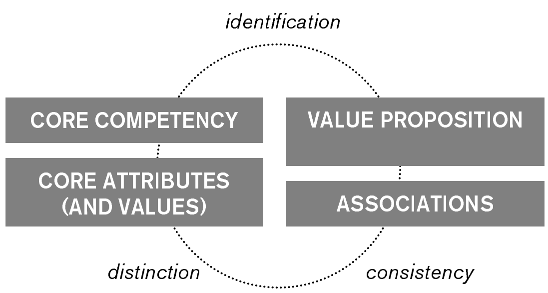

Figure 19. Main aspects of a company's identity, adapted from Karjalainen [2001].

Identity is important for creating value and meaning for customers, through which the brand positioning and distinction is reinforced, and is regarded as a *unique set of brand associations* representing what the brand stands for [Aaker, 1996]. According to Kapferer [1994], identity includes brands individuality, long term goals and ambitions, consistency, values, basic truths, and recognition signs. It emerges primarily through three designed (and visible) areas; products or services, environments, and communications [Olins, 1990]. Of these, products are often the strongest manifestation of brand identity, and an important issue is which product attributes embody differentiating functions [Karjalainen, 2001]. If consistently used across the entire product line of the company, specific design characteristics may contribute to stronger (recognizable, distinctive, and consistent) brand identity.

Monö's [1997] model of three 'dimensions' of the identity of a product can be seen from the design management perspective as describing the positioning of a product on the market. The product's identity can be described on three axes; the product range of the manufacturer; the products available on the market as a whole; and the historic succession of generations of products, Figure 20. From a company perspective, it is important to be able to handle the product identity from all three perspectives in order to convey a common identity and a to be perceived as consistent on the market. Here, semantic and syntactic aspects of product form are central issues, which have to be treated on different levels of management – from the corporate perspective to the operative design activity.

Svengren [1995] proposes three levels on which design management should be practiced: on the *philosophical level*, such as the valuing of the role of design for the company; on the *strategic level*, as the strategic management of design and strategic concepts (e.g., choice and definition of market segments and product types); and on the *operative level*, as operative management of a design area or project. On all three levels, design must be discussed and managed.

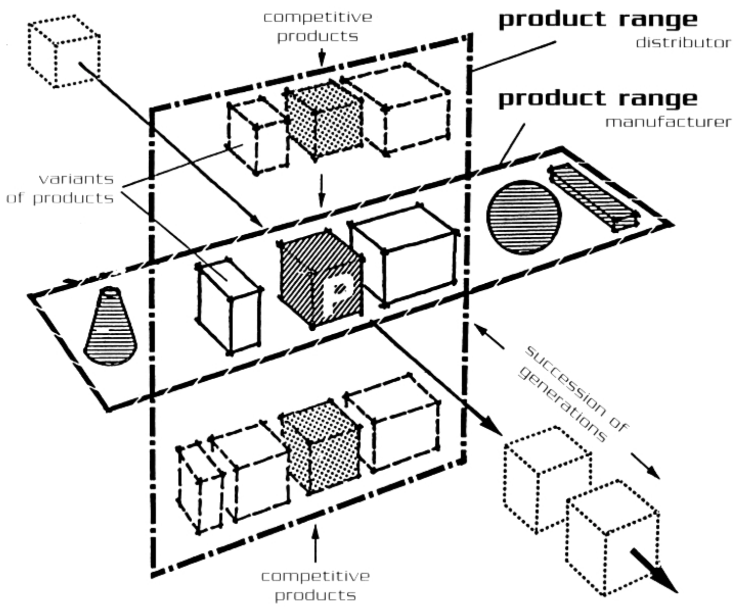

Figure 20. A model of three dimensions of the identity of a product [Monö. 1997].

Discussion of the contribution from design management

Design management is, as a research field, not a primary focus area of this work. However, it is important to consider how the results of the research are related to how design work is carried out in a company, how design is managed on operative and strategic levels, and how the company develops its identity through product design. Management prioritizations and decisions are also important for how well design is integrated into the product development process. These aspects are focused and elaborated on in section 5.7.

4.5 SEMIOTICS IN DESIGN

The study area of semiotics is a vast area, and to go into any details would bear too far away for the purpose of this research study. However, the most relevant aspects of semiotics for this work will be treated in the following. Basically, semiotics is the study of signs and their meaning. The transferred use of semiotics from the linguistic sense, pioneered by Saussere (1857-1915), to objects was first introduced in the 'Sprachtheorie' by Bühler [1984] with the aim of analyzing the communication capacity of images.

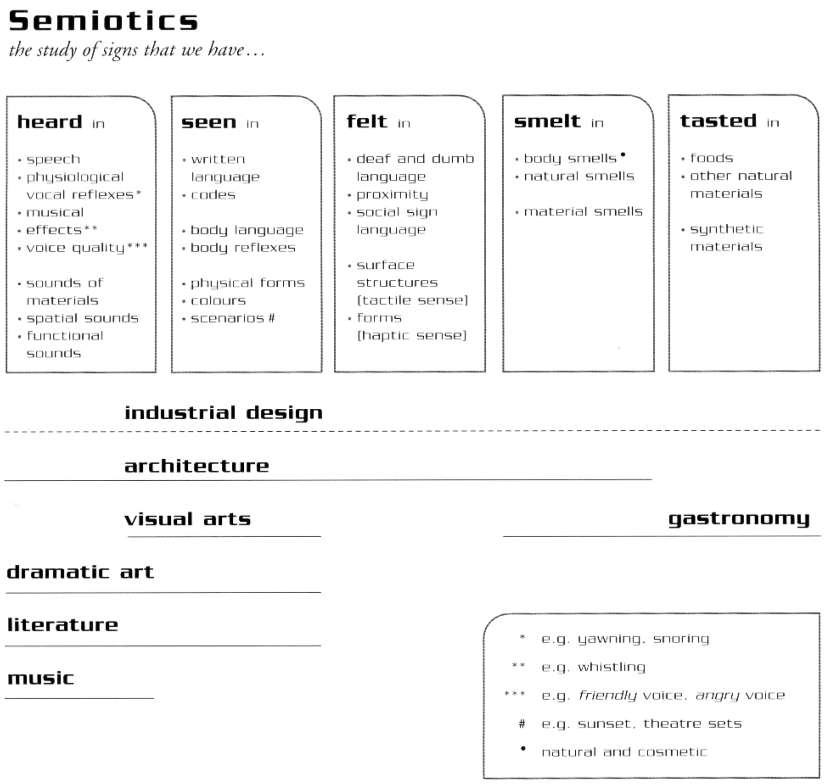

Figure 21. The study area of semiotics interpreted as signs perceived by our senses, according to Monö [1997].

Based on the work of Morris, semiotics includes three dimensions of sign study; *semantics*, the study of the sign's message (the meaning of the sign); *syntax*, the study of the sign's relation to other signs and the way it interacts in compilations of signs; and *pragmatics*, the study of the sign's use in different cultures and contexts [Monö, 1997]. Everything around us can be appreciated as signs, which we perceive through our senses, as indicated by Figure 21.

The semiotic sign

A sign is not a thing or an object, but a relation. According to Pierce [1931-66], a sign is defined as "something that stands to somebody for something in some respect or capacity." The Piercian triadic sign is based on a relationship between three aspects, or perspectives, of the sign, as illustrated in Figure 22. The sign consists of the relationship between the representamen R, the object O, and the interpretant I. The representamen R, which is also called the 'sign vehicle', is the form the sign takes. The object O is what the sign 'stands for', what it denotes. O can be another thing, action, fact, event, quality, or the like [Vihma, 1995]. The interpretant I is the understanding engendered by the sign, how we interpret it. Related to an everyday example such as the classic street cross-walk sign, the representamen is the square blue metal plate illustrating a walking person, the object is the zebra pattern in the street (the cross-walk), and the interpretant is our understanding that this is a 'safe zone' we can use to get over to the other side of the street.

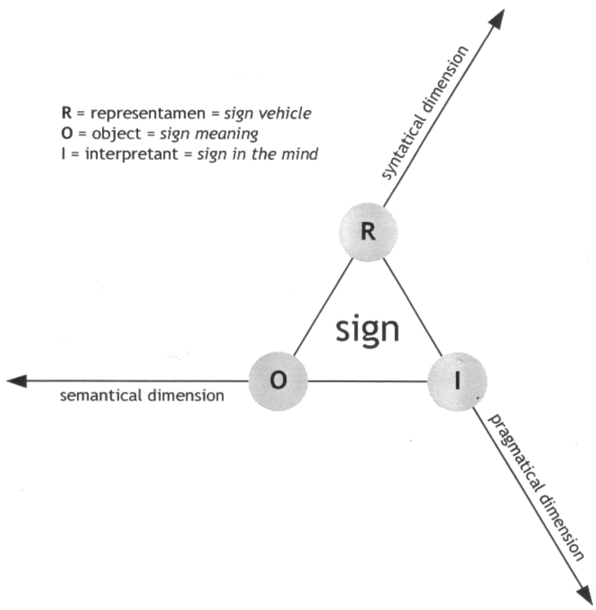

Figure 22. The semiotic concept adapted by Lange [2001] from Morris's models of sign semiosis [Morris 1971a, 1971b] and Pierce's sign model. The three dimensions of semiotics include the semantical, the syntactical, and the pragmatical dimensions of the sign. The three aspects of the sign are the representamen R, the object O, and the interpretant I. From the semiotic perspective, the research of this thesis concerns the syntactic dimension; the relation R-O.

The point of interest in this study is the ‘form’ of the product. The aim is to develop a way of describing the structure and content of visual form in a more normative and objective way. From a semiotic perspective, this correlates to the syntactic dimension of the sign, and how the representamen R functions in referring to the object O. The semantic dimension O-I, the meaning of the sign, is also interesting, but it is not within the scope of this research. After this short and fragmentary introduction to the semiotic world follows a review of the applications of semiotics in product design which are of interest for this study.

The semiotic dimensions of a product

Based on work of Bense [1971], Vihma [1995] presents a semiotic model including the syntactic, material, semantic, and pragmatic dimensions of the product. Compared to Bense’s model, Vihma considers the pragmatic dimension as a separate basic feature of the product for the purpose of semiotic analysis. The reason for this is the view that usefulness is not something, which is ‘added’ to a product after its material and form have been determined. Usefulness of a product is determined by the user, and is dictated by form and material of the product, designed to serve a practical purpose. Vihma’s model included the dimensions of material, syntax, semantics, and pragmatics, according to Figure 23. The constituent dimensions are described in the following.

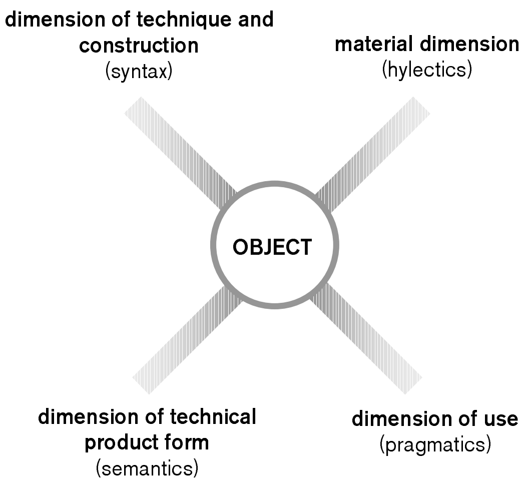

Figure 23. The four dimensions of a design product. After Vihma [1995], adapted from Bense [1971].

The semantic dimension

Product semantics may be seen as the application of the theories on information messaging to product design. The process of communication and the concept of signal messaging is a crucial aspect of product design. To quote Monö [1997], “to be used, they [i.e. products] must first and foremost be capable of being understood”. One approach for improving products in this respect is the school of product semantics, which has gained increasing attention and growing importance during the last decade. The term *product semantics* was pioneered by Butter and Krippendorff [1984], who defined it as “…*a study of the symbolic qualities of man-made forms in the cognitive and social context of their use and application of knowledge gained to objects of industrial design.*” Furthermore, Butter and Krippendorff state that “the symbolic meanings of forms, shapers and texture are the most characteristic concern of product semantics”. According to Butter [1987], the use of product semantics can:

- contribute to make the use of products self-evident,
- help to make products culturally meaningful, and
- supply products with a distinct character.

Vihma [1997] notes that the semantic dimension of a product corresponds to its ‘purpose’ and ‘final cause’. As an example, the characteristic shoulder of modern Volvo cars might help us identify the car as a Volvo among other cars. It might also express solidity or weight. The semantic interpretation is related to how we interpret the curve, what it means to us, its effect in our minds. The semantic question is thus what the product form represents, and how that representation is achieved. Vihma introduces the topics of product identity, ideal type, model, and adaptation to the environment as part of the qualities of a product that can be characterized as semantic.

According to Ellinger [1966], the product can inform the intended target user about its characteristics by way of the language of the product (die ‘Produktsprache’). The better the product informs, the stronger its identity. The product language includes the use of dimension, form, material characteristics, surface, color, movement, product graphics, type and means of functionality, sounds, smell, and packaging, for conveying information about the product. The first four of these factors are identical to the basic properties by Tjalve [1979]. Based on Ellinger’s information theory, Klöcker [1980] categorizes three kinds of information available from a product; information about *existence*, information about *origin,* and information about *quality*.

Other work in the field has focused on the use of product semantics in order to reason functionally about product form [Monö 1985, 1997], to evaluate semantic properties of a product [Wikström, 1996; 2002], and to distinguish and characterize relevant disparities of product forms against each other [Vihma, 1997].

The syntactic dimension

According to Vihma [1995], the syntactic dimension includes both the analysis of the technical construction and an analysis of visual details of the product's appearance, features of visual composition. Such features include simplicity and complexity of the overall form, symmetry, balance, dynamics and rhythm. These are visual effects of form composition, which is related to the laws of gestalt perception. One detail of the form can influence other visual details, as well as the overall form. The same applies to color; one color can affect other colors in a composition, as well as the visual impression of size and the dynamics of form.

For the work of this thesis, it is interesting to note that the syntactic dimension of a product form can thus be viewed from at least two perspectives: the syntactic dimension from the point of view of *semiotics*, and the syntactic dimension from the point of view of *aesthetics*.

From the viewpoint of *semiotics*, the form is, as a *representamen R* (semiotic sign vehicle), a means for our interpretation of the product viewed as a semiotic sign. The form, refers to something else, that is, its *object O*. For example, we might identify a specific form of a product, such as a characteristic curve on a car body, as being a typical 'Volvo-curve'. It refers to 'typical' Volvo forms. This is the semiotic interpretation of the O-R relation.

From the point of view of *aesthetics*, the perception of the same form requires no interpretation. We simply perceive the curve without attributing any semiotic meaning or reference to it. The observation of the curve is dictated by our pure visual experience; we might appreciate it as being elegant and appealing, we might sense that it visually balances other forms of the car, and we might enjoy its thematic repetition in other parts of the car body which gives us a harmonious feeling of a well held together, whole form.

The pragmatic dimension

The pragmatic dimension includes the analysis of the product from its point of use, e.g., from an ergonomic or sociological point of view, as well as the whole life-cycle of the product from planning to recycling, according to Vihma. The pragmatic dimension also allows for seeing other uses for the product than it was originally designed for.

The material dimension

The material dimension is related to the product's material and physical constitution and structure. The material dimension is considered to be a well-known area sufficiently covered by engineering sciences, and constituting the physical domain of the domain theory, it is not further discussed here.

Discussion of the contribution from semiotic theory

Although no effort is made in this work to contribute to semiotic theory, the field is acknowledged as an important related knowledge area. With the overall aim of this work to contribute to a holistic product design perspective, the findings must be compatible to established semiotic approaches, as proposed by, e.g., Vihma [1995] and Monö [1997]. Product semantics contributes with important aspects and is an established field of study in industrial design, which must be considered when developing a general approach. Product semantics is associated with the representative properties of the product form. The focus of this work is on the formal aesthetic properties of the product form. For those purposes, the elaborations by Vihma regarding the syntactic product dimension seem specifically promising. Focusing on the study of visual details of the material product form, the approach by Vihma is compatible with design science reasoning, and provides a straightforward connection to form aesthetics, discussed in the following.

4.6 AESTHETICS IN FORM DESIGN

Aesthetics is popularly understood as "dealing with the nature of beauty, art, and taste and with the creation and appreciation of beauty" [Merriam-Webster, 2001]. The question of what is appreciated as 'beautiful' or 'appealing' is naturally as delicate as a diverging issue, and the purpose of this work is not to investigate what is judged as aesthetically pleasing regarding to product design. However, in trying to relate the visual form of products to the concept of function, the study of the nature of visual form and our perception of visual form, is an important aspect of this work. The following section will give a short review of the field of aesthetics as related to this work.

Appreciation of aesthetic values of visual form is part of the science of perception psychology. "We study perception in an effort to explain our observation of the world around us", states Julian Hochberg (1964), and continues: "We can not begin to understand the human perception of the world unless we also understand something about the world as a set of physical events and something about the human being as a physiological structure"[11] [Westerman, 1976]. In the study of visual perception of design products, we must thus understand something about human appreciation of form as a phenomenon, as well as something about the structure of product form.

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[11] Quotations by Hochberg translated from Swedish, based on Westerman [1976].

On perceptual modes of visual form

In this section, the nature of aesthetics and a number of approaches for treating aesthetic issues in product design will be discussed. The term aesthetics comes from the Greek *aisthetes*; one who perceives. Industrial designer Monö [1997] defines aesthetics as "*the knowledge one obtains through the senses, in contrast to the knowledge one obtains through the mind*". Aesthetic appreciation can thus be regarded as everything we are able to perceive with our senses, including experiences, which we see, hear, feel, taste, and smell. In this thesis, the focus is on visual perception of form, which here includes shape (geometry), dimension, structure, and composition**.** Thus, e.g., the sensation of touch, perceived by our haptic[12] and tactile[13] senses, is not included. Color properties, such as hue, lightness, and saturation, are also excluded in this work.

Muller [2001] reviews different 'schools' of theory of aesthetic appreciation, which have been predominant in the 20th century:

Numerical aesthetics, pioneered by Birkhoff in the 1930s, were devoted to providing a formula, which describes the relationship between complexity and preference of form. Representatives of the movement such as Bense [1960], Garnich [1968], and Maser [1970], developed an 'aesthetic measure' of the relationship between degree of ordering and the complexity in appearance. A high coherence in the product form requires a minimal effort of appreciation, and leads to a quick aesthetic reward.

Minimalist aesthetics[14] indicated that the impression of beauty was determined by simplicity: the higher the degree of ordering and the lower the complexity, the more beautiful, was a belief shared by gestalt psychologists, represented by, e.g., Wertheimer, Köhler and Koffka, and functionalists from the 1930s and onwards. The well-known statement "form follows function" stems from the functionalist stream of the movement, maintaining that unnecessary forms disguise functionality [Arnheim, 1979]. However, the original meaning of the term, as used by Louis H. Sullivan, recognized not only the material utility aspect of function, but also included the value of gestalt and its semantic dimension. The contemporary, derivative, translation of the statement, suggesting that form and function are causally related, is a misconception [Muller, 2001]. The fact that the perception of form and its geometrical properties are not determined by a one-to-one relationship was shown by psychologist Ernest Mach in the 1860s [Westerman, 1976].

Psychological aesthetics was represented by Berlyne, who in the 1960s presented a model which refuted the minimalist movement of aesthetics. Berlyne's theory suggests that a certain optimal degree of complexity is most

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[12] Haptic: related to the sense of form by touching

[13] Tactile: related to the sense of surface structure by touching

[14] Term used in this thesis only

pleasing; a higher, as well as a lower, complexity renders the appreciation less attractive. This phenomenon is illustrated by Figure 24. The visual attractiveness is primarily determined by what is observed by the subject. Here, familiarity with the object plays a certain role for the perceived complexity: an aesthetically complex product may be perceived simpler and hence more attractive if the subject is familiar with it [Baxter, 1995].

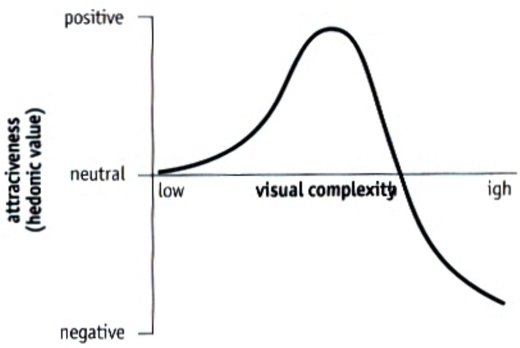

Figure 24. The relationship between the visually perceived complexity and the degree of attractiveness according to Berlyne. Adapted from Muller [2001].

Semantic aesthetics[15] rests on the supposition that classification of objects gives a feeling of satisfaction. A proposed hypothesis is the "preference-for-prototypes model", which dictates that the preference for an object increases as the 'distance' to the prototype decreases [Hekkert, 1995]. The attractiveness of an object increases the more we are exposed to it, and preferences are time-dependent and determined by the object's familiarity with specific objects of a category. The role of repeated exposure, time-dependency and symbolic meaning for the aesthetic appreciation of product form is also supported by the work of Berlyne [Baxter, 1995].

The schools reviewed above provide different points of view regarding the perception of aesthetic quality of form. However, this does not necessarily mean that they constitute incompatible ideas, but that different aspects or levels of the perception of form may simultaneously be explained by different models.

Visual perception as a dual aesthetic and semiotic experience

Vihma [1995] adopts an approach proposed by Goodman [1976] related to the semantic mode of aesthetic appreciation, in proposing that aesthetic appreciation of a product be associated with the interpretation of an aesthetic symbol. Vihma argues that the perceivable (aesthetic) and semantic levels are part of the interpretation of the product as a symbol, and concludes that "aesthetic experience can be characterized as a sense impression, a subjective appreciation of an object in which, however, also interpretations of references

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[15] Term used in this thesis only

take part". Thus, a new dimension of semantic study is introduced; the appreciation of a product for its own sake. The aesthetic experience, thus, is determined by a semiotic sign, and the aesthetic value of a product depends on how well it functions as an aesthetic symbol.

The 'aesthetic sign function' of Vihma includes the "perception and interpretation of something through sense impressions, emotions and knowledge of the object", background information consisting of knowledge of the product's design and manufacture. Goldman [1990] also distinguishes between the modes of experiencing based on sense perception and those that are representational or expressive. According to Goodman [1976], the aesthetic properties of a product are not intrinsic, but are formed in the interpretation of the product when the product functions as a symbol. Apart from adopting a semiotic approach, this view of aesthetics is compatible with the quality concept of Mørup [1993], discussed in section 4.2.

Monö [1997] also adopts the approach of aesthetics comprising a dimension of understanding, in addition to pure sensuous knowledge: "the aesthetics of design also comprises the study of the way in which human beings read and understand how to interpret the parts and the whole of a visual gestalt". Monö's definition of semiotics illustrates the close connection between aesthetic appreciation and the study of signs, both stemming from the same perceptual experience achieved through our senses (Figure 21).

It seems that it is possible to distinguish between, at least, two types of aesthetic appreciation; an interpretative mode of perception, related to semiotics; and a 'pure' sensuous experience of the form. In section 5.2, this issue will be discussed and elaborated.

Gestalt perception in design aesthetics

The term 'gestalt' is a German word with no equivalent in English. McKim [1980] suggests the terms form, shape, configuration, pattern, or 'organizational essence' for describing the meaning of gestalt. The phenomenon of gestalt perception was initially studied by Austrian and German psychologists in the late 19th century, and established the study field of 'gestalt psychology' in visual perception. McKim continues, that according to gestalt psychology, every perceptual image consists of more than the sum of its parts; it also possesses a 'gestalt', a patterning force that holds the parts together. The perception of gestalts is not limited to the seeing of forms, but everything we perceive which can be discerned as a whole constitutes a gestalt, including colors and olfactory sensations [Monö, 1997].

From the perspective of industrial design, Monö adopts a phenomenological view based on gestalt perception in proposing a more specific definition of *design aesthetics*: "*the study of the effect of product gestalt on human sensations*." The product gestalt is defined by Monö as "*a discernible whole; an arrangement of parts so that they appear and function as a whole which is* *more than the sum of the parts*." According to gestalt phenomenology, this implies that form, color, and material structure are not introduced into the whole as isolated factors, but are experienced in a way in which they work together and influence each other. This concept of aesthetics is illustrated in Figure 25.

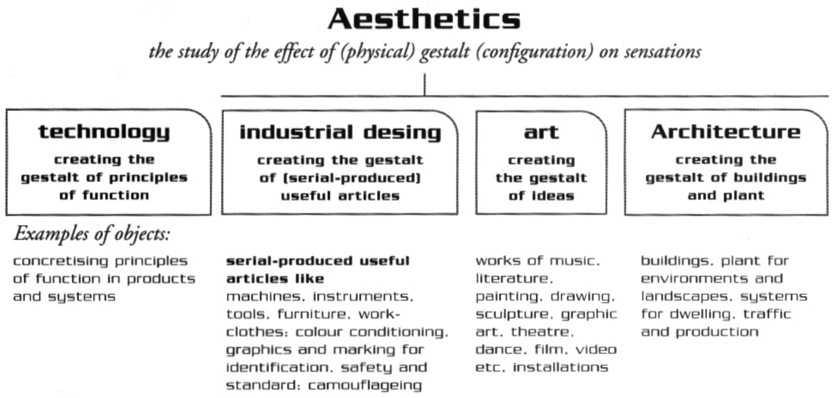


Figure 25 The concept of design aesthetics [Monö, 1997].

The perception of gestalts is central in the appreciation of the visual appearance in product design. In presenting a psychological view of aesthetic appreciation, it represents a mode of form perception, which is not determined by semiotic interpretation. Our ability to perceive gestalts is a basic ability of our visual perception, determined by the mind trying to create order in our act of seeing [Klöcker, 1980]. In the process of seeing, the first step in the perception of any, initially apparently unorganized, visual composition is pattern-seeking; the perception of an un-detailed overall pattern. This mode of seeing is referred to as *pre-attentive*, since it requires no deliberate effort on part of the viewer [Baxter, 1995]. The first impression we get when seeing a product, which allows us to judge the first image of it as appealing or attention grabbing, is determined by pre-attentive global processing. The second step, which is determined by personal needs and interests, is the analysis of the overall pattern for details. Baxter refers to this mode as *attentive*, since it involves deliberate focusing on details of the image to examine its component parts. This two-stage process is also evident in the act of drawing and the act of imagining; the overall relationships are established first, the details are developed afterwards [McKim, 1980].

Rules of gestalt perception

The perception of gestalts is driven by the innate strive of our mind to create order and simplicity in what we see. Through gestalts, we perceive how formal elements relate to each other, how they are organized into wholes, how they are arranged to create harmony, contrast, dynamism, rhythm, etc. [Monö, 1997]. Many authors have discussed the factors, or rules, which help us discern gestalts, e.g., Tjalve [1979], Klöcker [1980], McKim [1980], Uttal

[1988], Bruce and Green [1990], Baxter [1995], and Monö [1997]. In the following, the gestalt creating factors will be quickly reviewed.

The basic ability to discern regular patterns or groupings in visual compositions is determined by three factors:

The *proximity* factor: the closer between objects, the clearer the gestalt, Figure 26.

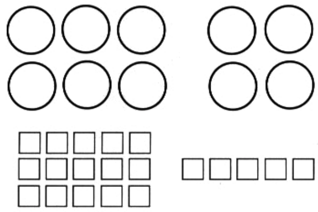


Figure 26. The proximity factor [Monö, 1997].

The *similarity* factor: figures with the same properties create gestalts, also called ‘the principle of common properties’ [Monö, 1997], Figure 27.

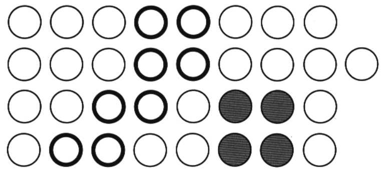


Figure 27. The similarity factor [Monö, 1997].

The rule of *good continuation*: also called ‘the good curve’ and ‘the common determining factor’ [Monö, 1997] or ‘the line of direction’ [McKim, 1980], allows us to group objects into a uniform curve or contour, Figure 28.

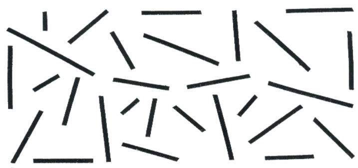


Figure 28. The rule of good continuation [Monö, 1997].

Other gestalt rules include the following:

The *symmetry* factor allows us to detect symmetry even in objects, which are symmetrically distorted, Figure 29.

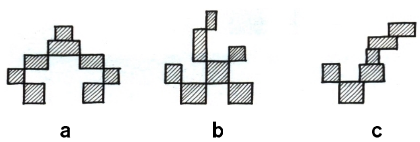


Figure 29. The symmetry factor, exemplified by visual balance (a: symmetrical, b: asymmetrical) and visual imbalance (c). Adapted from Tjalve [1979].

The *geometric* rule: closely related to the symmetry factor, it allows us to detect simple geometric forms more easily than irregular or highly complex geometric forms [Baxter, 1995].

The rule of *relative size*: The smaller the figure is in relation to some other figure, the more likely it is to be seen as a figure.

The rule of *surrounded-ness*: The figure surrounded by another figure is likely to be more easily perceived.

The rule of *orientation*: Figures oriented away from the vertical or horizontal plane are more easily perceived.

The rule of *figure and ground*: this rule is dependent on the four previously mentioned factors and describes our tendency to distinguish part of an image to be the figure or object and the remainder to be the background of the image [Baxter, 1995]. Monö [1997] refers to this rule as ‘the area factor’.

The *inclusion* factor: lines that enclose an area are more easily seen as a whole [Monö, 1997]. Also known as ‘the contour law’ [Klöcker, 1980], Figure 30.

The factor of *common movement*: different elements moving in a similar manner stand out as a gestalt

The *experience* factor: we perceive gestalts based on previous learning or experience of similar gestalts, Figure 31.

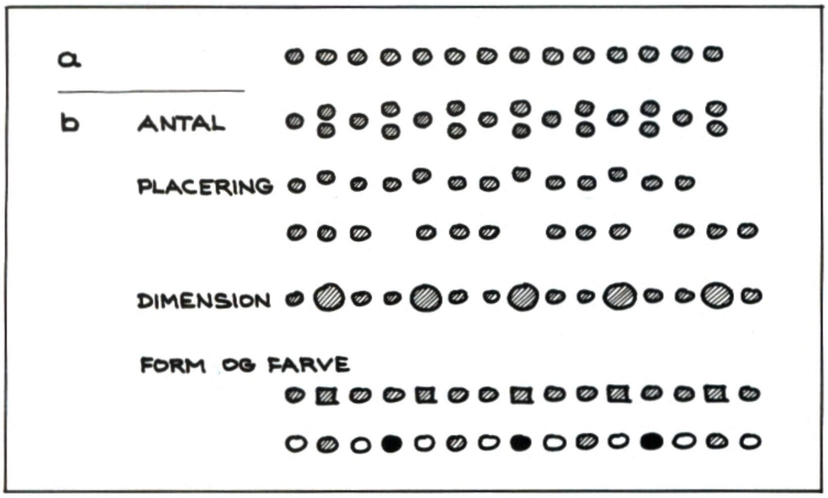


Figure 32. Rhythm through variation of arrangement, dimension, number and form of the elements [Tjalve, 1979].

The aesthetic phenomenon of rhythm is an example of a visual effect created by the combination of several gestalt rules. In Figure 32 [Tjalve, 1979], rhythm created through the use of the gestalt rules of proximity, symmetry, relative size, and similarity is shown. The illustration shows the use of the basic properties, the variables which the designer can manipulate in design, for the creation of the different types of rhythm effect. It also indicates that the syntactic function of ‘rhythm’ can be achieved in a number of alternative ways.

In addition to these gestalt rules, Klöcker [1980] suggests a number of ‘secondary gestalt phenomena’, including:

- *Optical illusions* such as ‘impossible figures’;
- The *tensioned line* (“gespannte Linie”) or the dynamic curve according to Monö [1997]; and
- *Ambiguous figures*, allowing for different interpretations in viewing.

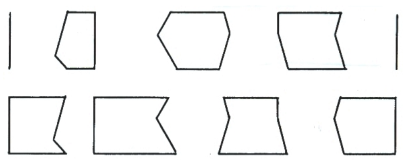


Figure 30. The inclusion factor [Monö, 1997].

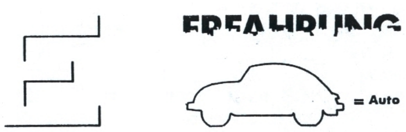


Figure 31. The experience factor [Klöcker, 1980].

Klöcker adopts a methodological approach in applying the gestalt elements and critera for the analysis of products according to the semantic, syntactic, and pragmatic dimensions. In the study, different tendencies in the development of form over time (in product series) and across product families are identified. These include a tendency for the optimization of form (reduction of unnecessary product form) resulting in a simplification of the form over time; a tendency towards the addition of information regarding use and functions of the product; and a tendency towards semiotic, functional and ergonomic order of the product form. Klöcker concludes that compromises are made between creating a strong product gestalt (a high order of the form) and the incorporation of clear product and quality information (through reduction of unnecessary information) in the product form.

The order of form

Muller [2001] presents a structured approach for a discussion of the order of product form. He distinguishes between three categories of features constituting order and meaning in product form:

- *prototypical features:* spatial characteristic of products indicating identical functional origin (solution principle), they *denote* (indicate) its function, its ability for use;
- *behavior-typical features:* spatial characteristics of products referring to a specific kind of use, they *connote* (refer to) the usage; and
- *solution-typical features:* specific ordering features of a product form determining the solution type, the visuo-spatial and material order of the three-dimensional solution.

The first two kinds of features are semantic features, which convey meaning and constitute significance for the user relative to the intended use, originating from the cultural usage of things. The third kind of feature refers to the form as such, covering the spatial ordering features. In Figure 33, the three kinds of categorization are illustrated.

For the purposes of the research presented in this thesis, the third kind of features are of primary interest, since they determine the visuo-spatial (in other words *syntactic*) characteristics of the product form. They are the result of a specific organization of elements determining the ultimate appearance of products. Muller defines three ordering levels of solution-typical features:

- A *topological ordering* (element distribution), relating to the position of spatial elements with regard to one another and in phenomenal space (space as we experience it perceptually). Four topological positioning and orientation arrangements can be observed: linear, radial, central, and orthogonal.
- A *typological ordering* (element ordering), relating to the form type of the spatial elements. The geometric form is created by dimensional, additive, and subtractive transformation of the basic forms, including the circle, all polygons, and the primitives.
- A *morphological ordering*, relating to the spatial-material quality of the embodied elements. Three morphological classes of materialized form are identified: linear, flat, and solid.

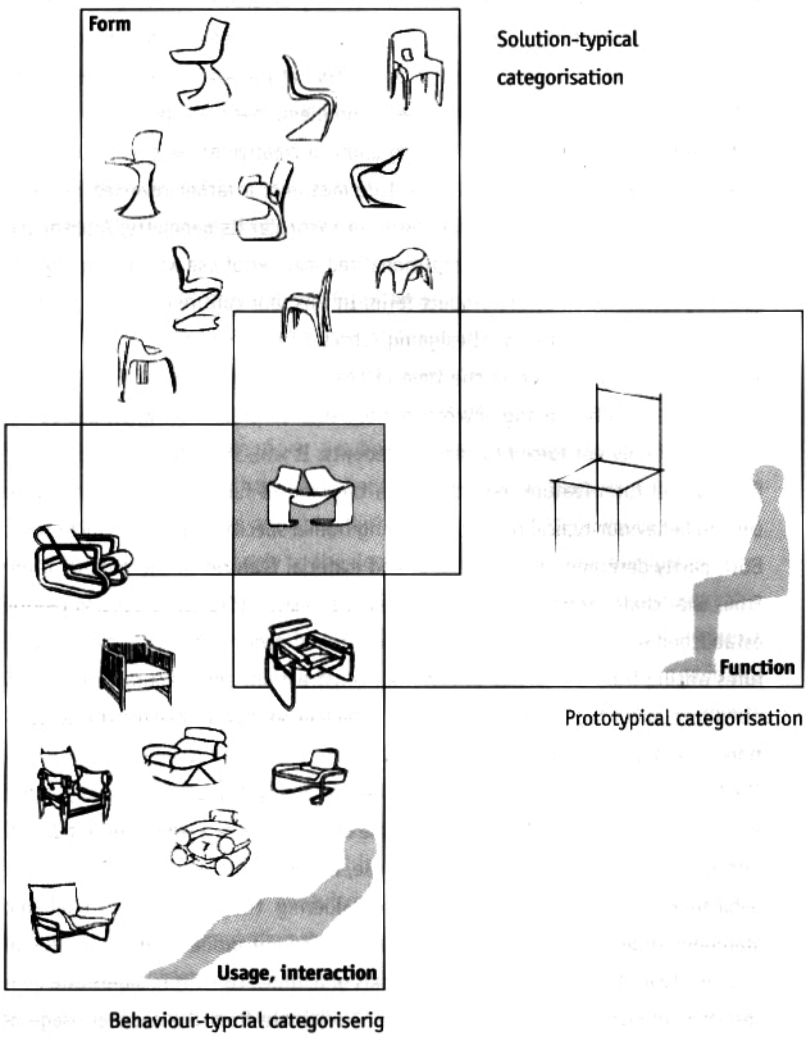


Figure 33. Prototypical, behavior-typical, and solution-typical categorization of the product kind 'chair' [Muller, 2001].

These different types of orderings can be used for description and classification of a product's form, manifested as a physical, material object. They reflect the categorizations of features presented earlier, and thus provide three ways to discuss and evaluate product function on all three levels. The order on each level is dictated by the order on preceding levels.

The creation of spatial order is determined by the structure of three-dimensional solution-typical features, producing a characteristic appearance of a product. The solution-typical features are produced by a specific, spatial/material organization of space. The structure associated with the internal, spatial/material ordering of the product form can be described by the concept of 'carrier', which denotes "the skeleton of which the concrete product form is one possible materialization". If the structure of the three-dimensional ordering is considered during form design, the structure is called *formal*. The designer uses this formal structure, e.g., a network of spatial relationships or ordered systems of geometric shapes, in establishing the form of a product or a family of different products. According to Muller, the formal structure aids the designer in choosing dimensions, determining position and form, the type and number of forms to be applied, etc. In doing so, the designer excludes 'randomness' in the form and creates coherence or relatedness. The coherence is regarded as the visible resemblance of parts, which compose the form through the use of common features.

Muller presents a comprehensive overview of structural elements on the topological level (including the dimensions of orientation and distribution), the typological level (the dimension of proportion), and the morphological level (the dimension of plasticity, constructivity, and materiality), which determine the visual 'articulation' of the product form. A related approach with a similar aim of analyzing and structuring the three-dimensional form is presented by Akner-Koler [1994]. Akner-Koler organizes a terminological framework for visual, three-dimensional form, based on four classes of visual features: elements and their properties, movements and forces, relationships, and organization, and develops a detailed nomenclature describing the properties and structure of all classes of forms.

Discussion of the contribution from aesthetic theory

Form aesthetics can be seen both from the perspective of our perception of visual form, and from the perspective of the content and structure of the form of the physical product. It is important to consider that we might 'read' the visual form differently, depending on previous experience, knowledge, cultural and social background, and the like. We must therefore acknowledge that aesthetic appreciation is can be explained by several theories, and that they must also be considered simultaneously. This is elaborated in section 5.2.

The perception of gestalts is fundamental to our appreciation of visual form. In product design, the gestalt phenomenon may be utilized for creating desired visual effects, which are part of the syntactic features of the form, as suggested by Vihma [1995], section 4.3. The possibility of utilizing the effect of gestalt perception is often not utilized to its full potential in product design, yet it is a significant factor for our appreciation of a coherent and visually 'well-working' form. The importance of gestalt factors is returned to in section 5.5, as a means for creating syntactic effects in product form.

The structure and order of form as discussed by Akner-Koler [1994] and Muller [2001] is an important related aspect for defining the articulation of the physical, visuo-spatial manifestation of the form. As a terminological framework for discussing and defining form, and for introducing a functional perspective on form design, the approach of Muller is valuable to this work. However, the functional aspects of form are treated only on the prototypical and behavior-typical levels of the form, and only as semantic functions. On the solution-typical level, which is related to the specific visual product form, the functional language is missing. In design science, this is the product level where function is most successfully discussed. As a result, the discussion of product form from the technical and aesthetic perspectives is 'limping'. A large effort of this work is to integrate the two perspectives in this respect. The discussion is elaborated in section 5.4.

4.7 THE FUNCTION CONCEPT IN DESIGN

The review of frame of references for this work is concluded with a presentation of the singularly most important concept of this thesis; the concept of *function,* related to product design. The term 'function' is as a concept found in a wide variety of fields, each having its own specific meaning to the term. However, it is interesting and important to note that despite the many definitions of function found in literature, common for all perspectives of function, is that in the function of a product is embodied the reason for its existence, the *purpose* of the product. A second characteristic of the functional language is that it also provides a way to discuss physical and immaterial solutions of the product on an abstract level, without referring to specific solutions. In this work, it is important to consider the various function definitions and approaches for functional representation found in various fields related to product design, associated with synthesis as well as analysis of product functionality. Therefore, the presentation of different perspectives of the function concept deserves its own section.

Function in product design

Here, the term product design is used to denote the areas of design related to mechanical engineering design, industrial design, and ergonomic design.

Starting with the *mechanical engineering* perspective of product function, the function definition used in the domain theory states that "*a (purpose) function is the capability of a machine to create a usable effect*" [Andreasen, 1980]. A slightly modified definition of function is provided by Jensen [1999]: "*Function is intended and purposeful behavior, i.e., the subset of a behavior that subjectively is considered purposeful by a human being*". This definition of function suggests that functionality can be valued on a subjective level, i.e., it is to be seen as being 'in the eyes of the beholder'. This is an important aspect of the functional language, when applying the concept to aesthetically determined properties of the product.

Hubka and Eder [1988] recognize, in the theory of technical systems, five classes of function according to purpose of the functions. The *transformation function*, with the selected mode of action, fulfills the purpose of the technical system and is necessarily accompanied by a series of *additional* *functions*. These include auxiliary functions; driving, propelling or energy delivering functions; regulating and controlling functions; and connecting and supporting functions. According to the function complex law [Andreasen, 1992], a means realizing a function determines the types of secondary functions on a lower function level, as indicated in Figure 34.

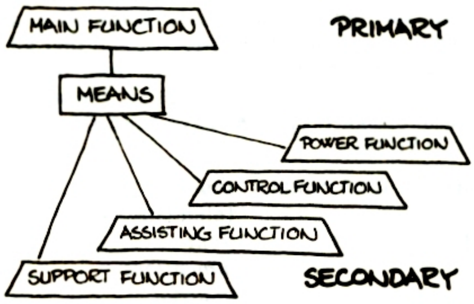


Figure 34. The function complex law [Buur, 1990].

For the purposes of mechatronic systems design, Buur [1990] suggests a slightly modified complex of *secondary functions*. Buur states, in line with other authors, that “there is a general set of secondary functions to be found in the vicinity of any main function”. The set of functions supporting the main function includes:

- *cover function*: provides energy for the primary (power-requiring technical) means,
- *control function*: governs the state of the means, e.g., on/off control,
- *interface function*: if needed, converts inputs or outputs to fit the environment of the primary means,
- *protection function*: protects primary means from, e.g., overheating, and from exerting unacceptable impact on the system environment,
- *communication function*: permits means to exchange (status-) information with the surroundings, e.g., a control loop,
- *structural* (or *support*) *function*: ensures that spatial conditions are satisfied to make the primary means work.

Buur’s proposed set of secondary functions seem to provide a more promising outset for creating a range of function types suitable for human-product systems, than the categorization of Hubka and Eder [1988]. An example of a functional structure according to Buur is shown in Figure 35.

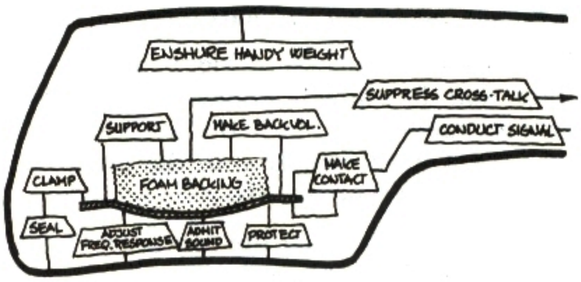


Figure 35. The functional structure for a telephone handset. The ergonomically and semantically related function 'ensure handy weight' has been attached to the form of the casing [Buur, 1990].

Andersson [2001] classifies product functions according to the taxonomy of Figure 36. *Active functions* describe the activities required by the technical system to deliver the effects necessary to bring about a transformation. *Passive functions* refer to functions that are static in nature, where no transformation is involved. *Internal functions* designates functions associated with the internal action of the product, while *external functions* are associated with the interaction between the technical system and surrounding systems, such as humans and life-cycle systems. Furthermore, functions can be classified as *primary* or *secondary* according to the function complex law.

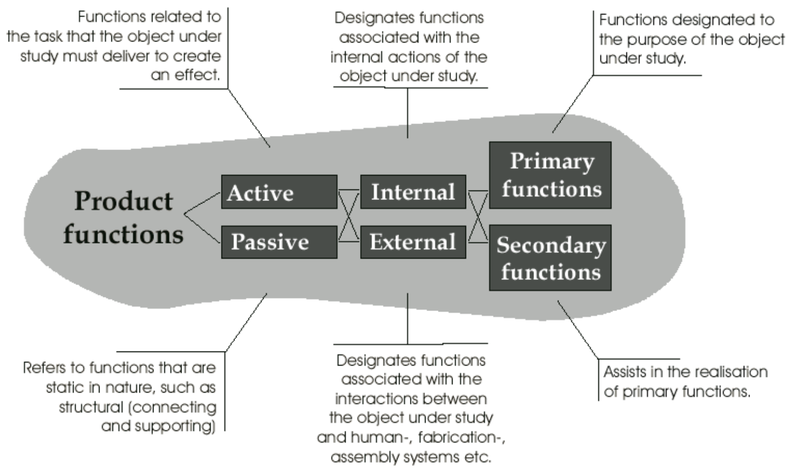
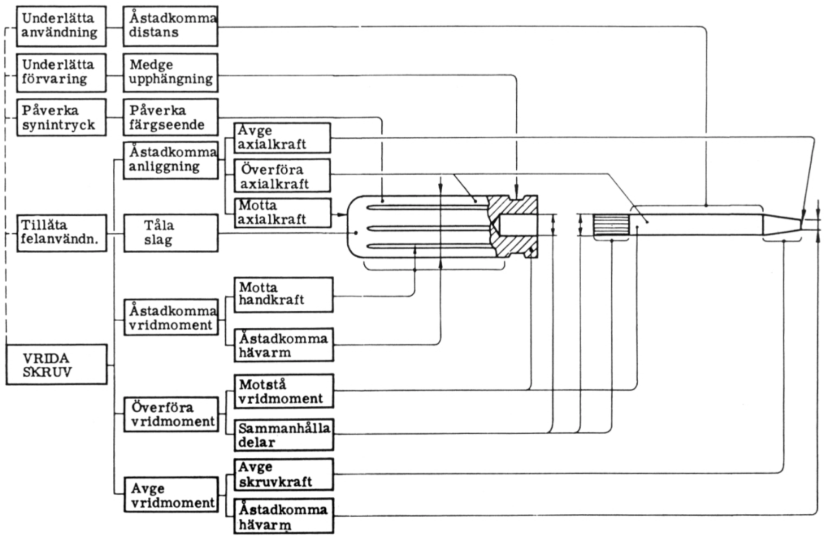


Figure 36. Classes of functions, according to Andersson [2001].

Roozenburg and Eekels [1996] recognize functions as statements of intended behavior of a product, which, unlike statements on properties, are *normative*. A product has certain properties or does not have them, irrespective of the purpose of the user. A distinction is made between intensive and extensive properties. Intensive properties depend on the physico-chemical form only, such as specific gravity. Extensive properties result from the intensive properties and the form of the product, such as the weight of an object. The extensive properties are of special significance to the designer, since they determine the functioning of the product. Functions on the other hand, are imposed on a product; if not fulfilled, the intended goal of the product will not be reached. Roozenburg and Eekels stress that ‘function’ is a general concept, referring to the purpose of the product. Their definition of function reads: “*the function of a product is the intended and deliberately caused ability to bring about a transformation of a part of the environment of the product*”.

From the perspective of *industrial design*, Monö [1974] defines function as *an activity of a concrete or abstract object* and uses ‘design functions’ for value analysis of products. Olsson [1972] divides product functions into three types: *main functions*, the function which the product primarily is intended for; *support functions*, which support the use, attractiveness, or manufacturing without being necessary for the main function; and *partial functions*, which collectively constitute a higher-order function. For the purposes of this work, the support functions are particularly interesting. Examples of support functions according to Olsson are ‘provide grip’, ‘support hand’, ‘facilitate handling’, and ‘influence visual impression’. Of these, the first three are associated with ergonomic or semantic functionality of the product, while the latter is related to aesthetics, particularly syntactic, aspects of the form. An example of a functional decomposition of a screwdriver is found in Figure 37.

Figure 37. Function tree of a screwdriver, according to Olsson [1972].



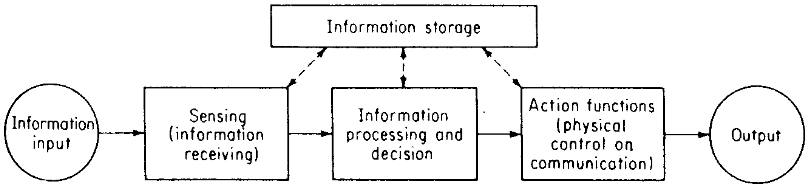


Figure 38. Types of basic functions performed by humans or machine components of human-machine systems [Sanders and McCormick, 1987].

In the field of *ergonomics*, a function is related to the fulfillment of one or more of a system's goals, where every component (the lowest level of analysis) in a system serves at least one function [Sanders and McCormick, 1987]. Components typically serve a combination of four basic functions; *sensing* (information receiving), *information storage*, *information processing and decision*, and *action functions* (physical control on communication), see Figure 38. These functions are performed by human or machine components of human-machine systems; one task of the human factors specialist being to aid in the allocation of functions during the design process.

Aesthetic functionality of products

Sandström [1973] approaches the visual aesthetic experience from a functionalistic perspective in defining four functional levels of visual aesthetic experience of everyday products. The functions are defined according to the following[16]:

- The *attributive function* is an extrovert function, related to what the subject (e.g., the user, owner, designer) wants to express about him or her self, the group to which they belong, the society etc., regarding properties, values, ambitions and activities.
- The *idolic function*, which is an introvert function, regarding the relation between the subject and the object. The idolic function is related to, e.g., affective or religious values and experiences.

According to Sandström, the attributive and idolic functions are intimately associated with each other with respect to mode and level of action, and may jointly be termed *symbolic functions*. The remaining two functions are associated with semantic and emotional experiences:

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[16] Translated from Swedish, based on Westerman [1976].

- The *iconic function* has an illustrating role, related to informative and factual aspects of the object. All visual impressions, which can be associated with, or which create associations to, concrete reality or tradition, can be assigned to iconic functions. Thus, the iconic function according to Sandström constitutes a type of semantic functions. Their function is to create references to reality; they have an interpretative role.
- The *sensual function* creates within the perceiver a direct stimulus to the senses, such as a feeling of pleasure or discomfort, balance or conflict, etc. The sensual function is dependent on personal factors, and is often associated with emotional reactions, particularly in the interaction with other functional levels, such as the iconic function. Sandström emphasizes that the role of emotion in aesthetic reactions should be taken cautiously, since it represents a tendency towards relying on 'feeling' of visual impression instead of reasoning or discussion.

Sandström concludes that the experience of visual impression can occur on one or several functional levels, and that there is always an interaction between these levels in the aesthetic experience. The iconic and sensual functions are constantly interacting, and that they always affect the symbolic function level through feedback action. Related to the field of semiotics, the attributive, idolic, and iconic functions may collectively be seen as types of semantic functions associated with attribution of meaning to an object, while the sensual function is more directly associated with a 'non-interpretative' mode of perception based on aesthetically determined experience.

Semantic functionality of products

Gros [1983] presents a functional decomposition, which is related both to the function concept found in mechanical design and to the aesthetic appreciation of product form. According to Vihma [1995], the product function of Gros is regarded as the relationship between product and user. Functions of a product are of two types, Figure 39:

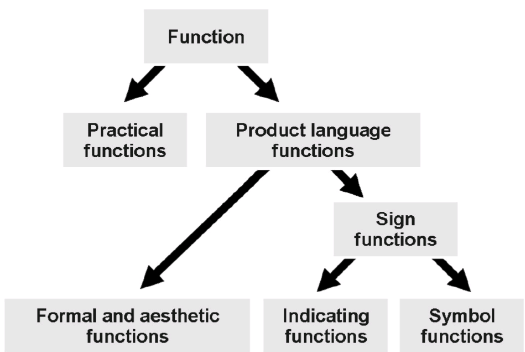

Figure 39. Product functions according to Gros [1983], after Vihma [1995].

- *Practical functions*, which are associated with the ability of the product to function in practical use. Here, it is easy to see the connection to the (purpose) functions found in engineering design, and to ergonomic functions associated with usability and safety of the product.
- *Product language functions*, which refer to the appearance of the product.

Product language functions are of two types. The *sign functions* function by way of the semiotic sign. They refer to the practical functions and serve purposes of 'self-explanation' of product properties. They function through signs, which point to properties and symbolic representation of the product form, i.e., they represent semantic functioning of the product. The *indicating function* provides 'factual' information about use and product properties, associating the product with a group of products. The *symbol function* provides 'qualitative' information, which is dependent of, e.g., subjective, personal, and cultural interpretation of the user. The *formal and aesthetic functions* include the non-semantic part of product functionality, associated with the visual aesthetic content of the product.

Muller [2001] presents a refined version of Gros's function structure. According to Muller, the communicative function is created by 'space structuring' and 'sign carrying' features of the product form, Figure 40. These features determine the 'formal-aesthetic' and 'sign' functions of Gros. *Spatial structuring features* enable the user to perceive the visual form as such, "they generate the conditions for gestalt formation and thus for categorizing an object", according to Muller. The *sign carrying features* enable the user to interpret the product's purpose, a kind of semantic functioning. These are categorized into two types:

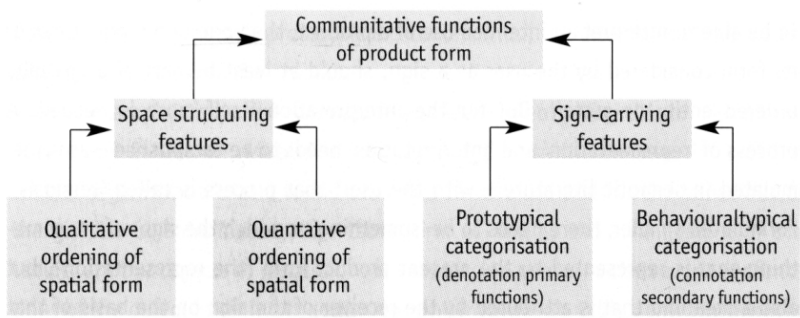

Figure 40. Communicative function of the product form, distinguished by space-structuring and sing-carrying features [Muller, 2001].

Functions on the *prototypical level*, referred to as *primary functions*, signify the material utility value of the product form. Through a specific set of features, these functions *denote* (indicate) the primary functional significance (the solution principle) of the form, which is considered to be the sign carrier. The primary functions are considered the basis of origin for each product.

Functions on the *behavior-typical level*, termed *secondary functions*, signify the socio-cultural utility value of the product form. They are sub-ordinate to the primary functions and *connote* (refer to) the secondary functional significance (the intended way of use) of the form through a specific set of features, considered to be sign carriers.

For the third feature level, concerning the *visuo-spatial and material order* of the three-dimensional solution, Muller attaches no functional significance, but regards it as important for achieving internal visual coherence of the product's appearance. However, in discussing the 'perceptual effects' of form from an aesthetic viewpoint, one may state that also at this level of product form, a functional dimension can be identified, which is determined by the visuo-spatial and material order of the form. In suggesting that the space-structuring features contribute to communicative function of the product form, Muller in fact acknowledges this type of functionality.

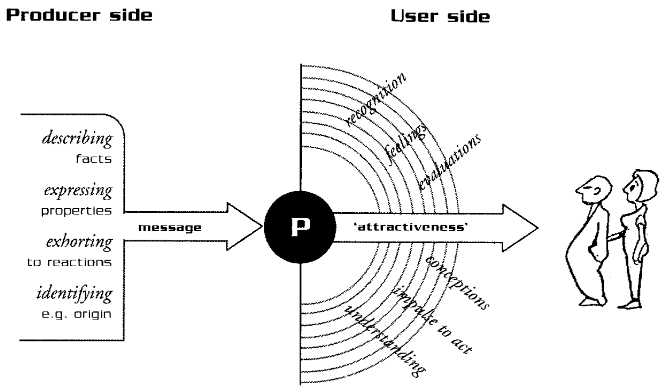

Figure 41. The semantic functions of the product and their role in communicating 'attractiveness' of the product [Monö, 1997].

The *semantic functions* of Monö [1997] are similar to the sign functions of Gros [1983]. Monö defines four semantic functions, which are related to the user's perception of 'attractiveness' of the product, Figure 41. All four functions semantic functions;

- *to describe*: purpose, technical function, mode of operation
- *to express*: properties
- *to exhort*: reactions
- *to identify*: a product, its origin, kinship, location, nature, or category

are distinguishable by the receiver. The expressing function is designed into the product by the designer, while the describing function is inherent to the product. The identifying function can belong to the expressing as well as the describing function. Compared to the sign functions by Gros [1983], Monö's semantic functions point to specific semantic functionality of the product form, and are both indicating and symbolic in nature. Compared to Muller

[2001], the semantic functions attach functional significance to the form elements on the solution-typical level of the form, which reaches a deeper, and more specific, level of the form. The connection to the function concept in engineering design science is thus stronger, and the approach of Monö therefore seems more promising in that respect.

Discussion of function concepts in design

The function concept in product design is important for analyzing and synthesizing product solutions. By stating the purpose of a solution in function terms, it becomes possible to generate and evaluate competing solutions with each other. The review of function concepts shows different approaches for relating the function concept to products. Authors present function concepts representing different modes of action and different levels of abstraction related to product structure. Despite the differences, there are similarities in the classification and purpose of functions from the different perspectives, which seem to provide a promising starting point for the creation of a functional approach, capable of handling technical, ergonomic, syntactic, and semantic perspectives of product form design.

The purpose of this work is to provide support for development of visual product form. In order to be effective, the level of the specific product form must be reached. This level corresponds to the solution-typical level of form according to Muller [2001]. On that level, the contribution of Monö [1997] regarding semantic functions is very suitable. However, the syntactic dimension of product form has been neglected in terms of having functional contribution. Here, there is a potential for reaching a deeper level of product form discussion, which is related to semantical and technical functionality of the product.

For supporting form development, there thus seems to be an unexploited potential of assigning functional significance to the visuo-spatial structure, i.e., the syntactic dimension, of the product form. Several authors, e.g., Gros [1983] and Muller [2001], acknowledge the gestalt-creating effect of the form on this level. Having perceivable effects, the form, according to the definition provided by design science, thus has functionality. This syntactic functionality of visual product form is introduced and elaborated in the next section.

5 CONTRIBUTION

The results presented in contribution are based on work published in appended papers A-F. The presentation of the contribution of this work is structured into descriptive results, encompassing sections 5.2-5.7, and prescriptive results, section 5.8. In descriptive results, the framework of design syntactics describing the structure and nature of visual product form is presented. In prescriptive results, methodical approaches for development of the visual design aesthetics of the product form, based on the framework, are presented. Each section is concluded with a discussion chapter. First, the contribution is positioned in relation to design science.

5.1 POSITIONING THE CONTRIBUTION

In an effort to map the different areas of design research, Hubka and Eder [1988] describes design science as the relation between four poles: aspects of the technical system and studies of the design process as one main axle, and prescriptive and descriptive knowledge on the other main axle. Between these axes, areas of design object and process knowledge are found, according to Figure 42.

The research carried out during the work with this thesis mainly involves descriptive statements about design artifacts (the object of the design process) and the theory of design processes related to visual form design of the product. It also involves prescriptive statements in the form of methodology approaches for visual form design.

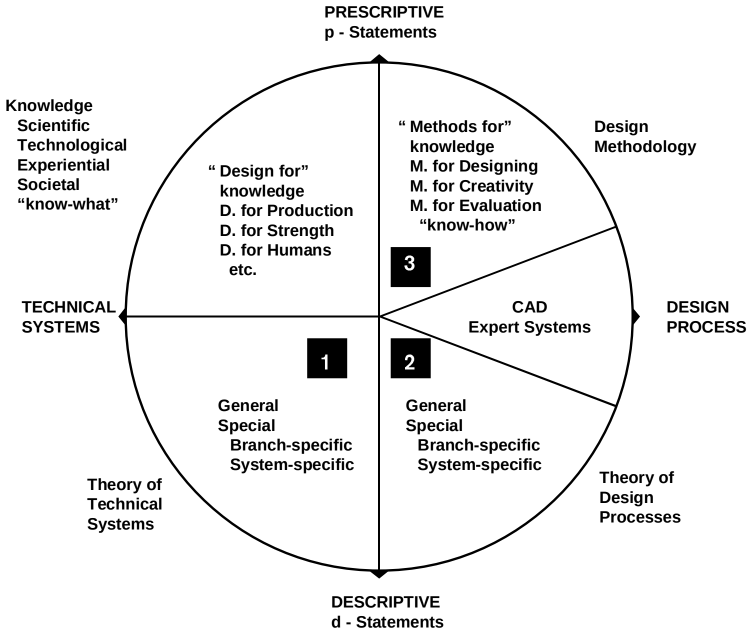

Figure 42. The structure of contributions to design science, after Hubka and Eder [1988]. This research work contributes with descriptive knowledge about the designed product (1), descriptive knowledge about the design process (2), and prescriptive knowledge in the form of methodical approaches (3).

The contribution from a modeling perspective

The theoretical contribution proposed in this thesis is a constitutive artifact and phenomena model related to visual form design of discrete, physical products. A model is by Buur [1990] defined as “*an artifact, which reproduces a subset of the properties of an object*”. Figure 43 defines a model according to Buur and Andreasen [1989].

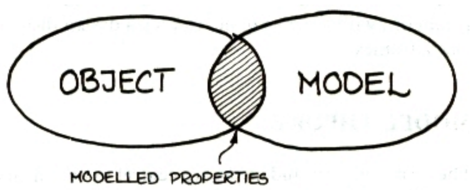

Figure 43. Relation between object and model [Buur and Andreasen, 1989].

By property, Buur means any attribute or characteristic of the object, and the object is the product or rather the designer’s idea of the product to be designed. The modeled properties include the properties, which are common for the model and the intended product, but also ‘non-intended’ properties inherent to the model. For example, a physical model may have material properties, such as the modeling material (e.g., cardboard or plaster), which are not part of the modeled object. Models can also be non-physical, based on a theory.

According to the theory of modeling [Mortensen, 1995], objects and phenomena can be described by theories and models. Such theoretical models have certain attributes, e.g., constitutive and behavioral, in common with the modeled object or phenomenon. Modeling can therefore be seen as a process where observed facts are filtered through a theory [Tomiyama et al., 1989], Figure 44.

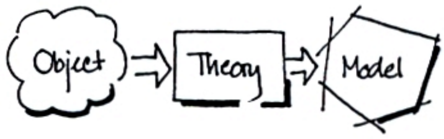

Figure 44 Object and model. From Mortensen [1995], after Tomiyama [1989].

The theory proposed in this thesis describes how the human perceives visual aesthetic form related to the characteristics of the visual form of the product. The theoretical elements are based on insights on how the human perceives and interprets visual form, including perception psychology, communication theory, and semiotic theory, and how the product form is structured and composed, based on theory of technical systems, the domain theory, and theory of order of form. The theoretical basis is found in section 4.

5.2 A MODEL OF AESTHETIC PERCEPTION OF VISUAL FORM

Why is it important to consider modes of visual form perception in this thesis? A problem identified early in the research work was the difficulty of discussing form design proposals on an objective, formal level during form design development and evaluation. As designers, we define the form of the product. And, as designers, we also perceive the form and make judgments based on the resulting appreciation of form. The outset for creating a model for form discussion thus seems to have two parts; a discussion of the form of the product, and a discussion of our perception of product form. The discussion will start with the latter issue.

Through perception, we gain an understanding of the world around us through our five senses. In this work, the focus is on visual perception of form. Thus, a basic assumption is that through increased understanding the visual product form, we will be able to discuss and reflect upon it more rationally and objectively in the process of designing. In order to understand how we appreciate the form design of a product, we must first understand how we as humans perceive visual form.

As a model for the visual perception of product form, aesthetic appreciation is in this work divided into two categories;

- a *sensuous, 'non-interpretative' mode*, denoting a primarily 'experiential' appreciation of the form, and
- a *semiotic, 'interpretative' mode*, denoting an appreciation based primarily on attribution of meaning to the form.

The division of perception into these two modes reflects two principally different ways of visually perceiving form, which is supported by semiotic and aesthetic literature, as well as perception psychology (e.g., Sonesson [1989], Goldman [1990], Vihma [1995], Monö [1976, 1997]). The two modes are also related to the division of Sandström [1973], who differentiates between the sensual function of an object and a group of functions related to semantic interpretation. The differentiation between these two modes of perceiving an object also reflects the basic philosophy of the schools of psychological and semantic aesthetics, as discussed in section 4.7.

The two modes of perception is a model for describing the nature of the phenomenon of appreciation of visual form. Of course, it may be argued that it is difficult or even impossible to determine what mode is employed at a specific time or in a certain situation of appreciating a form. The different modes may also, to various degrees, occur simultaneously. No postulation is made regarding which one of these modes of perception occurs before the other, or under which circumstances a certain mode of perception prevails, issues which have been subject to an ongoing discussion in different schools of perception. Our judgment of an object as being, e.g., 'ugly', 'attractive', or 'pleasing' is likely due to a combination of our socio-cultural background and other subjective and contextual factors, resulting from a perception process involving both modes. For the purposes aimed at in this thesis, it seems more relevant to consider the characteristics of the two modes.

The sensuous mode of visual perception

The sensuous mode of perception is concerned with our direct, 'non-interpretative', appreciation of form, which is not 'filtered' through our deliberate search for meaning or purpose of the form. This mode is related to our perception of the general characteristics of a form, how it is structured, how it is composed, and the content of the form. Consciously or unconsciously, we experience the form on the overall, 'global' level, and on subordinate levels. On the overall level, we might perceive the aesthetic qualities of the form; if it is harmonious, balanced, well proportioned, etc. On subordinate levels, we might judge its visual complexity, coherence, and order.

The sensuous mode of perception can be regarded as resting on the principle suggested by Berlyne (see Figure 24), stating that our aesthetic appreciation is determined by the visual complexity, which is neither too high nor too low. Here, it is suggested that a low visual complexity may not only result in indifference, but may even produce a negative impression of attractiveness.

The extended model also suggests that visual complexity is relative; if the complexity is increased above a certain level, new harmonies arise in our perception of the visual form. The number of ‘harmonic levels’ in the visual form is principally infinite; it depends on the level of observing the object[17]. It is likely, that his level of form perception is less subjectively determined than the interpretative level. It can be proposed that the appreciation of the form on the sensuous level is more or less universal; the perception of order and complexity in the form is less dependent of contextual, cultural, or personal factors of the subject, than is the case for perception on the interpretative level.

The interpretative mode of visual perception

On the interpretative level, our appreciation of the product is determined by the meaning we interpret into its gestalt. This mode of perception is determined by our conscious or unconscious reasoning in interpretative terms, like: “what is this thing?”, “who made it?”, “how is it used?”; we try to ‘read the message’, to consider the representative and contextual meaning of the object. Here, our familiarity with similar products plays a significant role, as suggested by Hekkert [1995]. The field of product semantics, regarding the understanding of product form, its expressive and descriptive properties, etc., as discussed in section 4.6, belongs to this level of form perception.

To a larger degree than the sensuous level, the interpretative level is subjectively determined. Socio-cultural, experiential, and contextual factors are highly associated with the interpretative mode. The more often we are exposed to other objects with similar semantic characteristics, the greater the satisfaction. This perception level implies one possible reason for the differing opinions regarding styles and tastes between people, which is dependent on the varying traditions in use of shapes, colors, patterns, etc., in form design. The representational properties of product form are extensively treated in semantic literature, and are not further treated here.

The previous discussion suggests that we can differentiate between subjective and objective aspects of form appreciation, i.e., between what meanings we associate with the form, and its composition and structure, respectively. The discussion of whether we ‘like’ a certain form or not, if it is more appealing than another form, is a much more delicate issue, which will not be ventured into in this thesis. Here, the purpose of proposing a model for visual design aesthetics is not to evaluate the ‘attractiveness’ of a product, but to propose an approach for discussing the structure and content of the visual product form, which is more independent of subjective valuation.

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17 This phenomenon is observable, for example, when a material structure is observed in a scanning electron microscope; with increasing magnification, we will repeatedly perceive new visual harmonies, down to the molecular level and even further.

5.3 THE FRAMEWORK OF DESIGN SYNTACTICS

Design syntactics is a constitutive framework for visual product form design. It is a 'hybrid' theory, based on theoretical elements from various fields of knowledge, reviewed in section 4 of this work. The framework includes three main conceptual elements or models, see Figure 45.

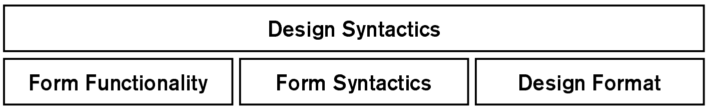

Figure 45. The framework of design syntactics.

The elements are denoted according to the theory of modeling [Mortensen, 1995]:

- *Form functionality*: A structural and behavioral model based on the domain theory, describing the effect of visual form on the function and organ levels
- *Form syntactics*: A constitutive model describing the structure and configuration of the form on the organ level (form entities), and material-physical level (form elements)
- *Design format*: A phenomenon model describing the pragmatic aspect of form design in product development, related to the philosophy of design at a company or design department level

The elements of the design syntactics framework aim at describing and explaining the nature and content of visual form design, i.e. the structure, composition, content, and functioning of form. In the following, the three elements of the framework are introduced and discussed.

5.4 FORM FUNCTIONALITY MODELING

Linking visual form aesthetics to functional reasoning

In many ways, functions rationally motivate the existence of products. In daily speech; *an object without a function is not useful*, i.e.; it does not have a *purpose*. Following the same line of reasoning, all elements of a product, whether they are systems, modules, assemblies, components, parts, etc. must have a function, or their existence would not be motivated. This implies that 'function' is understood to denote 'a task of a product' in a general manner, implying that the function itself is the motivating reason for the existence of some element of the product.

Previous efforts at integrating functional thinking with aspects of product form have been directed towards technical functionality of the product[18] (such as structural or power functions). Linking visual form aesthetics to functional reasoning provides the opportunity to handle visual aesthetics of product form on equal terms with other design aspects of the product, such as economic, ergonomic, and technical considerations, using a common terminology.

In the new theory of domains [Andreasen, 1998c] the product is modeled from three different perspectives; the transformation domain, the organ domain, and the parts domain, as previously illustrated in Figure 14. In the organ domain, organs deliver the desired functions of the product through its parts, belonging to the part domain. As a generic structural and behavioral model, the domain theory has in this work been adopted and modified in order to be able to capture and handle the structure and behavior of visual product form. The discussion regarding contributions to the domain theory will in the following be presented in relation to the structural model of the domain theory.

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[18] See, e.g., Andreasen [1980, 1992], Hubka and Eder [1988], Pugh [1990], Cross [1995b], Pahl and Beitz [1995], Roozenburg and Eekels [1995], Ulrich and Eppinger [1995].

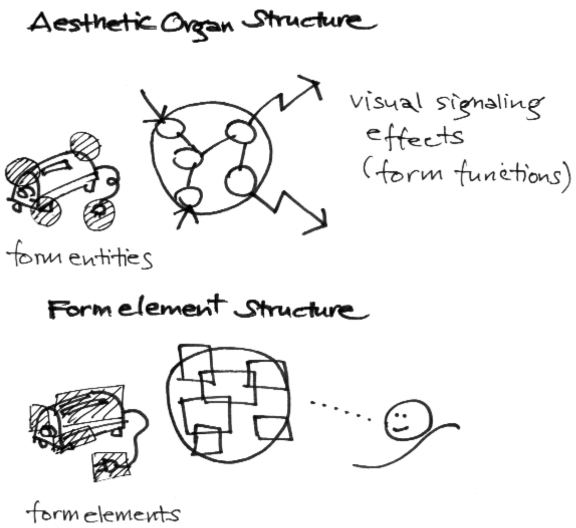

Figure 46. The functionality of form related to the structure of the theory of domains. Form functionality is delivered by aesthetic organs in the organ domain, and realized in the parts domain by form elements of the physical product.

Aesthetically determined influences on different domains

During aesthetic form development, the intent of the designer (his reasons for the form design) drives the aesthetic development of the product form. Here, the designer, by proposing specific aesthetic form solutions, lays the basis for, e.g., cost and quality properties of the finished product, which are associated with the *transformation domain*. Such decisions affect the transformation process. These intents, as statements of purpose, can be considered functions of the form; they *do* something in the eyes of the beholder. Like the engineering designer tries to fulfill technical functions of the product in the engineering design activity, the form designer, in the sketching process, searches the space of possible form solutions by help of certain aesthetic principles and means, in the quest for realizing the aesthetically determined functionality of the visual form, denoted *form functionality*. As for technical function design, the synthesis of product form aesthetics is also determined by the *law of vertical causality*. As formulated by Hubka [1976] and Andreasen [1980], this law states that a particular function cannot be decomposed into subfunctions, unless a means has been selected to realize the function.

By further developing the domain theory towards an ability to handle aspects of visual design aesthetics, it is possible to describe the technical transforming functionality as well as visual, communicative functionality in a generic model, capturing engineering design as well as industrial design intent and purpose of the form.

In the *organ domain*, form functionality is fulfilled by *aesthetic organs*, Figure 46. The aesthetic organ structure can be considered a specific viewpoint applied to the domain theory. In an aesthetic organ structure, different hierarchical levels of organs fulfilling various aesthetic purposes can be identified. When decomposed, organs realizing aesthetically determined sub-functions (form functions on a lower complexity level of a product form) can be defined down to the level where they are rendered by specific form elements in the form of a product.

In the *part domain*, aesthetic organs are realized by *form elements* of the product. *Form entities* constitute the relationship between physical form solutions and aesthetic organ reasoning.

In the following discourse, the reasoning is developed in relation to the structural order of the domain theory, beginning with the transformation domain and the nature of aesthetically determined functions.

Three classes of effects of the human-product system

For the human-product system to perform as intended, the product must contribute in delivering the necessary effects. The creation of desired effects is determined by the product having appropriate (necessary) functions.

> For example, the purpose of a car body exterior is to create a desire in consumers to want to own that car, to inform us about the brand of the car, its performance and qualities, and to relate the car to previous designs and brand values. Furthermore, it possesses technically determined structural and aerodynamic functionality. The visual form of the car body thus has the ability to deliver a purposeful effect to the perceiver, i.e. the form has a function.

The meaning of effect, Andreasen [1980], is in this work extended from a purely technical transforming, part-to-part sense, to a concept capable of explaining purpose of part-to-human relations as well. In a human-product system, i.e., a system consisting of a product and a user who interacts with the product for a purpose in an environment, it is possible to identify three classes of necessary effects, which are created by the functions of the product. In Figure 47, the effects are related to the model of the transformation process by Hubka and Eder [1988]. The types of effects include:

- *effects exerted on the operand* of the technical process *(i),*
- *internal effects* ensuring ‘physical stability’ of the technical system or product (*ii*), and
- *interaction effects*, necessary for the interaction between product and user (*iii*).

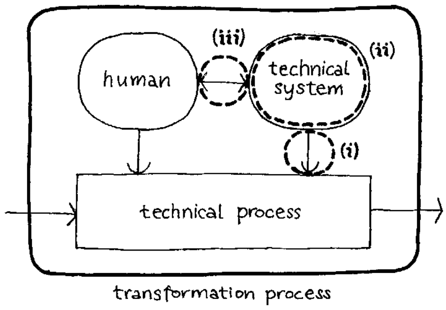

Figure 47. Three classes of effects of the human-product system in relation to the transformation process. After [Hubka and Eder, 1988].

Mode of action of interaction effects

The effects are principally different in terms of mode of action principles. The first type of effects for driving the technical process is extensively treated in the theory of technical systems, Hubka and Eder [1988]. Internal effects are associated with the internal structural solidity of the product or technical system, or for connecting products or technical systems, and include, e.g., static force field mode of action. The *interaction effects*, which are the object of study in this work, belong to human-product interaction, and are not internal to the product itself. Interaction effects are of two types;

- *physiological*, or *physically determined*, interaction effects, involving ‘physically’ stimulated interaction between the human and the product, such as anthropometric fit, noise, and vibration levels; and
- *sensorial*, or *non-physically determined* interaction effects, involving ‘non-physically’ stimulated interaction between human and product, such as cognition, aesthetic and semantic communication between product and user.

The second, sensorial, type of effect, related to aesthetic and semantic appreciation of products, is the primary effect of concern in this work. Both types of interaction effects are determined information signaling modes of action, perceived by humans through the five senses. The effect is carried by signals, a type of data transmission from object to human. The mode of action for the sensorial interaction effect related to aesthetics focused on here is primarily visual.

Function classes of the human-product system

Corresponding to the three main classes of effects are a number classes of product functions, which are required for creating the necessary effects. The definition of function used in this work is according to the following “*a* *function is what a product or an element of a product actively or passively does in order to contribute to a purpose, by delivering an effect. A function is intended or incidental.*"

By incidental is meant that functions may, in a situation of use, be found to exist, which were not intended by the designer. Such functions may provide an 'unintended' functional ability to the user, which was not predicted or foreseen during the design of the product.

The overall ability of a product to be of use in different situations can be summarized by the definition of functionality: "*the functionality of a product is the combination of all its effects, properties, and their behavior, that contribute to making the product useful for an intended purpose*".

Functionality, thus, can be seen as a general 'measure of usefulness' for a certain purpose; of the ability of a product to be of value to the user. Good knowledge of all conceivable scenarios of use during product design increases the functional ability of the product, by designing more intended functions into the product.

A summary of classes of product functions is found in Table 3. Two main classes of function are identified: technical functions and interactive functions.

Technical functions are the functions normally associated with technical systems in engineering design literature. The types of technical function are based on Buur's [1990] set of secondary functions, and Andreasen's [1980] classification into primary and secondary functions. The technical functions are divided into *operative* and *structural functions*, acknowledging that the operative functions are necessary for the transformation of the operand, and that the structural functions are necessary for ensuring the structural stability and solidity of the product and its parts.

The technical functions are by Andreasen [1980] referred to as 'purpose functions', stated as "the ability of a machine to create an expedient effect". Here, the term purpose function is avoided, since it is acknowledged that a product may be designed for a number of reasons in order to serve certain purposes (have certain functions), not only technical. The 'purpose function', construed as "the primary functional purpose of the product", may thus be related to other functional properties of the product than technical, such as improved ergonomics, aesthetics, or user-friendliness. Extensively treated by mechanical design science, the technical functions will not be discussed in further depth here.

Function class	Function type		
Technical functions (internal product functions)	Operative	Primary	*Transforming*
		Secondary	*Communication* *Interface* *Power* *Control* *Protection*
	Structural		
Interactive functions (human-product interaction functions)	Ergonomic		
	Communicative		*Semantic*
			Syntactic

Table 3. Function classes of products, including technical and interactive functions.

Interactive functions are associated with the interaction between product and user. The interactive functions are closely related to the 'support functions' by Olsson [1972], in the sense that they are not necessary for realizing the technical process, but to enhance the usability and attractiveness of the product. These functions physically and cognitively enable and support the use of the product and are necessaries of all interfacing elements of the product that come into contact with the user. In this class of functions, at least three sub-types may be identified: *ergonomic functions*, *semantic functions*, and *syntactic functions*. The latter function types are collectively known as *communicative functions*, since they are associated with the 'communication' between the product and the human. Another term frequently used in this thesis to denote the semantic and syntactic functions is '*form functions*'. The interactive functions are described in the following.

Ergonomic functions include those functions that enhance and enable use of a product with respect to adaptation to the physical and physiological requirements of the human body (also termed *physical ergonomics*) and the effects of the environment. They are related to the physiological and anthropometric characteristics and capabilities of human beings, which is extensively treated in human factors literature. Ergonomic functions also include functions associated with *cognitive ergonomics*. Such cognitive functions comprise those functions that are traditionally associated with mental capability, information processing, logic, reasoning patterns, and sensory perception of, e.g., virtual software interfaces. Common terms within this field are information ergonomics and cognitive psychology. Research into the synthesis of ergonomic functions in the design process, as opposed to the classical ergonomic approach of analysis of technical systems with respect to human limitations and capabilities, is presented by, e.g., Janhager [2002].

Semantic functions, as proposed by Monö [1997], capture the way the formative elements of the product communicate their purpose to the user by use of semantic signs. They can be divided into four groups: *describing* (purpose and mode of operation), *expressing* (properties), *exhorting* (to reaction and handling), and *identifying* (the product, its origin, producer, kinship, location, nature, or category) functions. The semantic functions play an active role in the use-process, providing means for the user to understand and comprehend the purpose and manner of use of other functions of the product. In the latter sense, they are identical to the 'sign functions' proposed by Gros [1983]. The nature of these functions is related to the human senses, including visual, tactile[19], haptic[20], auditory, olfactory, gustatory, and kinesthetic perception. For semantic functions, the mode of action of the effect is the transmission of a semiotic sign, which is interpreted by the perceiver. The sign, which is intended by the designer to be perceived by a user, is carried by form elements of the product, having properties that represent a sign. Given that the perceiver, in a suitable context and with suitable subjective 'qualifications', is able to receive and translate the signal into the meaning intended by the source (the designers or the company), the desired message can be communicated.

Syntactic functions are related to the constituent form elements, their structure and configuration. Syntactic functions may be forms that refer to each other by shape, or are related in terms of compositional principles, e.g., visually connecting or discerning. The syntactic properties of a product form are largely determined by visual gestalt principles. For syntactic functions, the mode of action of the effect is information signaling perceived visually, but without requiring any form of interpretation (as is the case for the semantic functions). The signals are carried by form elements, experienced by the observer in the composition and content of the form language. If the designer has done a good job at creating an aesthetically pleasing product form in terms of, e.g., a coherent and well-balanced set of form elements, which is readily legible, the perceiver will, if sufficiently 'equipped', appreciate the form having a high quality appearance.

> A certain form element, such as a fold along the side of an automobile (Figure 48), may have the structural function of increasing the strength and improving the aerodynamic properties of the body, which are technical functions. It may also have the functions of identifying the make of the car, convey brand values, relate the car historically to previous designs, and communicating a certain expression, which tells the onlooker something about the quality of the product. The tension in the shape of the fold may in the eyes of the beholder express power or high speed, or identify it as a certain car make. These are *semantic functions*. It may also, in characteristics of the shape, curvatures, etc, relate to other form elements of the car body, which creates an impression of unity and coherence in the form. In this sense, the fold has a *syntactic function*.

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[19] Tactile: relating to the sense of surface structure by touching

[20] Haptic: relating to the sense of form by touching

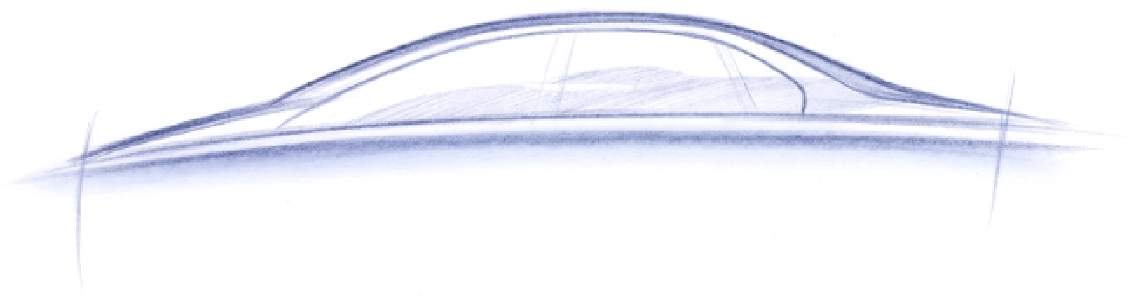


Figure 48. The 'Volvo Bridge'. The side-shoulder, also known as the 'catwalk', carries important semantic and syntactic functionality of the Volvo form language. Sketch material courtesy Volvo Car Corporation.

Organs of human-product interaction

The domain theory states that functions are realized by organs, which belong to the organ domain. A definition of organ provided by Jensen [1999] reads: "*An organ is a structural design element for the complete realization of a given function. An organ is a structure of wirk elements. Some organs consist of only one wirk element*". According to Jensen, one organ realizes one function. For a complex of functions, a structure of organs is needed.

The organ definition provided by Jensen is concerned with organs realizing technical functions, here denoted *machine organs*, since they are associated with mechanical engineering design. In this work, organs are proposed, which are related to the human-product interface. Such organs realize interactive functions according to Table 3. In Paper A, a classification of such organs is proposed, as illustrated in Figure 49.

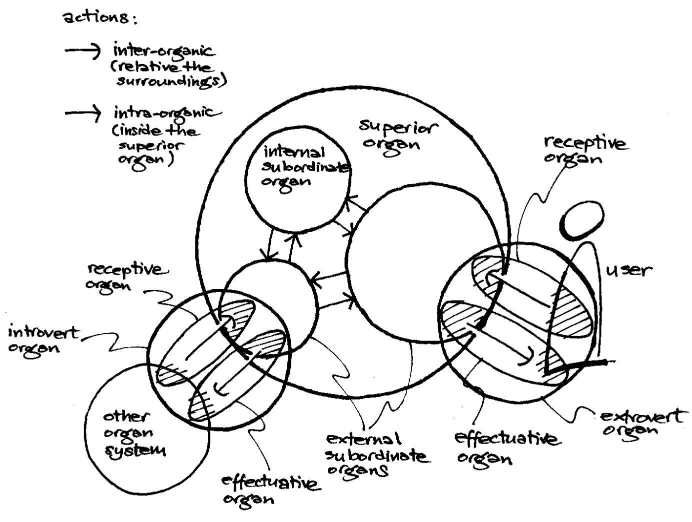


Figure 49. Hierarchy of organs, including superior organ, external and internal subordinate organs, and extrovert and introvert organs containing effectuative and receptive subordinate organs. Inter-organic (between the superior organ and the environment) and intra-organic (within the superior organ) action chains are also indicated.

Organs can also be classified according to the type of functionality they fulfill, i.e. operative, structural, ergonomic, and communicative organs, according to the function classes of Table 3. Depending on the system border of the studied organ, an internal organ viewed in one system may be an external organ in a system view with a different system border. Users are not considered part of the organ system.

Aesthetic organs – organs fulfilling communicative functions

Of special interest for visual form aesthetics is the class of organs, which fulfils communicative functions, i.e. semantic and syntactic functions. In the same way as it is possible to describe such *machine organs* as the technology that delivers the desired technical functions, *aesthetic organs* are introduced as the form solution, which creates the desired communicative functions. Aesthetic organs are thus a special class of organs, fulfilling syntactic and semantic functionality, existing together with technically determined machine organs. Aesthetic organs can, in line with Jensen [1999], be defined as: *"A structural design element for the complete realization of a form function. An aesthetic organ is a structure of form entities. Some aesthetic organs consist of only one form entity"*.

A question thus arises: are aesthetic organs found in a structure of organs *together* with machine organs, or does the aesthetic organ structure exist as a *separate* organ structure in a given product form? Given that technical functions, realized by machine organs, have different modes of action of delivered effects compared to communicative functions, the position is here taken that *aesthetic organs create their own organ structure*, which exists in a superimposed manner along with machine organ structures in a product. This view is supported by work of Andreasen et al. [1995], who state, "*in the product, we find multiple organ structures corresponding to tasks of different nature, realized in a superimposed manner in the parts structure*". Thus, the complete functionality of a product or a part may be allocated to several organ structures, consisting of machine organ structures realizing technical functionality, and aesthetic organ structure(s) realizing communicative functionality, see Figure 50.

Figure 50. The functions of a product or a part can be allocated to machine organ and aesthetic organ structures.

Discussion of form functionality modeling

Adopting a functional approach to discussing visual product form is not entirely novel. The approach by Monö [1997] suggests that semantic aspects of the product form can be treated by adopting a functional language. The contributions made in papers A, B, and C regarding functions and organs specifically associated with the visual syntactic aspects of product form, which largely based on a general theory of engineering design, should be seen in the light of the alternative situation; that we completely lack a theoretical foundation for arguing the connection between technical and aesthetic form aspects.

The proposition of organs constituting part of the man-machine interface, in this case regarding the visual aesthetic form of the product, is supported by Buur [1990], who states that a “starting point for systemizing the interface organs is the capability of man to perceive information by means of his five senses and to convey information/exert control by hands, voice etc.” As suggested by Buur, the “allocation [of functions between human and product in a man/machine system] cannot be completed in the functional domain, but needs decisions on principles in the organic structure”. This supports the view that the ergonomic functions may be allocated to a separate organ structure. However, this issue is not investigated further here. At the time being, ergonomic functions related to physical human interaction with the product are considered to be allocated to the machine organ structure. The reason for this supposition is that they deliver similar types of effects and share the same mode of action, governed by material interaction.

It must, however, be recognized that the contribution to form functionality also includes form aspects, which cannot be evaluated in the same manner. They require different knowledge bases, which are characteristically different in terms of focus, perspective, and approaches. The nature of the interactive functionality of a product is principally different from the technically determined functions. Technical functions may readily be measured and quantified by objective evaluation methods. The judgment whether they fulfill the specified criteria, i.e., whether intended and predicted behaviors actually match, is determined by principles of natural and engineering sciences, which usually leaves no one in doubt.

With communicative functionality, the question of intended behavior, as aimed for by the designer, and predicted behavior, as mapped to a ‘model’ of the target group or target user, is clearly not as obvious. As stated by Butter and Krippendorff [1984], “the designer […] can only hope to contribute to the way users create meanings and develop mental models commensurate with their needs to use the designers’ products”. There is no causal relationship between a shape and our appreciation of that shape; the stimulus-response relationship cannot be definitely determined. We cannot, with the same level of accuracy as in engineering, predict how an individual person will perceive and experience a certain design from an ergonomic or communicative point of view. The relations between intended, predicted, and perceived behavior is illustrated in the model by Jensen [1999], Figure 51.

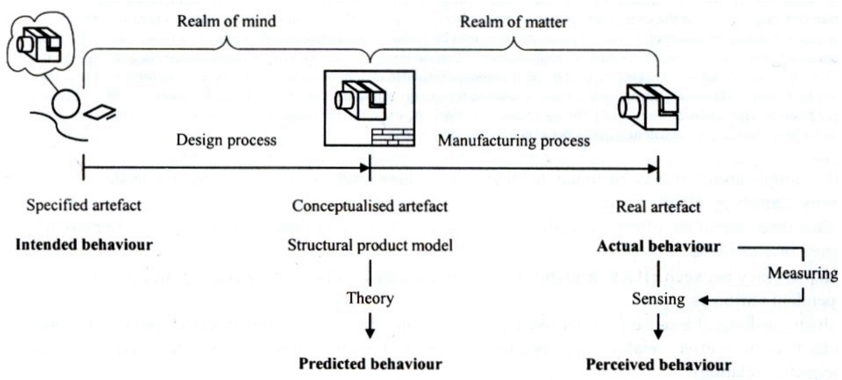


Figure 51. Relations between intended, predicted, and perceived behavior [Jensen, 1999].

In the ergonomics field, methods and tools are available for assessing systems or products with respect to the limitations and capabilities of the human being. We can measure quantities such as available space, vibration, or sound level, and evaluate if an acceptable level is achieved. However, there is always a degree of uncertainty, since all the individuals in a group do not have the same preferences or physiological characteristics. Therefore, the principle of percentiles and statistic methods are often employed in ergonomics.

For communicative functionality, principally the same situation as in ergonomics prevails. The significant difference, though, is that the models, if at all available, for predicting preferences regarding form perception and appreciation of form are very uncertain, due to their dependence of subjective, contextual, and socio-cultural factors of the subject. Semantic and syntactic functionality of the product are both determined by perceptual psychology and communication theory, which are heavily influenced by subjective factors. Some people may be more capable, experienced, or 'trained' in perceiving syntactic relations in the form, or at 'understanding the message' intended by the designer. The model of communication of design messages by Monö [1997] exhibits a multitude of potential factors of disturbance, ranging from an unclear message from the designer, to individual characteristics of the perceiver, as illustrated previously in Figure 18. Whether the appreciation on behalf of the intended subject is dependent on signs, as for semantic functions, or on sensual appreciation as for syntactic functions, is in this context irrelevant.

In the product semantics field, research is being made into methods for evaluation of the semantic functions [Wikström, 1996; 2002]. The aim is to develop methods, which more accurately can evaluate and predict semantic interpretation of product designs, for purposes of product synthesis and analysis. For purposes of assessing industrial design concepts, companies often utilize 'product clinics', where representatives of the intended target group are utilized for evaluating the aesthetic and representative properties of product form, primarily related to semantic aspects. The issue of evaluating visual form design of products is not part of the scope of this research, and there is no claim to propose models for such purposes. However, the problem of 'objectivity' is a delicate issue, which will need more research effort in the future.

In this research, the objective of proposing syntactic functionality is to provide a reasonable model of the structure of product form and an approach for design work, enabling a more coherent reasoning in the design activity regarding the nature and workings of aesthetically determined product form.

5.5 FORM SYNTACTICS MODELING

Form syntactics is concerned with the structure and composition of the visual product form. Vihma's [1995] definition of the syntactic dimension includes the analysis of the product's technical construction as well as the analysis of visual details (e.g., joints, openings, holes, form crossings, texture, graphics, etc.) of the design. Since the technical-behavioral structure of products is extensively treated in engineering design science, the definition of *design syntactics* applied here is narrower, encompassing visual form aspects of the product only.

Form syntactics modeling includes two basic concepts: *form elements*, and *form entities*. On the material-physical level related to the part domain, the visual form includes *form elements* and configurations of form elements. In connecting form elements to functional reasoning, we need a concept for reasoning about the visual form, which is related to the concept of organs. Thus, on the organ level, *form entities* are defined, which deliver syntactic and semantic functionality of the product form. The presentation will start with a short introduction to the form element concept, and then the concept of form entities will be discussed at greater depth.

Form elements

The syntactic level of the form determines the visuo-spatial characteristics of the product, which is what Muller [2001] refers to as 'solution-typical features'. These are specific ordering features of a product form determining the solution type; the visuo-spatial and material order of the three-dimensional form solution. In the definition of form used in this work, however, the material properties of the form are not included. Neither are the color properties, which are significant for creating the whole form experience. In this work, form is characterized by *shape (geometry), dimension,* and *surface texture*, for a single form element, and for compositions of form elements, also *structure* and *configuration*. This definition is related to the concept of basic properties of Tjalve [1979]: form, material, dimension, and surface, and for the product as a whole, structure.

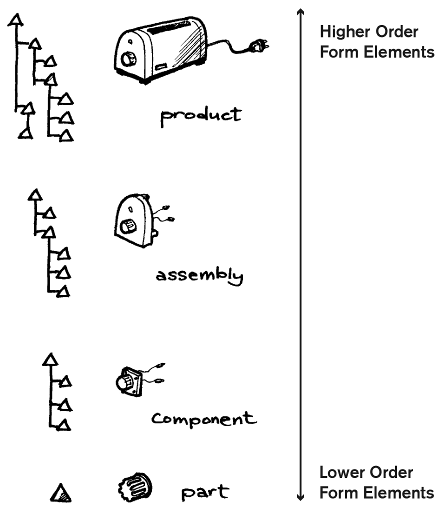


Figure 52. Form elements can be identified on all levels of the outer form of a product.

On the level of the whole form, we can reason about the constituent elements of the form, denoted *form elements*. Form elements define the appearance of all visible surfaces of a product and is a recursive term, applicable on all levels of form, whether on a whole product, a part, or a 'part of a part', see Figure 52. A form element is in this work defined as "*A form 'unit', a constituent element of a physical, visuo-spatial form. A recursive term.*"

The term form element, like form, is related to the characteristics of the external surfaces of a design and not explicitly to the internal material. The use of the term form element here differs from that provided by Jensen [1999], who states that a part is decomposed into form elements, which, in turn, are structural elements with one or more elements from a behavioral point of view. Here, a composed form is decomposed into form elements, which are not necessarily constrained to a single part but can be allocated across several parts as constituents of the outer visual form of a product.

> For example, the 'catwalk' running along the side of contemporary Volvo cars is a form element, shared by (distributed across) several parts of the car body. Likewise, the grooves on the cap of a Magic Marker constitute a form element. Moreover, each and every groove is a form element in itself.

The spatial relations between form elements constitute the *structure* of the form, consisting of form elements and their relations. We can also reason about the *configuration* of the form, which denotes the way the form elements are arranged in relation to each other. The intention of this work is not to provide a typology of possible forms, but to provide a model relating the structure and behavior of visual form to functional language. Contributions to form typology has been made by, e.g., Akner-Koler [1994] and Muller [2001], as reviewed in section 4.8.

In Figure 53, the difference between structure and configuration is illustrated. A certain form structure may have a number of possible form configurations. The number of possible configurations is dependent on the number of form elements and the number of relations. Thus, according to system theory, we can regard the form as a *system*; a structure which is separated from the surroundings by a borderline. Furthermore, since the properties of a system are more than the sum of the properties of the elements, we can attribute higher-level properties of the form system. Such properties include the gestalt properties of visual perception; in a system of forms, we perceive gestalts, which build up our visual appreciation of whole, composite forms.

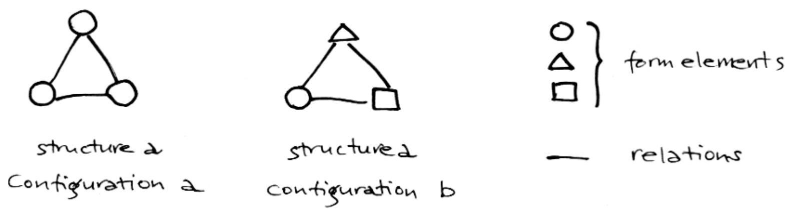


Figure 53. Structure and configuration of visual form.

Form entities– linking visual form to aesthetic organs

We have discussed function types of products, mode of action of effects of functions, and introduced aesthetic organs for purposes of visual form design. But how is the communicative functionality of the product fulfilled by aesthetic organs?

From the perspective of machine design, Tjalve [1979] introduced ‘functional surfaces’, being the surfaces of parts have an active function during use. Functional surfaces, thus, provide the causal relationship between the function of the product we perceive as purposeful, and the allocation of the function to an organ structure. Mortensen [1997] denoted such surfaces, which contribute to the realization of an organ and thereby its function, ‘wirk surfaces’. The remaining, ‘in-active’, surfaces of the parts, the ‘cover surfaces’, are according to Mortensen ‘free’ in the sense that they do not directly have functional contribution. For design syntactics theory, however, it is essential to state that *all* visible external surfaces contribute to organ functionality. As discussed previously, such functions are syntactic and semantic functions.

> For a bottle opener, the functional surfaces (wirk surfaces) are the metal lips enabling the removing of the bottle cap, and the gripping surface for the hand of the user. But bottle openers look different, depending on a number of, e.g., technical, material and economic factors. If having the opportunity to select between two bottle openers, we might prefer one before the other. Different form designs have different effect on us as perceivers, as a result of different semantic and syntactic functionality of the products. Thus, all visible surfaces contribute to aesthetic organ functionality.

Jensen [1999] states that an organ is a structure of *wirk elements*, where a wirk element is the structural element of an organ from a behavioral point of view. When subjected to a stimulus, i.e. an effect causing a behavior (a behavior being a transition of state due to stimulus), a wirk element is active regarding behavior; it has the ability to realize a function. Consequently, when not subjected to stimulus, the wirk element remains passive. With the model of Jensen, functionality of a part is dictated by the existence of ‘form elements’ that become wirk elements due to the structure’s transition of state.

However, when considering form functionality, no transition of state of the product occurs. The structure remains unaffected; the aesthetically determined functional effect, created by communicative functions, is only subjectively perceived and, if a semantic function, interpreted by an observer (by means of signaling).

To be able to handle such functionality with organ reasoning, another type of organ element is called for. This element is denoted *form entity*. In the part domain, form entities are manifested as physical form elements of the finished product. The concept of form entities links the physical-material manifestation of the visual product form to organ and functional reasoning and is a central concept of this work. Form entities have been developed to facilitate reasoning about structure and configuration of visual aesthetic form, and the relational properties of form. Form entities must be understood as “*the active units of an aesthetic organ*”, fulfilling syntactic and semantic functionality. It is thus a theoretical concept explaining the behavior of the form.

In the physical form of a product, form entities are evident as *providing the relational properties of the visual form* related to form functionality. This means, that form entities are essential for providing properties of the visual form related to gestalt perception, and can thus be identified in finished product form as well as during form design sketching, from the earliest idea sketches to the finished form design.

It can thus be stated, along with the reasoning by Jensen, that *an aesthetic organ is a structure of form entities*. An aesthetic organ may consist of only one form entity. Such is the case for, e.g., a logotype or some other identifying mark of a product stating the name of the manufacturer or the brand name. Hence, machine organs are composed of wirk elements, and aesthetic organs of form entities. The functionality of form entities is dictated by the presence of an observer. When form entities are perceived, they are functionally 'active', serving either syntactic or semantic functions.

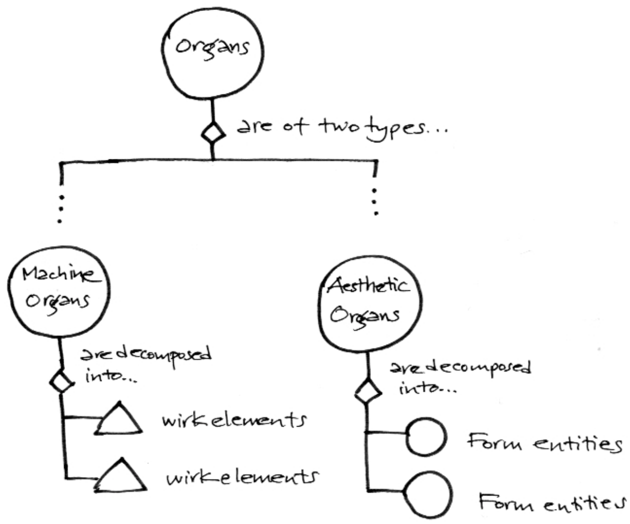


Figure 54. Organs can consist of one of two elementary entities or 'active units'. *Machine organs* are decomposed into wirk elements (fulfilling technical functions), while *aesthetic organs* are decomposed into form entities (fulfilling form functions).

Form entities are inherent to all designed objects. All shapes are perceived and reacted to, consciously or not, by, e.g., vision or touch. Likewise, other signals appreciated by our senses, such as smell and hearing, are also important for our impression and understanding of products. Thus, awareness of syntactic and semantic functionality, allocated on the product form through the use of form entities, is beneficial for the aesthetic appreciation of the product. The presence of form entities in visual form design gives an explanation to our perception of visual relations, coherence, order etc. in the form. As acknowledged by gestalt psychology, every perceptual image consists of more than the sum of its parts; it possesses a 'gestalt', a patterning force that holds the parts together. In a visual product form, this phenomenon is created by form entities, belonging to the organ domain, creating syntactic functionality.

A single form entity contributes to the function of an aesthetic organ, but may not be sufficient for realizing the whole function in itself. For realizing an interactive function, an aesthetic organ may be composed of several form entities. While a wirk element is a point, line, surface, or space of continuous geometry and uniform material, Jensen [1999], a form entity consists of a one-, two- or three-dimensional form (i.e. a point, line, surface or body), a spatial configuration of forms, or a structure with relations between forms. Thus, form entities lack any internal material attributes. This is in correlation to the definition of form as used in this thesis. Form entities, as wirk elements, are not constrained to belonging to a single part of continuous material or geometry, but may be distributed across several parts, which build up a form. Form entities may also be a visual interaction between form elements, a gestalt.

Types of form entities in visual product form

In a finished product design, form elements interact to create a system of visual relations, or gestalts, in the form. A gestalt is a typical realization of a form entity; a number of form elements interact, creating a visual entity of ‘higher order’. Form relations, i.e. couplings between form elements, can also be part of form functionality, since they connect form elements together in a visual sense. Since there may be no physical relation between such gestalt creating form elements, apart from them belonging to the same material product, their functionality is determined by the existence of a form entity. Examples of this are the creation of proximity, similarity, harmony, contrast, dynamism, symmetry, balance, rhythm, orientation, proportion, etc., by conscious arrangement of form elements. Such relations are part of the ‘gestalt rules’, as discussed in section 4.7. In Figure 55, examples of form entities in the visual form of an Ericsson mobile phone are shown. The depicted form entities each create an aesthetic organ, which has a syntactic function.

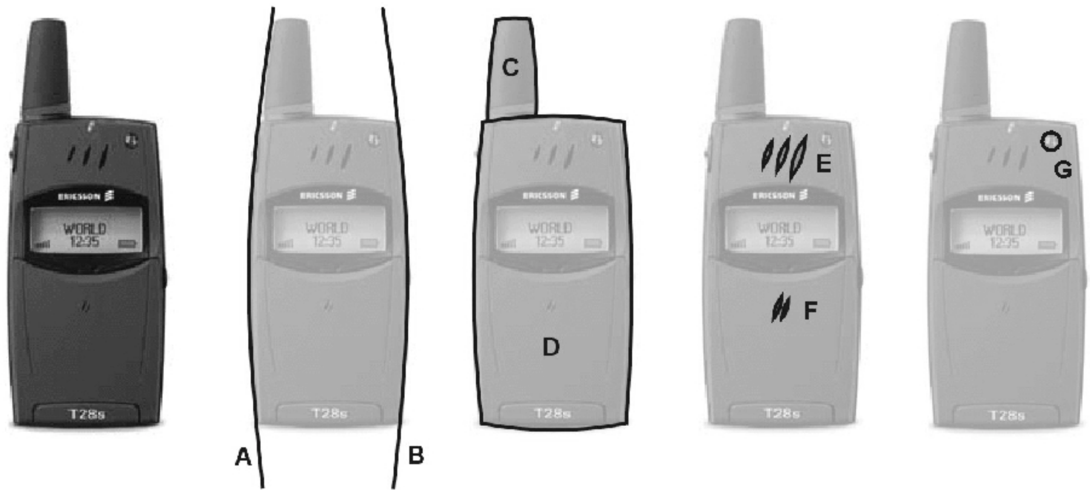


Figure 55. Examples of form entities realized in the physical form of the Ericsson T28s mobile phone. Curves A and B are visually coupled by means of interacting tension in the curves, creating the syntactic function unity in the form. Forms C and D create a dynamic interplay by their strong kinship in basic form and their contrasting size, resulting in a balancing syntactic function. Openings E and F are composed by similar graphical elements, sharing a common composition principle interpreted by different spacing and number, creating a uniting/linking syntactic function. Form entity G is created by the Ericsson logotype. Signaling the brand of the product, it has an identifying function.

In the physical product form, form entities created by four types of *visuo-spatial configuration* of form elements can appear, as illustrated in Figure 56.

- *distributed* (geometrically extended across other form elements) or
- *enclosed* (geometrically enclosed within another form element),
- *discrete* (form entity realized by a single form element), and
- *composed* (realized by groupings of form elements).

A specific form entity can thus only be of the type distributed *or* enclosed, in combination with the type discrete *or* composed. Thus, four combinatory form element configurations are possible: distributed-discrete, distributed-composed, enclosed-discrete, and enclosed-composed, respectively. In Figure 55, form entities A-B and C-D are both of the type *distributed-composed*, form entity E-F is of the type *enclosed-composed*, and form entity G is of the type *enclosed-discrete*.

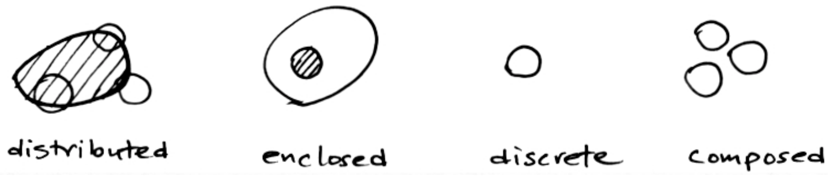


Figure 56. Schematic representation of form entities, created by different visuo-spatial configurations of form elements.

The *syntactic functions* of the visual form are created by relations between form entities in an aesthetic organ. The syntactic functions are created by the visual effect of the interacting form entities, as illustrated in Figure 57. The syntactic functions include, but are not limited to:

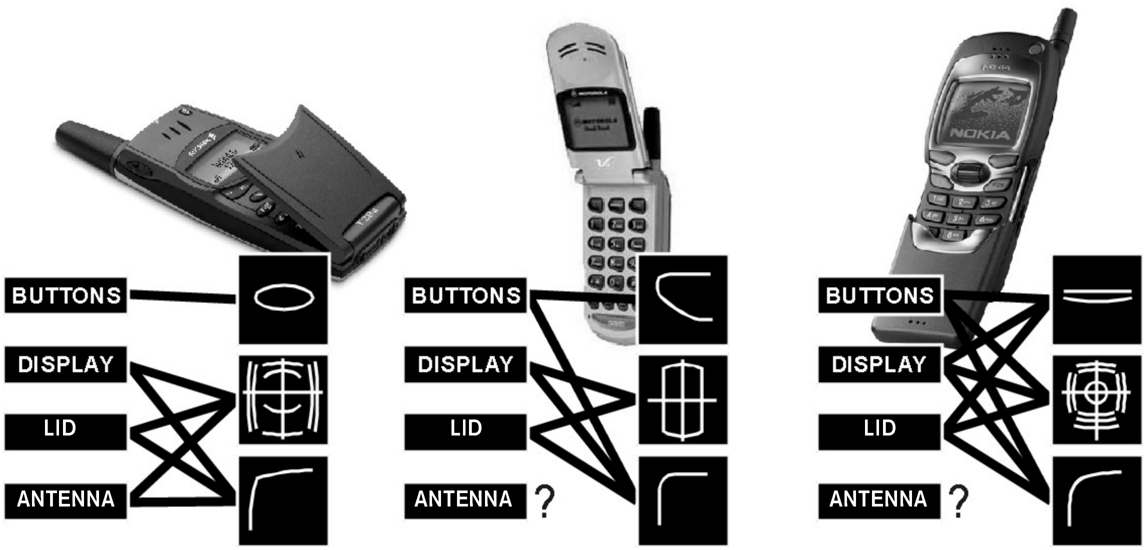
- *discerning*: separating one form entity from another
- *connecting*: creating visual couplings between form entities
- *referring:* relating visually to form solutions found in other products, e.g. of a common product family
- *uniting:* relating visually to other form elements present in the design by giving them a common gestalt
- *balancing*: harmonize by visual counteraction

Figure 57. Schematic representation of syntactic functions, created by perceptual gestalt effects between form entities.

Analyzing the form of a product, different hierarchical levels of form entities can be identified. On the highest level, the product is appreciated as a whole visual form experience, a superior gestalt. On intermediate levels, form entities appear as subordinate gestalts, while form details become apparent on the lower resolution levels. Each form entity can be matched to an aesthetic organ having syntactic or semantic function. Superimposed on each other, these layers of aesthetic organ structures together create a total form perception.

Figure 58. Perceptual syntactic relations in the visual form of three mobile telephones. More relations correspond to more syntactic functions, indicating a more coherent visual form design.

Figure 58 illustrates syntactic relations in the form of three mobile telephones. The comparison is made at the main component level, where form elements on an intermediate level of the form element structure are analyzed. The illustration shows how form elements of main physical components are interrelated in the visuo-spatial form. Perceptual relations, i.e., syntactic functions, between form elements are indicated.



Form entity development during form synthesis

Form entities can be manifested as very preliminary and rough form ideas during the early sketching phase of a design project, or as final form solutions of a finished design. Any expression of form, visualized at any stage of the design process such as sketches, renderings, drawings, real or virtual models, and appearing in different states of abstraction, completeness and detailing, can thus constitute a form entity. Serving specific purposes and fulfilling desired communicative functions, form entities in the organ domain can be described as preliminary, emerging form and as relations between forms, realizing syntactic and semantic functions. In this respect, form entities can be as abstract to the stylist as an anatomical structure is to the engineer.

Interview studies with industrial designers (Paper D) indicate, that as the designer starts thinking visually about a design problem by commencing his sketching process, form entities develop as a result of some form design intent. Goel [1995] identified two types of operation, lateral and vertical transformation, which occur between successive sketches in the early stages of sketching. Here, lateral transformation denotes an obvious change in thinking (divergent move to a different idea), while vertical transformation denotes a convergent movement towards a more detailed version of the same idea. One of the sketches produced during the early research phase of the Oxygen vacuum cleaner is studied in Figure 59. Marked lines serve to illustrate high-level form entities that have evolved and developed from initial sketches to the final product, 'surviving' the process of design development. The basic idea behind the first sketches was thus preserved to the finished product by vertical transformation according to Goel [1995].

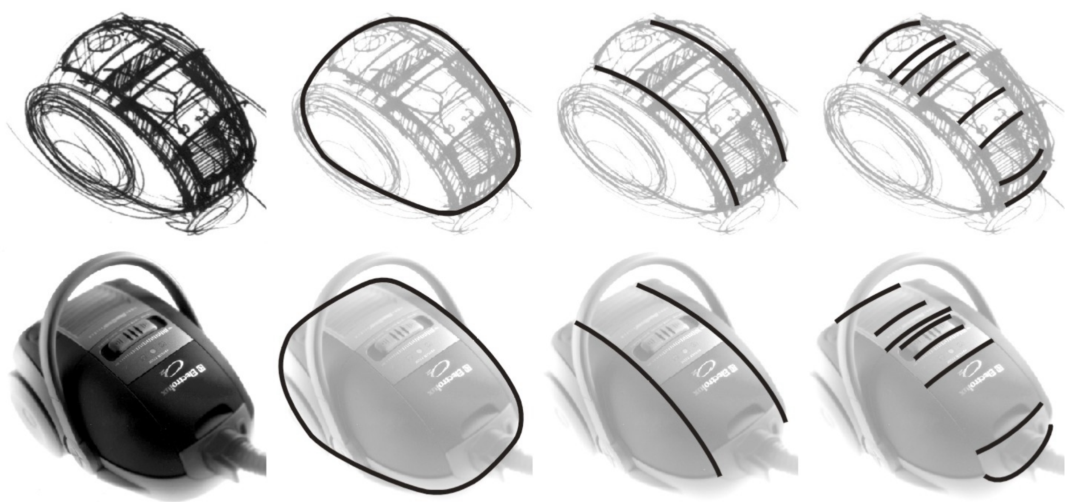


Figure 59. Form entities evident in an early sketch compared to the finalized design of the Electrolux Oxygen vacuum cleaner. Sketch material courtesy Electrolux Home Products Operations (Sweden) AB.

Discussion of form syntactics modeling

Form syntactics modeling provides an approach for relating specific form elements of the visual form to product functionality, i.e. their purpose and effect, as we perceive them. Form is often discussed on a general and ‘unspecific’ manner, and the introduction of form elements as a ‘tool’ for discussing the content and structure of the visual form may thus contribute to reaching further in form discussion. In papers B and C, form entities are introduced as an element for clarifying the relation between the content of the visual product form (i.e., form elements) and the communicative functionality of the product form. Form entity is thus a conceptual element, which is important for the discussion of the constitution of the physical form of the product, its structure and way of functioning. But it is also an important element for describing the form from the point of view of form perception. By help of form entities as a descriptive conceptual element, we can relate the principles of gestalt perception to specific form elements and to the communicative ability, interpreted as semantic and syntactic functions, of the product form. For analysis of visual form, form elements and form entities can thus contribute with a perspective, which has not previously been available.

For describing the form development process, form entities are also suitable. The studies carried out for Paper D indicate that reasoning in terms of form entities for describing the form synthesis process is a promising approach. It seems plausible that starting the sketching process from definition of basic form entities is a natural way of approaching the design problem. The designer commences his sketching process having partially pre-defined design intent on an abstract level, which he tries to capture and explore by rough and perspicuous search for basic form entities. In very early, immature sketches, the information content is small compared to drawings from later stages of the process. In fact, the only available information may be the definition of high-level form entities, i.e. basic gestalt features of the overall form. In this way, early sketches are ‘detailed in an un-detailed manner’, providing the information needed and relevant at the initial phases, where the amount of information available is often sparse. The findings are supported by a number of authors, suggesting that information content grows during the sketching process and that more information is available in more detailed sketches [e.g., McGown et al., 1998; Purcell and Gero, 1998; Rodgers et al., 2000; Söderman, 2001]

The form entity concept also seems to provide a way of seeing, decomposing, and analyzing visual form. The understanding of product design by form entities draws the attention to the wholeness of the form, and the relational and structural properties of form. The understanding of the form, its structure, composition and content, can be enhanced by the awareness of, and the ability to ‘read’, the form in terms of form entities in addition to form elements. Thus, the form can be more easily understood both geometrically, and in syntactic and semantic functional terms.

5.6 DESIGN FORMAT MODELING

The third leg of the design syntactics framework is the concept of *design format*. This part of the framework has many relations to aspects treated in design management, in providing a company view to the issue of product form development. The design management perspective (section 4.4) considers product identity from a number of viewpoints, including brand recognition, consistency over time, and distinctiveness among market competitors [Karjalainen, 2001]. This work must be practiced on the operative as well as on the strategic and philosophical levels of the company [Svengren, 1995].

Design format modeling concerns the content of the visual form of a product, i.e., what type of form elements are present in a visual form, how they are used in visual form design for creating products with a coherent 'form language' and identity, etc. Its principles are thus suitable for seing the product from a design management perspective. Design formats can be applied in form design work in one of two ways: as an *analysis instrument* for investigating the content of the visual form in product form design; or as a *specification and synthesis tool*, for describing intended form content and as a 'template', guiding and directing the form design work in a desired direction. The concept of design format will in the following be introduced and elaborated.

The concept of design formats

In a product development project, a traditional design specification formulates the specific requirements of the product-to-be in a solution-neutral manner. A product is a result of this specification, but it is also a result of numerous other factors influencing the development work. For a consumer, these factors may be the most evident differences between technically similar competing products in the same market segment, which can be described by very similar technical specifications.

The differences related to product identity, image, values, etc., can be captured and described in a *design format*, which states the ingredients that define a product from a specific manufacturer. Part of this format is sometimes specified and formulated in the market strategy or design manual of a company. However, most of the contents of a format that dictate design work are not pronounced and can thus not be deliberately applied during product design. This is often the case for factors such as 'form language', the choice of specific technology, priority of certain functions or properties, marketing strategy, corporate design philosophy, etc., Figure 60.

As a specification tool, the design format can be specified beforehand during the planning for a product design project. But is also developed and refined as a result of ongoing work, similar to the traditional product specification. A design format can be expressed, or stated, in a variety of possible media.

Apart from written documents, pictures, image or theme boards, models, movies, or scenarios, may be applied for capturing relevant aspects in the most efficient manner. A design format should be seen as an 'open' format, where the most suitable method of representation of desired form properties are used in order for formalizing and externalizing form design issues.

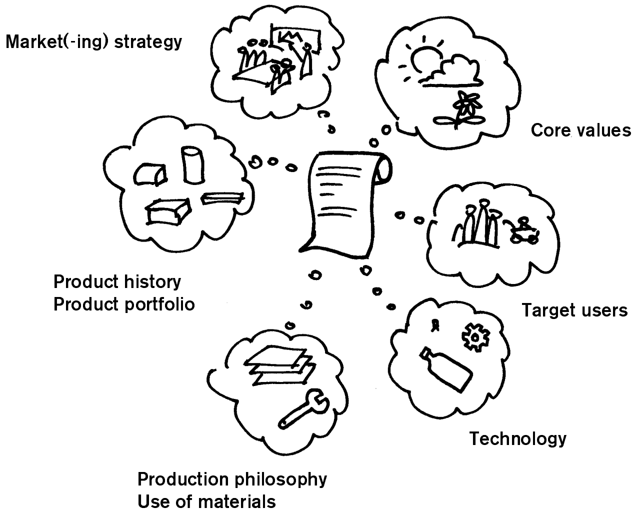


Figure 60. A design format describes tangible aspects of product design, such as visual aesthetics, identity, image, values, coprporate philosophy, etc. As such, it can be seen as a complimentary to the product design specification, e.g., for communicating a general idea of a product concept in a company.

In the design process, a design format can be seen both as a 'filter', reducing the number of possible choices during product development, and as a 'driver', since it navigates the search for possible solutions, Figure 61. For form development purposes on the *operative level*, formats can provide a way to efficiently capture information related to industrial design aspects such as visual form, color, material, surface structure, composition, basic product sign, etc. In design projects involving a large number of people, a design format on the *strategic level* could be valuable for communicating and embodying the design intent across design disciplines.

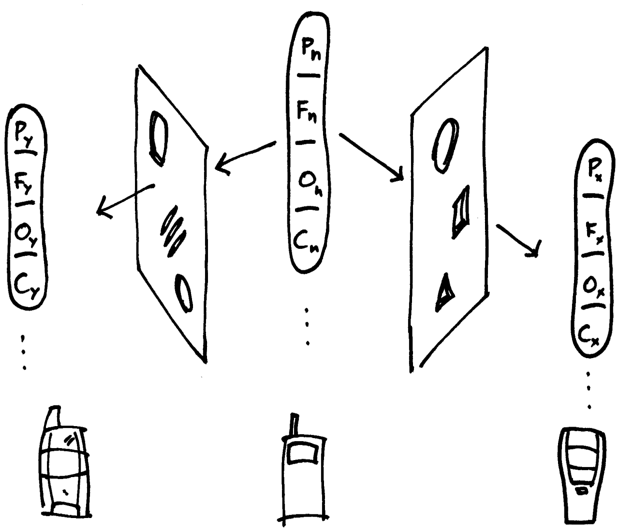


Figure 61. A design format can be seen as a template for visual form design, which can be used for 'navigating' design work in the desired direction. The design format describes the specific characteristics, such as 'form language' and content of the form, for a specific product or a range of products.

Related to the theory of domains, a format can be used to direct and influence the search for possible or 'good' solutions in all four domains. A design format has the most visible influence in the organ and part domains, where the geometrical form of the product is represented by form entities and form elements.

Companies frequently use significant styling features to identify the brand. Such features can be identifying form elements, such as certain curves, shapes or 'fifth elements' such as a radiator grille [Mollerup, 1997]. Smyth and Wallace [2000] denote such form elements, which convey the product's identity, the 'brand/product form DNA'. Examples of visual form ingredients in a Nokia mobile phone are found in Figure 62.

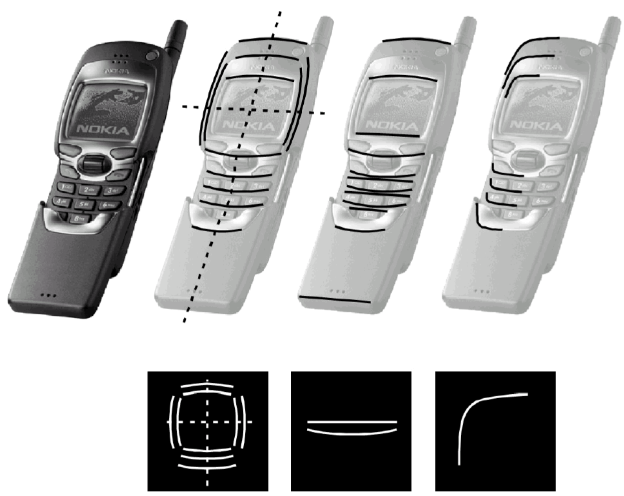


Figure 62. Main form elements (curves and their relations) included in the design format of the Nokia 7110 mobile phone. In the format, visual aesthetic principles such as the structure of form elements, curvature characteristics, and form design theme are evident.

The design format model

The concept of design format is in the following developed in relation to the schematic representation in Figure 63.

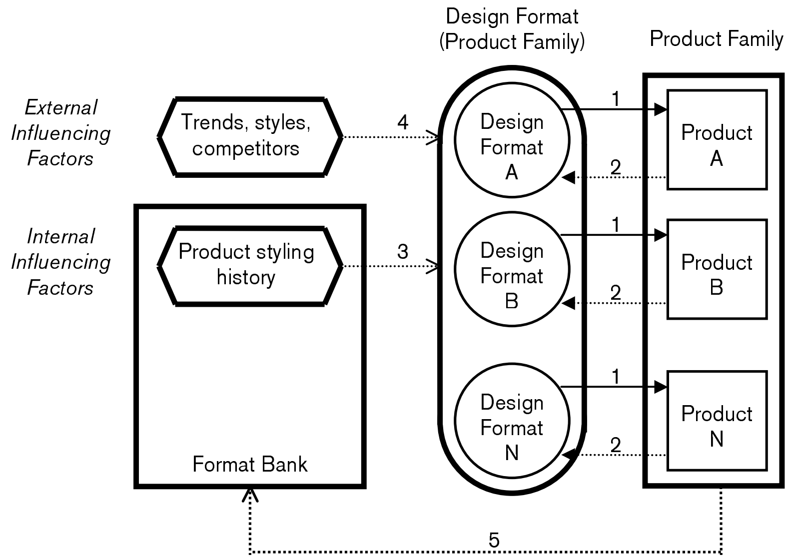


Figure 63. The design format model. A design format describes and prescribes (influences) the form design of a product (relation 1). In the design process, the form evolution of the emerging product also feeds back and further develops the contents of the design format (relation 2). Product styling history is an example of an *internal influencing factor*; a brand specific resource that the company can employ in product design to develop the design format of a new product (relation 3). Current trends and styles are examples of *external influencing factors*, which the company can use for enhancing contemporary characteristics of new product design (relation 4). In a product family consisting of N individual products, each product employs a unique design format. Styling features of all products are part of the *common design format* of the product family, employed in different combinations in respective product. The *format bank*, the public image of the products of a company, can only be changed indirectly by the presentation of new products on the market (illustrated by the feedback loop of relation 5). The format bank includes all company internal influencing factors, which can be employed in new product design.

The form of the product is described by the content of the design format and can be employed when designing a new product. During design, the contents of the design format influence, and to some degree stipulate, the form of the product (relation 1 in Figure 63). To some degree, the design format also evolves simultaneously with the design of the product, since new variations and form ideas arise during the design process. Thus, the emerging product form also contributes to the content of the design format (relation 2).

Influencing factors of the design format

In product design, company internal and external factors influence the common design format. Companies often use styling influences from earlier models when they design new products. As indicated by relation 3 in the design format model in Figure 63, styling history of previous generations of models is a 'company internal' factor, which influences the design of new products. Also, other factors such as contemporary styles and trends in design as well as in other areas, changing values in society, and products from competitors also influence the current design format (relation 4). These are 'company external' factors, in the meaning that they are not specific property of one company but available for all product designing companies to take part of and employ in product design. External factors also influence the design of a new product and give rise to form evolution from one product generation to the other.

By considering external and internal influencing factors, companies develop the form according to current styles and trends in combination with form ingredients that refer back to previous designs, Figure 64. Form elements from previous models are developed and interpreted in a more or less different manner depending on current influences.

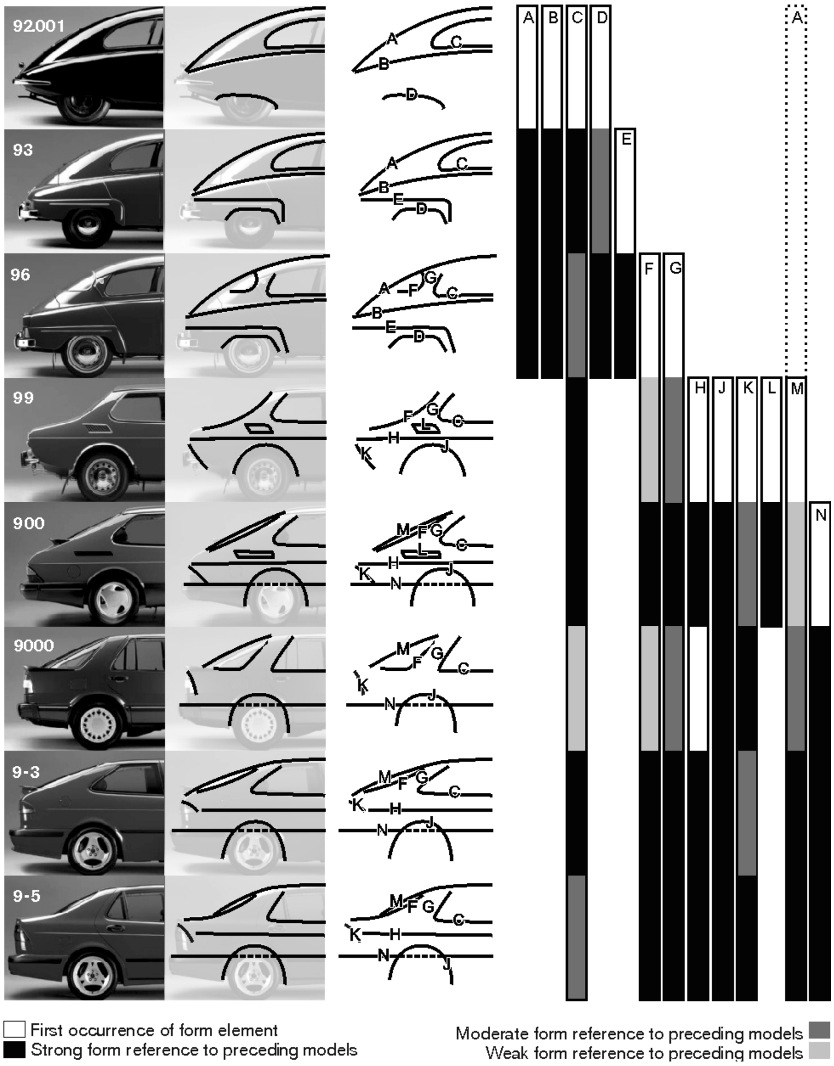


Figure 64. Styling history time line of Saab cars over five decades, ranging from the first prototype, the '92.001' from 1947, to the '9-5' model from 1997. Form element C, the 'Sason curve', has been present since the first car and is gaining in importance in recent models. The '99' model reveals an obvious shift in design paradigm, introducing a range of new styling features, but still referring to the preceding models (through form elements C, F and G). A more recent, but not as obvious, discontinuity is found in the '9000' model, designed by a consultant design firm, featuring weaker form references to preceding models. In the diagram, unfilled bars represent first occurrence of a form element, and filled bars represent various degrees of form reference to preceding models.

Design formats and design of product families

Companies designing and producing a range of products, e.g., a product family, have to consider the design of the products and the product family together in order to maintain a clear and unambiguous identity on the market. If the range of products in a product family employs styling features from a common design format, they will all be perceived as referring to each other, and the product family is more efficiently communicated visually.

Figure 65 illustrates a limited selection of Bang&Olufsen's product range of consumer home electronics. Visually, it is fairly evident that all products come from the same manufacturer. The overall form design theme for the products is similar, yet no product is identical to the other. Each and every product employs its own design format; it has its own unique appearance. At the same time, they can all be considered sharing a common design format; that of the product family. The ingredients of the common design format are noted in the top row. When dissecting the form of the products of the product family, it is evident that some styling features, ingredients of the whole visual appearance, are more commonly used than others. These are, e.g., form elements such as geometrical forms and connected volumes, or other styling features such as metal finishes and black-colored surfaces. Individually, these ingredients are not unique to the styling of Bang&Olufsen products, but used consistently together in a common design format, they become important for signifying that particular brand.

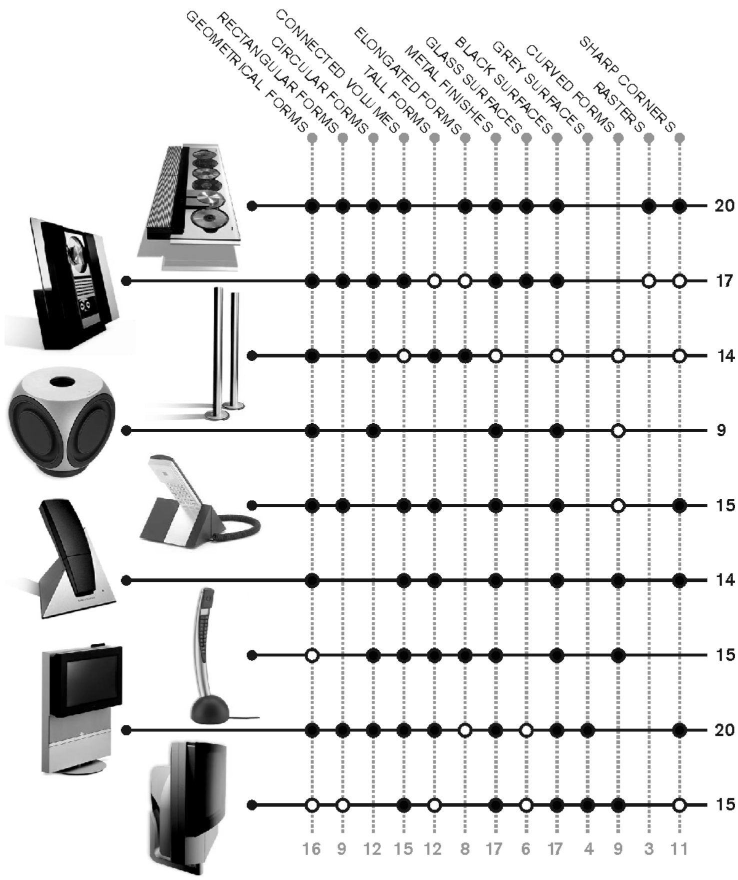


Figure 65. A selection of products from Bang&Olufsen's range of consumer home electronics, representing a product family. Vertical columns indicate the occurrence of styling features of the common design format of the product family. Some styling features are more frequently employed than others, thus representing more significant ingredients of the common design format. Horizontal rows indicate the degree of conformance of each product to the common design format. Some products employ more styling ingredients from the common design format, and thus represent 'stronger' products in terms of product identity. Filled dots indicate a strong correlation between specific product design and product family design format (two points); circles indicate weaker correlation (one point).

In the design format model in Figure 63, the common design format thus includes all significant styling features of all products of the product family. While design format A includes the form ingredients of product A, the common design format includes the form ingredients of all products (A, B, … , N) of the product family. Large companies may have several ranges of products intended for different market segments, and may thus employ different design formats for each product range.

Design formats and format banks

The total knowledge of the appearance and characteristics of the company's products, as well as other ways the company is visible on the market, e.g., through commercials and how the products are exposed and sold, is part of the format bank of the company. The format bank is formed by the products the company makes available to consumers on the market. It can only be indirectly changed through the design of new products or other deliberate product-related efforts of the company. More company-internal positioning means, such as corporate identity strategies, company values, and design philosophy, etc., are not directly evident to the ordinary consumer and thus not directly part of the format bank, but are important ingredients of the company's total design management philosophy together with the format bank.

The products or product families, which are designed based on design formats will directly influence the format bank of the company, i.e. the collected visual appearance of the company's image in the mind of the customer. If a company wants to change its image, it can only do so by introducing new products, or by presenting design concepts with the aim of changing the public image of the company or prepare the market for a change in company niche or product appearance. This relation is indicated by relation 5 in Figure 63.

Discussion of design format modeling

The market situation demands that companies are well aware of the product and corporate image, and how to manage form design issues in product development. The concept of design formats, presented in papers B and E, provides an approach to describe and handle visual form aspects in relation to operative as well as strategic, long-term objectives of a design activity.

For a design department, knowledge of what characteristics of the product form are important for the product's identity is a valuable resource. The design format model provides a way of identifying factors, which are of importance in that respect. With help of design format thinking, a design department can be aided in developing different form design strategies. It may also be of assistance for evaluating the coherence of form design across different products, and to identify form ingredients, which are important from the viewpoint of product identity.

Paper D also discusses the design format as being developed alongside with the emerging product form during form development, in an evolutionary process. New form ideas, which arise during sketching, add styling ingredients to the format, which consequently develops and ‘grows’ in content. In this process, the designer (or design team) alternates between (a) the exploration of form entities and form elements, and (b) the gradual application or development of a design format. The progression of form development is characterized by gradually completing and adding form content and structure characteristics to the evolving design format, see Figure 66.

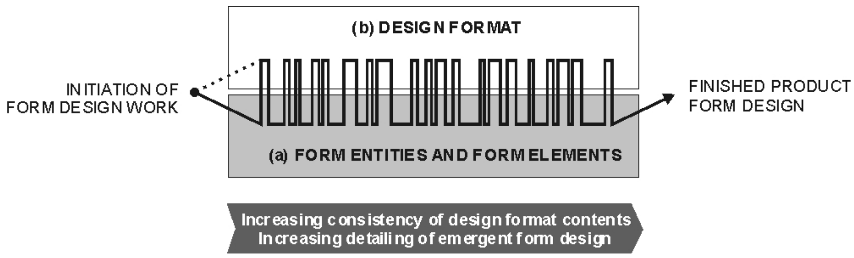


Figure 66. The cyclic, evolutionary process of designing against a design format. The dashed line indicates the alternative starting point of design work based on an existing design format.

Together with design manuals or design philosophies used during product design, design formats may provide a way of reaching long-term goals and for positioning products in relation to product families, competitors, and product history. In that respect, design formats can be seen as a way to operationalize the model by Monö, illustrated previously in Figure 20.

5.7 DESIGN SYNTACTICS – SUMMARIZING PRODUCT STUDY

The visual form of the Volvo V70 station wagon provides a good example of design syntactics reasoning, including a coherent design format, and examples of form entities, aesthetic organs, and form elements. In the following, an analysis of visual design aesthetic aspects of the V70 is presented. The coupling between form entities and organ modeling is shown in Figure 66.

Design format: On the overall level, economy, compactness and utility, with no extravagancies, are readily apparent in the form. The form language can be traced to previous Volvo models dating as far back as the 1940s: a clear indication of a deliberate search for identity and history. The Scandinavian origin is emphasized through a timeless, definite form language and through the choice of color combinations and materials.

Form syntactics: An analysis of form entity relations reveals a consistent treatment of a design format and an evident aesthetic organ structure. At least four form entity levels can be identified:

1 *The superior gestalt* consists of form entities and form elements on the highest hierarchical (global) level of the product form. All major ingredients of the form contribute in an efficient manner to the whole gestalt of the car. The result is a consistent form language.

2 *Characteristic shapes:* Significant form elements are the pronounced shoulders running from the front of the car along its sides all the way to the taillights. The shoulders appear again in the shape of the hood and in the protrusion around the grille. The characteristic shape of the hood meeting the front is repeated in the meeting between roof and windshield. Stretching across other form elements and integrating the form into a whole, these form elements are of the distributed and enclosed type, creating form entities with connecting and referring syntactic functions.

3 *A signifying curve* is found as a form ingredient in distributed across the car body: in the door handles, in the front lights, and in the grille, among other locations. This characteristic curve is a vital ingredient in the form, creating form entity relations, which connect discrete and spatially distributed form elements with each other. Together, these form elements create visually connecting form entities, an important ingredient for creating unity in the form.

4 *The fifth element:* The grille of the car featuring the distinctive diagonal cross member is a typical example of a 'fifth element', a symbol for the Volvo brand of cars, which over the years has been seen in many different variations. This is an example of a enclosed-discrete form element, serving discerning and referring syntactic functions. In recent models, the shoulder, as a distributed-discrete form element, has also become a 'fifth element', although it is not as strong a sign as the grille.

In the far right column of Figure 66, the superimposed structure of aesthetic organs is shown. Relations between organs in the organ models of form entity levels 2 and 3 indicate the presence of form entities connecting form elements to each other. A large number of couplings between form entities within each form entity level and between organ levels in the superimposed organ structure indicate a coherent visual form design.

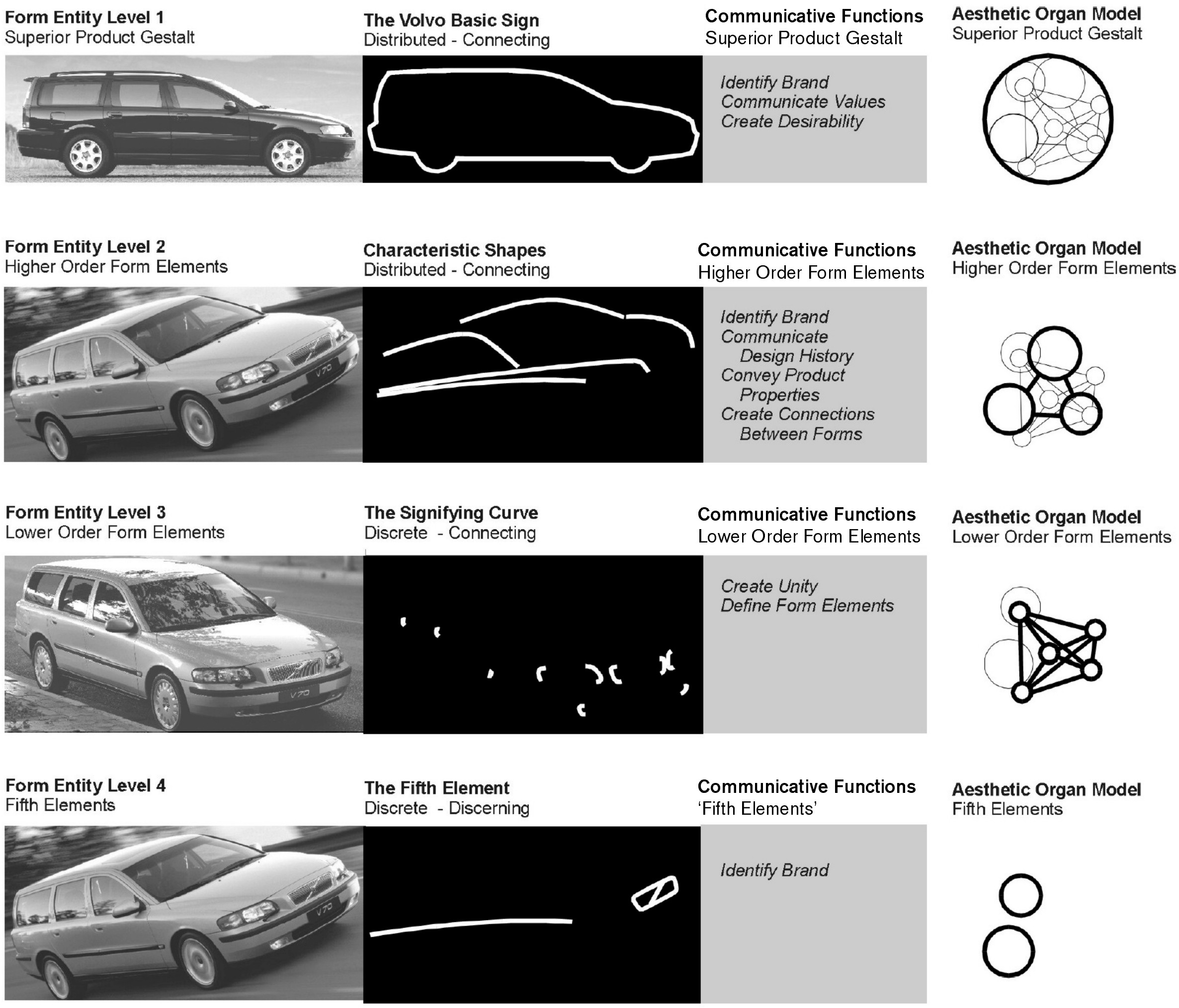


Figure 66. Form entities, characteristic form elements, communicative functions, and superimposed aesthetic organ models for the Volvo V70.

5.8 METHODICAL APPROACHES FOR VISUAL FORM DESIGN

In this section, three methodical approaches based on the design syntactics framework are presented, as described in Paper F. The intention has been to propose feasible methods, applicable for supporting tasks of specification, analysis, synthesis and evaluation of visual form design during form design development.

The following sections introduce three main tools, which are intended to address the issues presented in the previous sections of contribution. The methods are denoted 'Method for form functionality analysis', 'Method for form development', and 'Method for design format handling', respectively. Methodical procedures and illustrative examples are provided for each method.

Method for form functionality analysis

Function analysis methods for industrial design purposes exist, such as Landquist [1994] and Wikström [2001]. The contributions by Olsson [1972] also include the analysis of product functions related to industrial design. These methods are general in their approach, aiming at a wide understanding of product functionality, often from a user perspective. The main difference for the method proposed here is that it aims specific to reach the syntactic and semantic level of visual form design through functional reasoning. The method presented here supports 'multi-functional' analysis and synthesis of design concepts and products.

The method of identifying functions of a product has two complementary approaches, which support each other and can be used either separately or collectively. The approaches are based on *direct functional identification* and on *analysis of design intent*, respectively. Both approaches share the same goal: the identification of functions and their classification.

While direct functional identification can be seen as a way to quickly get functionally acquainted with the product, design intent analysis gives a more thorough understanding of the design and its functional content. Figure 67 shows a direct functional identification of the SAS coffeepot. For illustrative reasons, functions of different classes are shown in the figure. During an actual analysis procedure, functions of different classes can be analyzed separately.

The complete procedures for the two methods are presented in Paper F. In the following, the method based on analysis of design intent is described.

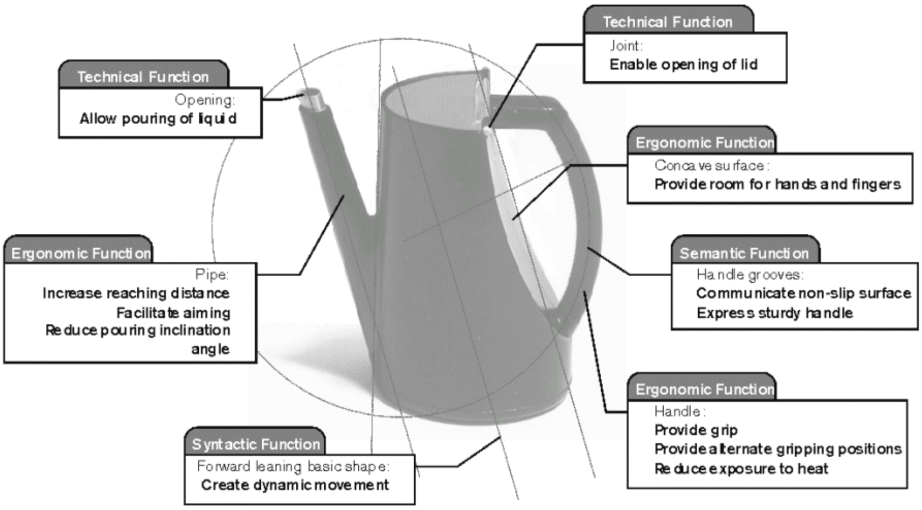


Figure 67. Direct functional identification of the SAS coffee-pot. Adapted from [EDG, 2001].

Methodical procedure

The main objective of the method is to identify and analyze the functional content of products. The starting point for the procedure is the analysis of design intent of solutions, parts, components, etc. The analysis covers all functional aspects of the product under study, including technical and interactive functions, according to Table 4.

The procedure can be formalized into a manual form-based tool. In contrast to direct functional identification, the product is analyzed part by part (or subsystem by subsystem) in this case, according to the following procedure.

1 The analysis starts on the superior, whole-product level and is then continued on subsystem levels. Design intent is searched by posing the question "Why is the solution/feature/mean present?" (column A).

2 By stating the purpose (reason for existence) of the particular solution, the design intent is given (column B).

3 The purpose is now transformed into a function statement by asking the question "What does the solution/feature/mean do?" The function should be stated as briefly as possible (column C), preferably using only one verb and one noun in combination, in accordance with established function analysis methods, e.g., Landquist [1994]; Hubka et. al [1988]; Jakobsen, [1990]; Wikström [2001]. Functions identified from using the procedure of direct function identification can be employed as input in this step.

Function class	Function type			Examples of descriptive verbs
Technical functions (internal product functions)	Operative	Primary	*Transforming*	Transform Transmit Rotate
		Secondary	*Communication* *Interface* *Power* *Control* *Protection*	Regulate Convert Supply
	Structural			Connect Support Restrain
Interactive functions (human-product interaction functions)	Ergonomic			Protect Enable Facilitate Fit/Suit
	Communicative	*Semantic*		Express Describe Identify Exhort
		Syntactic		Refer Connect Unite Discern Balance

Table 4. Function classes of products and human-product interaction, and examples of descriptive verbs.

4 In columns D-I, the function statement is then classified according to the function classes of Table 4. One function statement can be allocated to one function class only. Each subsystem can have one main function.

5 The procedure from step 1 to 5 is repeated for each subsystem of the product, until the product is satisfactorily analyzed.

An excerpt of a filled-in form of the functional analysis is illustrated in Figure 68. An additional step in the procedure can be added by weighing the importance of each function against the other functions (pair-assessment) for each subsystem. Thereby, the relative importance of each function can be assessed, and primary and secondary functions can be identified.

Discussion of the method for form functionality analysis

In the engineering design field, many methods for functional synthesis of mechanical engineering systems have been developed, e.g., by Tjalve [1979] and Hubka et. al [1988]. A common denominator for these methods is that they are limited to the analysis and specification of functionality determined by engineering processes, i.e. internal technical functions that are related to mechanically transforming purposes of the product. Thus, they do not consider interactive functionality, e.g., product functions associated with use, handling and appearance, which is the focus of industrial design. Function analysis methods provided by, e.g., Olsson [1972], Landqvist [1994], and Wikström [2001] aim at providing the designer with tools for such purposes.

Col.	A	B	C	D	E	F	G	H	I
Row No.	**Question** "Why is the solution/feature/ mean present?"	**Purpose/Reason/Cause (design intent)** "In order to…"	**Function statement (verb + noun notation)** "What does the solution/feature do?"	Main	Structural	Additional	Ergonomic	Syntactic	Semantic
1	Why is a pot needed?	…enable serving seated aircraft passengers from main coffee container in cabin kitchen	Hold liquid	X					
	Body								
2	Why is there an opening in the top of the pot body?	…enable (re)filling	Allow filling			X			
3	Why is the cross section of the pot elliptical in shape?	…facilitate (re)filling from tap in cabin kitchen	Facilitate filling				X		
4		… create an visual composition in balance with other form solutions	Couple form elements					X	
5		…facilitate serving by occupying less space when serving	Decrease bulkiness				X		
6		…lighten the visual impression of the pot body	Express lightness						X
7	Why is the pot body made of plastic?	…increase the longevity of the appearance (no dents)	Decrease visual aging						X
8	Why is there a cutout concave curve surface of the pot body facing the pot handle?	…give room for hands and fingers of different sizes	Fit hand				X		
9		…counter-weight the curvature of the pot handle	Balance visual composition					X	
10	Why is the bottom welded to the pot body?	…enable injection-molding of the pot body	Connect parts		X				
	Lid								
11	Why is there a lid?	…retain heat	Reduce heat loss	X					

Figure 68. Example of functional analysis of the SAS coffeepot. Excerpt shows superior product level and two subsystems; the pot body and the lid. The example suggests possible reasons for solutions found in the coffeepot. Other interpretations of the purpose of indicated solutions are conceivable.

In the approach of identifying the functions of the product through a question-based procedure, the procedure suggested here has similarities with the methods of Olsson [1972] and Wikström [2001]. The main difference is that the identified functions are classified according to function type. This is a main feature of the method; by categorizing each function, its importance from a technical or aesthetic perspective is emphasized and recognized.

Functional analysis can be an important and powerful tool in early product development phases, where specifications and targets for product development are set. By facilitating the analysis of existing products, e.g., for product benchmarking purposes, the aim with the method is to provide the design team with a tool for understanding and assessing the total functional content of competing products and systems. The information obtained can be used for developing new product specifications, for balancing functional content in products, and for the evaluation of designed concepts.

Method for form development

The method for form development is intended to be a generally applicable tool for form analysis and form improvement, usable by the individual designer or a team of designers, working with form design development on the operative level of product design.

Methodical procedure

The procedure is principally identical in the cases of the individual designer and the design team. During the search for promising form design alternatives, the designer sketches using, e.g., freehand sketching or computer-aided modeling tools. At suitable stage(s) during the process, when the need for reflection and evaluation of the generated proposals arises, the designer can apply the method for assessment of syntactic form properties, product semantics, and ergonomic aspects. This can be done on the detailed level of specific form elements or on the whole form of the product. In the process, the designer follows the basic steps:

1 The designer applies a scrutinizing stance towards his proposal by asking "*Is this a good form solution?*", i.e. is this a solution that fulfills the requirements on form functionality, coherent design format, product semantics, ergonomic criteria, etc.? By asking this question the designer turns his thinking into a critical mode of analysis, moving from a purely stylistic form appearance perspective to focusing on purpose and effect of the form solution.

2 By analyzing the functionality of the constituent form elements, the designer searches for underlying design intent. The designer poses the question "*What does this form element do?*", i.e. what visual effect does it have, how does it contribute to the whole form experience, is it a sound solution in terms of production, cost etc.? By asking the question, the designer reaches the syntactic dimension of the form design, i.e. features of the visual composition [Vihma, 1995], the effects of individual forms, how they interact with other form elements, how they contribute to and interact with the whole form on the superior gestalt level. As in form functionality analysis, the syntactic functions are stated with verb-noun notation describing their visual effect. The verbs used to describe the syntactic functionality include, but are not limited to, the following, presented in section 5.5 (see also Table 4):

- *refer*: relate visually to form solutions found in other products, e.g., of a common product family
- *connect*: relate visually to other form elements present in the same product form design
- *unite*: relate visually to other form elements present in the design by giving them a common gestalt
- *discern*: separate visually from other forms present in the design by giving them a differentiating gestalt
- *balance*: harmonize by visual counteraction

The identified syntactic functions describe the visual effect of the interacting form elements and gestalts. The designer now has to determine whether the identified visual effects are purposeful, i.e. whether the functions of that form element are necessary and desired. More importantly, the designer or design team also has to decide whether other types of functionality should be more or less emphasized in the form. If functions of several classes are lacking in the design, this may indicate a potential for adding functional content to the design.

3 (A) Functions, which are found necessary and desired, are subject to modification and refinement in order to further optimize their syntactic effect, considering semantic, ergonomic, and technical requirements. The designer should now aim at finding solutions, which elucidate and enhance their visual effect. Form solutions which are too 'weak', e.g. due to having a theme which has few or no connections to other form elements or to the design format, need to be strengthened and simplified. By focusing on the function statement, the designer should, function by function, commence to generate new or modified form design solutions, which all fulfill each respective syntactic function. In this process, new and beneficial functionality that is not found in the existing solutions might arise, which adds to the functional content of the solution. The functions may also be fulfilled by radically new form solutions that use other or additional form elements that have identical syntactic functionality but properties, which fulfill other requirements of the product more effectively.

(B) If one or more functions are deemed unnecessary or undesired, e.g. by adding redundant or abundant visual impact, their effect should be reduced or eliminated in terms of visual impact. If not, the form may be too 'rich' in content, thus reducing the readability and apprehension of the product [Klöcker, 1980].

(C) If functions of other classes are missing, the opportunities for adding functional content to the design should be considered.

Method application: Ericsson mobile telephone

An Ericsson mobile telephone is used as an example to illustrate how the method can be used for form development purposes. A mobile telephone has been chosen due the large amount of technical, semantic, interactive and aesthetic criteria, which apply to a modern hand-held electronic consumer product.

The example provided here focuses on one stylistic feature of the Ericsson 't68m' mobile phone: the characteristic curve on the front of the phone. It can be argued that it is not possible to extract one single form element out of its context since the visual impression is determined by syntactic synergy (e.g., gestalt effects). However, this example only aims at illustrating the general ideas of the methodology. A full analysis would have to consider the whole form design on all levels.

As seen in Figure 69, the curve is part of the common design format of Ericsson mobile telephones. With small variations, the curve is present in all contemporary Ericsson phones. The following discourse aims at illustrating the procedure for capturing the potential for further form development using form function analysis as a starting point.

Figure 69. The studied styling feature, the characteristic curve of the Ericsson t68m mobile telephone (1), which is part of the common design format of the Ericsson product family of mobile telephones, including (2) R310s; (3) ER209i; and (4) T28s.

Step 1: Form functionality analysis

Is this a good form solution? The featured curve has become an important form element for identifying the product as an 'Ericsson'. From the perspective of relating the phone to other phones of the Ericsson range, it also serves its purpose. The treatment of the curve and the buttons carries a similar theme in phones (1) and (2); in the other phones (3)-(4) the curve is part of a lid. While its manifestation in phone (1) gives the impression of the curve being a split line between separate plastic parts, it is, however, a notch in the single-part front cover. Thus, the curve can be seen as an 'ornament'; a form idea having undeveloped potential which might be exploited.

What does this form element do? What function does curve A have? An analysis of functional content according to the function classes of Table 4 reveals the following (Figure 70):

Internal (technical) functions:

None

The curve could potentially have e.g. a structural function, by serving as a split line between parts.

Ergonomic function:

None

The curve could potentially have e.g. a tactile or haptile function, enhancing use by form guidance.

Semantic function:

Identify brand

The curve has the function of identifying the phone as an 'Ericsson'.

Syntactic function:

Visually referring and connecting

The curve refers to the design format used in the phone as a whole and to the corresponding curves found in other phones, thereby 'strengthening' the format (by thematic repetition).

Visually connecting

The curve relates visually to the dynamic movement of curve D.

Visually uniting

- The curve A-B is visually extended from point C to point A. The curve would otherwise have ended abruptly at point C (creating visual imbalance).
- The segmentation of the curve, arising through the repeated interruption by the buttons of the keypad, is an example of the laws of gestalt perception: the segments of the curve are visually united according to the principle of 'the good curve'. As such, the segments of the curve are form entities.

Visually discerning

- The surface E is enhanced by splitting it up into two separate surfaces, E1 and E2.
- The buttons are enhanced by breaking curve A-B.
- By segmenting curve A-B, the buttons are also allowed to unite surfaces E1 and E2.

Visually balancing

The curve places the buttons firmly onto surface E by their unification of surfaces E1 and E2 and motivates the positioning of the buttons, creating balance in the visual composition. Without the curve, the buttons would have a tendency to 'float around' on surface E.

Figure 70. The characteristic curve A-B of the Ericsson t68m mobile phone.

It should be noted that this functional analysis is only illustrative and does not aim at being complete. Other, or additional functions may very well be identified. The aim is to show the types of functions associated with visual form elements.

Step 2: Form development

The analysis of form functionality indicated that the curve serves several syntactic functions. The apparent lack of other classes of functionality, however, suggests that there are unexploited opportunities for form development, which are waiting to be investigated. These opportunities can be explored by further idea generation, with the aim of finding means for the ‘missing’ functions.

In Figure 71, possible alternative solutions for the studied curve are illustrated. The main characteristic of all alternatives is that they each fulfill one or more functions belonging to function classes not represented in the current design.

Alternative 1: A structural function has been added. The notch has the additional function of connecting to separate parts.

Alternative 2: Ergonomic and semantic functionality has been added. The ‘trench’ provides tactile guidance to the user for orientation on the keypad. It also adds a more powerful expression to the phone by the dynamically curved surfaces.

Alternative 3: Has properties similar to Alternative 2, but a form with other syntactic characteristics.

Alternative 4: The notch has been eliminated completely and replaced by a 'ridge' form of the buttons. The ergonomic functionality is similar to Alternatives 2 and 3. Semantically and syntactically, it has other properties.

The example serves to illustrate that functional reasoning presents a feasible approach for form development. The method can be applied on detailed and overall levels of product design, and in several stages of the form design process.

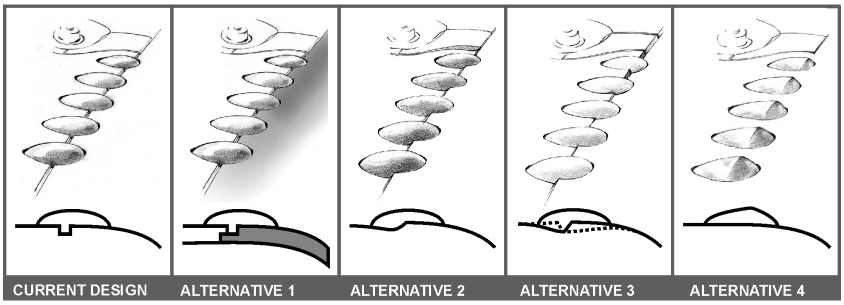


Figure 71. Alternative, possible solutions for articulating the characteristic curve of the Ericsson t68m. Each concept is illustrated by a free-hand sketch (top) and a cross-section view (bottom).

Discussion of the method for form development

The method for form development is intended to provide support for the designer, in an area where methodical approaches are largely lacking. The main purpose of the method for form development is to question the initial form solutions and to generate improved or different form solutions which fulfill the same desired functions in a visually, ergonomically and technically more efficient way.

In its approach, the method can be seen as an implementation of the principles of gestalt perception, including the gestalt creating factors similarity, proximity, good curve, common movement, symmetry, experience, area, and enclosedness [Monö, 1997; Klöcker, 1980] to the active synthesis process of form development. By transforming the gestalt principles of perception psychology into a tool for applying the gestalt principles during styling development, the designer is supported in bringing order and simplicity into the design and in differentiating the product. As noted by Klöcker [1980], these tendencies have to be balanced against each other in the process of creating a product, which is visually perceived as a coherent whole.

The method can be used in a variety of different circumstances during the form development process, for the purpose of comprehension, evaluation, and improvement of the emerging form. The reasoning can also be applied in design teamwork, as a tool for interdisciplinary communication of design intent.

Method for design format handling

Design formats are intended to provide an approach for describing and analyzing styling aspects in product design, as described in Papers E and F. Design formats can be used to describe styling features and principles of product form, what is commonly referred to as the 'form language' of a design.

A company or design team that wishes to achieve a greater understanding of the appearance of its products may do so by analyzing form content and composition in a single product, a product family, or a product generation series. Since they are procedurally similar, only the design format analysis of a single product will be described here. The suggested methodical approaches are described in full in paper F.

Methodical procedure

Design format handling includes several feasible tools, usable for the purposes of analysis, assessment, specification, and synthesis of product styling. These include descriptive and prescriptive approaches. Descriptive approaches include design format analysis of a single product, a product family, or a product generation series. A prescriptive approach can be applied for specification or synthesis purposes. In all cases, the first step in creating a descriptive design format is the examination of product styling features, i.e. visual form ingredients and compositional principles.

Descriptive design format analysis and assessment

In order to analyze the design format of a single product, the product form must be broken down into visual ingredients such as form elements, gestalts, form entities, physical components, etc. The way the decomposition of the form into visual ingredients is done varies from case to case, depending on styling features and component structure. The basic procedure includes the following steps.

1. Identify main physical components or subsystems of the product. For a vacuum cleaner, these can be the top cover, chassis, wheels, handle, etc.

2. The physical components are recorded in writing or by sketches, in the left column of a format assessment matrix, Figure 72.

3. Identify styling features of the product form, such as form elements, material treatment, colors, graphics, surfaces, form meetings, curves, symmetries, form relations, composition and balance principles, etc. These styling features represent ingredients of the design format of the product.

4 Record the identified styling features, in writing or by sketches, in the top row of the format assessment matrix.

5 For each physical part (or subsystem) of the product, the styling feature can be illustrated by, e.g., a free-hand sketch, highlighting the use of the styling principle in each part. In Figure 72, the form elements in the top cover of the vacuum cleaner ‘carrying’ the styling feature are reinforced. The relative degree of visual coupling with each identified styling feature of the design format is assessed with the help of scores on a two-point scale; one point indicates a weak relation (an unfilled circle), two points indicate a strong relation (a filled circle). The form design of one physical component can carry form elements corresponding to several styling features.

6 The procedure is repeated for each physical component or subsystem until all relations are considered.

7 The scores in the rows of the format matrix are added, yielding a figure in the right column, which represents the visual relation of each physical component to the design format of the product.

8 The scores in the columns of the format matrix are added, yielding a figure in the bottom row, which indicates the degree to which each styling feature is represented across the form solutions of the parts of the product, i.e. how ‘strong’ the design format of the product is.

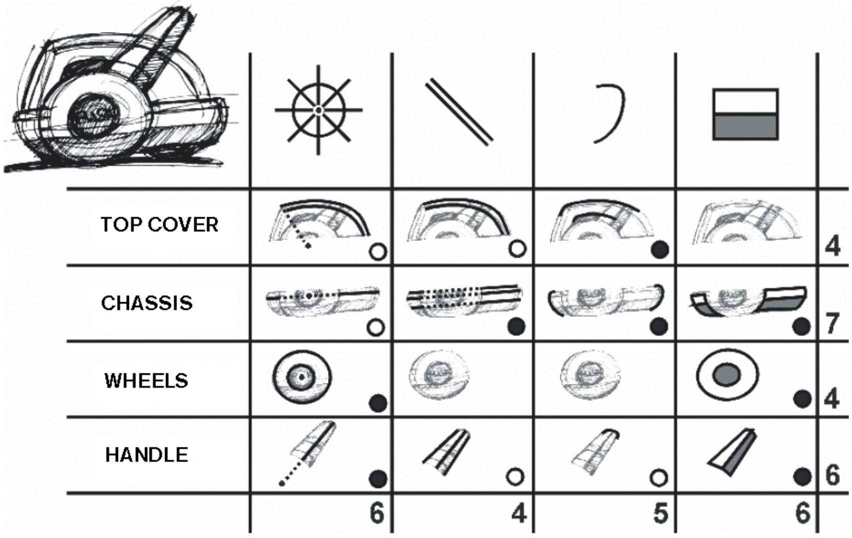


Figure 72. Descriptive design format analysis and assessment of a single product. Sketch material courtesy of Electrolux Home Products Operations (Sweden) AB.

Prescriptive design formats specification and synthesis

Design format modeling can also be applied for prescriptive purposes, as a method for specification and synthesis. Starting from the establishment of a design format for a specific product, a product family, or a generation of products, a general design format for new products of the company can be developed. Such design formats can be used as part of a specification for the form development of a new product. Furthermore, several design formats representing different alternatives in terms of form language can be developed, which gives the design function of the company the opportunity to systematically do research into, and cultivate, several form language alternatives during early pre-design stages as a continuous design development activity, where new approaches for future styling directions are investigated.

Discussion of the design format method

The different variants of the design format method provide the design team with approaches, usable for purposes of specification, analysis, synthesis and evaluation of form design.

For product planning purposes, analysis of form design content across product families is a method, which can help bring coherence into the whole form design activity. By the analysis method, a design format can be established and defined for use in the form development of new products. By assigning a value to indicate the degree of similarity with styling features of the other products in a product-for-product manner, it is possible to assess the degree to which each product conforms to the common design format of a product family.

The assessment obtained by the format analysis method may assist the designer and design team in acquiring a useful perspective on the styling content of the product's form design. The format analysis makes it evident what styling features are present in the design. The assessment by scoring indicates to what degree different styling features are represented in the design, if any form ingredients need to be visually strengthened or suppressed, if important form elements need to be enhanced, etc.

An important aspect is that the philosophical and strategic levels of the form design activity of a company may be communicated and applied on the operative level of the individual designer or the design team by help of the suggested methods.

Discussion of proposed methods

Designers work with different views of the problem and with different levels of experience and raining. Experienced designers might work with approaches to problem solving, which do not appear to them as a method, since it is a 'natural' way of working. This situation might be regarded as an 'ideally' implemented method, which is achieved by repeated use and training of applying a specific way of approaching a problem. For novel designers, the use of a method can guide them in adopting a structured thinking pattern for approaching and solving the problem in a more efficient way than would otherwise have been possible.

In general, design methods can only recommend ways of thinking and operation sequences for the human designer to follow [Buur, 1990]. While a theory describes reality, a method defines, on the basis of the declared facts, how the scientific and practical activities and behaviors of humans ought to take place [Hubka and Eder, 1996]. It is important to note that methodical procedures should not be regarded as the only way, or always the 'right' way, of approaching a specific problem. Important characteristics aimed at during the formulation of the proposed methods include:

- *'Scalability'*: The ability to apply the method in a variety of different design situations, for different purposes, and by different users.
- *Ease of use*: To be efficient, methods must be easy to learn, simple to use, enhance understanding of disciplinary issues, and promote interdisciplinary communication.
- *Compatibility*: The methods must also work together with other tools and methods, which are available for different aspects of design work. They must also comply with normal and established working procedures.

For the sake of simplicity of use, the methods presented here have been manifested as readily applicable, manual paper-based tools. However, they may also be suitable for implementation in computer-based support systems.

The context of use of the proposed methods and tools presented here can be seen from three different perspectives, according to the following.

Different purposes and stages in the design process

The methods cover needs found in different stages of the design process. These include pre-design tasks such as benchmarking or competitor analysis, strategy formation and specification, and design tasks such as functional analysis, form design development, and form evaluation.

Different users and stakeholders

The methods are intended to be usable on all operative levels in design development, where decisions are taken on a daily basis, both on detail and system levels of design. Thus, the tools provided must be easy to apply for the following groups: the individual designer, who needs tools and methods for design synthesis and styling development; for the design team in need of tools for design specification, design evaluation, and interdisciplinary communication; and on design management levels, for managing company design activities and product planning issues.

Different design objects and applications

The methods should be generally applicable, meaning that they should not be restricted in their use to any specific type of product. Although primarily intended to support the development of products where technical-aesthetic aspects are a complex issue, such as automobiles or mobile telephones, the methods should work equally well for the design of simple, everyday products such as a pencil or a fork.

It must finally be emphasized that the suggested methodical approaches have not been implemented or evaluated in a real design situation in industry. They are, however, in terms of overall purposes and general procedures, based on patterns of reasoning found in methods, which are in use in industry and design education.

6 SUMMARY OF APPENDED PAPERS

Paper A Artifact Theory for Industrial Design Elements

In this paper, the fundamental elements of the proposed modeling language for product design, denoted the 'form functionality framework' are described. Taking a standpoint in the central issue of communication of messages between product and user, product semantics is acknowledged as an important field contributing to the research area. The need for concepts, which establish the 'missing link' between the top-down approach of the industrial design field and the bottom-up approach of engineering design, are identified. A theoretical contribution is made towards the development of elements that provide a logical and objective language for relating communicative qualities to form design. Based on the domain theory, elements are developed related to the function, organ, and part domains, which connect the visuo-spatial form of the product to its technical structure and behavior. The concepts include *form elements*, as the building blocks of form; *functional regions*, which describe how form elements of parts carry functions; and a *classification of organs*, related to aspects of user-product interaction.

Paper B A Model for Visual Design Aesthetics Based on Form Entities

The paper presents an approach for linking product aesthetics to the domain theory. *Aesthetic organs* are introduced as an organ modeling entity, which fulfils aesthetically determined functionality of the visual product form. The aesthetic organs are realized by form elements in the part domain. The concept of *form entities* is introduced as a modeling unit facilitating reasoning about purpose, constitution and relational properties of aesthetic visual form. *Design formats* as a concept for capturing and describing product characteristics related to industrial design issues are proposed. During form design development, design formats are suggested as a tool to be applied for directing design work in a desired direction, by acting as a template for form design work, on operative and strategic levels of design development.

Paper C Design Syntactics - A Contribution towards a Theoretical Framework for Form Design

The article develops the theoretical basis for the *design syntactics theory*. The concepts of *form functionality*, including *syntactic* and *semantic functionality*, are developed and related to the domain theory. The mode of action of form functions is related to signaling. Form entities are elaborated, and it is proposed that they constitute a type of organ unit for aesthetically determined functionality, which is similar to wirk elements for technically determined organs. The relation between gestalt configuration in product form design and the form entity concept is elaborated on. The article establishes the theoretical basis for creating a common model for product form, relating technical and aesthetic aspects.

Paper D Emergent Form Design Development Modeled by Form Entities

This article aims at gaining an understanding of the emergent form design process from the perspective of form entity modeling. Sketching processes of designers were investigated to determine whether it is possible to find evidence of the existence and development of form entities during early design sketching. Industrial designers were interviewed about their reasoning during the early sketching process, to find indications if it is possible to model the emergent form evolution process with the design syntactics theory. It was found, that the elements of the theory are well supported by the empirical studies, and that form entities provide a reasonable model for describing emergent form development.

Paper E Managing Product Identity and Form Development Issues Using Design Format Modeling

In the paper, a descriptive framework for visual form design, denoted *design format modeling,* is further developed and elaborated. In a step-wise, incremental presentation, the concept of design formats is developed based on studies of single products, product families, and product generation series of products from various industrial companies. The presented concepts are discussed from the perspective of product and corporate identity, and it is proposed that companies may use the model for capturing and describing their visual form content, and for managing product design on the operative and strategic company levels. It is also proposed, that companies can use the concepts for developing a philosophy and strategy for form design.

Paper F Methodology Support for Form Design Development in Industrial Design Engineering

The paper concludes the development of the design syntactics framework by proposing methodology approaches supporting form design development work. The methods presented are designed to be applicable for different purposes in the design process, by users on operative and strategic levels, and for different design objects and applications. Three methods are proposed; a method for form functionality analysis, a method for form development, and a method for design format handling. The procedures are described in a step-by-step manner and illustrated by product cases.

7 CONCLUSIONS

The concluding chapter of this thesis is structured into sections of discussion of the results, an evaluation of the results including a discussion of validity and verification, a discussion of the novelty of the contributions, and finally, an outlook for future work.

7.1 DISCUSSION

The need and demand for knowledge of industrial design increases with the importance of aesthetic product form design as a competitive factor. However, several challenges need to be addressed. Firstly, available knowledge is relatively difficult to reach, due to the limited number of designers with competence in industrial design. Also, the academic community has to make an effort to raise the level of industrial design education in Sweden. Industrial design programs are largely characterized by a pragmatic and craftsmanlike approach to the design profession, which has a shallow theoretical basis and little interaction with other design fields during course work, although exceptions are found. Secondly, available knowledge is relatively divergent, stemming from different knowledge areas. The industrial design area, by nature consisting of a number of interrelated fields, is in lack of 'its own science', and needs to be strengthened by a strong, coherent knowledge base.

Thus, there is a great need for increasing the academic level and the research effort in the field. As an answer to part of this need, industrial design engineering is emerging as a new competence area with a promising future. In line with this trend, research efforts into the field of industrial design and engineering design interaction are increasing. Several ongoing research projects, mainly based at technical universities in Sweden, will contribute to this development.

The research presented in this thesis largely reflects the current situation. The work is characterized by a number of contributing knowledge areas, which each add their ‘piece to the puzzle’. As a basic foundation for the work, a basis in mechanical engineering design has contributed with a conceptual structural product model, to which other relevant fields of knowledge have been added. The choice of engineering design science as a theory basis for the framework is not wholly unproblematic. Since it is based on a product-centered approach, the human element is largely missing in the theoretical discussion. Its strength in providing a structural and behavioral model of the product, and an elaborated model of the design process, however, has no equivalent in any other field encountered during the research work. A basic assumption has been that what is lacking in design science reasoning can be contributed by other relevant research areas, which provide a specific focus on human appreciation of product form from different aspects. Such knowledge areas have contributed with the perspectives of semiotics, aesthetics, and visual perception. The focus has been on identifying relevant fields of knowledge and their potential contributions to the work from a holistic perspective, adding to the understanding of the nature of visual product form.

Discussions of the contribution and value of the theoretical frame of reference have been presented in connection with each area presented in the thesis. The discussion of the contributing areas’ positioning in relation to each other, or their relative value for the research as a whole, is an important issue which must be considered in the future of design research. The presented frame of reference indeed suggests a wide and, sometimes, little interrelated field of knowledge. The theoretical foundation is divergent, which has been a difficulty and an asset of the work. The common factor for the presented fields is the concept of function, which has been the scarlet thread in the research. A main challenge of the work has thus been to find a concept, which ties the different function concepts together. In that sense, the functional perspective has been a ‘key to success’ in the effort of interrelating various approaches to the product in the ‘horizontal’, cross-disciplinary perspective.

Discussion chapters on each area of results are, likewise, found throughout the contribution chapter. The main contribution of this work, the theoretical framework of design syntactics, has as a model been formulated to tie the three interrelated elements together into a conceptual framework. The focus of the work on the framework has been on developing a conceptual basis for the studied field, which is not previously available. The focus expressed for the work is naturally reflected in the research methods applied, where empirical methods have been utilized to gain a basic understanding of the needs within the field and for gaining an understanding of the product development process in company settings. The development of theory and methods has been carried out using a formal research approach, which is based on the empirically identified needs.

A logical next step in the research area is, apart from a continued development of the theoretical foundation, more intensified empirical studies of form design processes and perceptual aspects of product form. The situation illustrated here can be compared to the field of product semantics, where conceptual development of theory and methods has been a main topic since the mid 80's. It is not until recently, that empirical approaches have been adopted for studying the field of product semantics. A similar situation is found in the area of engineering design science.

7.2 EVALUATION OF RESEARCH RESULTS

In the discussion of the value of research results, it is important to note that the issue of evaluation must be seen as a continuous, ongoing process during the course of research. For the purposes of evaluation of a research work, it is not satisfactory to introduce a final 'evaluation study' at the end of a research project. Doing research without constantly reflecting on issues related to validity and verification of the work, is like sailing in darkness without a nautical chart: where did I start, where am I now, in which direction am I heading? Are there any shoals or other obstacles ahead? Am I in a main fairway, competing for space with supertankers?

A sound research effort must constantly be questioned. The research approaches applied in this project, and the goals set up for the research work, have during the course of work been subject to continuous scrutinizing both from outside sources, such as the scientific evaluation procedure of the ENDREA program, as well as from within the project, by researchers and supervisors. Also, personal experiences of design work, e.g., through coursework, industrial projects, project supervision, and industrial studies, as well as continuing discussions with industrial and engineering designers, colleagues, and university tutors, have been an important part of the total navigational process.

In this discussion, it must be acknowledged that most of the internal validation of the theoretical results has been carried out through logical reasoning. The proposed methods have not been implemented or evaluated in actual design processes in industrial settings. In that respect, they may still be regarded as 'drafts'. Dedicated empirical studies are needed to verify the applicability of the methods in such cases. The work as a whole, however, is based on a foundation of external knowledge of the situation and needs in industry, which has been arrived at through several empirical studies, as discussed in section 3.3. As presented in Paper D, an empirical verification study of the proposed conceptual framework has also been carried out in order to verify specific issues. However, more work is needed in this respect in the future. In the following, a summarizing evaluation of the work presented in this thesis is carried out with respect to validity and verification of research results.

Validity of research results

Validation of research results is concerned with establishing the relevance and meaningfulness of theories, models, and methods. Thus, the question arises whether the research questions posed in section 2.4 have been satisfactorily answered through the findings of the research work. This issue is discussed in the following.

Question 1. How are visual form aesthetics related to other product aspects in a descriptive product model?

As a descriptive product model, the design syntactics framework presents theoretical concepts, which relate aspects of the visual product form to design science theory, especially the domain theory. Based on studies of contributing theory areas, the approach has been adopted to relate visual product form to technical aspects of the product through functional modeling, and to contribute with the necessary models needed for realizing that approach. The product aspects aimed at include technical aspects, but also semantic and ergonomic aspects have been considered.

Question 2. How can visual product form be described, explained and communicated in form design work, based on a functional approach?

The development of elements describing visual product form has been based on the outset of creating concepts, which can be used across disciplinary boundaries in product development. An emphasis has been on providing objective descriptive models, which take the standpoint in the structure and function of the visual product form. The goal has been to establish a foundation for more efficient communication of form aspects between different stakeholders active in form design work, which is based on functional reasoning. It is shown that such an approach is possible and compatible to different theoretical foundations. It is also shown that theory and models can be developed which address needs of form description. More work is needed for implementation and evaluation of the results in actual product design processes in industry.

Question 3. What is the nature of a tool or method for use in design work, integrating industrial design and engineering activities in early conceptual design?

The nature of the methods proposed in this thesis is largely determined by the theoretical basis from which they have been developed, and from the needs for methods and theoretical development identified through studies of the design process at various companies. General important characteristics for the proposed methods identified in the studies included their ease of use, scalability to different design situations, and compatibility with existing methods in use. The suggested methods have been developed with the aim of contributing to enhancing the interaction between technical and aesthetically related activities in product design. They aim at addressing issues, which are of focus in that area. Studies of different types of products and at different companies and branches done during the research have served to lessen the focus on one type of application. The characteristics of proposed methods suggest a wide applicability range in terms of stages, users and objects of design, which is important when aiming at contributing to a holistic perspective.

As discussed in section 3.4, contributions regarding validation of design research have been suggested by Cross [1995b] and Yin [1994]. The five criteria proposed by Cross, that design research should be *purposive inquisitive, informed, methodical,* and *communicable*, have all been addressed as part of the 'process-related' continuous validation of this research work, which has been supported by the scientific evaluation procedure of the ENDREA program. The basis for a valid design research result according to Cross, is intimately related to the applied research method.

Yin [1994] suggests four tests related to the validation of empirical research activities. It must first be emphasized that the main body of knowledge generated by this research work has not been established through empirical research studies. The significant contributions are related to artifact theory, which have been arrived at through a speculative, reflective and philosophical research approach. The role of empirical research studies have primarily been to initially establish the research area, to acquire an understanding and insight into the field of study, and to develop the argumentation related to the need and value of the research work. However, for the empirical studies made, the tests suggested by Yin are considered relevant and applicable. They are discussed in the following.

Construct validity is in this research related to the quality of data gathering. The empirical studies related to industrial design and product development issues, presented in section 3.3, have been carried out by interview and participative studies at four different, major company locations in Sweden. A major questionnaire survey on use of design methodology, disciplinary competencies, and communication issues, was based on a wide response sample of respondents in various branches and company sizes. When applicable, reporting and feedback on the studies have also been part of the studies. An issue, which has to be acknowledged in discussing the validity of studies carried out in industry, is that interviews and observations always give a somewhat superficial understanding of a research problem. Acquiring profound, in-depth knowledge requires more comprehensive and prolonged studies, which on the other hand drastically reduces the possibility to gain a general understanding of the research issue across a range of companies.

Internal validity is interpreted as acquiring knowledge based on inference from sound data gathering. This issue is thus largely related to the discussion above. A large part of the motivating argumentation for the research is acquired through the studies, but the results of this work are otherwise not heavily dependent on internal validation.

External validation; establishing whether a study's findings can be generalized beyond the domain of the study. It is in this study largely supposed, that the problems identified early in the work, and which constitute a major part of the incentives for the research, are in their nature general for characterizing the studied phenomenon across companies in similar branches and sizes.

Finally, the *reliability* of the empirical studies is most easily reviewed by an outside source. The aim with all studies has been to generate knowledge, which is as 'true' as possible. However, this issue is largely dependent on factors such as the number of research subjects, their 'suitability' for giving a relevant view of the problem, the degree to which a researcher is allowed to study and get access to relevant information, etc.

Verification of research results

Verification of research results is concerned with establishing the truth or accuracy and the predictive and explanatory power of proposed theories, methods, and models. The issue of verification is in the following discussed in relation to the suggestions by Buur [1990] and Olesen [1992].

Logical verification

This research work is largely characterized by a multidisciplinary approach of understanding the problem. As a consequence, theoretical elements from a number of fields have been identified, sometimes modified, and interrelated, to form a 'hybrid' theory, which aims at proposing concepts, which explain a phenomenon in a novel way. A wide approach has been searched for. As a consequence, a profound, specific, and in-depth understanding into each field has not possible within the frame of the project. It is thus recognized that a potential risk of some degree of inconsistency, as viewed from within each contributing knowledge field, cannot be ruled out. It is stressed, however, that during the course of the work, no such issues have been raised by any involved party. Its consistency and completeness should be seen from the viewpoint of general applicability and integrative ability.

Verification by acceptance

Verification by acceptance can be discussed from the two perspectives of the practical goal of the research in accordance with the ENDREA program, including the issues of industrial and academic contribution.

From the industrial standpoint, an effort has been made to verify the results by the involvement of experienced designers. An empirical study of professional industrial designers working in large product developing industries served to investigate the issue of value and 'reasonableness' of proposed models and methods. The outcome of that study was promising, however, it is recognized that deeper studies must be made to verify the proposed theoretical models. The proposed methods also need to be implemented and evaluated in real design work.

One example of spontaneous implementation of results from the work in the industrial styling design process of one of the studied companies strongly supports the issue of verification by acceptance. The modified styling process embodies a novel approach to the systematic development of alternative styling concepts, which is directly based on results from this research work. This case also supports the issue of novelty value, as suggested by Olesen [1992].

From the academic viewpoint, verification by acceptance can be seen as its ability of being accepted among other researchers and to contribute to educational efforts. Admittance of all papers included in the thesis to international design conferences can be seen as a proof of the first point. Regarding the latter issue, several of the proposed models and methods, which have resulted from this work, have been introduced to university design courses at the mechanical engineering program at Linköping University and are now part of the industrial design course curriculum at the master degree level. These implementations show that the developed concepts have strong pedagogic value.

7.3 NOVELTY OF RESEARCH RESULTS

The novelty value of the results is suggested by Olesen [1992] as an evaluative criterion. The novelty of this work can be discussed from a number of viewpoints. Research efforts in the field of industrial design and engineering design interaction are very sparse. Few works are found, which address the nature and structure of aesthetic form related to product design development. In the semiotics field, conceptual research has been done relating the product form to its representative qualities. Product semantics provides an important contribution, which is evident from its impact in industrial design education and examples of applications in industry. The results presented in this thesis may contribute to a new perspective on the discussion of form, which is of importance from the industrial as well as from the educational perspective.

Focusing on the development of a conceptual model for the structural and behavioral nature of the product form, the results of this work can be seen as providing a novel perspective. The conceptual framework of design syntactics proposed in this thesis contributes to a theory and terminology focusing on the articulation of the purpose of form, which is important from a product development perspective, where product form is discussed from a number of viewpoints. Here, industrial design is provided with a framework, which might assist in conveying design intent from an aesthetic form perspective, using terminology and approaches compatible with the field of engineering design. Also, the contributions regarding methods for form design provide approaches in an area where formal, documented, and published methods are largely lacking.

Most importantly, the thesis presents a novel way of reasoning about form design, which is more relieved from subjective valuation than is the case today. The discussion of product form can thus be externalized and be made more objective and more formally evaluable. The contribution of the thesis can thus be seen as a tool for enhanced communication and understanding between different disciplines and perspectives of product form. Apart from being of support in the operative product design activity, the results can also be of value for design planning and company decision-making on the strategic level.

7.4 OUTLOOK

The perspectives of the field studied in this thesis are wide and open. More work on understanding the phenomenon of form design as well as providing tools to support the process is greatly needed, both for academic and industrial purposes. The work presented in this thesis approaches form mainly from a theoretical artifact perspective. Efforts are needed to further develop the suggested theoretical framework.

The perspectives of aesthetic form, product semantics, and ergonomics from a product and user perspective are closely related to the presented work, and are in need of increased research efforts. From the empirical perspective, research on how users perceive and value aesthetic product form, related to form functionality and form structure, is an important issue. Particularly, the effect of the syntactic dimension of the form on appreciation of product form is an interesting research area.

More studies on industrial design processes, the use of methods and tools, and on understanding the design process of designers are also needed, as is the implementation and evaluation of proposed methods in design work in an industrial setting. The issue of how to efficiently manage form design development from a company perspective, related to the proposed framework and methods, is also an area worth studying.

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9 APPENDED PAPERS

PAPER A

Warell, A. [1999]: “Artifact Theory for Industrial Design Elements”, *ICSID Design ‘99 Conference*, Sydney

ARTIFACT THEORY FOR INDUSTRIAL DESIGN ELEMENTS

ABSTRACT

The purpose of the paper is to relate elements of industrial design reasoning and engineering design theory found in European schools of design. According to the domain theory, a mechanical product can be described as a process, function, organ, and/or part system. Organs and components realize the functions of the product. Parts of products may be described as having function surfaces of different types that are connected by material fields. Existing engineering design theories focus only on technical functionality of a product. However, functions of other types, e.g. related to the use-process, the user-product interface, semantics and ergonomics, also exist and have to be considered during conceptual product design. The contributions in this paper aim at formulating the basic elements of a coherent form design language, applicable for all types of form design reasoning during the early stages of product design and development. In this light, the present paper will contribute to a future growth in knowledge and competence in this area, presenting new insight into the special area of design science known as *artifact theory*.

A product's form is built up of *form elements*. Form elements characterize the product aesthetically, semantically and ergonomically in a manner analogous to the way machine elements describe the technical characteristics of a machine system. The concept of form elements is applicable on all levels of the design of a product, whether on the form as a whole, on the form of individual parts, or as features. Features, defined by parameters that describe the geometry, are the smallest elements to characterize the physical form of any product. *Form factors* provide the rules governing the creation and transformation of the shape of form elements. Form factors, in turn, are governed by the basic design properties; the only design characteristics that can be directly manipulated by the designer.

As function carriers, *organs* and *functional regions* realize the functions of the product. Functional regions, as the active parts of components, implement functions and provide the link between the functions of a product, the organs (function carriers, describing action principle for the function), and the form of the product. Three classes of organs, *operative*, *structural*, and *usability organs* correspond to the classes of functions they fulfil. Usability organs include organs serving ergonomic, cognitive, and semantic purposes.

With the framework presented in the paper, usability functions of products can, by the introduction of functional regions, be logically and causally related to the shape of form elements of products and individual components, thus providing rational evidence for the classic device "form follows function". Product case studies exemplify presented models and concepts.

1. INTRODUCTION

Industrial design[21] has traditionally been quite isolated as a professional business in Sweden. The number of active industrial designers amounts to about 300, of which most are private or small firm consultants. During the last few years, there has been an increase in the number of industrial designers employed in industry and large consultant businesses, amounting to around 100 people totally. University degree programs dedicated to industrial design have been offered since 1978 [Svengren 1995], with a total yearly graduation rate of about 40 during the last decade.

The Swedish Society of Industrial Designers (SVID) has, during the last few years, invested a large amount of time and effort in promoting the use of industrial design competence in product development, mainly in SME:s, but also, as a first step, to make companies and associations aware of the existence and benefits of using industrial design in their product development activities. This promotion program has had some positive effects. In conjunction with a general positive change of attitude and a growing public interest in design, there is now a trend in Swedish industry towards a greater awareness of the benefits of using industrial design to develop more competitive products for an increasingly demanding market.

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21 The term *industrial design* is here defined as "the ideation, specification, and development of functions, properties, and concepts of industrially manufactured products, systems and environments, regarding mainly aesthetic and identity aspects, considering a totality of ergonomic, usability, technical, economic, and social factors".

In the same way as the natural use of industrial design in industry is still in its infancy, so is the academic history in the area. During the 1990's, industrial design has received larger attention and gained growing importance in education and research. There is a growing interest in making the traditionally 'pragmatic' knowledge of the industrial design field more academically oriented and research-based, in line with e.g. the tradition of the engineering design field in Sweden. This trend will certainly grow stronger in the future with more resources being put into new educational programs and research in the field of industrial design. Industrial design has come to stay - a *viewpoint in time* for industrial design in Sweden.

Several authors have stressed the importance of using industrial design as well as indicated the value of investments in product design and development activities [Kahlman 1989, Pearson 1992, Roy and Potter 1993, Svengren 1995]. The integration of activities in the product development process is also essential for efficient product development, and there is a need for enhanced interaction between engineering and industrial design in industrial activities.

One approach for achieving this effective collaboration is to provide designers and other internal product development stakeholders with efficient means for communicating product development considerations and design priorities during product development. Some tools have appeared that have proved useful in this respect, such as the method for evaluation of semantic functions provided by Monö [1997]. At Volvo Truck Corporation, the framework presented by Monö has successfully been used for communicating aesthetic design decisions between the product design department and corporate management[22]. Elaborate methods, such as general procedures and methodologies, aimed at enhancing the design process in a similar manner would provide means for an improved cooperation and understanding between other fields in the product development process as well, such as industrial designers and engineers [Warell 1998]. Such general procedures do not yet exist; however, methods and tools aimed at different aspects of design are available and in use [Svengren 1995, Warell 1999]. Procedures focusing on engineering design specifically are also found, e.g. Hubka and Eder [1992], and Pahl and Beitz [1996], but these are not appropriate for solving industrial design-related design problems in an efficient manner [Warell 1998]. Elements of an enhanced theoretical framework and methodology aimed at solving the underlying problems associated with existing procedures in this context have been proposed [Warell 1999]. The contributions presented in this paper constitute a direct development and continuation of that effort.

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[22] Aina Nilsson, Design Manager Volvo Truck Corporation, HDK Seminar, December 12, 1998.

2. COMMUNICATION OF 'DESIGN MESSAGES'

One important task of industrial design is the design of the human-product interface, it being the most important factor for effective use of the product. The interface may be seen as the 'arena' for communication of messages between the designer and the user; a successful design communicates the intentions of the designer and effectively aids in the use and handling of the product. It is thus advisable to investigate the factors which influence the information carrying capacity of the interface.

Buur and Andreasen [1989] talk about the role of design models for modeling certain product properties. The design model in Figure 1 may be regarded as part of the communication process when transferring information from a sender (the designer) to a receiver (the model user). The intended information is coded by the designer in the form of the product, and is decoded by the user during use of the product. The information is transferred in the form of a signal[23] by use of a medium of some sort (e.g. talking, writing, or a cardboard model). The 'medium' is what Karlsson [1996] refers to as a 'mediating object'. During the transition of the signal, noise (distortions) may be added, or loss of information may occur, rendering the information received by the user differently from the information intended by the designer.

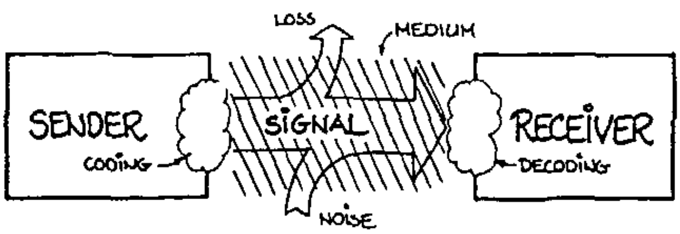

Figure 1 The general communication process [Buur and Andreasen, 1989].

By applying the communication model not only to design *models*, but to finalized products as well, the reasoning may be taken a step further. If the receiver of the information is the user of the finalized product, it becomes apparent that the 'code'[24] of the product must be consciously incorporated

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23 The term 'signal', as used in this paper, is defined as being of data character during transmission, and of information character before coding, and after decoding, by designer and user, respectively. Thus, signal content becomes interpretable information only after being decoded by the user.

24 One meaning of 'code' is "a system of signals, figures, or symbols, with arbitrary, convention-alized meaning, used for communication" [Funk & Wagnall 1964] (from [Monö 1985], translated from Swedish). Monö [1997] defines 'code' as a "system of rules for the interpretation of signs/signals". Monö continues the reasoning by saying that "semantically speaking, the technology is a technical code which gives rules for reading the semantic functions of the product sign, for being able to understand the design's message".

into the design of the user-product interface, in order to convey the appropriate message (the information intended by the designer[25]) via the expressed properties of the product. Monö [1997] presents a communication model that includes signal messaging from the designer's intentions to the user's interpretations, illustrated in Figure 2.

According to Monö's model, the coding is done by the designer (the *source*), giving form to e.g. controls and graphics of the use-interfaces of the product (the *transmitter*, medium, or mediating object), with the intended purpose in mind. The signals are conveyed by the design (the formal aesthetics) of the product or by elements of the product's form. The decoding of the message is performed by the user (the *receiver*) during use of the product, as he interprets the message (*target*). Ideally, the conveyed message is identical with the information intended by the designer. However, a familiar and frequently observed situation is that the use and operation of the product are unclear due to design deficiencies, resulting in low product functionality, apart from frustration and confusion on behalf of the user.

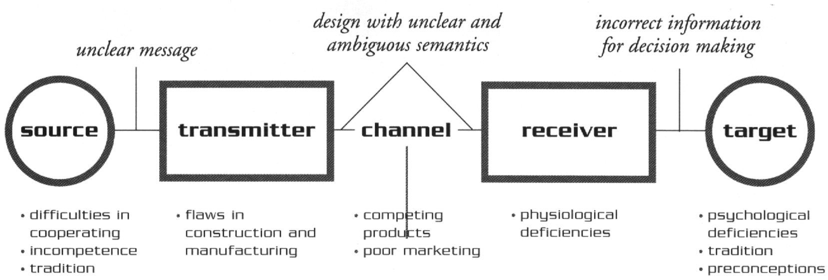

Figure 2 Monö's model of communication of design messages, with potential factors of disturbance [Monö 1997].

According to the model of the general communication process in Figure 1, the reason for this situation may be (1) a *loss*, or even (2) a *non-existence* of certain types of codes and signal content in the design of the product. This situation is typically experienced during programming of certain video tape recorders, copying machines and other multi-functional electronic or mechatronic products. Other reasons may be (3) the introduction of *noise*, i.e. disturbing, obstructive, or unclear design of other parts of the product or system (this is a common situation in state-of-the-art jet fighters, where the abundance of controls and displays often results in signal overload), or simply (4) the *inability* of the user, due to differences in culture, previous

25 The term 'designer' in the singular form is used for denoting cases where several designers are present as well.

experience, social or personal factors, to understand the coding provided by the designer.

3. PRODUCT SEMANTICS

The process of communication is not the focus of this paper. However, in this context, the concept of signal messaging is crucial to product design. To quote Monö [1997], "to be used, they [i.e. products] must first and foremost be capable of being understood." One approach for improving products in this aspect is the school of product semantics, which has gained increasing attention and growing importance during the last decade. Product semantics may be seen as the application of the theories on information messaging to product design.

Semantics is one of the three legs of semiotics, which also includes syntactics and pragmatics[26]. The transferred use of semiotics from the linguistic sense to objects was first introduced in the 'Sprachtheorie' by Bühler [1984] with the aim of analyzing the communication capacity of images. The term *product semantics* was pioneered by Butter and Krippendorff [1984], who defined it as "…*a study of the symbolic qualities of man-made forms in the cognitive and social context of their use and application of knowledge gained to objects of industrial design.*" According to Butter [1987], the use of product semantics can:

1. contribute to make the use of products self-evident,
2. help to make products culturally meaningful, and
3. supply products with a distinct character.

The are many reasons for the growing interest in product semantics. The increasing amount of different technologies in new products, but also in traditionally mechanical products incorporating electronics and software, makes product functionality less transparent due to shrinking size and the lack of physical clues to the functions of the product. The increased functionality, which becomes easily and inexpensively obtainable through the use of software, and the globalization of products and markets, increase the importance of product appearance for efficient use and maintenance in different cultures and contexts.

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26 Semiotics: The study of signs.
Semantics: The study of the sign's message (the meaning of the sign).
Syntactics: The study of the signs relations to other signs and the way it interacts in compilations of signs.
Pragmatics: The study of the sign's use in different cultures and contexts [Monö 1997].

Traditionally, the area of product semantics was primarily handled by industrial designers in an intuitive, subconscious manner. It is not until quite recently that efforts have been made at theorizing the knowledge or setting up models and methods for use, and introducing the subject in teaching. It is quite astonishing that, in spite of increasing competition and in the light of all the research that has been carried out on technical matters, the area of product semantics has gained so little attention. To quote Butter [1987], “It doesn’t seem good enough to consider a product’s shape by sheer intuition, when all other factors crucial for the satisfactory function of products are dealt with in systematic, if not scientific, terms.”

4. THE NEED FOR ‘LINKING CONCEPTS’

It is not hard to see the obvious benefits of being able to utilize product semantics as a tool or method for assessing and specifying aesthetic aspects, and for communicating functionality and properties of products. Previously, this process was guided by mere intuition on the designer’s part. Earlier work in the field has focused on the use of product semantics in order to reason about product form [Monö 1985, 1997], to assess form and expression in relation to the properties of the product [Wikström 1996], and to distinguish and characterize relevant disparities of product forms against each other [Vihma 1987]. More research in this field is needed and has also been initialized in different areas of product development research.

One inherent insufficiency of previous work, however, is that the concepts of product semantics are not set in relation to a firm base or a stringent theory concerning the concepts which product semantics is to address. The situation today can be characterized by a series of serious efforts at defining the role of product semantics, its nature, and its applications in design work. But no link has yet been established between the semantic approach of product design, being much of a “top-down” process where aesthetic expression is the key element. Contrary to that runs the “bottom-up” engineering approach, where characteristics such as properties, functionality, and structure are vital issues that make up the backbone of mechanical engineering design.

Linking the characteristics of product semantics used in the industrial design field to the engineering design theory base would provide a very powerful foundation that would establish the prerequisites for creating a generic tool for product design communication, methodology and modeling. The non-existence of such concepts may be the very reason why these aspects of product design have not been sufficiently treated, to address the previous statement of Butter [1987].

The purpose of this paper is thus to establish these “missing links”, by creating a language and the theoretical concepts necessary to unite the two fields. The focus is thus on the development of theoretical elements that provide a logical, causal, and objective language for relating communicative qualities to form design; not on the evaluation or assessment of form elements in relation to other form or object properties.

5. THEORETICAL BASIS

This paper takes the standpoint of a theoretical foundation for mechanical engineering design, the 'Theory of Domains' [Andreasen 1992], which is based on the theories and models of the so-called WDK-school[27]. The strength of the work of this school lies in a well-defined theory base, which is unequalled by any other theory of mechanical engineering design. It thus constitutes a solid framework for enhanced theoretical construction aiming at a general product design theory, and this paper can be seen as a contribution to those models from the specific viewpoint of industrial design elements.

A Coherent Product Modeling Framework

Since the aim is to bring together elements to form a coherent framework, the reasoning of this paper must, to be generally applicable, be related to a general product modeling and system context. According to Andreasen and Mortensen [1996a], a system (any artifact or product) can be described in two different ways: by an external description explaining the constitution of the system by way of 'design characteristics' ('what it *is*', or '*how* it is'), and by internal description, i.e. the behavior of the system described by 'design properties' ('what it *does*', and '*how* it does it'). This taxonomy is illustrated in Figure 3.

A system is constitutively defined by means of *design characteristics*, and its behavior is described by means of *design properties*, including functions. Design properties depend on system characteristics and stimuli from the environment. Design characteristics, i.e. the design attributes defining the design, are the only characteristics that can be determined directly by the designer [Mortensen 1997].

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[27] Workshop Design Konstruktion – the *WDK-school* – is an international society for the science of engineering design. Basic theoretical concepts include the theory of technical systems by Hubka and the domain theory by Andreasen.

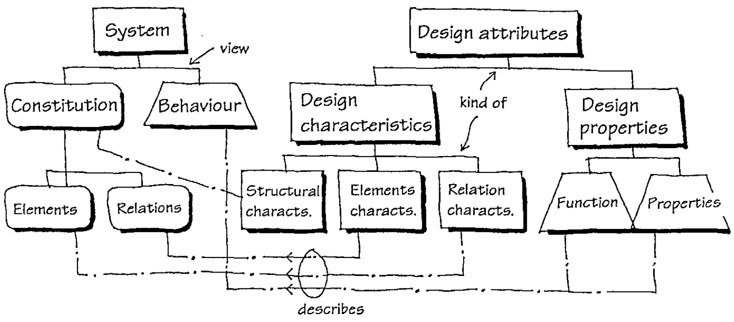

Figure 3 System and design attribute taxonomy [Andreasen and Mortensen 1996].

The theoretical contribution described in this paper proposes an artifact model concerned with the form of the design object, which can be described as a constitutive product model. This type of model thus provides a means for describing the results of the synthesis process (the creation) of the product in relation to the different phases of the product life cycle (e.g. design, manufacturing, assembly, operation, etc.). A modeling approach of this type is essential in order to motivate design decisions taken during the process. In this paper, insight is also provided into the internal nature of the design object, trying to explain certain aspects of the behavior of a product in a human-product system by means of relating form design aspects to functionality.

The Theory of Domains

The domain theory is based on four different views of a mechanical system, the so-called four 'domains', which each represent principally different, but necessary, ways of describing a product in a complete and sufficient manner. The four domains are:

1. ***The process system***, describing the transformation that takes place in the machine.
2. ***The function system***, describing the effects the machine is to create.
3. ***The organ system***, describing the function carriers, which create the effects.
4. ***The parts system***, describing the way in which the organs are realized.

A graphic representation of the domain theory is found in figure 4. Since the theoretical models presented in this paper are related to the concepts of the domain theory, its entities are described in the following.

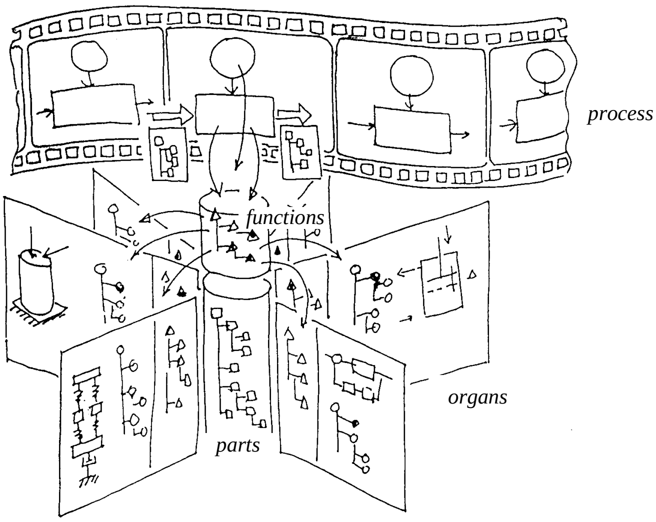

Figure 4 A model of the domain theory, adapted from Andreasen [1992].

Starting from the first domain, the ***process system*** describes the operation states a machine is going through during the transformation (change of state) of its operands (energy, material, and information) in a technical process. Seen from an industrial design viewpoint, this process-view is not very helpful, since it is restricted to the technical purpose or task of the product. A process view enabling the designer to grasp a wider range of processes experienced by a product in a human-product system during its entire life cycle is necessary for capturing relevant information of the product-to-be. Processes of interest may be design processes, production processes, assembly processes, and processes including use and liquidation activities. For these purposes, a process-view termed *use-process* may be adopted [Warell 1999]. The use-process makes it possible to include activities of the entire life cycle process where humans, as users, interact with the product. Activities of all phases of human involvement can thus be captured and explicitly brought into the early phases of design thinking. To attain a use-focus is an important characteristic of a suitable method for industrial design purposes.

When viewed upon as a ***function system***, the task of a machine is to produce the desired effects (output) which are necessary for carrying out the appropriate transformation of the operand, which is the focus of the process system as described above. The function definition used in the domain theory states that "*a function is the capability of a machine to create a usable effect*" [Andreasen 1980]. This definition of function implies that products which do not carry out a transformation do not have a function. A simple example such as a coffee mug shows that this reasoning is not sufficient for general product design; the mug has the one obvious function to contain coffee, which is a quite static function, it does not *transform* anything in the sense described above. This raises the need for a wider definition of function that makes it possible to describe all types of product functionality: *a function is what an element of a product or human actively or passively 'does'* [Warell 1999]. The introduction of a new class of functions, termed *usability functions*, renders it possible to include product semantics into reasoning about product functionality (Figure 5). Usability functions, including *ergonomic*, *cognitive*, and *semantic* functions, cover functionality aspects of the human-product interface [Warell 1999]. Introduced by Monö [1997], semantic functions include the functions *describe*, *express*, *exhort*, and *identify*. Returning to the mug example, the handle of the mug has a semantic function - it describes the use of the handle for holding the mug and expresses its properties of being comfortable to hold and rigid enough to support the weight of the mug and its contents. It also has ergonomic functions - it aids the user in holding the mug, and reduces the risk of burnt fingers.

According to the WDK-school, a function or effect is a ***property*** of the machine. Properties describe the way an object (an artifact, a human, or a system) is constituted. Control of the characteristic properties during product design is thus essential in order to achieve the desired functionality. Properties can be classified in a number of ways. Hubka and Eder [1988] provide a thorough classification of properties, where e.g. ergonomic and aesthetic properties relate to issues of industrial design importance. The *elementary design properties* constitute a special class of properties – they are the only properties that can be directly manipulated by the designer, i.e. they are identical to the "design characteristics" [Mortensen 1997]. These include *structure* (for the product as a whole), *form*, *material*, *dimension*, and *surface* [Tjalve 1979]. Hubka and Eder [1988] add tolerances and manufacturing method to this class, but it could be argued that these are dependent on the other basic design properties. According to Roozenburg and Eekels [1996], there are only two basic design properties – *form* (geometrical form), and *material* (physio-chemical form). The basic design properties are interrelated in a complex manner (e.g. form is directly dependent on shape, arrangement of parts, and overall structure). All other properties of the product (such as strength, corrosion resistance, price, quality, appearance) are derived from the basic design properties, and are also interrelated, which is the reason why designing products and mechanical systems is such a complex task [Tjalve 1979].

In the product, functions are realized by an ***organ system***. Organs are also known as 'function carriers' or 'functional units' [Hubka and Eder 1988], and are the 'active units' that produce the functions, which the machine is to create [Andreasen 1992]. A definition of organs provided by Liedholm [1998] reads: "*… an abstract representation of relations between parts or* *functional surfaces, which describes functionality without consideration of material and physical embodiment"*. By introducing 'functional surfaces' as one of the main building blocks of the theory of form design, Tjalve [1979] established the link between the design of parts, organs and their function from an effect-delivering, mechanical design viewpoint. Functional surfaces are described as the 'active' surfaces of parts, where functional effects are delivered to the surroundings. The concepts of functional surfaces and organs are further discussed and elaborated in sections 7 and 8.

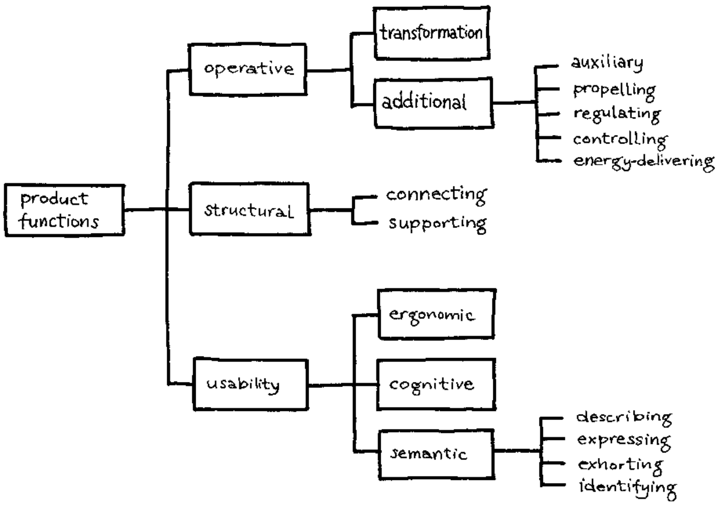

Figure 5 Classes of functions in a human-product system [Warell 1999].

Returning once more to the coffee mug, the handle constitutes part of a *holding organ* with an external functional surface on the surface of the handle for the user to grab on to. The shape of the function surfaces of the organ gives the handle its ergonomic and aesthetic properties. The insides of the mug also constitute an external functional surface, having the function of containing the coffee inside the walls of the mug, hopefully without leaking. A door hinge illustrates another example of organ reasoning. A hinge is one of several possible solutions to a 'joint organ' for a door. Alternative solutions are, e.g., elastic, plastic strips, or metal hooks and loops. A metal hinge consists of three principal parts; a pin and two fastening irons. The pin has internal functional surfaces to the two irons, which in turn have internal functional surfaces to the pin, and also external functional surfaces to the doorpost and to the attaching screws.

Finally, the ***part system*** materializes the organs in the form of parts, components and constructional elements in a product. The part system is the only *real* (physical) manifestation of the entities of the domain theory, as all other domains are models describing the part system (to-be) from different viewpoints. One part – defined as *"a non-decomposable element of an* *artifact*" - will often contribute to the realization of several organs, and one organ will normally need several machine parts for its realization [Andreasen 1992]. In this case, a traditional, ceramic coffee mug would be a one-part product. A door hinge would be a component, consisting of three parts.

6. INTRODUCING THE 'FORM FUNCTIONALITY' FRAMEWORK

The theory of domains and the additions to it described above play a central role when taking the reasoning a step further, i.e. beyond technical functionality. In connection with the theory of form design and the contributions to the process and function domains described earlier, it is possible to introduce new entities that create a logical, causal chain from process to part domain and form element reasoning, which is useful for objective form design reasoning purposes. The following sections will address these issues, collectively denoted the 'form functionality framework'.

Previous Contributions to the Field

An important purpose of extending the theoretical framework within the form design field is to provide a language for the communication of form decisions taken during the design process. As mentioned earlier, the aim is to develop theoretical elements that enable the designer to causally describe form decisions and the logic of contents, function, and features of form elements in an objective and logical manner. Thus, the focus is not on comparative form evaluation or assessment but rather on the objective description of forms of products.

Apart from the contributions by Tjalve [1979] and Monö [1997], the literature provides little in this field. Wikström [1996] builds on the work of Monö and introduces methods for the assessment of semantic functions of products. Akner-Koler [1994] presents a comprehensive framework for the visual analysis and description of three-dimensional form. For comparative evaluation purposes, Vihma [1987] introduces an "analysis of form" with which it "should be possible to distinguish and characterize relevant disparities of product form." The approach is directed towards finding relative comparison parameters for assessment of similar products, and does not make any connections to engineering design theory in the sense of entities causally linked to other schools of design. However, according to Vihma, the analysis of form in design is concerned with the visual and functional *properties* of the product. Thus central concepts such as functionality and property are used in a manner compatible with engineering literature, and the basic prerequisites for merging the two fields exist.

The Concept of Features

Research on features has previously been directed towards the classification of form elements from different viewpoints of product development, such as engineering design and production [Andreasen and Mortensen, 1996a]. This has given the engineering domain a means of discussing form decisions based on technical considerations, which in turn provided the designer with a very powerful language for e.g. CAD tools and NC programming purposes. Work on creating a computer-based product model engineering design tool based on the feature language has been considered [Andreasen and Mortensen, 1996b]. The term feature has also been used for aesthetic design purposes, describing characteristics of forms of objects [Akner-Koler 1994].

Several authors have defined features. According to Shah [1991], features are "*generic shapes with which engineers associate certain properties or attributes and knowledge useful in reasoning about the product.*" Similar definitions are provided by Rosen [1993], describing features as "*meaningful abstractions of geometry that engineers use to reason about components, products and processes,*" and by Brown et al. [1995], stating that "*features are application and viewer-dependent interpretations of geometry.*" Wierda [1991] states that "*a feature is a partial form or a product characteristic that is considered as a unit and that has semantic meaning in design, process planning, manufacture or other engineering disciplines.*"

Features are used to describe and build up part characteristics, and several classes of features can be identified. Shah [1991] identifies *form features* consisting of shape elements, semantics, and relations, where semantics in this case is the engineering meaning related to the shape elements. *Functional features*, consisting of entities, relations and physical phenomena that describe the product mode of action, are reported by Ishii et al. [1994]. Andreasen and Mortensen [1996a] state that features are relations, and introduce three new types of features: a *production design feature*, which is a relation between a set of product design characteristics and a set of production characteristics; a *part design feature*, which is a relationship between part characteristics and the matching organ (function carrier) containing experience concerning the materialization of organs; and an *organ design feature*, which is a relation between characteristics of an organ and the matching functionality, explaining the design solution from functional reasoning. It is thus possible to identify features on the functional level (functional features), as well as on the organ level (organ design features), and the part level (part design features, form features).

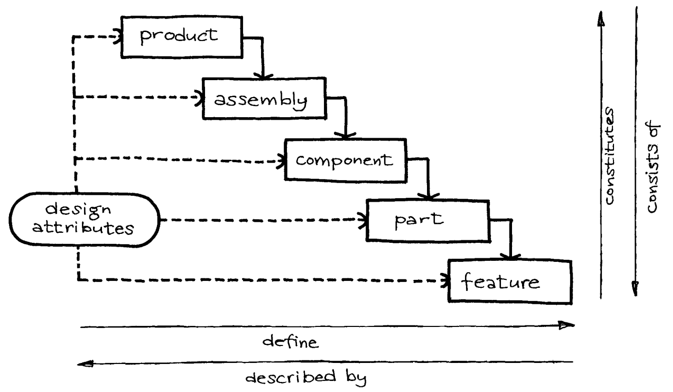

Figure 6. Design attributes at different levels of a product structure.

There seems to be a general conformity that the feature concept in this context implies entities (abstract or concrete) of the product, and relations between entities and the life-cycle process. A feature could thus be defined as a physical entity describing a prominent part or an important characteristic of a product. A feature may be a hole in a part, or a corner connecting a number of planes in a certain manner. A “corner feature” may have edges, surfaces (planes) and intersection attributes, and the forms of these are quantitatively described by parameters such as radii, curvatures, areas, positions, etc. Design attributes, a characteristic or a quality of something, define a product at all levels of the product structure (Figure 6). A part is defined by part attributes, e.g. material specifications and part numbers. Features are defined by feature attributes, parametrically defining a feature in terms of e.g. dimensions, shapes, and tolerances.

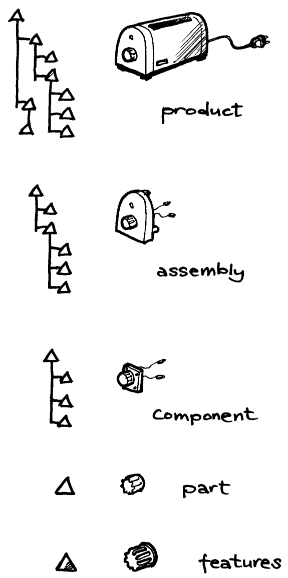

Figure 7. ‘Form element’ is a generic term for ‘building blocks’ of form on all levels of the product structure.

Matching engineering features of a product part to life cycle aspects such as design and production, and to product modeling such as function, organ and part relationship modeling has been done by other authors in the field. Mating the feature concept to causal reasoning about functional carriers on the organ and part levels, as well as introducing an industrial design viewpoint related to feature reasoning, would tie ‘loose ends’ of product artifact theory. This in turn would encompass aesthetic form functionality reasoning of domain theory reasoning and add to a complete picture. The linking of form features to product functionality is the topic of the remainder of the paper.

Form Elements – the ‘Building Blocks’ of Form

On the lowest level of decomposition, products consist of a number of components and parts. Components consist of at least one part. Parts are constituents of subassemblies, several subassemblies make up an assembly, and assemblies make up products. It is common for all parts that they are made up of features (elements of form on the lowest level) as their smallest 'ingredients' of form (Figure 7). Looking at a product's form, a basic characteristic is that the 'outer' form incorporates a number of '*form elements*'. Form in this case is defined as including the shape (geometry) of the elements and their spatial relationships (configuration). 'Form element' is a generic term, which may be applied on any level of the product form. Form elements include basic shapes, parts of basic shapes, and other shapes [Tjalve 1979]. Examples of basic three-dimensional shapes are the cube, cylinder, sphere, pyramid, cone, ellipsoid, or parts of these.

Form Factors – the 'Creators' of Form

Form elements are defined by attributes called 'form factors'. An attribute is a characteristic or quality of a thing, and may be applied at any level to a whole product, an assembly, a part, a form of a part, a collection of features, or a single feature [Shah 1991]. A thorough investigation of form factors influencing the creation of form elements is provided by Akner-Koler [1994]. For example, a part in a mechanical system can be fully described by the basic design properties, i.e. form, material, dimensions, and surface, as discussed earlier. For an assembly (a whole product), the structure characteristic is added. These design characteristics define the form factors, the elementary concepts of the product gestalt[28], which influence the form of the product (Figure 8). A conscious and deliberate use of form factors when creating form elements during product design enables the designer to integrate aesthetic, semantic, and ergonomic (including cognitive ergonomics) aspects into the form of the product.

Form factors provide the rules governing the creation and constitution of form elements. All form elements, whether on the highest hierarchical level such as a whole product or on the lowest level in the form of features, are subject to manipulation by means of form factors. There is an infinite number of form factors. However, they may be classified according to types of form factors that are applicable on the elementary level (form of individual elements), form factors applicable on whole forms (form of constellations), and generic form factors (applicable on all forms). Table 1 presents an overview of form factors according to the three classes, partly based on Akner-Koler [1994] and the list of 'design factors' by Monö [1985].

[28] Monö [1997] defines the term '*gestalt*' as "an arrangement of parts which appears and functions as a whole that is more than the sum of its parts." The gestalt of a component or product includes its basic character, shape, and figure as a whole entity, either as a sub-component of an assembly, or as a complete product.

The rules governing the creation of form elements of a product by the use of form factors, derived from the basic engineering design properties, have thus been established. The next step is to causally relate these form elements to functionality. This issue will be discussed in the following section.

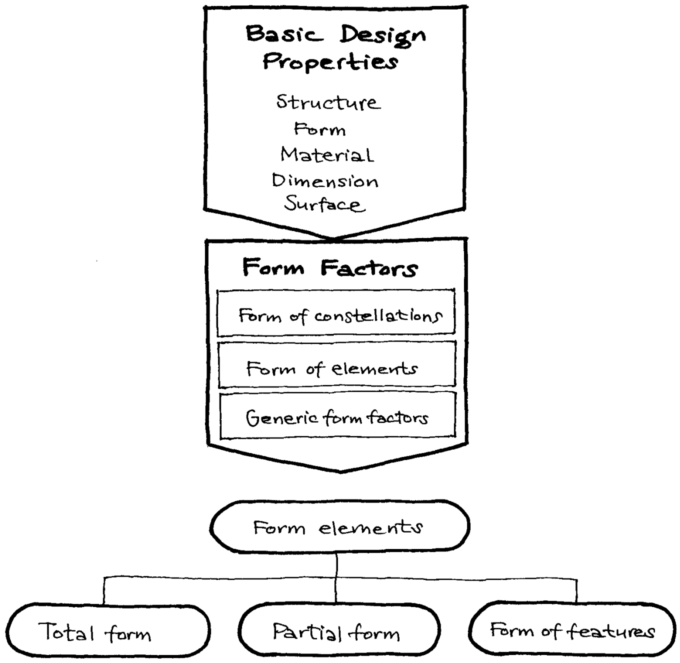

Figure 8. Form design attributes of a product, including basic design properties, form factors, and form elements.

7. LINKING FORM ELEMENTS TO FUNCTIONALITY

The Concept of Functional Surfaces

In the theory of form design, Tjalve [1979] introduces central elements that link the form of components to their technical functionality. According to Tjalve, functional surfaces, defined as *surfaces that have active functions during use*, provide a link between the form of parts and their functionality. The form of the functional surfaces – as well as the form of the product as a whole – is dependent on a number of parameters that are derived from the basic design properties: relative arrangement, dimension, number, and form geometry.

Functional surfaces belong to parts and realize the functions of organs. In products consisting of more than one part, functional surfaces of engineering significance may be divided into two types – *internal* and *external*. *Internal functional surfaces* have an active function in relation to other parts of the product, while *external functional surfaces* have active functions in relation to the surroundings, such as the operator or other products. Examples of internal functional surfaces are the balls and the tracks of the rings of a ball bearing. The handle of the coffee mug is an example of an external functional surface.

The functional surfaces of Tjalve cover the functions directly associated with the mechanical system and its constructional structure, providing a one-to-one mapping between functions and parts realizing the functions. This means, however, that only the parts of the product with technical functions (operative and structural functions) are considered. Other areas of the product and its components, e.g. material connecting these functional surfaces, are left without associated, causal functionality. Enhancing the form design theory to handle ergonomic, cognitive, and semantic functionality would make it applicable to all types of functionality of a product.

Taking a mobile telephone as an example, it is obvious that the cover of the phone has several functions apart from the most obvious functions such as protecting the insides from damage and holding the components in place. Such functions are, e.g., to provide a comfortable grip, identify the manufacturer and the type of product, and give advise on using the phone. These aspects of functionality, termed *usability functions*, cover the interaction between product and user [Warell 1999]. A logical alternative name for these functions may be 'interface functions', since they are related to the functionality of the human-product interface. One task of the interface is to enhance usability of the product, but also to add quality to other areas not directly related to practical usability, such as adding value and contribute to customer satisfaction and pride of ownership.

Form of elements	Form of constellations	Generic form factors
Primary geometric volumes – straight rectangular/cube triangular pyramid tetrahedron **Primary geometric volumes – curved** ellipsoid/sphere cylinder cone **Axis** primary secondary tertiary **Axial movement** inner axial movement continual axial movement directional movement **Force** directional force **Curve** neutral accented simple (mono-force) twisted (bi-force) compound (multi-force) **Organic forms** convexity concavity **Color** color tone color value blackness	**Hierarchy of order** dominant subdominant subordinate details grouping **Axial relationships** adjacent across space oppositional parallel continual gesture **Comparative relationships** configuration placement arrangement composition **Joints** partial complete **Intersections** compound core **Transitions - modeled forms** division *accordance* *discordance* *adaptation* *assimilation* *dissimilation* merging *convergence* *divergence* *gradual* *abrupt* *unity* *separation* distortion *direct, physical forces* (twist, squeeze, roll, pull, push, bend, hit, erode) *interpreted forces* (optical distortion, implosion, explosion) *conformation* *deformation* **Organizational frameworks** static dynamic organic **Proportion**	**Basic visual elements** volume plane line point **General Proportions** extensional (length) superficial (flatness) massive (volume) **Positive elements** form **Negative elements** spacial enclosure **Orientation** direction position tip/rotation **Form properties** roundness squareness lightness thickness weight stability *symmetry/asymmetry* balance *structural* *visual* direction rhythm articulation haptility (sense of form) tactility (sense of texture) kinesthetic perception smell, taste and other senses conceptions

Table 1. Examples of form factors governing the form of elements, the form of constel-lations of elements, and generic form factors. Partly after Akner-Koler [1994] and [Monö 1985].

Introducing Functional Regions

Returning to the terminology of Tjalve, functional surfaces related to human-product interaction are of the external functional surface type, since they are active in relation to the surroundings of the product. Thus, they are characterized by the fact that they imply functionality belonging to surfaces of the human-product interface not previously considered, thus putting the 'white areas' of the product on the map of functionality. Such functional surfaces may be manifested as real, physical elements (parts) of the product, such as the concrete shape (curvature, convex/concave, positive/negative, etc.) and texture (surface quality, material, color, etc.) of the design of a vacuum cleaner body, all adding to its functionality as a total product by expressing its qualities, properties, functionality, and identity.

Many products also have other interface elements that do not have functional 'surfaces' in the traditional sense, as physical, concrete, two-dimensional areas with a function carrying capacity. Their functionality is embedded as part of the underlying structure accessible through the electronic interface. To be able to explain how these 'virtual' interface elements such as electronic displays fulfil, e.g. cognitive functions, it is necessary to widen the concept in order to include other types of function-carrying entities, or *regions*, of components, other than concrete surfaces. Such regions[29], whether concrete or virtual, may be termed '*functional regions*'. Like functional surfaces, functional regions carry out specific functions of the product. Different types of functional regions may be identified, of which functional surfaces in the traditional technical system sense are one. Other types of functional regions realize usability functions; they have communicative characteristics (see Table 2).

Functional regions, thus, describe how form elements of parts carry functions. Form elements, e.g. features, are realized as concrete (material or immaterial) elements of parts and components of the product. Their creation is governed by the influence of form factors, which may be considered the 'alphabet' of form. The rules for creating form elements are given by the basic design properties. 'Form element' is a generic term applicable on all levels of product form, whether as the whole form of the product (primary level), as the form of elements (elementary), as form features (characteristics of forms), or as parameters (defining form geometry of features).

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29 The term *region* has, like the term *organ*, analogies to the corresponding term used in medicine: a region is a part of the body near some organ. A region, in this case, comprises part of an organ, having definable boundaries and characteristics.

8. ELABORATING ORGANS AND FUNCTIONAL REGIONS

Classification of Organs

Functional regions, being the active parts of organs, i.e. the means for realizing the functions of the product, link functionality aspects of parts and components to organ reasoning. Organs are the “carriers of functionality,” i.e. they define which functionality exists and provide the principles for the means to achieve said functionality. However, since organs are abstract function carriers by definition, they lack physical embodiment and can thus not be defined without the help of functional regions, which physically implement functions. It can thus be stated that organs need (are realized by) functional regions as function carriers, and are realized as material (physical) parts and/or form elements, or as immaterial (e.g. electronic/digital) ‘function-carrying domains’, of the product. Functional regions may thus be seen as a type of sub-level function carriers of organ systems. According to accepted engineering design terminology, ‘function carrier’ is thus a collective term for any material or immaterial entity that fulfils a function, whether as a part, component, system, domain, or action/physical principle.

In a system of organs, several organs are present as elements of that system. In such a system, different classes and types of organs can be identified (see Figure 9 and Table 2). On the highest hierarchical level, a *superior organ* can be identified. This organ may represent the whole organ as a means: a function carrier (e.g., a component) fulfilling a particular (main) function. How a superior organ realizes its functionality is determined by it having *subordinate organs*. These are of two types: *internal* (fully inside the boundaries of the superior organ) or *external* (at, or in contact with, the boundary) organs. The external organs come in two types, namely *introvert* (active relative to other parts of the product) and *extrovert* (active relative to the environment or users). All superior organs must have external extrovert organs, or they would not be purposeful.

Furthermore, external organs may be *receptive* or *effectuative*. A receptive organ receives, or accepts, functionally determined input from other organs, the environment, or from users. An effectuative organ effectuates, or delivers, functional output to other organs, the environment, or to users, which is determined by the functional input. Thus, external organs provide the functional coupling to the environment, such as other organ systems (components) or users. Actions (and action chains) are of two types, i.e. *inter-organic* (actions/effects exchanged between the superior organ and its environment, e.g., other organs or users), and *intra-organic* (actions/effects exchanged between subordinate organs within the superior organ).

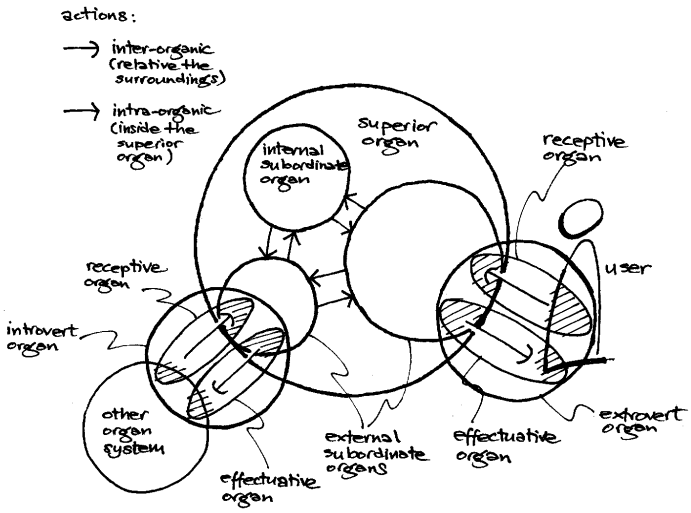

Figure 9. Hierarchy of organs, including superior organ, external and internal subordinate organs, and extrovert and introvert organs containing effectuative and receptive subordinate organs. Inter-organic (between the superior organ and the environment) and intra-organic (within the superior organ) action chains are also indicated.

Organs can also be classified according to the type of functionality they fulfil, i.e. operative, structural, and usability organs, according to Table 2. Depending on the system border of the studied organ, an internal organ viewed in one system may be an external organ in a system view with a different system border. Users are not considered part of the organ system.

Classification of Functional Regions

According to Table 3, organs have functional regions classified according to the same classes as organs, i.e. operative, structural and usability functional regions. In one given organ, several classes of functional regions may be represented. Irrespective of type of functionality, peripheral functional regions are active towards their environment. Structural functional regions may be totally included in a superior organ, and may thus also be of the embedded type. All superior organs must also have embedded, structural, functional regions, e.g., a material or immaterial structure, providing the connection between internal and external organs. Since functional regions map abstract organ entities to real (material or immaterial) embodiment, one functional region is dependent on its counterpart (present in another organ, organ system or the user) to form a whole organ. Organs and functional regions according to Tables 2 and 3, respectively, are illustrated in Example A.

Type of functionality	Class of organ	Hierarchical level	Type	
Technical *Effect delivering characteristics of the technical system*	**Operative organs** transforming additional *(auxiliary, propelling, regulating, controlling, energy-delivering)*	**Superior** or **Subordinate**	**Internal**	**External** Extrovert *receptive* *effectuative* Introvert *receptive* *effectuative*
	Structural organs Connecting Supporting	**Subordinate**	**Internal**	**External** Extrovert *receptive* *effectuative* Introvert *receptive* *effectuative*
Usability *Use-enabling characteristics of the human-product interface*	**Usability organs** Ergonomic Cognitive Semantic *(describing, expressing, exhorting, identifying)*	**Superior** or **Subordinate**		**External** Extrovert *receptive* *effectuative*

Table 2. Classification of organs, hierarchical levels, and types, according to type of functionality. Users are not part of the organ system.

The way usability functionality is realized in the form of functional regions of parts determines how well the product communicates with the user, i.e. to what extent the usability functions are realized. A product, which is hard to operate may have a weak coupling between form elements of parts and their functionality. The extent to which a product expresses its (right) qualities to a potential user or customer may be directly associated with the decision to use, or buy, the product. If the technical performance of the product is satisfactory to the customer, but the semantic functionality is unsuccessfully communicated in terms of form elements of the human-product interface, the customer may opt not to buy the product. The importance of this type of product functionality becomes even more important in a situation where the customer has the opportunity to choose from a selection of competing products in a purchase situation.

Type of functionality	Class of functional region	Action principle	Examples
Technical *Effect delivering characteristics of the technical system*	**Operative** peripheral	**Effect delivering** (*mechanical, electronic, hydraulic*)	Guiding, motion, storage, motor, transmission
	Structural peripheral embedded	**Effect delivering** (*mechanical, force field)*)	Fasteners, shells, connections, support beams, protections
Usability *Use-enabling characteristics of the human-product interface*	**Usability** peripheral	**Haptic** (*showing form, guiding by sense of shape*) **Tactile** (*characteristics of surfaces, guiding by sense of texture*) **Kinesthetic** (*perception of muscle movements*) **Cognitive** (*informative, information processing*) **Aesthetic** (*visual, olfactory, auditory, taste, semantic*)	Shapes, mass, fit, size, expression, comfort, spaciousness, feedback, text, instructions, data, signs, logotypes, shapes, mass, fit, size, expression, comfort, spaciousness

Table 3. Classification of functional regions, action principles, and examples, according to type of functionality.

Example A: Organs, Functional Regions, Action Principles

On/off Button of a Vacuum Cleaner

The on/off button of a vacuum cleaner (see Figure 10 and Table 4) may be termed *actuation organ*, belonging to the *motor control organ*. In order to fulfil the functionality of this system of the vacuum cleaner, the motor control organ must receive input from the environment in terms of a user pushing the button to turn the motor on. This is done by the subordinate *external-extrovert receptive organ (1)*, materialized in the button, which has a certain outer form. When pushed, the button activates a switch, which sends an electric signal to other parts of the motor control organ, and eventually the motor is turned on. The activation of the switch is done by the *external-introvert effectuative organ (2)* of the button, realized in form of a plastic surface of the insides of the button that pushes against the switch.

If the user is to know how to turn the vacuum cleaner on, he needs information on what to do. Thus, the design of the button incorporates semantic signs that tell the user that it is the actuation organ for turning on the motor, and that it needs to be pushed in order for this to be achieved. The signs are part of the *external-extrovert effectuative organ (3)* of the button, which is active in relation to the user in terms of the eyes of the user and the shape of the button. When the user has decoded the message conveyed by the signs, he starts the vacuum cleaner by pushing the button. Thus, another organ, the *external-extrovert receptive organ (4)*, is involved. However, this organ is materialized by the same physical entities realizing organ (3), as is discussed in the next paragraph. For logical reasons, there must also be an *external-introvert effectuative organ (6)* belonging to the button, materialized as part of the plastic surface of the button that exerts a force on the switch, as well as an *external-introvert receptive organ (5)* in form of the plastic material of the button accepting the pressure from the switch when turned on.

The actions necessary for fulfilling the functions of the organs are realized (carried) by the *functional regions*, being the link between the organ and part domains of the button. Part of the effectuative and receptive organs constitute *functional regions* belonging to the button. The external-extrovert (1) and external-introvert (2) organ groups are realized by the same physical functional regions, respectively, but the functionality types of each subordinate organ, i.e. organs (3) & (4) and (5) & (6), respectively, are different. According to the terminology in table 3, the *extrovert receptive organ (4)* fulfils *technical functionality*, constituting an *operative* functional region, and working according to mechanical action principles; while the *extrovert effectuative organ (3)* fulfils *usability functionality*, constituting a *usability* functional region, and working according to cognitive and semantic action principles. The functionality of organ (3) is physically carried and conveyed by the *peripheral usability functional regions* of the button (7) and of the user's eye (not indicated). These are both *peripheral functional regions*, since they have functionality relative to the environment (towards the user from the button's point of view, and towards the button from the user's point of view). Similarly, the functionality of organ (4) is physically carried and conveyed by the *peripheral operative functional regions* of the

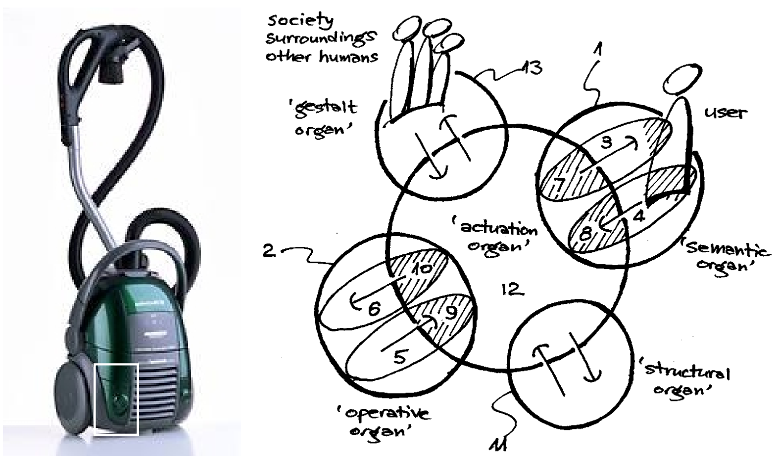

Figure 10. Structure of function carriers of the on/off button of the Electrolux Oxygen vacuum cleaner in Example A, representing the superior 'actuation organ'. Oxygen vacuum cleaner courtesy Electrolux Floor Care.

Organ	Physical realization (function carriers) of organs	Functional regions related to organs	Action principle related to functional regions
(1) External-extrovert organ	Form of the button towards the user	*see subordinate organs (3) and (4)*	Visual, semantic and effect delivering
(2) External-introvert organ	Form of the button towards the electronic switch	*see subordinate organs (5) and (6)*	Effect delivering
(3) External-extrovert *effectuative* organ	Visual codes and signs of the button, conveyed to the user	**(7) Peripheral usability functional region + user's eye** *(not indicated)*	Visual, semantic
(4) External-extrovert *receptive* organ	Material accepting the pushing action exerted on the button by the user	**(8) Peripheral operative functional region + user's finger** *(not indicated)*	Effect delivering
(5) External-introvert *receptive* organ	Plastic surfaces of the button and the switch	**(9) Peripheral operative functional region of the button + do. of the switch** *(not indicated)*	Effect delivering
(6) External-introvert *effectuative* organ	Plastic surfaces of the button and the switch	**(10) Peripheral operative functional region of the button + do. of the switch** *(not indicated)*	Effect delivering
(11) External structural organ	Plastic joint mechanism connecting the button to the vacuum cleaner body	Peripheral structural functional regions of the button and the vacuum cleaner body *(not indicated)*	Effect delivering
Internal structural organ *(not indicated)*	Plastic material of the button	**(12) Embedded structural functional region**	Effect delivering
(13) External usability ('gestalt') organ	Quality of surfaces, precision in dividing lines between components, sound and feel when operating the button	Extrovert usability functional regions of the button and the vacuum cleaner body *(not indicated)*	Visual, semantic

Table 4. Organs, their physical realization, functional regions, and their action principles, of the superior 'actuation organ', representing the on/off button of the Electrolux Oxygen vacuum cleaner in Example A. Numbers within parentheses indicate organs and functional regions found in Figure 10.

button (8), and of the user's finger (not indicated). Through the *external structural organ (11)*, the button is connected to the main body of the vacuum cleaner, physically realized by a plastic hinge mechanism. This organ includes dual subordinate organs in the same type of manner as organs (1) and (2) described previously, having *peripheral-structural functional regions* which belong to the button and the body. It can also be noted that the plastic material of the button constitutes an *embedded structural functional region (12)*, providing a connection to the peripheral functional regions, and is an organ in its own right. This organ may be termed *internal structural organ* since it works according to mechanical action principles, and comprises an embedded structural functional region realizing technical connecting functionality.

The organs discussed previously are all related to practical functionality of the product, such as handling, operation and technical aspects. But the button is also an important element, among all other parts of the vacuum cleaner, in creating the whole aesthetic gestalt of the product, adding to affective, social and value-dictated functionality. The button has its individual visual, tactile, and haptic (among many other) characteristics that differentiate it as a button from the rest of the vacuum cleaner, yet it is a vital element of the whole aesthetic and expressive unity of the product. As such, it is possible to define a *'gestalt organ' (13)*, in part belonging to the button, and in part belonging to the rest of the vacuum cleaner, that connects it aesthetically to the product gestalt as a whole. Treated as an organ, it has visual links to the total appearance: the same form language, and the same characteristics in overall "feel", sound, and expression. It thus communicates in a subtle yet very obvious manner with the user, e.g. in the store when buying the product, in different situations of use, and as a social object in different contexts. In response to the factors perceived through the 'gestalt organ', such as the impression of quality, the precision of part dividing lines, the fit of components to each other, and the sound and feel when pushing the button, the user is - often unconsciously - influenced by the product and interacts with it in a manner dictated by how it is perceived. Like the organs related to practical functionality, the 'gestalt organ' thus is an *external usability organ*, including dual subordinate organs, acting in a two-way communication between the human, the object, and other humans in a social context.

The other organs and functional regions of the button not discussed in detail here are defined and denoted according to the same principles as the examples discussed above.

It is quite obvious that the number and types of organs and functional regions quickly becomes immense when trying to explain the causal functionality structure of complex products, which incorporate a large amount of human-product interface functionality.

Example B: Organs and Functional Regions
Electronic Display Unit

Electronic displays found in many types of electronic and mechatronic consumer products, e.g. mobile phones, cameras, palm notebooks, and GPS units, contain a large amount of ‘non-mechanical’ functionality. The LCD unit of such a product is one half of a *usability organ*, making available to the user the functions embedded in the software of the product. The other half of the organ consists of the eye (sense of vision) of the user. Here, the LCD unit constitutes one peripheral functional region; the human eye is the other. Digging even deeper into the logical structure of the LCD unit, one may consider the program structure of the software interface an embedded functional region of an *internal operative organ*.

Example C: Form Elements, Organs and Functional Regions
System Camera

A typical mechatronic consumer product such as a 35-mm SLR system camera (Figure 11, left) reveals a wide selection of different organs, functional regions, and form elements, all linked to functionality.

The whole form of the camera may be seen as a *gestalt organ* on the superior level. Other form elements constitute gestalt organs on subordinate levels. Form features would thus be gestalt organs on the lowest hierarchical level. The overall form of the camera reveals to the user information related to its use:

- The main orientation of the camera during use (picture-shooting); lens pointing forward towards the motif,
- the “top side” of camera facing upwards (oriented for landscape pictures) or to one side (oriented for portrait pictures),
- gripping surfaces of the camera body during aiming and handling,
- operating areas, including buttons and display, for adjusting e.g. shutter speed, auto-focus, film rewind, flash, viewfinder, etc., and
- servicing areas for switching films, batteries, etc.

The overall form describes that it is to be operated using the right hand. Left-handed people have to adapt to this pre-determined restriction on the handling of the camera, dependent of the internal architecture of mechanics, electronics, film, and optics. This is a characteristic of the gestalt organ on the superior level, communicating to the user the type of product, the maker, its identity (model), characteristics, quality, etc. Furthermore, the gestalt organ contains functional regions that identify the product as a ‘system camera’ (a semantic function).

Figure 11. The Minolta Dynax 500si 35-mm camera.

Function carriers on this level are form elements to identify the product as a system camera, such as the lens being a separate element separated from the main form of the body, the viewfinder positioned in line with the main axle of the lens, etc. Other function carriers include the form language of the camera, the 'visual expression' including choice of curvatures, shapes, radii, concave and convex surfaces, etc.

Features that describe the form on the parameter level characterize the form of individual form elements such as features of components. One example is the concave groove around the shutter-release button (Figure 11, right), which is a typical *usability organ*. Visually, it describes the placement of the index finger on top of the button (semantic organ), and by haptile feedback, it guides the user in locating the button without looking (ergonomic organ). Function carriers for these organs are the form features of the button and the groove. The convex surface, the radius around its circumference, and its elevated position above the bottom of the groove, are features that carry the usability functionality. The ellipsoid shape and the orientation of the perimeter of the groove suggest, as a feature, the use of the index finger for operating the button, so that it also carries usability functionality.

9. CONCLUSIONS

In this paper, it is shown that functionality aspects associated with human-product interaction such as product semantics are compatible with conceptual models of engineering design, and can causally be linked to those models.

Form modeling tools of industrial design, such as form factors, are linked to property and feature reasoning compatible with form giving in mechanical engineering design. Enhanced concepts, such as new types of organs, functional regions and their classification, are introduced, showing that industrial design and engineering aspects can be treated with a common modeling framework.

Elements of industrial design such as usability aspects and interface design issues can be described and explained in conjunction with technical aspects, using a common language. Form elements and product functionality belonging to the domain of industrial design are given causal, rationally motivated reasons for their existence through a form functionality framework, compatible with domain theory reasoning in mechanical design.

Based on the concepts elaborated and illustrated in this paper, it should as a next step be possible to develop generic models, methods and tools that treat a totality of design aspects, ranging from engineering design to industrial design issues. Such models and tools are a prerequisite for improving communication between different stakeholders of the product development process and enhancing the efficiency of development activities.

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PAPER B

Warell, A. and Nåbo, M. [2000]: "A Model for Visual Design Aesthetics Based on Form Entities", *Proceedings of NordDesign 2000*, Technical University of Denmark, Lyngby

A MODEL FOR VISUAL DESIGN AESTHETICS BASED ON FORM ENTITIES

Abstract

The lack of theoretical models that describe the relationship between visual aesthetic form and technical aspects is a problem in product development. In this paper an effort is made to create elements of a theory for visual design aesthetics in product design. Design formats are developed as a means to specify aesthetic ingredients in a product design project. The concept of form entities makes it possible to describe the constitution of, and relations between, forms related to organ reasoning. Thus it is possible to describe the causal reasoning chain from design intent and form functionality, to specific form solutions and how they are interrelated. Product cases, developed during the course of the research, illustrate the theoretical models.

1. INTRODUCTION

The purpose of the research behind this paper was to investigate aesthetic relations between form elements of products, and whether these form elements can be ascribed functionally determined properties, i.e. if they are purposeful. Insight into the composition and underlying structure of visual form aesthetics will enhance our understanding of specific form solutions, the relation between single form elements and composed form, and the link to design intent, design history, possible design evolution and subsequent development.

The creation of a model for visual design aesthetics also has other implications. By developing a model that relates aesthetic design work to functional causality, the experience-based work of the form developer can be formulated, explained and motivated based on design rationale, thereby improving the possibility of communicating design intent and motivating aesthetic form solutions across design disciplines. In the future, such a model will provide the opportunity to develop tools or methods for assisting design synthesis during aesthetic form development, and for rational evaluation of proposed form design concepts. Since there is a shortage of such tools [1] at present, they would be of great value for design teaching as well as for industrial use.

Our approach to treating visual design aesthetics is based on the creation of a theoretical, objective model for treating form solutions and visual couplings between form solutions. Related to a coherent theoretical model, the theory of domains [2], the model we propose provides the basis for a formal language with which to reason and discuss about visual solutions of products.

2. PREVIOUS WORK IN THE AREA

The impact of the aesthetic qualities of a product's visual form has mainly been discussed from the standpoint of personal preferences, cultural and social trends, and value adding to products [1]. However, more emphasis is now being put on these aspects, much due to the growing awareness of the influence of product aesthetics on consumer behavior [3], and the increasing importance of trademark, identity, product desirability for achieving market impact and success [4]. It is also widely recognized that well developed aesthetics play a significant role in how the product is perceived and handled, the degree of product acceptance, and customer satisfaction.

Although no previous attempt at integrating technical, usability and aesthetic aspects in a generic theoretical model has been made, several approaches to form design research in neighboring areas can be identified. In the area of visual form analysis, Klöcker [5] developed a systematic approach for the analysis of design products. Schürer [6] investigated factors influencing product form from a life-cycle approach. Akner-Koler [7] presents a formal analysis of specific form elements and compositional principles. Breemen and Sudijono [8] develop a theory for the communication of aesthetic intents related to the shape of a product. Quantitative approaches for the analysis of characteristics of aesthetic curves and shapes have been explored by Harads et. al. [9] and Chen and Parent [10]. Jindo and Hirasago [11] investigate the influence of certain design elements on the aesthetic impression. Product design and aesthetic response have also been treated from the angle of consumer research, see, e.g., Veryzer [3, 12], and Veryzer and Hutchinson [13].

Product semantic theory studies the communication of meaning through product signs. Vihma [14] discusses the representational qualities of design products through the application of a semantic analysis of the product's form, i.e. how signs of the product's form relate to product type, expression, use and identity. Butter and Krippendorff [15] introduce the term product semantics, treating the area from the standpoint of user-product communication and the symbolic qualities of form. Gros [16] developed a theory for product language that approaches the semantic world by discussing "self-explanation" in product signs.

Product form has also been explained by functional reasoning. Tjalve [17] links mechanical engineering intent to product form through the use of function surfaces. Monö [18] explains product understanding with semantic functions, including describing, expressing, exhorting and identifying functions. Warell [19] introduces usability functions as a function class together with transforming and structural functions, and proposes a link to product form by means of functional regions.

3. LINKING PRODUCT AESTHETICS TO THE DOMAIN THEORY

Previous efforts regarding the integration of functional thinking with form aspects have been directed towards practical functionality of the product. The next step, linking design form aesthetics to functional reasoning, provides the opportunity to handle product aesthetics on equal terms with other design aspects such as economic and technical considerations, using a common language and terminology, and within a common modeling framework.

The theory of domains [2] provides the basic requirements for such an attempt. In the theory of domains the product is modeled from four different perspectives or domains; the process domain, the function domain, the organ domain, and the component domain. Each domain is causally related to the other domains and represents the product on different levels of abstraction and detailing, from general process view of product need and purpose, to physical, materialized parts of the finished product. The domain theory takes the standpoint in the technical transforming functionality of the product, but as shown by Warell [19], it can be modified to include usability functionality as well. By further developing the domain theory towards an ability to handle aspects of visual design aesthetics, it will be possible to describe the causal relational chain from technical transforming functionality to visual, communicative functionality in a generic model, capturing design as well as industrial design intent and purpose.

According to the terminology of the domain theory, the *process domain* applied to design aesthetics includes the manufacturing company's intention to deliver the desired message to the designated customers. Such intent may consist of communicating the values of the product and the manufacturing firm; the properties, performance, qualities of the product; and to create desirability, pride of ownership, and excitement in owning the product. These design intents comprise the purpose of the product and are communicated to the user during the use-process [19] through the aesthetic appearance of the product. During aesthetic form development, these intents are transformed into functions driving the aesthetic development of the product. Such statements of purpose, describing aesthetic design intent, can be considered functions of the form, since they drive the development of form solutions by help of certain aesthetic principles and means; they *do* something in the eyes of the beholder. In the *function domain*, these functions fulfil the stated aesthetic form purposes of the product, such as identifying the brand, creating harmony and consistency in the form, expressing power, speed, elegance, etc.

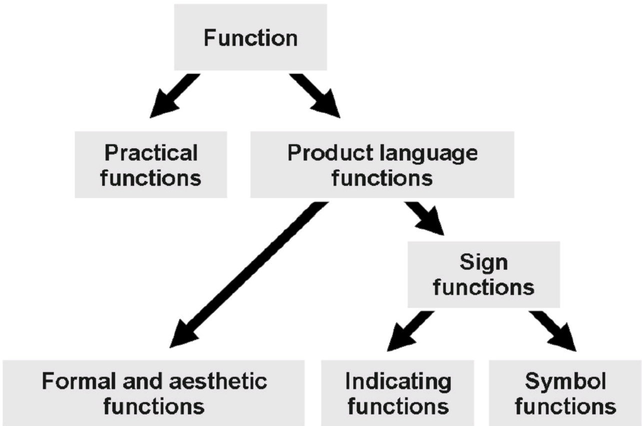

Figure 1. Functional decomposition by Gros [16]. Practical functions include transforming, structural, and usability functions according to Warell [19].

Gros [16] presents a functional decomposition that divides functions of a product into "product language functions" and "practical functions." Product language functions fulfil aesthetic design intent, while practical functions include, e.g., transforming, structural, ergonomic and semantic functions, Warell [19]. In the model according to Gros (see Figure 1), the "indicating function" of the sign delivers objective facts about the product such as information about product type, while the "symbol function" adds subjective, associative and interpretive meaning to the product sign. Compared to the semantic functionality by Monö [18], which treats describing, expressing, exhorting, and identifying functions, product language functions are related to visual appreciation, and are not primarily associated with product understanding or use of the product.

A certain form, such as a fold along the side of an automobile, may have the structural function of increasing the strength and improving the aerodynamic properties of the body, but may also have the form language function of identifying the make of the car and communicating a certain impression. The tension in the shape of the fold may have the function of telling the on-looker that the car is very powerful or sporty.

In the *organ domain*, form language functions are fulfilled by *aesthetic organs*. The aesthetic organ structure can be considered a specific viewpoint applied to the domain theory. In an aesthetic organ structure, different hierarchical levels of organs fulfilling various aesthetic purposes can be identified. When decomposed, organs realizing sub-functions can be defined down to the level where they are rendered by specific form elements and form features in a finished product. In the *part domain*, aesthetic organs are realized by form elements of the product. Functional regions constitute the causal relationship between physical form solutions and organ reasoning, Warell [20].

4. THE CONCEPT OF DESIGN FORMATS

In a product development project, a design specification formulates the specific requirements of the product-to-be in a neutral manner. A product is a result of this specification, but also a result of numerous other factors influencing the development work. These factors are the main reason for the differences between competing products in the same market segment, such as e.g. Ericsson and Nokia mobile phones, which both can be described by very similar technical specifications. These subtle differences can be captured and described in a *design format*, which states the ingredients that define a product from a specific manufacturer. Part of this format is sometimes specified and formulated in the market strategy or design manual of a company. However, most of the contents of a format that dictate design work are not pronounced and can thus not be deliberately applied during product design. This is true for form language, the choice of specific technology, priority of certain functions or properties, marketing strategy, corporate design philosophy, production methods, etc.

The term “format” is a metaphor from computer word processing, where the specific format of a document template directs the style, structure, and form of a document, without specifying its contents. For example, applying a document template may change the appearance of a document from a personal letter to an executive report from a specific company.

A design format directs the development of the product in a specified direction. It can thus be seen both as a “filter”, reducing the number of possible choices during product development and as a “driver”, since it navigates the search for possible solutions. For form development purposes on the operative level, formats are particularly useful, as they provide a way to efficiently capture information related to industrial design aspects such as visual form, color, material, surface structure, composition, basic product sign, etc. In design projects involving a large number of people, a design format on the strategic level would be very valuable for communicating and embodying the design intent across design disciplines. The design format can be specified beforehand during the planning for a product design project, but is also developed and refined as a result of ongoing work.

Related to the theory of domains, a format directs and influences the search for possible or “good” solutions in all four domains. For aesthetic design development, the effects of a design format is most visible in the organ and part domains, where the geometrical form of the product is developed. Examples of visual form ingredients in a Nokia mobile phone are found in Figure 3.

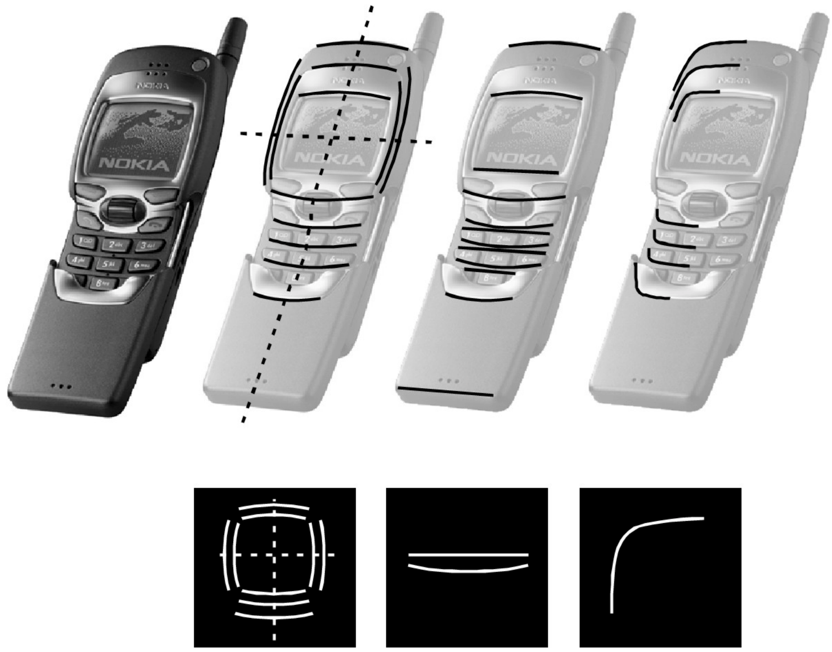

Figure 3. Main stylistic components (curves and their relations) of the design format of the Nokia 7110 mobile phone. In the format, visual aesthetics principles such as the composition of form, curvature characteristics, and form design theme are evident.

5. THE CONCEPT OF FORM ENTITIES

The concept of *form entities* is central to the modeling approach presented in this paper. Form entities have been developed to facilitate reasoning about purpose and constitution of aesthetic visual form, and relations between aesthetic visual form. In this first study, we have made the restriction of considering visual aesthetic aspects only. Our intention is thus not to treat other aesthetic elements, such as those implied by color, surface texture, material, and olfactory, tactile and haptic qualities of a form.

A form entity can be described as a “stylistic component”. As the designer starts thinking visually about a design problem by commencing his sketching process, form entities develop as a result of some design intent guided by a design format (articulated or not by the designer). Form entities can thus be represented as very preliminary and rough form ideas during the early sketching phase of a design project, or as final form solutions of a finished design. Any expression of form, visualized at any stage of the design process such as sketches, renderings, drawings, real or virtual models, and appearing in different states of abstraction, completeness and detailing, can thus constitute a form entity.

Serving specific purposes and fulfilling desired aesthetic functions, form entities in the organ domain can be described as preliminary, emerging form and as relations between forms. In this respect, form entities can be as abstract to the stylist as an anatomical structure is to the engineer. In the part domain, form entities are manifested as physical form elements or features of the finished product. In Figure 4, examples of form entities in the design of an Ericsson mobile phone are shown.

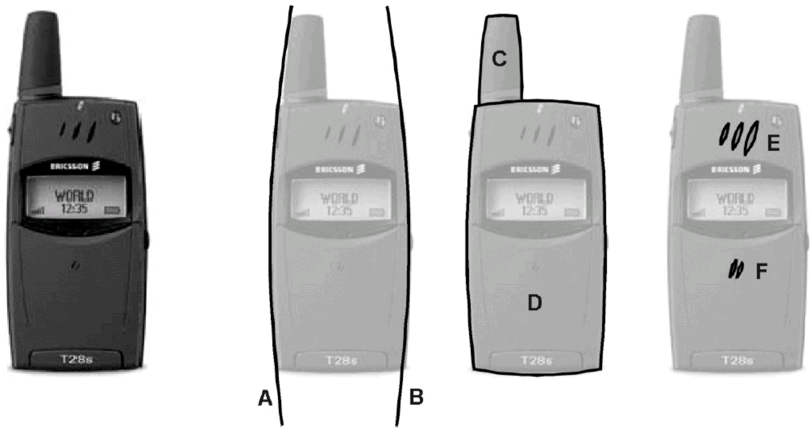

Figure 4. Examples of form entities realized in the physical form of the Ericsson T28s mobile phone. Curves A and B are visually coupled by means of interactive tension, creating unity in the form. Volumes C and D create a dynamic interplay by their strong kinship in form and their contrasting size. Openings E and F are composed by similar graphical elements, sharing a common composition principle interpreted by different spacing and number.

6. THE RELATIONAL NATURE OF FORM ENTITIES

The intention is to develop a model for form entities that answers questions about how form is constituted, i.e. what stylistic components are present, and how they are related. Analyzing the form of a product, different hierarchical levels of form entities can be identified. On the highest level, the product is appreciated as a whole form experience. On intermediate levels, form entities appear as subordinate gestalts, while form details become apparent on the lower resolution levels. Superimposed on each other, these layers together create a total form expression. Each form entity can be matched to an aesthetic organ or a relation between organs. Form entities representing form elements or emerging form elements are represented by aesthetic organs in the organ domain, while form entities that connect visual form solutions to each other are represented by relations between aesthetic organs.

Form entities can appear as *distributed* (i.e. geometrically extended across other form elements) or *distinct* (i.e. geometrically enclosed). Distinct, as well as distributed form elements, may constitute a “fifth element” of a product design as, i.e. a form element with a basic shape that serves identifying purposes, signalling a certain product brand [21]. Furthermore, form entities can appear as *simple* (single form entities) or *composed* (groupings of form entities). Relations between form entities can be described as either *discerning* (separating one form entity from another) or *connecting* (creating visual couplings between form entities).

7. EXAMPLE: VISUAL DESIGN AESTHETICS OF THE VOLVO V70

The design of the Volvo V70 station wagon provides a good example of design format, form entity, and aesthetic organ reasoning. The following citation describes Volvo’s own interpretation of the form of the product [22]:

> “The new V70′s design combines sensuality and strength. Its curves trace a proud heritage all the way back to Viking warships. Its angles convey a uniquely Scandinavian penchant for modernity and functionality. The roofline has been extended back, making the rear door almost vertical. This provides even more cargo space and a dynamic, uncompromising look.”

In the following, our analysis of visual design aesthetic aspects of the V70 is presented. The coupling between form entities and organ modeling is shown in Figure 5.

Format: On the overall level, the design format can be traced to Volvo’s target customer group and Volvo’s core values: safety, quality, environment. The form has a clean, friendly and sober expression. Economy, compactness and utility, with no extravagancies in the form, are readily apparent. The form language can be traced to previous Volvo models dating as far back as the 1940s: a clear indication of a deliberate search for identity and history. The Scandinavian origin is emphasized through a timeless, definite form language and through the choice of color combinations and materials.

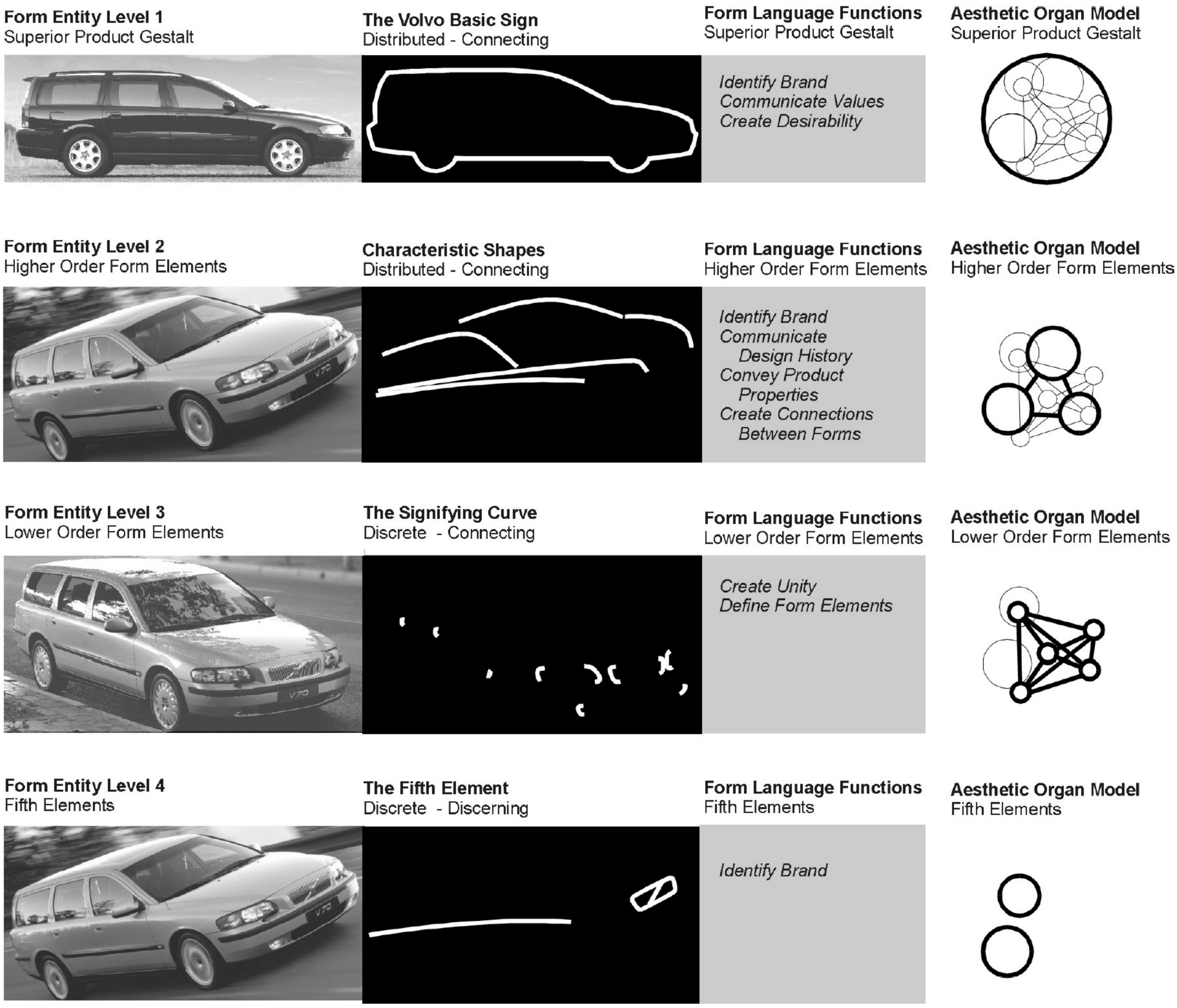

Figure 5. Form entities, form language functions, and superimposed aesthetic organ models for the Volvo V70.

Form entities: An analysis of form entities reveals a consistent treatment of a design format and an evident aesthetic organ structure. At least four form entity levels can be identified:

1. *The superior gestalt* consists of form elements on the highest hierarchical level. All major components of the design contribute in an efficient manner to the whole gestalt of the car. The form language is consistent; the form has a dynamic and efficient expression. All form

elements work efficiently together to form a new interpretation of the classic Volvo station wagon.

2. *Characteristic shapes:* Significant form elements are the pronounced shoulders running from the front of the car along its sides all the way to the taillights. The shoulders appear again in the shape of the hood and in the protrusion around the grille. The characteristic shape of the hood meeting the front is repeated in the meeting between roof and windshield. Stretching across other form elements and integrating the form into a whole, these form elements are of the distributed and connecting type.

3. *A signifying curve* as a form element is found in several components across the car body: in the door handles, in the front lights, and in the grille, among other locations. This characteristic curve is a vital feature in the form, connecting discrete and spatially distributed form elements with each other. Together, these form elements create a visually connecting aesthetic organ, an important ingredient for creating unity in the form.

4. *The fifth element:* The grille of the car featuring the distinctive diagonal cross member is a typical example of a fifth element, a symbol for the Volvo brand of cars, which over the years has been seen in many different variations. This is an example of a discrete and discerning form element. In recent models, the shoulder has also become a fifth element, although it is not as strong a sign as the grille.

In the far right column of Figure 5, the layered structure of the aesthetic organs is shown. Relations between organs in the organ models of form entity levels 2 and 3 indicate the presence of form entities connecting form elements to each other. A large number of couplings between organs within each form entity level and between levels in the superimposed organ structure indicate a consistent visual form design of high quality.

8. CONCLUSIONS AND OPPORTUNITIES FOR FUTURE RESEARCH

In this paper, we have shown that it is possible to create a theoretical model that supports the reasoning about visual design aesthetics in product design. The coupling of those theoretical models to the domain theory indicates that product aesthetics can be treated together with technical aspects, using functional and organ language, in a general theoretical model. The creation of the form entity concept makes it possible to handle visual form relations during aesthetic design development and to discuss the design of finished products. Design formats provide a way to specify, e.g., aesthetic ingredients such as stylistic components of a specific product. In the future, research efforts may be directed at explaining aesthetic form development through the study of the evolution of form entities during design work. Understanding the application of design formats for product families and product evolution is another possible research approach.

Acknowledgements

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P A P E R C

Warell, A. [2001]: “Design Syntactics - A Contribution towards a Theoretical Framework for Form Design”, *Proceedings of ICED’01*, International Conference on Engineering Design, Glasgow

DESIGN SYNTACTICS - A CONTRIBUTION TOWARDS A THEORETICAL FRAMEWORK FOR FORM DESIGN

1. INTRODUCTION

Products can be analyzed and evaluated from a variety of viewpoints and disciplines. From the viewpoint of industrial design, literature abounds with studies from the perspectives of ergonomics and human factors, economics, design management and marketing, cognitive psychology, ecology, and society and culture. The lack of “its own science” seems to be evident in industrial design. Compared to other disciplines in product development, such as engineering, the lack of a theoretical basis for form design has often allowed styling activities to become a discussion based on opinion and subjectivity. In product development, engineering design proposals are more easily evaluated and justified due to its causal nature and the ability to “validate” a solution with scientifically based argumentation. The increasing importance of styling as a competitive edge for market success has lead to a need for more communicable and stringent design development strategies of the product’s aesthetic form. The situation is improving, however. Through the advances in e.g. product semantics, we are achieving an understanding of the product with regard to how we as human beings interpret its appearance, its use and its context. Our ability to interpret the meaning of form elements – the “representative viewpoint” – is thus provided by product semantics. Yet, however, we do not have a tool or language for “spelling” visual composition and ingredients of form– the “formal viewpoint” – a theory modeling and explaining the content and structure of the visual form design.

In this paper, a first step is taken towards developing a theoretical framework for visual form design, which is compatible with models and theories found in industrial design and in engineering design science. The overall objective is to merge aesthetic and technical issues in form development, thereby bridging the gap between disciplines. The uniting keyword is functionality: not only technical engineering functionality, but a wider functional definition which incorporates "subjectively" determined functional aspects such as semantics, syntactics, and ergonomics. The framework is denoted "design syntactics", referring to a modeling approach which aims at capturing the contents – form entities and form elements – and structure – the compositional principles – of visual product form.

2. RELATED WORK

Efforts at understanding styling from different outsets have been carried out by many researchers. In the industrial design field, product semantics has emerged and grown into one of the most promising approaches for describing form design from the communicative perspective. Vihma [1, 2] applies semiotic and aesthetic theory in his development of a model for evaluating the representative qualities of modern design products, and presents a semantic analysis of product form relating to type, expression, use and identity. Product semantics as a growing discipline has been treated by a large number of authors, including Klöcker [3], Butter and Krippendorff [4], and Gotzsch [5]. Monö [6] examines product understanding from the perspectives of aesthetics, semiotics, and perception. He proposes four semantic functions as a way to introduce product semantics into active design work and for use in the analysis of products. Wikström [7] builds on Monö's work and proposes a method for evaluating the four semantic functions. Akner-Koler [8] studies the structure of three-dimensional form and proposes an approach for formal analysis of compositional principles and specific form elements, "a descriptive anatomy of products". In engineering design, product styling has yet had only minor influence. An influential exception is the work of Tjalve [9] who developed a theory and methodology for form development, based on research in engineering design science and aesthetics.

3. INTRODUCING DESIGN SYNTACTICS

While product semantics tries to explain what a product represents or expresses as a conveyor of a subjectively interpretable message from the designer to the user, design syntactics aims at describing and explaining the ingredients of the visual form composition, i.e. the shapes and their arrangement, in an objective manner, see Figure 1. Sonesson [10] divides semiotic analyses into a plastic and an iconic level, reassembling the division into syntactic and semantic dimensions. In Vihma's [2] definition the syntactic dimension includes the analysis of the product's technical construction as well as the analysis of visual details (e.g. joints, openings, holes, form crossings, texture, graphics, etc.) of the design. Since the technical and behavioral structure of products is extensively treated in engineering design science, the definition of design syntactics applied here is narrower, encompassing visual form aspects only.

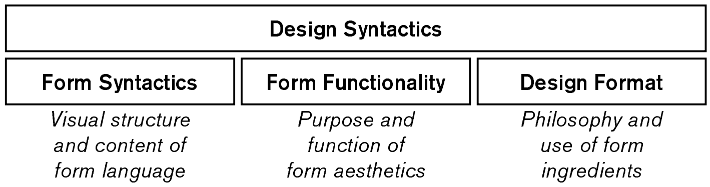

Figure 1. The framework of design syntactics.

Product semantics and design syntactics represent the two main ingredients of a “form language”. In a simplified manner, a language requires four grammatical elements: alphabet, syntax, semantics, and phonology, according to Klaus [11]. Related to form design, the alphabet is represented by form elements, the building blocks of the physical shape, used for certain purposes. Form elements build up the visual brand identity, which is different from one brand to the other, and in some cases from one product (or product family) to the other. Syntax is the rules governing the composition of the form elements into “meanings” or gestalts, i.e. how the visual ingredients are arranged in the design. As proposed by Warell and Nåbo [12], syntax can be described as part of a ‘design format’: a manual containing guidelines for form ingredients and rules for their use in form design work. Semantics is concerned with the meaning of the visual ingredients, i.e. what they signify as signs. The meaning is only apparent when a human perceiver is present who interprets the signs into a message. Phonology, the accentuation, is not relevant in this case, since we are dealing with a visual and not a spoken language.

Both the semantic and the syntactic aspects are necessary components for describing qualitative respectively quantitative communicative aspects of form design. Product semantics is finding its way to industrial use, mostly thanks to the introduction of theories and methods in design programs during recent years. Large product developing companies are beginning to think of the product design in semantic terms, i.e. “charging” the product with desired expressions and communicative values, which is an important ability in the battle of attracting target consumers. However, the knowledge and application of product semantics is of no value if it lacks the awareness of a well-formulated form language, and its relation to company image and identity. This regards the message conveyed by the entire product system, including the product, packaging, advertising, sales campaigns, etc. The visual structure and contents (e.g. identity) of the design, its syntactics, must work in synergy with the semantics of the design, in order to “speak the same language” of the visual product brand. If not successfully correlated, the semantics may send one message of the product's properties and qualities to the market, while the product syntactics conveys another. This situation is illustrated in a study by Opperud [13], which indicated that the Ericsson A2618s mobile phone is not perceived by consumers as conveying the signals suggested by marketing efforts and advertising, while the Nokia 8210 had been more successful in that respect.

4. THE DEFINITION OF FORM

A materialized product consists of parts. All parts have external surfaces, arranged according to a 'structural skeleton', Mortensen [14]. The skeleton spatially defines the surfaces in relation to each other. Furthermore, material fields constitute the "body" of the parts and connect the surfaces to each other. All surfaces are made up by shapes, the outer skin, defined by geometrical characteristics. The term "form" thus describes the characteristics of the external surfaces of a design, whether it is a whole product, a part, or a part of a part. Form is defined as consisting of shape (i.e. geometry and size) and configuration (i.e. spatial arrangement of shapes). Compared to the definition of form provided by Jensen [16], the term as used here does not include material attributes, but is concerned with external characteristics only.

From the standpoint of industrial design, the purpose of form is to enhance understanding of the product and to create appeal on part of the observer. As such, form is part of the quality Q of a product, i.e. what a customer or user experiences of a product's properties, Mørup [15]. Form is thus a subjective qualitative experience, which can be appreciated through various senses, e.g. sight (i.e. the properties of the form can be categorized as belonging to e.g. aesthetics or product semantics), and the haptile and tactile senses (if the shape is perceived by touch).

5. THE NATURE OF FORM ELEMENTS

A product's form is made up of form elements, which are defined as the constituent parts of a form. Form element is a recursive term, applicable on all levels of form, whether on a whole product, a part, or a part of a part, Warell [19]. Form elements define the appearance of all visible surfaces of a product. For example, the 'catwalk' running along the side of contemporary Volvo cars is a form element, shared by (distributed across) several parts of the car body, Warell and Nåbo [12]. Likewise, the grooves on the cap of a Magic Marker constitute a form element. Moreover, each and every groove is a form element in itself.

Thus the term form element, like form, is related to the characteristics of the external surfaces of a design and not explicitly to the internal material. Thus, the use of the term form element here differs from that provided by Jensen [16], which states that a part is decomposed into form elements. They, in turn, are structural elements with one or more elements from a behavioral point of view. Here, a form is decomposed into form elements, which are not necessarily constrained to a single part but can be allocated across several parts as constituents of the outer visual form of a product.

6. FORM FUNCTIONALITY

Form functionality in design syntactics relates to interactive functionality of a product, see Figure 2. Here, semantic as well as syntactic functionality is included as constituents of the communicative functions, i.e. functions that are related to form language. While the semantic functions, Monö [6], deal with the representational qualities of the product form, syntactic functions are related to the constituent form elements and their compositional structure. Syntactic functions may be forms that refer to each other by shape, or are related in terms of compositional principles, e.g. visually connecting or discerning, Warell and Nåbo [12]. The syntactic properties of a product form are largely determined by visual gestalt principles, as discussed in section 8.

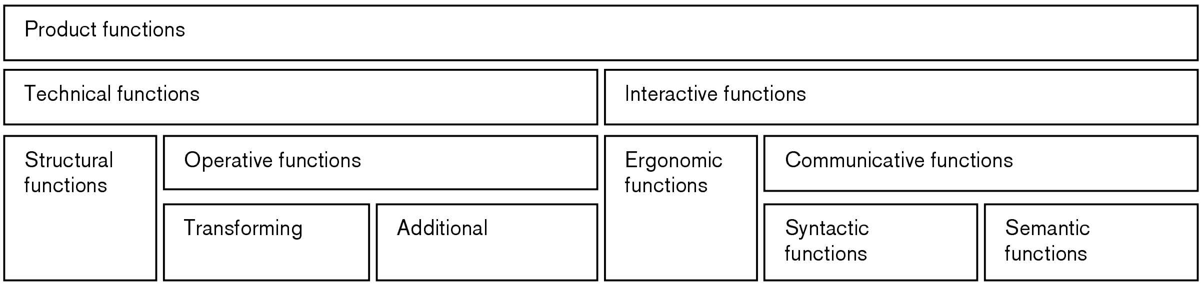

Figure 2. Function classes of a product.

Interactive functions are compatible with the function concept in design science, stated as follows: “a function is what an element of a product or human actively or passively *does*, in order to contribute to a certain purpose”, Warell [17]. The nature of the communicative functions, i.e. their mode of action, is determined by information theory. Their functionality is carried by signals, a type of data transmission from object to human. Shannon and Weaver [18] define a signal as “an action (gesture) or processed object (artifact) that provides a directive in a particular direction.” For semantic functions, the sign intended by the designer is carried by the form elements of the product having properties that represent a sign. The sign is transmitted by a signal, which is interpreted by the observer. Given that the perceiver, in a suitable context, is able to receive and translate the signal into the meaning intended by the source (the designers or the company), the desired message can be communicated. The syntactic functions, i.e. the form elements used and the way they are arranged, are likewise communicated by signals. These signals are carried by form elements, experienced by the observer in the composition and contents of the form language.

The encounter with a product with an appealing form may provoke a direct aesthetic, emotional experience, appreciated as a pure aesthetic experience, defined by syntactic functionality. In addition to the direct excitement of the form, the product gestalt (the totality of form, color, surface structure and so on) may also be interpreted as representing something else, that is, the function (in the sense of purpose), as noted by Monö [6]. Monö defines a sign as "any phenomenon which has significance that is independent in relation to its material form." Thus, a sign and its semantic function refer to something else, e.g. a practical product function. The product's appearance is thus a sign for its function. However, this does not mean that everything in the product gestalt can be (or is intended to be) interpreted as a sign. For example, the forward-pointing arrowhead shape of a modern high speed train may express high speed, the aluminum body state-of-the-art technology, and the clean side surfaces express weight and massiveness, a confidence-creating factor for the potential passenger (semantic functions). On the other hand, the sweeping, clean lines, uncluttered shapes and horizontal graphic surface treatment may also simply appear to the onlooker as a very exciting and appealing form (syntactic functions). The latter may in many cases be a stronger incentive for finally buying or using a product than the representative aspect of the product form may be.

The domain theory, Andreasen [20], is used as a basic structural design model to capture and describe part-to-human functionality, denoted 'interactive functionality'. According to the domain theory, organs in the organ domain deliver the desired functions of the product through its parts, belonging to the part domain. Previous theory has not been capable of capturing the effect of product form, apart from the form of surfaces that have a direct contribution to technical functionality (such as structural or operative functions, see Figure 2). Tjalve [9] introduced 'functional surfaces', where the surfaces of parts have an active function during use. Mortensen [14] denoted such surfaces, which contribute to the realization of an organ and thereby its function, 'wirk surfaces'. The remaining, "in-active", surfaces of the parts, the 'cover surfaces', are according to Mortensen "free" in the sense that they do not directly have functional contribution.

For design syntactics theory, however, it is essential to state that *all* visible external surfaces have functions, and thus contribute to organ functionality, as proposed by Warell [19]. For example, the purpose of a car body exterior is to create a desire in consumers to want to own that car, to inform us about the make of the car, its performance and qualities, and to relate the car to previous designs and brand values. Furthermore, it possesses technically determined structural and aerodynamic functionality. The visual form of the car body thus certainly has the ability to deliver a purposeful effect to the observer, i.e. the form has a function. The meaning of effect, Andreasen [20], is thus extended from a purely technical transforming, part-to-part sense, to a concept capable of explaining purpose of part-to-human relations as well, Warell [17].

7. THE NATURE OF FORM ENTITIES

Jensen [16] presents a revised organ-based structural model and recognizes wirk elements as the structural element of an organ from a behavioral point of view. When subjected to a stimulus, i.e. an effect causing a behavior (a behavior being a transition of state due to stimulus), a wirk element is active regarding behavior, i.e. it has the ability to realize a function. Consequently, when not subjected to stimulus, the wirk element remains passive. With the model of Jensen, functionality of a part is dictated by the existence of form elements that become wirk elements due to the structure's transition of state.

However, when considering communicative functionality, no transition of state occurs. The structure remains unaffected; the functional effect is only subjectively perceived and interpretable by an observer (by means of signaling). To be able to handle such functionality, another type of organ element is called for. This element is denoted form entity, Warell and Nåbo [12]. Hence, organs can be decomposed into wirk elements as well as form entities. The functionality of form entities is dictated by the presence of an observer. When form entities are perceived, they are functionally "active", serving either syntactic or semantic functions. Form entities are inherent to all designed objects. All shapes are perceived and reacted to, consciously or not, by vision or touch. Likewise, other signs appreciated by our senses, e.g. smell and hearing, are also important for our impression and understanding of products. Thus, awareness of syntactic and semantic functionality, allocated on the product form through the use of form entities, is beneficial for the aesthetic appreciation of the product. Thus, organs which are decomposed into form entities or fulfil communicative functionality, may be denoted aesthetic organs.

Like a wirk element, a single form entity contributes to the function of an aesthetic organ, but may not be sufficient for realizing the whole function in itself. For realizing an interactive function, an aesthetic organ may be composed of several form entities. In the same way as it is possible to describe machine organs as any type of technology that delivers the desired technical functions, an aesthetic organ can be described as any form solution that creates the desired communicative functions. Aesthetic organs are thus a special class of organs fulfilling syntactic and semantic functionality, existing in a superimposed manner along with technically determined organs. Thus, the functionality of a certain part may be described by several organ structures which realize different types of functionality, and have wirk elements and form entities as the ‘active units’ (functional regions, Warell [19]). While a wirk element is a point, line, surface, or space of continuous geometry and uniform material, Jensen [16], a form entity consists of a one-, two- or three-dimensional shape (i.e. a point, line, surface or body), a spatial configuration of such shapes, or a relation between such shapes. Thus, form entities lack any internal material attributes. Furthermore, form entities are not constrained to belonging to a single part of continuous material or geometry, but may be distributed across a form.

For example, the door handle of a car door has a multitude of functions and organs. Just to mention a few, the door handle should make it possible to open the door (transforming function, delivered by wirk elements). The handle should withstand the force applied to it during opening (structural function, wirk element). The user must understand that the handle is in fact a device for opening the door, and he must furthermore understand how to use it, and he must want to use it (semantic functions, form entities). The handle must give the impression of belonging to the car, i.e. its form must be in accordance with form elements of the handle and of other form elements of the car. All forms and the whole gestalt must create a harmony and a balance, in order to not stick out as unmotivated (syntactic functions, form entities).

8. FORM ENTITIES AND VISUAL DESIGN AESTHETICS

In a finished product design, form elements interact to create a system of visual relations, or gestalts, in the form. A gestalt is a typical realization of a form entity; a number of form elements interact, creating a visual entity of “higher order.” It is the creation of gestalt configurations that enables us as human perceivers to “read” a product’s design, too see its form. Monö [6] defines a gestalt as “a discernible whole; an arrangement of parts so that they appear and function as a whole which is more than the sum of the parts.” The form, color and material structure are not merely isolated factors in the wholeness of the design, but they influence each other, and - in high quality designs- create synergetic effects.

Form relations, i.e. couplings between form elements, can also constitute form entities. Examples of this are the creation of proximity, similarity, harmony, contrast, dynamism, symmetry, balance, rhythm, orientation, proportion, etc., by conscious arrangement of form elements. Such relations are part of the ‘gestalt factors’, Monö [6], certain factors that create and help us discern gestalts during visual perception. Important research into this field has been done by Akner-Koler [8], who provided a systematic categorization and classification of such factors, and Klöcker [3], who called such interacting features of visual composition the ‘mathematical qualities of form’. He further distinguished between arithmetic, geometric, and topological qualities of form.

9. CONCLUSIONS

The main contribution of design syntactic theory is the integration of models and concepts of the industrial design and engineering design fields. From industrial design, concepts like product semantics and gestalt theory are adopted. Engineering design contributes with design science, including functional theory, domain theory and organ modeling. The sharing of theoretical concepts with those found in engineering design science makes it possible to ascribe functional properties to aesthetic aspects of form design. Thereby, the basis for creating a common theoretical model, which is capable of explaining and relating all aspects of the product's design (technical as well as aesthetic), has been established. The emerging composite theory is denoted "design syntactics."

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PAPER D

Warell, A., Nåbo, M. [2001]: "Emergent Form Design Development Modeled by Form Entities", *Bulletin of ADC'01, the 5th Asian Design Conference*, Seoul

EMERGENT FORM DESIGN DEVELOPMENT MODELED BY FORM ENTITIES

Abstract

Research into emergent form design development in industrial design greatly lacks studies of the underlying structure and reasoning behind the form evolution process, i.e. the reasons and factors driving form development of a product's visual form aesthetics. In view of ever tightening time frames for new product development and the increasing importance of styling aspects in particularly highly engineered, technically complex products, which are developed in large multidisciplinary projects, more support is needed for balancing aesthetic aspects: Examples are form content and visual composition in relation to technical engineering specifications such as manufacturing, cost and material requirements.

In this scenario, models and methods directing and aiding the form design synthesis process are imperative. However, tools that support the designer in searching for aesthetic solutions during form design are very sparse. The first step in developing such methods is to gain an increased understanding of the form design process during early design development where the form emerges. The research presented in this paper takes the standpoint in the framework of design syntactics, a theory for aesthetic form design. Sketches from actual design projects are studied and experienced industrial designers are interviewed in order to investigate whether it is possible to model the form evolution process with the help of the theory. It is found that the elements of the theory are very well supported by the empirical studies.

1. PURPOSE OF THE STUDY

The objective of the research presented in this article is to gain insight into the development process of visual form aesthetics during the early phases of consumer product development. In the study, the aim was to investigate the design rationale during form design development, i.e. how the designer reasons in the process of creating the form of the product. The following research question was central in guiding the approach of the study:

- Is the framework of design syntactics a feasible model for describing and explaining the nature of aesthetic form development, i.e. does the designer unconsciously or to some degree consciously reason in terms of form entities, form functionality, and design formats during the form design process?

In order to be usable in interview situations with designers, the research question had to be broken down into a number of more specific questions applicable to the operative work of the designer:

- How does the form of a product develop from the initial ideas to the finished design concept during the form design process?
- What is the function of the sketching activity for emergent form evolution, i.e. what role does sketching play in the development of the product's aesthetic form?
- Do experienced industrial designers feel familiar with the design syntactic theory as a descriptive model for aesthetic form development?

Based on the insights gained from the study, the aim of the research is to develop tools and methods to support the designer during form design development activities.

2. PREVIOUS RESEARCH ON THE SKETCHING PROCESS

Several researchers have studied the externalization of the form development process through research of design sketches. However, few efforts have been directed at understanding the content of the design sketch and the factors determining choices made during form development. Most previous research efforts have studied general aspects of the design process associated with sketching, such as structure and sketching behavior [Rodgers et al., 2000; Scrivener et. al., 2000; Kavakli et al., 1998; Verstijnen et al., 1998; Goel, 1995], the role and function of sketching in design [Cross, 1999; Purcell and Gero, 1998; Ferguson, 1992], complexity and information in sketches [Rodgers et. al., 2000], and cognitive aspects of the design process [Kavakli and Gero, 2001; Birgerstam, 2000; Schön, 1983; Lawson, 1980].

For the purpose of the research conducted for this article, some studies are of special interest. McGown et al. [1998] and Rodgers et al. [2000] studied the sketching process of industrial design students with special emphasis on the transformation activity during different phases of design sketching. Both quantitative and qualitative material was studied, based on workbook sketches and interviews with design students. The study was based on work by Goel [1995], who identified two types of operation, namely lateral and vertical transformation, which occur between successive sketches in the early stages of sketching. Here, lateral transformation denotes an obvious change in thinking (divergent move to a different idea), while vertical transformation denotes a convergent movement towards a more detailed version of the same idea.

Through the sketch, the designer externalizes his ideas in the envisioning process of articulating an idea in the mind into something more concrete, which can be used for further understanding, reasoning and shedding light on the problem. Through sketching, the designer can see the problem from other perspectives and highlight a variety of aspects in different stages in search for the most promising solution to the problem. Several authors have noted this interactive process occurring between the designer and his sketching. Schön [1983] calls this “reflection in action”, and Birgerstam [2000] describes it as a constant switching between the aesthetic-intuitive and the rational-analytical modes of action.

Surprisingly, none of the presented studies have focused on the content of the design sketch, i.e. what elements of the form design emerge and how they develop through the different phases of the sketching process to the finished product. Some exceptions are found in engineering design literature, such as Hubka et. al. [1988], Tjalve [1979], and Andreasen [1992]. Andreasen notes that design progression is achieved by moving from abstract to concrete, and from undetailed to detailed and complete. Early sketches, produced during the initial phases of the sketching process, are characterized by their abstract and undetailed representation of design ideas, while sketches at late stages are elaborate and quantitatively informative.

3. THEORETICAL BASIS

The standpoint for the research carried out in this study is the framework of design syntactics [Warell, 2001]. The theoretical framework includes the concepts of form syntactics, form functionality and design format, according to Figure 1. The three concepts explain and model the visual structure and content of the form composition, the purpose and function of form aesthetics, and the philosophy and use of form ingredients of the product design.

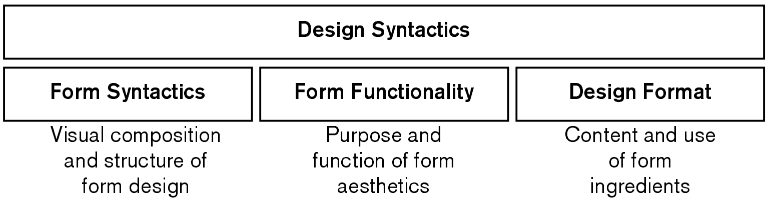

Figure 1. The theoretical framework of design syntactics.

As a core component of the form syntactics concept, form entities [Warell and Nåbo, 2000] relate the physical appearance of the product form design to the functional intent of the designer. Inspired by the domain theory by Andreasen [1980], form entities are non-physical entities linking the functionality of the product to its realization in physical parts. Hence, form entities carry aesthetically determined functionality, which is realized by form elements of the form of the physical product.

In the process of transferring design intent into some physical realization, the designer works with early form ideas, i.e. form entities, which are subsequently developed into form elements of the finished product. As such, form entities are ‘seeds’ of the emergent form, ‘planted’ in the process of sketching, and grown into finished form in the evolutionary process of form design. In the finished form, form entities are finally manifested in form elements; mature, detailed form solutions of a product, realizing the aesthetically determined functionality carried by form entities. Thus, a form entity can be defined as a “visually perceivable modeling unit with aesthetically determined functional purpose.”

The second concept, form functionality, implies that all visible surfaces of a product carry functionality, which is aesthetically or technically determined. Aesthetically determined form functionality comprises syntactic and semantic functionality [Warell, 2001]. Respectively, they represent functionality carried by form elements and relations between form elements such as wholeness and unity in the form design by e.g. linking, relating and associating visual effects. Functionality conveys meaning by expressing, identifying, exhorting and describing [Monö, 1997].

Finally, the design format concept [Warell and Nåbo, 2000] includes the main theme and philosophy of use of form ingredients, i.e. what form elements are present and how they are used. Designers commonly refer to this as the ‘form language’ of the design. Thus, the design format in a way is the ‘template’ for the design, used by the individual designer or the entire design team in the search for form solutions.

4. RESEARCH METHOD

Cross [1999] outlines a number of methods for researching the nature of design thinking: interviews with designers, observations and case studies, protocol studies, reflection and theorizing, and simulation trials. For the research questions posed in this article, it seemed natural to approach the structure of design thinking during early sketching through two of the methods, namely case studies of design projects and interviews with designers. Since the use of sketches is an important part of the natural processes of designing [Cross, 1999], and since freehand sketching has become an invaluable part of the design process for a majority of designers [Pipes, 1990; Lawson, 1994], it seems reasonable to use sketches as the main object under study for both research methods.

Here, the term 'sketch' is used to denote the result of a sketching process. A sketch is thus an externalized idea, manifested in some type of two- or three-dimensional image or object, and in a variety of materials and media, such as a free-hand drawing, a foam model, or a CAD sketch. Ferguson [1992] identifies three types of sketches made by the designer or engineer: the *thinking sketch*, used to focus and guide nonverbal thinking; the *prescriptive sketch*, used to direct a drafter in making a finished drawing; and the *talking sketch*, produced during exchanges between designers and engineers in order to clarify complex or unclear parts of a drawing. In this study, we are interested in the sketch mainly as a tool for self-communication, i.e. thinking sketches according to Ferguson.

Sketch analysis

The research undertaken followed two basic approaches. The first approach included the study of design sketches produced in various design projects, in order to investigate whether the design syntactics theory is suitable for explaining how styling design ideas emerge and subsequently develop from initial idea to final product during the design process. Sketches from styling design projects of technically advanced consumer products were collected from first-hand sources such as design projects, and from second-hand sources such as design magazines. The sketches were studied and analyzed focusing on identifying form entities that arise early during the sketching process, and subsequently are embodied in form elements in the design of the finished product. The sketches were also examined in order to determine whether the presence of design format thinking was evident, e.g. if a coherent styling theme was used for guiding the work during form development.

Interview study

The second approach constituted interviewing experienced industrial designers from three internationally renowned Swedish product developing companies, regarding their thinking and reasoning processes during form design development. The purpose of this part of the study was twofold. Firstly, to investigate the thinking process underlying form design development during early phases of the styling process, i.e. whether it is possible to see evidence of design syntactics reasoning. In other words, we were trying to determine whether designers start out the design process thinking in an abstract and undetailed manner about the form, but still with a definite design intent, which is traceable to functional reasoning of the emergent form design. Secondly, the aim was to investigate whether the designers, from personal design experiences, feel familiar with the proposed theoretical models, i.e. whether they recognize and accept the concepts and theories of the design syntactics theory. Each interview was based on a discussion around an ongoing or completed design project, for which the designer was currently, or had previously been, responsible. Information retrieval was carried out in the form of semi-structured, discussion-oriented interviews, which were audio-recorded and transcribed for subsequent analysis. During the interviews, three-dimensional sketch models and photographs were used in addition to two-dimensional freehand sketches for reasoning about the design process.

5. RESULTS OF THE STUDY

Sketch analysis

Figure 2 exhibits a number of sketches where the main characteristics of the final form are evident in rough idea sketches from the early research phases of the design development process. Indeed, the design process that led to the set of stylistic choices of the Alfa Romeo 156 was a very ‘linear’ one, where project documentation reveals that the objectives attained were very clear to the designers all the way from the initial research phase [Baruffaldi, 1997]. A number of variations of the theme used to define the form of the car are visible on a form entity level in the sketches. Examples are the interpretations of the classic triangular shield of the grill, the divergent feature lines of the bonnet, the low and wide air-intake, and the crease along the flank of the car.

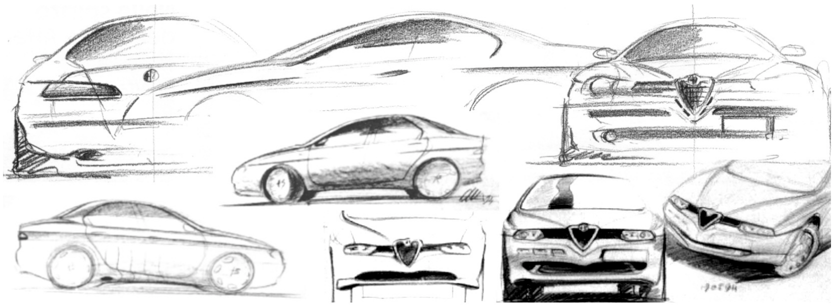

Figure 2. The variation of the “156 theme” in early research sketches of the design development of the Alfa Romeo 156. Adapted from Baruffaldi [1997].

The features marked in the sketches in Figure 3 are typical examples of form entities: early, rough form ideas fulfilling an obvious design intent of the designer - to identify the car as a typical Alfa Romeo, and to express properties, historical heritage and other qualities of the car.

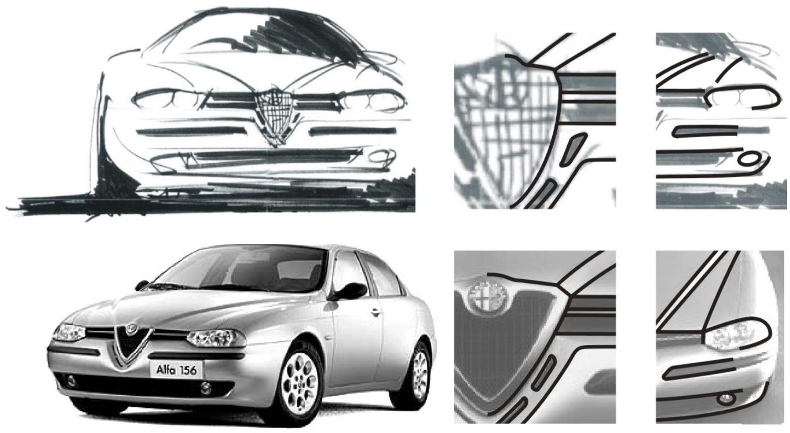

Figure 3. Form entity development, evident in emergent form during the research phase, and in the final form of the Alfa Romeo 156. Adapted from Baruffaldi [1997].

The crease along the flank of the car as shown in Figure 4 is a new interpretation of the traditional longitudinal ‘Alfa-style’ side panel indent. This specific feature, visible in early sketches as well as in the final form of the car, represents a typical form entity: a form idea emerging on initial sketches, carrying a specific design intent, which subsequently develops into geometrically fine-tuned form elements of the finished product form. As a physical form element of the car body, the crease comprises a second form entity feature, described as “two pencil strokes perfectly united by the door handles”[30]. The relation between the two fine lines, visually joined by the front door handle, efficiently employs gestalt law principles in creating an impression of a long continuous line along the flank, serving the same syntactic (e.g. visually coupling) and semantic (e.g. brand-identifying) functions as the traditional crease.

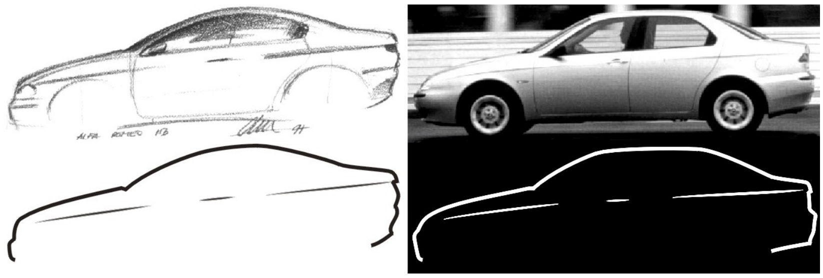

Figure 4. The evolution of the new interpretation of the classic Alfa flank crease from the sketch phase to the finished design, an example of a form entity transformed into physical form elements. Adapted from Baruffaldi [1997].

In Figure 5, early, rough sketches generated during the development of the Electrolux Oxygen vacuum cleaner are shown. Despite their roughness and lack of detail, they give a clear idea of the basic gestalt and form language, which was elaborated during the initial phases of the styling design process, indicating that the basic definition of form language is made very early during sketch development.

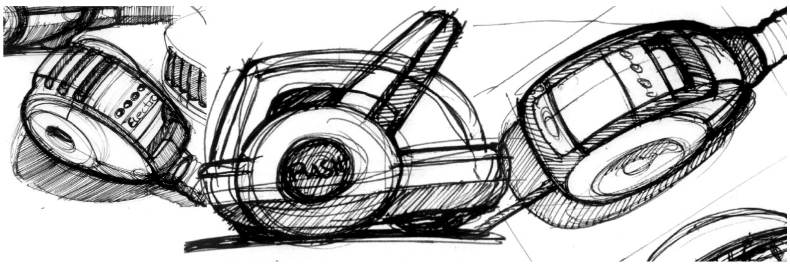

Figure 5. Sketches illustrating the initial form ideas during the development of the Electrolux Oxygen vacuum cleaner. Sketches courtesy Electrolux Home Products Operations (Sweden) AB.

One of the sketches produced during the early research phase of the Oxygen vacuum cleaner is analyzed in Figure 6. Marked lines serve to illustrate high-level form entities [Warell and Nåbo, 2000] that have evolved and developed

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30 Citation of Walter de' Silva, director of the Alfa Romeo style center, Arese, Italy [Baruffaldi, 1997].

from initial sketches to the final product, 'surviving' the process of design development. The basic idea behind the first sketches was thus preserved to the finished product by vertical transformation [Goel, 1995].

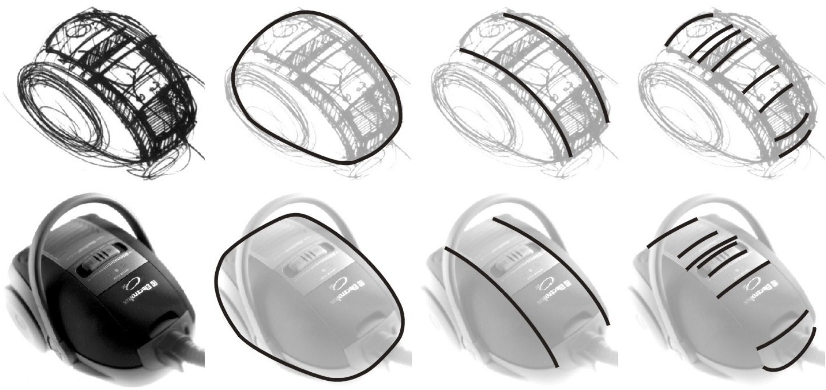

Figure 6. Form entities evident in an early sketch compared to the finalized design of the Electrolux Oxygen vacuum cleaner. Sketch courtesy Electrolux Home Products Operations (Sweden) AB.

Interview study

The purpose of the interview discussions was to develop an understanding about the process of form creation, the thinking during form research and development, and the factors that influence the development of form. Our effort was to investigate whether there was evidence of any structured process, which the designers employ in their search for suitable form ideas, whether the designers start from scratch when initiating the sketching process, or to what degree they have some pre-existing idea about what the product should look like. Short quotations of statements made by the designers during the interviews are presented here in order to illustrate their reasoning on a few issues that were discussed. For reasons of confidentiality, the designers from the three respective companies are denoted designer A, B, and C, respectively.

When commencing the form design work, the designer generally starts out searching for ideas with only a short design brief as input. Generating ideas freely from his mind, the designer envisions the product-to-be. The starting point for the sketching process lies in some vague idea of trying to create a form that has certain qualities as a carrier of expression and other important product properties:

> "Normally you start with a basic shape and you want to … radiate the things that they are supposed to [do], like safety, or youth etc, the keywords that you try to address. You try to develop shapes that do the job, that radiate that."
> *Designer A*

During design, the form emerges and develops in an evolutionary manner. In this process, certain form ideas may develop into strong statements which, in turn, begin to influence the form development as a whole:

> "When some parts are starting to feel like we have found the way to go, then we let them take control over the other parts. [...] Solutions have emerged and grown into something, ..., we might work with some radius, some swelling, or whatever it is, and we then try to apply this to the whole form." *Designer B*

> "This way of working with a facet and an indentation is exactly the same [as the previous product]. [...] In the end it is the designer who takes those decisions [about certain form solutions], and the reason for that is, that it should all work together." *Designer C*

The designer lets the sketch 'work for itself'. Form ideas emerge, give rise to new ideas, and the process goes on in a quite unpredictable manner. This is what Cross [1999] refers to as "design being opportunistic"; the path of exploration cannot be predicted in advance. In this manner, design work is characterized by uncertainty:

> "You never know what comes out. If you give ten designers the same briefing, different things would come out." *Designer A*

It seems a large part of the designer's work is hard to capture by verbalization. What the designer sees in the form, how he reasons about form design decisions, seems largely determined by skill and experience, by tacit knowledge.

> "It is difficult to explain it, it is like something that, I think, you in some way have practiced yourself into seeing." *Designer C*

From the interviews, it is quite obvious that the designers lack a stringent and consistent way of talking about the form and the process of form development during design. Terms used are very general in meaning, and are often used signifying not only one, but several purposes depending on context. The reasoning followed during design is very difficult to explain or describe, as noted by many researchers. General conclusions can hardly be drawn from this very limited sample of interviewed designers, but the result can still be considered as indicative, pointing at tendencies in design reasoning.

6. DISCUSSION

From the interview study, it can be concluded that it is very hard to discuss the issue of design reasoning with the designers. In communication with other disciplines, the lack of terminology may be a reason for uncertainty and misunderstanding when communicating design intent and purpose of specific form solutions. The understanding of, and ability to reason about, the form would possibly also benefit from the presence of an enhanced vocabulary for discussing structure, composition and content of form. Thus, form awareness may increase both geometrically as well as syntactically and semantically. The following sections highlight specific issues obtained from the interview study regarding the form design process of individual designers.

On the convergence of form during sketching

Experienced designers often claim that an initial, strong idea lives through the whole design process of further development and refinement to form the basis for the final, realized concept. This is also evident in many of the studied sketches. It could be hypothesized that a reason for the longevity of early ideas depends on two factors: the degree of given design direction, and the characteristics of the initial divergent phase. Design projects starting from a well-defined design brief, stating the direction of the design project in a clear and well-communicated manner, may exhibit a lesser extent of divergence than an ill-defined design task. By comparison, a “free” start, unbiased and undirected, may exhibit a greater degree of divergence. Also, if the divergent phase is short compared to the total time spent searching for design solutions, the sketching process may exhibit a lesser extent of design divergence.

On the emergence of form entities during sketching

In very early, rough sketches, the information content is small compared to drawings from later stages of the process. In fact, the only available information may be the definition of high-level form entities, i.e. basic gestalt features of the overall form. In this way, early sketches are “detailed in an undetailed manner”, providing the information needed and relevant at the initial phases, where the amount of information available is often sparse. From the interviews, it seems plausible that starting the sketching process from definition of basic form entities is a natural way of approaching the design problem. A hypothesis could be that the designer commences his sketching process having a partially pre-defined design intent on an abstract level, which he tries to capture and explore by rough and perspicuous search for basic form entities.

On form entities as a means for form understanding

The form entity concept provides a way of seeing, decomposing, and analyzing visual form. The understanding of product design by form entities draws the attention to the wholeness of the form, and the relational properties of form. The understanding of the form, its structure, composition and content, can be enhanced by the awareness of, and the ability to ‘read’, the form in terms of form entities in addition to form elements. Thus, the form can be more easily understood both geometrically, and in syntactic and semantic terms.

On the application of a design format during sketching

As evident from the interviews, certain elements of the form emerge and grow into prominent form entities during sketching. These ‘strong’ forms may develop and gradually dominate the form in terms of visual style, i.e. a design format is developing. It can be hypothesized that the process of designing either with a pre-existing design format as a template, or developing a new design format, follows an evolutionary and cyclically repetitive process. In this process, the designer (or design team) alternates between (a) the exploration of form entities and form elements, and (b) the gradual application or development of a design format. The progression of form development is characterized by gradually completing and adding form content and structure characteristics to the evolving design format, see Figure 7.

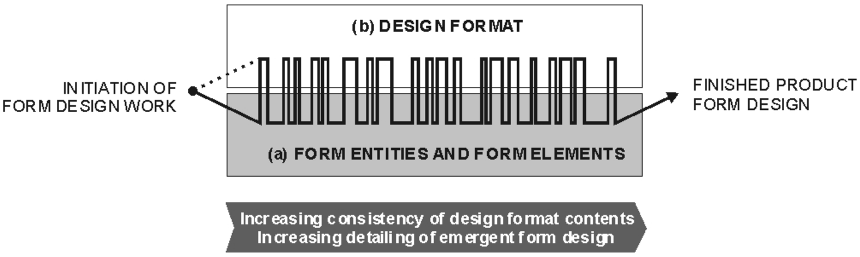

Figure 7. The cyclic, evolutionary process of designing against a design format. The dashed line indicates the alternative starting point of design work based on an existing design format.

7. CONCLUSIONS

In this research, the aim has been to determine whether the design work during form development can be explained and reasoned about using the theory and models of design syntactics. It can be concluded, based on the study of sketches and the interviews with designers, that designers do in fact work with conscious or unconscious mental models and reasoning patterns during design that fit the theory of design syntactics.

One implication of this is that by the introduction of form entities, the opportunity arises to develop a method which supports form evolution and captures the essence of the gestalt laws in a tool for form synthesis. Thus, it may be possible to actively apply the principles of gestalt factors in the synthesis process and not merely use them as a way to analyze the gestalt principles of finished designs. Furthermore, to know the characteristics of a ‘good’ idea in terms of e.g. the early identification of promising form entities and form syntactics may possibly provide us with the ability to identify those promising ideas early in the process. Then, the design work could be directed towards generating and developing ideas which run lesser risks of meeting with a ‘dead end’ situation. This would not only make the idea exploration process during sketching more efficient, but would also increase the designer’s ability to generate and develop higher quality form concepts more confidently and with less effort, frustration and hardship.

Method development is an important task for the future in an area where models and tools are extensively lacking. The ability to manage design work on the operative level from a strategic company level is also an important aspect. The framework of design syntactics provides the opportunity to develop approaches for specifying, communicating, and evaluating form design solutions based on design format modeling.

Acknowledgements

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HANDLING PRODUCT IDENTITY AND FORM DEVELOPMENT ISSUES IN DESIGN MANAGEMENT USING DESIGN FORMAT MODELING

Abstract

Aesthetic appeal is becoming increasingly important for consumer products in order to be competitive on the market. In corporate product development, form design development is carried out by industrial designers, who interact with other design disciplines in integrated product development. Studies show that the form development process is often characterized by inefficient collaboration and limited understanding between disciplinary competencies, e.g. between industrial design and engineering design functions. One reason for this situation can be explained by the lack of a theoretical basis for form design, which often lets styling discussions become based on opinion and subjectivity alone. There is a need for a holistic and transparent model of product design, where requirements and the goals of different disciplines can be easily communicated and balanced against each other, thus enhancing understanding and collaboration in product design work.

In this article, we propose a descriptive framework for visual form design, denoted 'design format modeling'. With the model, it is possible to describe aesthetic form design content on the operative as well as the strategic levels of product development. Based on the model, the individual designer can explain and motivate form design solutions, and the design team is provided with a tool for discussing and evaluating form design in relation to other, e.g. technical aspects. On the managerial level, the model provides a way to plan design evolution and to describe aesthetic design content of products related to corporate identity and product planning issues.

1. RELATED RESEARCH

Many researchers have made efforts to understand industrial design from different outsets. In the field of design management, research has focused on the role of industrial design in product development, and how design resources are used and managed from a corporate perspective (e.g. Gemser and Leenders, 2001; Hertenstein and Platt, 1997; Svengren, 1995; Dahlén, 1992; Gorb, 1988; Topalian, 1979). Collaboration and communication between different design disciplines in product development has also been studied by a number of researchers (Janhager et. al., 2002; Persson, 2001; Olson, 1992).

Product semantics has emerged and grown into one of the most promising approaches for describing form design from the communicative perspective. Vihma (1995, 1987) applies semiotic and aesthetic theory in developing a model for evaluating the representative qualities of modern design products and presents a semantic analysis of product form relating to type, expression, use and identity. Product semantics as a growing discipline has been treated by a large number of authors, including Monö (1997), Butter and Krippendorff (1984), and Klöcker (1980).

A few researchers have tried to understand the aesthetic aspects of form design. Akner-Koler (1994) studied the structure of three-dimensional form and proposes an approach for formal analysis of compositional principles and specific form elements, "a descriptive anatomy of products". Van Breemen and Sudijono (1999) studied the relation between designers' aesthetic intent and product shape and developed a theory of communication of aesthetic intents. Chen and Owen (1997) established a style description framework that equips the designer with the ability to analyze existing styles and to describe new styles for target markets.

Methods for form design development on the operative design level are also sparse. An influential exception is the work of Tjalve (1979), who developed a theory and methodology for form and structure variation based on research in engineering design science and aesthetics.

2. THEORETICAL BASIS

Design format modeling is part of the theoretical framework of design syntactics (Warell 2001). The framework includes the concepts of form syntactics, form functionality, and design format, according to Figure 1. Respectively, these three concepts describe and explain the visual structure and content of form composition; the purpose and function of form aesthetics; and the philosophy and use of form ingredients.

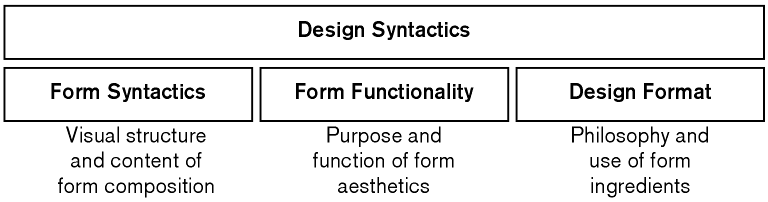

Figure 1. The framework of design syntactics.

The design format concept (Warell and Nåbo, 2000) includes main themes, design philosophy, and rationale of form ingredients during product design, i.e. it defines what styling features are present and how they are used. Designers commonly refer to this as the ‘form language’ of the product’s design. Thus, design format modeling can be seen as a ‘template’ for aesthetic form design, usable by the individual designer or the design team in search for form concepts, or by the design management for planning and guiding design work. Styling features are of two types; form entities and form elements. Form entities are forms that carry form functionality on an abstract level, e.g. they identify the brand, express important properties of the product (semantic functions), or relate form elements to each other in creating visual coherence (syntactic functions). Form elements are physical, geometrical shapes of the product, e.g. curves, lines and surfaces of a car body. The distinction between form entities and form elements is necessary in order to distinguish between functional characteristics and characteristics of the physical shape of product form.

3. INTRODUCING DESIGN FORMAT MODELING

It is becoming increasingly important for product developing and manufacturing companies to have a strong identity on the market. The brand and corporate identity must be easily communicable and clearly visible in the products. The design must also ‘speak a coherent language’, so that customers recognize products from the company when new models or generations are introduced on the market. Design format modeling provides a way to capture and describe the visual styling content of products, and to use that knowledge for managing design development processes.

Design formats and product design

Most companies with success on the market are aware of the importance of a strong identity, and most often, this awareness is evident in the design of their products. Companies frequently use significant styling features to label the brand. Such features can be identifying form elements, such as certain curves, shapes or ‘fifth elements’ such as a radiator grille (Mollerup, 1997). As illustrated by Porsche design, the total appearance alone may be a significant feature of a brand:

> “Our brand is not identified by any distinctive elements such as a radiator grille, so its personality derives from the way we design the details and handle the surfaces. The typical Porsche shape is set by the combination of surface treatment, highlighting and tension, which to a large extent comes from the transition from convex and concave shapes.”
>
> *Porsche design director Harm Lagaay* (Weernink, 2001)

Designers can quickly illustrate the signifying features which visually communicate the product brand. In Figure 2, designers have illustrated the basic characteristics of their products in terms of form design. It is evident that only a few lines can capture the most important features that signify the respective brand on the overall form gestalt level.

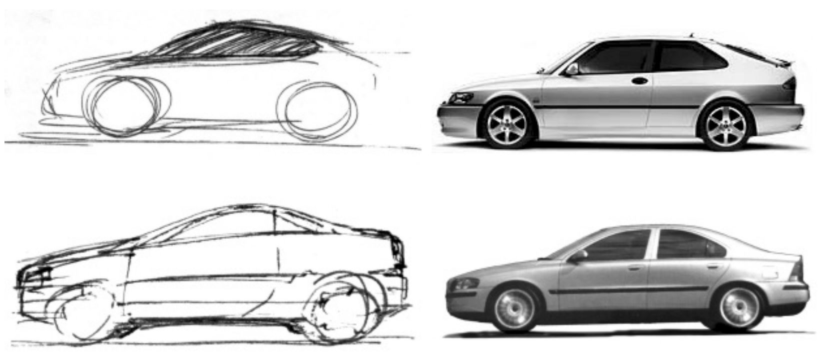

Figure 2. The characteristic features of future Saab (top) and Volvo (bottom) cars, as drawn by Saab design director Michael Mauer and Volvo senior designer Örjan Sterner, respectively. The Saab sketch illustrates significant form features such as the characteristic hatchback shape, the curved windscreen and rear side window shape (the ‘Sason curve’) and the basic front form, in relation to the current ‘9-3’ model (adapted from Andersson, 2000). The Volvo sketch in turn illustrates the articulated, convex ‘cat walk’ shape along the flank of the car body, and the pronounced V-shaped bonnet and the vertical front, also evident in the contemporary ‘S60’ model (adapted from Andersson, 2001).

The examples illustrate that certain stylistic features are used to compose the basic form of products. It is important to be aware of the product’s significance in terms of visual form design, and how to use these features in a conscious and unmistakable way to communicate and develop a product brand. Such features are often referred to as ingredients of the form language of the product.

Form content that labels a product in terms of identity, type, brand etc. can be captured in a design format, which contains all prominent characteristics of a product’s visual aesthetics, as illustrated in Figure 3. The form of the product is described by the content of the design format and can be employed when designing a new product. During design, the contents of the design format influence, and to some degree stipulate, the form of the product (relation 1). Thus, the design format can be seen as an ‘applied design philosophy’, i.e. a template for design on the product design level. However, it should not be seen as a design manual, which is a detailed guide specifying the visual appearance of company logotypes, documents, vehicles, etc., in order to give the company a coherent public image. Due to the multitude of factors influencing the development of a new product, such detailed specifications are not feasible for directing product design work. To some degree, the design format also evolves simultaneously with the design of the product, since new variations and form ideas arise during the design process. Thus, the emerging product form also contributes to the content of the design format (relation 2).

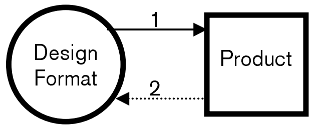

Figure 3. A design format describes and prescribes (influences) the form design of a product (relation 1). In the design process, the form evolution of the emerging product also feeds back and further develops the contents of the design format (relation 2).

Design formats and product history

Companies often use styling influences from earlier models when they design new products. In this way, they can develop the form according to current styles and trends in combination with form ingredients that refer back to previous designs. Form elements from previous models are developed and interpreted in a more or less different manner depending on current influences. Thus, the new product will be perceived as new and recognizable at the same time, thus attaining a coherence in time and a recognition of the brand. Balancing the degree of novelty against established and familiar forms is a delicate “walk on a tightrope” in product design. Too much novelty may not be accepted by the customers, while a model which is only incrementally different from the previous one will not be perceived as a new product.

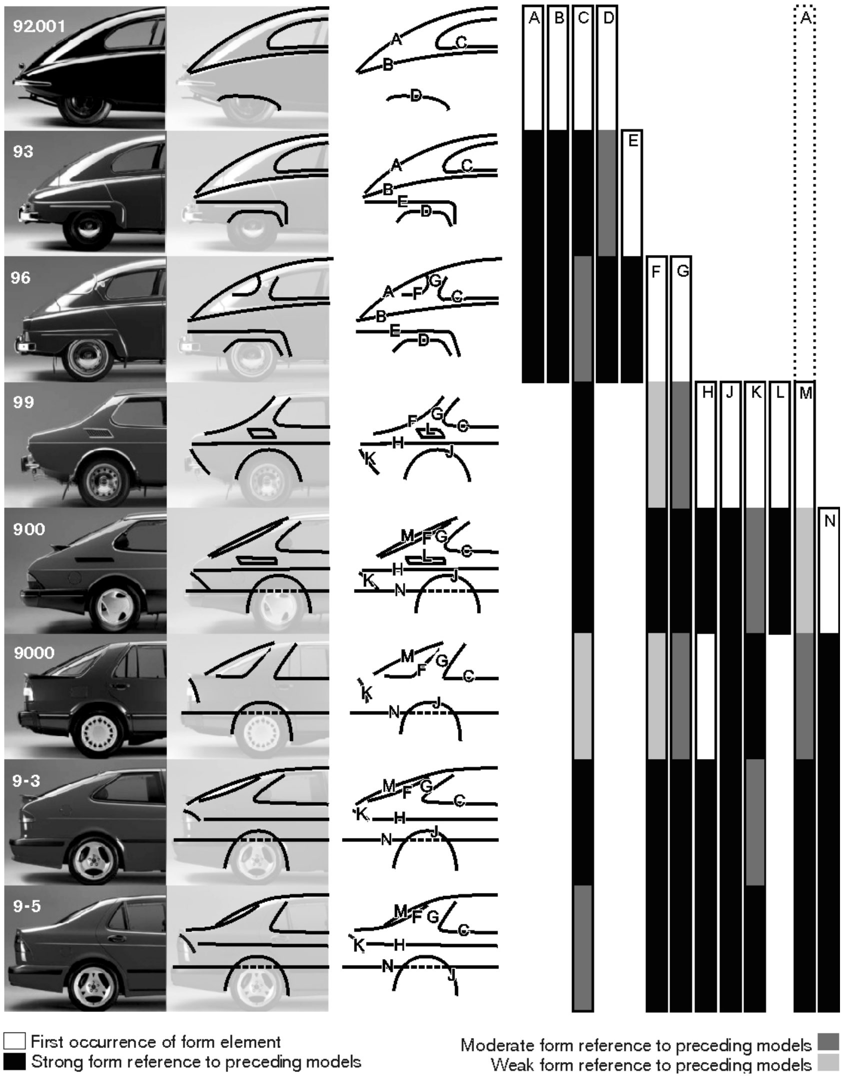

Figure 4. Styling history time line of Saab cars over five decades, ranging from the first prototype, the '92.001' from 1947, to the '9-5' model from 1997. Form element C, the 'Sason curve', has been present since the first car and is gaining in importance in recent models. The '99' model reveals an obvious shift in design paradigm, introducing a range of new styling features, but still referring to the preceding models (through form elements C, F and G). A more recent, but not as obvious, discontinuity is found in the '9000' model, designed by consultant design firm ItalDesign, featuring weaker form references to preceding models. In the diagram, unfilled bars represent first occurrence of a form element, and filled bars represent various degrees of form reference to preceding models.

Styling history is created when a succeeding model refers back to a preceding model in appearance. In Figure 4, a selection of sterns of Saab car models illustrates the styling history through five decades of design. In the shown sequence of generations, significant ingredients of the form are indicated. It is evident that preceding models have influenced the design of later ones. Form evolution over time is not totally continuous, however; at least two major changes in design direction are evident. As seen in the diagram on the right, some form features are very long-lived, while others are present in only a few generations and finally disappear to be replaced by others.

While each individual model has its own unique design format, each format referring to previous models, it is also evident that the common ‘Saab design format’ is very significant and that it evolves over time. The consequent treatment and development of form elements is obvious and indicates a deliberate use of form language in design. The Saab design philosophy is described in the following words:

> “We want to make sure that any car of ours seen on the road will stand out as something different and unique but different in a positive way, with extra sporty character and dynamism. ...we will be looking for highly three-dimensional, sculptured shapes, but covered by simple, clean-cut surfaces... Every shape will have to serve a purpose and be designed to fulfill its function.”
>
> *Michael Mauer, director of design at Saab Automobile* (Baruffaldi, 2001)

As indicated by the design format model in Figure 5 (relation 3), styling history of previous generations of models is a ‘company internal’ factor, which influences the design of new products.

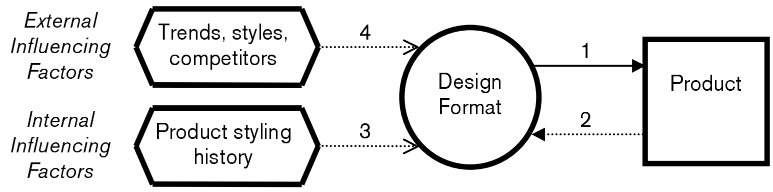

Figure 5. Product styling history is an example of an internal influencing factor; a brand specific resource that the company can employ in product design to develop the design format of a new product (relation 3). Current trends and styles are examples of external influencing factors, which the company can use to enhance contemporary characteristics of new product design (relation 4).

All products are also ‘products of their time’. Thus, other factors such as contemporary styles and trends in design as well as in other areas, changing values in society, and products from competitors also influence the current design format (arrow 4). These are ‘company external’ factors, in the meaning that they are not specific property of one company but available for all product designing companies to take part of and employ in product design. External factors also influence the design of a new product and give rise to form evolution from one product generation to the other.

Design formats and design of product families

Companies designing and producing a range of products, e.g. a product family, have to consider the design of the products and the product family together in order to maintain a clear and unambiguous identity on the market. If not, customers may not perceive the products as coming from the same company, the identity of the company as well as of the products will be blurred and unrecognizable to the customers, and large-scale opportunities may be missed. A product family is a number of products from the same manufacturer which belong together, based on use (e.g. a modular and configurable stereo equipment range), or on target group (e.g. children's toys). If the range of products in a product family employs styling features from a common design format, they will all be perceived as referring to each other, and the product family is communicated visually.

Figure 6 illustrates a limited selection of Bang&Olufsen's product range of consumer home electronics. Visually, it is fairly evident that all products come from the same manufacturer. The overall styling theme for the products is similar, yet no product is identical to the other. Each and every product employs its own design format; it has its own unique appearance. At the same time, they can all be considered sharing a common design format; that of the product family. The ingredients of the common design format are noted in the top row. When dissecting the form of the products of the product family, it is evident that some styling features are more commonly used than others. These are e.g. form elements such as geometrical forms and connected volumes, or other styling features such as metal finishes and black-colored surfaces. Individually, these ingredients are not unique to the styling of Bang&Olufsen products, but used consistently together in a common design format, they signify that particular brand.

The figures in the bottom row indicate the 'frequency of occurrence' of each respective styling feature. These are summed up vertically in each column, each black dot representing two points, while each circle represents one point. For example, geometrical forms and metal finishes are very well represented throughout the product family. Some styling features, such as the grill-like raster and the use of glass surfaces, are not as commonly employed. Still, if used consequently on at least a few products of the family, they can still evolve to become significant ingredients of the common design format. In the far right column, the presence of the indicated styling features in each respective product is noted. Some products use almost all of the styling features of the design format, and can thus be said to represent 'strong' products, which are very typical of the common Bang&Olufsen styling theme. Using the scoring scheme, other products appear less representative of the common design format, such as the 'dice-like' speaker in the forth row from the top.

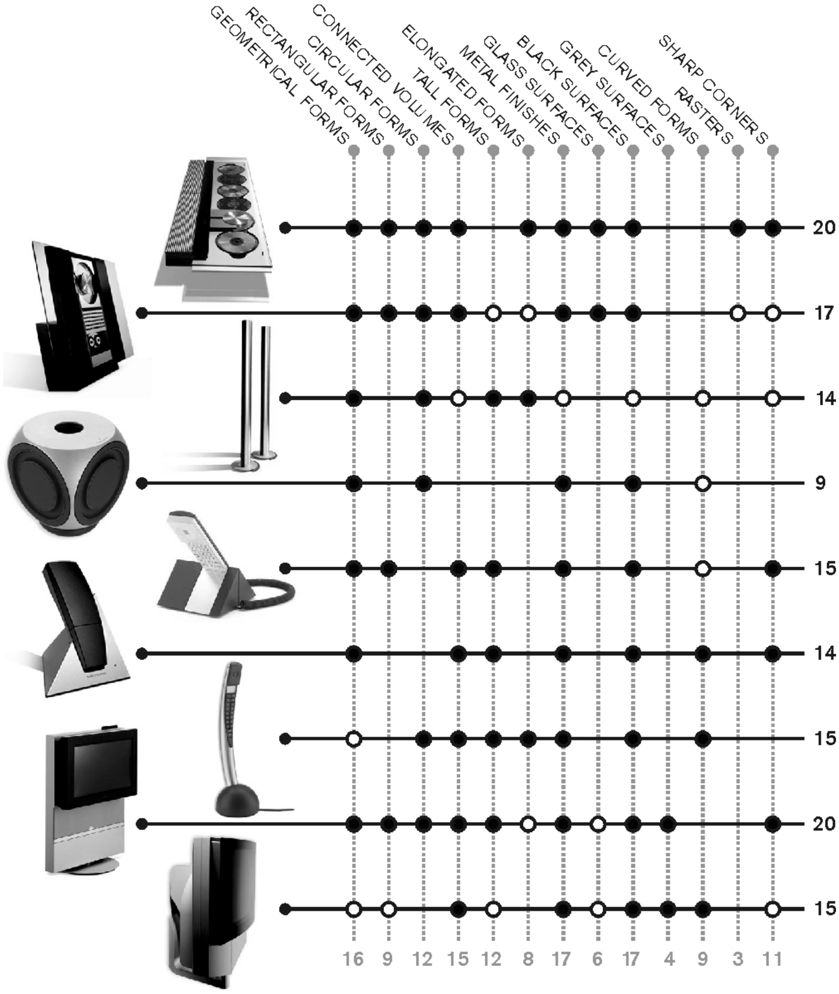

Figure 6. A selection of products from Bang&Olufsen's range of consumer home electronics, representing a product family. Vertical columns indicate the occurrence of styling features of the common design format of the product family. Some styling features are more frequently employed than others, thus representing more significant ingredients of the common design format. Horizontal rows indicate the degree of conformance of each product to the common design format. Some products employ more styling ingredients from the common design format, and thus represent 'stronger' products in terms of product identity. Filled dots indicate a strong correlation between specific product design and product family design format (two points); circles indicate weaker correlation (one point).

In the design format model in Figure 7, the common design format thus includes all significant styling features of all products of the product family. While design format A includes the form ingredients of product A, the common design format includes the form ingredients of all products of the product family. For a product family, company internal and external factors influence the common design format. Large companies may have several ranges of products intended for different market segments, and may thus employ different design formats for each product range.

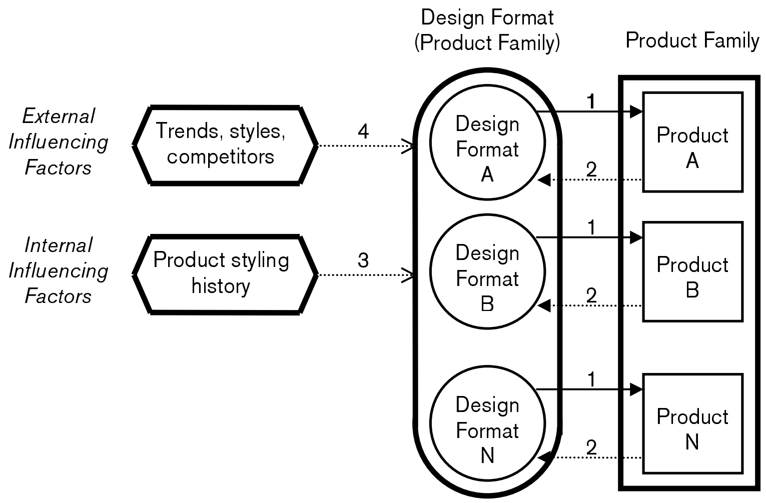

Figure 7. Design format model for a product family consisting of N individual products. Each product employs a unique design format. Styling features of each individual product are part of the common design format of the product family, employed in different combinations in respective products.

Design Formats and Format Banks

We have seen that styling features of products in different product generations and in product families can be referred to as individual, product specific design formats, or be regarded as common design formats for a range of products. This awareness can be very important from the product development perspective of a company. For the customer or user, however, the picture of a company is formed by the total knowledge that the customer has acquired of all products that are currently, and previously have been, available on the market. A large corporation may sell different products on different markets; hence, consumers' picture of the company will differ depending on the market.

This total knowledge of the appearance and characteristics of the company's products, as well as other ways the company is visible on the market, e.g. through commercials and how the products are exposed and sold, is part of the format bank of the company. The format bank is formed by the products the company makes available to consumers on the market. It can only be indirectly changed through the design of new products. More company-internal positioning means, such as corporate identity strategies, company values, and design philosophy, etc., are not directly evident to the ordinary consumer and thus not directly part of the format bank, but are important ingredients of the company's total design management philosophy together with the format bank.

The products or product families, which are designed based on design formats will directly influence the format bank of the company, i.e. the collected visual appearance of the company's image in the mind of the customer. If a company wants to change its image, it can only do so by introducing new products, or by presenting design concepts with the aim of changing the public image of the company or prepare the market for a change in company niche or product appearance. This relation is indicated in Figure 8 (relation 5).

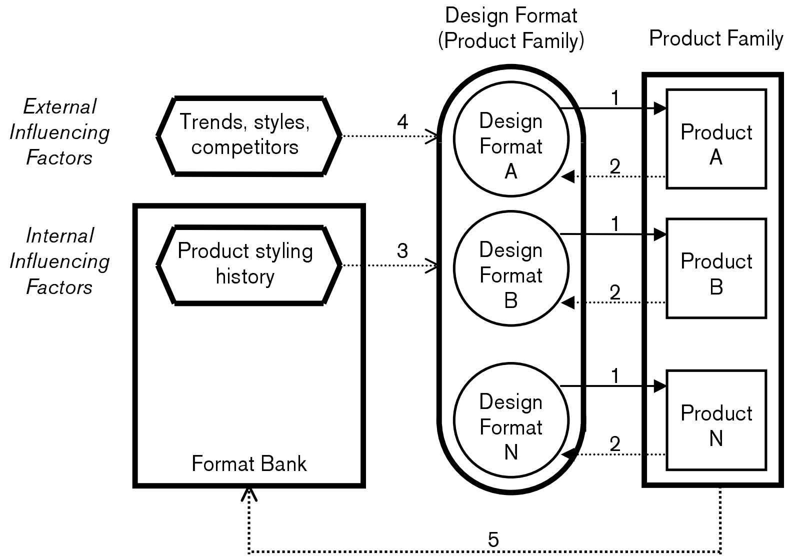

Figure 8. The format bank, the public image of the products of a company, can only be indirectly changed by the presentation of new products on the market (illustrated by the feedback loop of relation 5). The format bank includes all company-internal influencing factors, which can be employed in new product design.

As a resource for the company, product styling history is thus part of the format bank together with all other company-internal influencing factors, which can be employed in new product design. The term 'format bank' can be seen as a metaphor to a monetary bank. By withdrawing assets of the format bank and investing them in the design of a new product, employing a design format, the company can make profits on the market which can be used in future product development. The company can increase its assets by the rate that it gets from using the assets of the format bank wisely in new product design. An example would be a company going back in time to pick up styling features of previous models, which are refined and introduced in the design of a new product. This is a way of strengthening a company's heritage, which is frequently employed in automotive styling.

4. DISCUSSION

Design format modeling as part of a theory of industrial design

An inherent problem in the area of industrial design is the lack of 'its own science'; models, methods and language of aesthetic design which makes it possible to reason and evaluate product form design. Compared to other disciplines in product development, such as engineering design, the lack of a theoretical basis for form design often lets styling activities become a discussion based on opinion and subjectivity. In product development, engineering design proposals are more easily evaluated and justified due to their causal nature and the ability to 'validate' a solution with scientifically based argumentation. It is important to develop theories which enable a stringent and rational communication of form design issues, in order to raise the discussion to a level where aesthetic and technically determined requirements can be balanced in integrated product development settings.

Design format modeling is an attempt to create a model with which it is possible to capture and describe the visual form content of product design. The theory models the reasoning of designers in a formal manner, transforming tacit knowledge about form design reasoning to externalized knowledge, communicable across design disciplines and corporate levels. In this perspective, design format modeling constitutes an important contribution to design management.

Design format modeling as a resource for design management

Svengren (1995) proposes three levels on which design management should be practiced: on the philosophical level, such as the valuing of the role of design for the company; on the strategic level, as the strategic management of design and strategic concepts (e.g. choice and definition of market segments and product types); and on the operative level, as operative management of a design area or project. On all three levels, design must be discussed and managed.

Many companies describe their intentions and core values in a design philosophy, often in an abstract manner using images and wordings for profiling the brand. Such philosophies are primarily intended for internal company use and often serve at least two purposes; first, to communicate the philosophy of the company and the intentions of the design department to other departments of the company, as a way to explain the thinking and reasoning during design development. Secondly, to 'set the stage' for the design work; to bring members of the design team into the right 'mood' when approaching a new design task, and also to introduce new or inexperienced designers to the philosophy and thinking of design at the company. An example of such a philosophy is Braun Design's 'Set of Values':

> "Braun Design is guided by a set of enduring values which find expression in the following attributes of the finished product: innovative, distinctive, desirable, functional, clear, honest, aesthetic.
>
> Braun Product Design stands for: Distinctiveness and global acceptance.
>
> Braun Design is: distinctive *and* valid globally, functional *and* aesthetic, innovative *and* natural, emotional *and* long-lasting. The solution is to find a symbiosis of values."
>
> (Braun, 2001)

Likewise, Saab Automobile define their approach to design in the 'Saab Philosophy':

> "The Saab name stands for dynamic cars with a distinctive design. We combine high performance with impressive safety, and place firm emphasis on putting the driver in control. We're renowned for our unconventional approach to designing cars - an approach that can be traced to our aircraft-building heritage. It characterizes everything we do and it has resulted in numerous innovations over the years. Our cars are a synthesis of enthusiasm, experience and creativity. A lot of thought goes into a Saab."
>
> (Saab, 2001)

While design philosophies such as the ones mentioned are useful for corporate management, they are less applicable by the designer and design team during operative design work. Thus, the transformation of corporate design philosophy to operative design guidelines must be done at the design department or on project level for new design projects. A risk associated with this methodology is that it is hard to manage design development in the long term, across design projects, for product families, and for successive product generations, especially in large companies with large design departments.

Hertenstein and Platt (1997) report from a study on design management in new product development where senior management may not have achieved an awareness of the role that design plays in implementing strategy in the new product development process. They also raise the question whether design managers adequately and effectively communicate their actions back to senior management. Using design format modeling as a way to describe the strategy and future actions may be a way to bridge the vertical gap between different levels of design management. Instead of discussing design strategy using the abstract language of a design philosophy, design formats may provide a way to discuss design on a more product-related level, in terms of approaches for product styling. For example, design format modeling may be a way for product planning functions to more specifically define intentions and approaches for new products and product families, using styling features as a complement to information about target group, competitor activities, and technical specifications. It also becomes possible to plan design on a long-term basis, by incrementally introducing new styling features, which can become significant form ingredients in future products. As reported by Hertenstein and Platt (1997), product design managers want the issue of strategic alignment of design work to be measured, presumably because they want to be engaged in discussions concerning strategy. Using design format thinking may be a way to define design objectives more concretely, thus facilitating the evaluation of design performance.

Studies of design on the operative level show that the form development process is often characterized by inefficient collaboration and limited understanding of disciplinary competencies, e.g. between industrial design and engineering design functions. Olson (1992) reports that designers often run into communication problems and conflicts with technical departments and marketing, while these departments experience neither communication problems nor conflicts with design departments. Olson draws the conclusion that the design department is neither understood, nor appreciated, by other departments. A reason for the indicated lack of understanding between disciplines may be the low communication frequency between managers and industrial designers. Janhager et. al. (2002) report from a survey of 99 product developing companies which indicated that only eight percent of the responding project managers, development managers, and design engineers have daily contact with industrial designers. Of the same respondents, 60 percent had daily contact with design engineers. Moreover, Persson (2001) reports that interaction between design and engineering departments is sometimes characterized by prestige and cultural differences, a factor which may also affect communication negatively. It seems that many of these problems are due to lack of understanding between design disciplines, resulting in conflicts and an unwillingness to compromise in design work. Design format modeling may provide a way to make the rationale and reasoning behind styling design development transparent and communicable between disciplines. This would facilitate the evaluation of design proposals, where styling design objectives must be balanced against engineering requirements.

For the industrial design function, design format modeling can provide a way to externalize and verbalize design thinking in order to enhance communication within the design department, as well as with technical and marketing functions. Since the operative approach to design is often not explicitly documented, but rather ‘in the walls’ of the design department, it is very difficult for the designers to translate the corporate design philosophy into operative plans or approaches. Knowledge and tradition of design is not formalized, and thus they often vanish when designers or influential design managers leave the company. When using consultant designers in design projects, the question also arises of how to efficiently introduce the designer to the design tradition of the company, as well as how to capture the knowledge which the designer takes with him when leaving the project. Here, design format modeling would provide a means for defining the specific design identity of the company's products. Design formats can be used to describe significant features of the styling approach for a new product, or for a product family. Evolution of design across product generations can be studied and analyzed, and strategies for future design development can be drawn up.

5. CONCLUSIONS

One of the most important assets for a company is its trademark. It becomes increasingly important to manage and strengthen corporate brand identity through product design. With design format modeling, it becomes possible to capture, describe and manage such identity aspects on the concrete level of product form design.

The design format model is a general framework for form design, applicable across product types, company levels, and processes. The model is scalable in different product dimensions (individual product, product family, and product generations), in different design management levels (operative, strategic, and philosophical), and across design processes (individual designer, design team, and corporate design tasks).

Design formats provide a way to externalize tacit knowledge at different levels of design and to use it for managing design in product planning and development. With the language provided by the model, collaboration between disciplines can be enhanced, and design objectives can be more efficiently communicated and balanced.

The model is of a descriptive nature and builds on existing and observed phenomena in product design work. Future research will focus on investigating more aspects of design format thinking, and on the development of tools and methods which support specification, synthesis, and evaluation of aesthetic form design, all applicable at different levels of the product design process.

Acknowledgements

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METHODOLOGY SUPPORT FOR FORM DESIGN DEVELOPMENT IN INDUSTRIAL DESIGN ENGINEERING

Abstract

Methodology support for aesthetic form design development in the industrial design–engineering field is very sparse. With the increasing importance of appearance for consumer products, which are developed in large multidisciplinary projects, more support is needed for specification, development and evaluation of design aesthetics in relation to technical engineering aspects. Examples would be manufacturing, cost and material demands, in order to efficiently and effectively develop successful products. In this article, we propose methods and tools for aesthetic form development, based on the theoretical framework of design syntactics. The methods are intended to be applicable in various contexts: for different purposes and stages in the design process, by different users or stakeholders, and for different objects and applications. Thanks to these methods, designers or design teams are given approaches for analyzing, evaluating and synthesizing visual form aesthetics of product design in a transparent manner, which can enhance interdisciplinary understanding and communication.

1. INTRODUCTION

Appreciation of product form design is highly dependent on subjective factors related to expectations, taste, and attitudes (Schürer 1969; Tjalve, 1979). This may be a reason for the apparent lack of formalized methods in the field of design aesthetics. The ability to handle such factors has traditionally also been considered an intrinsic part of the tacit knowledge of the experienced designer; knowledge which cannot be captured, described, or externalized as public knowledge, let alone be made available to and usable by other stakeholders. However, since such subjective factors highly influence the success of consumer products, it becomes increasingly important to be able to consider them in a stringent and transparent way, so that communication and discussion of appearance factors is rendered possible. The question of how to efficiently specify, assess and evaluate product aesthetics is a key challenge especially in complex design projects involving multidisciplinary design teams.

There are few tools that support the designer during the process of searching for aesthetic solutions, as are tools supporting specification, communication and evaluation of industrial design intent and knowledge in multidisciplinary design work. The aim with this article is to propose drafts for such methods and tools, and to illustrate their use.

2. METHODS IN AESTHETIC FORM DESIGN

Tools and methods for design support in the area of aesthetic form design development are very sparse. In the field of product semantics, some tools for assessing the symbolic and representative qualities of product form are found. Klöcker (1980) provided an analysis of product form characteristics such as form optimization, differentiation, and order, but provided no method for the designer to achieve these objectives. However, few attempts have been made at applying semiotics to design (Vihma 1995), by creating tools and techniques readily available to the designer for design development purposes. Monö (1997) introduces the ‘semantic functions’ to assess purpose, properties, use, and origin of products. Building on the work of Monö, Wikström (1996) presents methods for the evaluation of products’ semantic functions. The ‘semantic transfer’ method relates descriptive words and the features of the product to each other in order to determine whether the product conforms to the user’s expectations or is misleading (Lannoch, 1984).

For product development purposes, Butter (1987) presents an eight-step systematic procedure for semantically driven design, including listing of desired and undesired ‘semantic attributes’, and the transformation of those attributes into manifestations like metaphors and ‘semantic themes’.

The method for structure and form variation (Tjalve, 1979) is still one of very few formalized tools for form synthesis available to the form designer, which is applicable to hands-on form design work. Based on systematic variation of five ‘basic properties’ of a product - structure, form, material, dimension, and surface - Tjalve presents a step-by-step procedure for finding the most promising alternatives for basic structures, total form and form of elements of a product. In the methodology, Tjalve places no specific emphasis on semantic or aesthetic criteria, but focuses on operation, space, and technical functionality as main evaluation parameters.

On the strategic company level, general design guidelines, often denoted 'design philosophies', 'identity guidelines', or 'design manuals', are important tools for describing and communicating identity and design approaches, see e.g. Braun (2001), and Saab (2001). Such general policies or vision statements are, however, not very useful for transforming overall design goals to product form design specifications or objectives, and hence can not be directly applied to design work by the individual designer (Warell and Nåbo, 2001a).

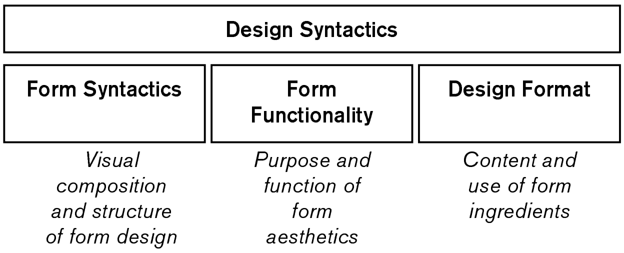

Figure 1. The theoretical framework of design syntactics.

3. THEORETICAL BASIS

The methods presented in this article are developed based on the theoretical framework of design syntactics (Warell, 2001). The framework includes the concepts of form syntactics, form functionality and design format, according to Figure 1. Respectively, the three concepts model the visual composition and structure of the product's form design, the purpose and function of form aesthetics, and the content and use of form ingredients in product design.

As a core component of the form syntactics concept, form entities (Warell and Nåbo, 2000) relate the physical appearance of the product form design to the functional content of the product. Inspired by the domain theory of Andreasen (1980), form entities are non-physical entities, which link aesthetically determined functionality of the product to the physical realization in the form of the product. Hence, form entities carry aesthetically determined functionality, which is realized by form elements of the material product.

In the process of transferring design intent into some physical realization, the designer works with early form ideas, which carry syntactic functionality. At this stage of the process, the designer works with form entities, being unfinished and undetailed form solutions of the product aesthetic form. The form entities are subsequently developed into form elements of the finished product. As such, form entities are 'seeds' of the emergent form, 'planted' in the process of sketching, and grown into finished form in the evolutionary process of form design development (Warell and Nåbo, 2001b). In the finished form, form entities are physically manifested in the product as form elements; mature, detailed form solutions of a product, realizing the aesthetically determined functionality carried by form entities. Thus, form entities can be defined as “visually perceivable modeling units with aesthetically determined functional purpose.”

The second concept, form functionality, states that *all* visible surfaces of a product carry functionality, which is aesthetically, technically, or ergonomically determined. Aesthetically determined form functionality comprises syntactic and semantic functionality (Warell, 2001). Respectively, they represent functionality carried by form elements and relations between form elements, such as wholeness and unity in the form design by e.g. linking, relating and associating visual effects; and functionality conveying meaning by expressing, identifying, exhorting and describing (Monö, 1997).

Finally, the design format concept (Warell and Nåbo, 2000, 2001a) describes main themes, form content, and philosophy of use of form ingredients, i.e. what form elements are present and how they are used in the form design. Designers commonly refer to this as ‘form language’. The design format in a way is the ‘template’ for the design, unconsciously or deliberately used by the individual designer or the design team in search for form solutions.

4. THE NEED FOR FORM DEVELOPMENT METHODS

Industry’s need for design methods and tools can be deducted from its situation, as summarized by Andreasen (1991):

- shorter market lifetime;
- increased competition;
- increased rate and frequency of innovation;
- reduced profit margin;
- increased demands on product quality.

It is not unreasonable to suppose that methods within the field of aesthetic form design are needed, as in other areas of design. Many examples in industry point to the difficulties in a design project to prioritize and reach successful compromises between styling and engineering aspects. The following case illustrates the complexity of a typical problem in the automobile industry[31]:

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[31] Almefeldt, L., personal communication, 2001

> During the development of a new automobile range, the decision was taken to make the luggage compartment lid in aluminum in order to reduce the total weight of the car. In the project, aesthetic form design issues were considered of prime importance. The proposed styling concept featured complex shapes, which were not possible to produce in aluminum within the available manufacturing process. In order to realize the styling solution, the decision was made to produce the back panel of the lid as a separate part in injection-molded plastic, while the rest of the lid remained in aluminum. The resulting solution ended up being not as efficient regarding visual quality, geometric fit, weight and cost. A more structured design process, enabling more efficient specification, communication, and evaluation of form design issues, would likely have contributed to more agreed strategic decisions made earlier in the project, and reduced amount of rework, cost, and time spent in the project.

In a scenario like the one described above, it seems likely that methods facilitating the evaluation of styling proposals in relation to, e.g., production issues, would have been of value for estimating the consequences of design decisions. Synthesis methods for generating new form solutions would likely have contributed to additional styling concepts, retaining the desired syntactic and semantic functionality of the form, within the capability of the available production process.

5. CHARACTERISTICS OF THE PROPOSED METHODS

What is a method? According to Newell (1983), a method has the following characteristics:

- A method is a specific way to proceed (among other procedures).
- A method is a rational procedure; following the prescribed steps increases the chance of solving the problem (in comparison to ‘just doing something’).
- A method is general – that means: applicable to more than one problem.
- The use of a method is observable.

It is also important to clarify that methods and procedures, based on a theory, have to be deliberately developed[32]. While a theory describes reality, a method defines, on the basis of the declared facts, how the scientific and practical activities and behaviors of humans ought to take place (Hubka & Eder, 1996).

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32 “Tools and instruments are inventions, they do not result directly from a theory but have to be created” (Andreasen, M. M., ENDREA Engineering Design Research School Conference, Luleå, June, 1999)

Important characteristics aimed at during the formulation of the proposed methods include:

- '*Scalability*': The ability to apply the method in a variety of different design situations, for different purposes, and by different users.
- *Ease of use*: To be efficient, methods must be easy to learn, simple to use, enhance understanding of disciplinary issues, and promote interdisciplinary communication.
- *Compatibility*: The methods must also work together with other tools and methods, which are available for different aspects of design work. They must also comply with normal and established working procedures.

For the sake of simplicity of use, the methods presented here are manifested as readily applicable, manual paper-based tools. However, most of the methods are also suitable for implementation in computer based support systems.

The context of use of the proposed methods and tools presented in this article can be seen from three different perspectives, according to the following.

1. Different purposes and stages in the design process

The methods cover needs found in different stages of the design process. These include pre-design tasks such as benchmarking or competitor analysis, strategy formation and specification, and design tasks such as functional analysis, form design development, and form evaluation.

2. Different users and stakeholders

The methods are intended to be usable on all operative levels in design development, where decisions are taken on a daily basis, both on detail and system levels of design. Thus, the tools provided must be easy to apply for the following groups: the individual designer, who needs tools and methods for design synthesis and styling development; for the design team in need of tools for design specification, design evaluation, and interdisciplinary communication; and on design management levels, for managing company design activities and product planning issues.

3. Different design objects and applications

The methods should be generally applicable, meaning that they should not be restricted in their use to any specific type of product. The methods should work equally well for the design of simple, everyday products such as a pencil or a fork, or for highly complex consumer products such as automobiles or mobile telephones.

6. PROPOSED METHODS

The following chapters introduce three main tools, which address the issues previously mentioned. The methods are denoted “Method for form functionality analysis”, “Method for form development”, and “Method for design format handling”, respectively. Methodical procedures and illustrative examples are provided for each method.

Method for form functionality analysis

In the engineering design field, many methods for functional synthesis of mechanical engineering systems have been developed, e.g. by Tjalve (1979) and Hubka et al. (1988). A common denominator for these methods is that they are limited to the analysis and specification of functionality determined by engineering processes, i.e. internal technical functions that are related to mechanically transforming purposes of the product. Thus, they do not consider interactive functionality, e.g. product functions associated with use, handling and appearance, which is the focus of industrial design (Warell, 1999).

Since the majority of consumer products depends on other characteristics for market success than merely technical performance, it becomes increasingly important to consider interactive factors in product design and development. Functional analysis provides a way to identify, describe, and assess internal product functionality such as transforming and structural functions, as well as interactive functionality including syntactic, semantic, and ergonomic functions, Table 1.

Function class			Descriptive verb
Internal functions (technical product functions)	Main		Transform Convert Rotate
	Structural		Connect Support Restrain
	Additional		Regulate Control
Interactive functions (human-product interaction functions)	Ergonomic		Protect Enable Facilitate Fit/Suit
	Communicative	Syntactic	Associate/Relate Connect/Couple Separate Balance
		Semantic	Express Describe Identify Exhort

Table 1. Function classes of products and human-product interaction, and examples of descriptive verbs.

The method supports multi-functional analysis and synthesis of design concepts and products. By facilitating the analysis of existing products, e.g. for product benchmarking purposes, it provides the design team with a powerful tool for understanding and assessing the total functional content of competing products and systems. The information obtained can be used for developing new product specifications, for balancing functional content in products, and for the evaluation of designed concepts.

Methodical procedure

The main objective of the method is to identify and analyze the functional content of products. The starting point for the procedure is the analysis of design intent of solutions, parts, components, etc. The analysis covers all functional aspects of the product under study, including internal functions (i.e. structural, transforming, and additional functions) and interactive functions (ergonomic, syntactic, and semantic functions).

The method of identifying functions of a product has two complementary approaches, which support each other and can be used either separately or collectively. The approaches are based on direct functional identification and on analysis of design intent, respectively. Both approaches share the same goal: the identification of functions and their classification. The two procedures are described in the following.

Starting from direct functional identification

During functional identification, the product under study is scrutinized with the objective of identifying functions which belong to different classes by direct observation. Depending on availability and size, the analyzed object can be the studied product in itself, or a representation of the product, such as a picture, sketch, or a cad model. The procedure follows the basic steps:

1. Select the first function class to be analyzed, e.g. structural, ergonomic, syntactic, etc. The goal is to study all function classes, but to limit the complexity of the study, each function class is analyzed separately. This facilitates the analysis by limiting the scope of the search to only one function class at a time.
2. The whole product, or a subsystem, is searched for solutions with the selected, e.g. structural functionality. The identified functions are recorded on e.g. a picture of the product, for later reference.
3. The next function class is selected and the product is searched for functions in the same manner. The identified functions are recorded, and the procedure is repeated for each function class of interest.

Figure 2 shows a direct functional identification of the SAS coffeepot. For illustrative reasons, functions of different classes are shown in the figure.

During an actual analysis procedure, functions of different classes can be analyzed separately.

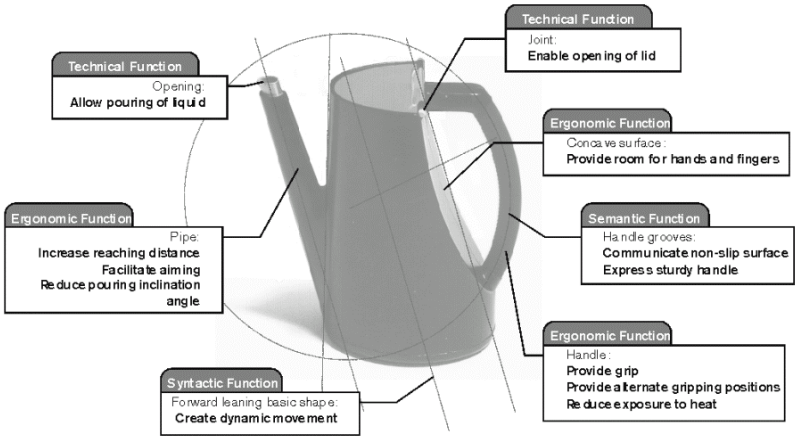

Figure 2. Direct functional identification of the SAS coffeepot, designed by ErgonomiDesignGruppen, Stockholm. Adapted from [EDG, 2001].

Starting from analysis of design intent

While direct functional identification can be seen as a way to quickly get functionally acquainted with the product, design intent analysis gives a more thorough understanding of the design and its functional content. The procedure can be formalized into a manual form-based tool. In contrast to direct functional identification, the product is analyzed part by part in this case (or subsystem by subsystem) according to the following procedure (see Figure 3).

1. The analysis starts on the superior, whole-product level and is then continued on subsystem levels. Design intent is searched by posing the question “Why is the solution/feature/mean present?” (column A).
2. By stating the purpose (reason for existence) of the particular solution, the design intent is given (column B).
3. The purpose is now transformed into a function statement by asking the question “What does the solution/feature/mean do?” The function should be stated as briefly as possible (column C), preferably using only one verb and one noun in combination, in accordance with established function analysis methods (e.g. Landquist, 1994; Hubka et. al., 1988; Jakobsen, K., 1990; Wikström, 2000). The identified functions which use the procedure of direct function identification can be employed as input in this step.

Col.	A	B	C	D	E	F	G	H	I
Row No.	**Question** "Why is the solution/feature/ mean present?"	**Purpose/Reason/Cause (design intent)** "In order to…"	**Function statement (verb + noun notation)** "What does the solution/feature do?"	Main	Structural	Additional	Ergonomic	Syntactic	Semantic
1	Why is a pot needed?	…enable serving seated aircraft passengers from main coffee container in cabin kitchen	Hold liquid	X					
	Body								
2	Why is there an opening in the top of the pot body?	…enable (re)filling	Allow filling			X			
3	Why is the cross section of the pot elliptical in shape?	…facilitate (re)filling from tap in cabin kitchen	Facilitate filling				X		
4		… create an visual composition in balance with other form solutions	Couple form elements					X	
5		…facilitate serving by occupying less space when serving	Decrease bulkiness				X		
6		…lighten the visual impression of the pot body	Express lightness						X
7	Why is the pot body made of plastic?	…increase the longevity of the appearance (no dents)	Decrease visual aging						X
8	Why is there a cutout concave curve surface of the pot body facing the pot handle?	…give room for hands and fingers of different sizes	Fit hand				X		
9		…counter-weight the curvature of the pot handle	Balance visual composition					X	
10	Why is the bottom welded to the pot body?	…enable injection-molding of the pot body	Connect parts		X				
	Lid								
11	Why is there a lid?	…retain heat	Reduce heat loss	X					

Figure 3. Functional analysis of the SAS coffeepot. Excerpt showing superior product level and two subsystems; the pot body and the lid.

4. In columns D-I, the function statement is then classified according to the function classes of Table 1. One function statement can be allocated to one function class only. Each subsystem can have one main function.

5. The procedure from step 1 to 5 is repeated for each subsystem of the product, until the product is satisfactorily analyzed.

An additional step in the procedure can be added by weighing the importance of each function against the other functions (pair-assessment) for each subsystem. Thereby, the relative importance of each function can be assessed, and primary and secondary functions can be identified. Functional analysis can be an important and powerful tool in early product development phases, where specifications and targets for product development are set. During competitor benchmarking, this ranking of functions can give a valuable hint about compromises made during product design. In a product development project, rankings obtained from analysis can be used as input for balancing functional requirements during product specification.

The information acquired through functional analysis can assist in providing a holistic view of requirements, considerations and factors of importance for product design. With the help of a functional ranking, decisions regarding the need for special design competence and allocation of resources in a design project can be made, thereby reducing the risk of costly and time-consuming design rework loops at later stages in the process.

Method for form development

The method for form development is a generally applicable tool for form analysis and form improvement, which can be used by the individual designer who works with form design development on the operative level of product design.

In its approach, the method can be seen as an implementation of the principles of gestalt psychology, including the gestalt creating factors similarity, proximity, good curve, common movement, symmetry, experience, area, and enclosedness (Monö, 1997; Klöcker, 1980) to the active synthesis process of form development. By transforming the gestalt principles of perception psychology from the mere model, which explains gestalt perception into a tool for applying the gestalt principles during styling development, the designer is supported in bringing order and simplicity into the design and in differentiating the product. As noted by Klöcker (1980), these tendencies have to be balanced against each other in the process of creating a product, which is visually perceived as a coherent whole.

The method can be used in a variety of different circumstances during the form development process, for the purpose of comprehension, evaluation, and improvement of the emerging form. The individual form designer (usually an industrial designer) can apply the method during the sketching and form-finding process for generating more promising form solutions, for improving visually ambivalent or unsatisfactory solutions, or for motivating and communicating purpose of form solutions. In this respect, the method is closely related to the method for design format handling, which is described later in this article. In actual design work, the two methods are highly interdependent for form design development purposes.

The reasoning can also be applied in design teamwork, as a tool for interdisciplinary communication of design intent. In a design team including various competencies such as industrial design, ergonomics, engineering, and marketing, the method can be applied for the purpose of objectively balancing aesthetic characteristics of form design proposals against requirements defined by other functions than industrial design e.g. ergonomic, production and cost factors.

Methodical procedure

The procedure is principally identical in the cases of the individual designer and the design team. During the search for promising form design alternatives, the designer sketches using e.g. freehand sketching or computer-aided modeling tools. At suitable stage(s) during the process, when the need for reflection and evaluation of the generated proposals arises, the designer can apply the method for assessment of syntactic form properties, product semantics, and ergonomic aspects. This can be done on the detailed level of specific form elements or on the whole form of the product. In the process, the designer follows the basic steps:

1. The designer applies a scrutinizing stance towards his proposal by asking "*Is this a good form solution?*", i.e. is this a solution that fulfills the requirements on form functionality, design format use, product semantics, ergonomic criteria, etc.? By asking this question the designer turns his thinking into a critical mode of analysis, moving from a purely stylistic form appearance perspective to focusing on purpose and effect of the form solution.

2. By analyzing the functionality of the constituent form elements, the designer searches for underlying design intent. The designer poses the question "*What does this form element do?*", i.e. what visual effect does it have, how does it contribute to the whole form experience, is it a sound solution in terms of production, cost etc.? By asking the question, the designer reaches the syntactic dimension of the form design, i.e. features of the visual composition (Vihma, 1995), the effects of individual forms, how they interact with other form elements, how they contribute to and interact with the whole form on the superior gestalt level. As in form functionality analysis, the syntactic functions are stated with verb-noun notation describing their visual effect. The verbs used to describe the syntactic functionality include, but are not limited to, the following (see also Table 1):

   - ***refer***: relate visually to form solutions found in other products, e.g., of a common product family
   - ***connect***: relate visually to other form elements present in the same product form design
   - ***unite***: relate visually to other form elements present in the design by giving them a common gestalt
   - ***discern***: separate visually from other forms present in the design by giving them a differentiating gestalt
   - ***balance***: harmonize by visual counteraction

   The identified syntactic functions describe the visual effect of the interacting form elements and gestalts. The designer now has to determine whether the identified visual effects are purposeful, i.e. whether the functions of that form element are necessary and desired. More importantly, the designer or design team also has to decide whether other types of functionality should be more or less emphasized in the form. If functions of several classes are lacking in the design, this may indicate a potential for adding functional content to the design.

3. (A) Functions, which are found necessary and desired, are subject to modification and refinement in order to further optimize their syntactic effect, considering semantic, ergonomic, and technical requirements. The designer should now aim at finding solutions, which elucidate and enhance their visual effect. Form solutions which are too 'weak', e.g.

due to having a theme which has few or no connections to other form elements or to the design format, need to be strengthened and simplified. By focusing on the function statement, the designer should, function by function, commence to generate new or modified form design solutions, which all fulfil each respective syntactic function. In this process, new and beneficial functionality that is not found in the existing solutions might arise, which adds to the functional content of the solution. This procedure of generating solution means to a superior function is in accordance with the Function Complex Law (Andreasen, 1992), which states that during synthesis a function cannot be decomposed into subfunctions before the means realizing the function are chosen. In the search for form solutions, the designer can trust his own creative capacity, or be influenced by idea stimulating techniques such as brainstorming techniques, Osborn's idea incentives, Tjalve's basic design properties (Tjalve, 1979), or the principles of gestalt perception. Generated solutions may be improved versions of an earlier idea, fulfilling the same functions by modified form elements. The functions may also be fulfilled by radically new form solutions that use other or additional form elements that have identical syntactic functionality but properties which fulfil other requirements of the product more effectively.

(B) If one or more functions are deemed unnecessary or undesired, e.g. by adding redundant or abundant visual impact, their effect should be reduced or eliminated in terms of visual impact. If not, the form may be too 'rich' in content, thus reducing the readability and apprehension of the product (Klöcker, 1980).

(C) If functions of other classes are missing, the opportunities for adding functional content to the design should be considered.

The main purpose of the method is to question the initial form solutions and to generate improved or different form solutions which fulfill the same desired functions in a visually, ergonomically and technically more efficient way.

Illustrative example: Ericsson mobile telephone

An Ericsson mobile telephone is used as an example to illustrate how the method can be used for form development purposes. A mobile telephone has been chosen due the large amount of technical, semantic, interactive and aesthetic criteria, which apply to a modern hand-held electronic consumer product.

The example provided here focuses on one stylistic feature of the Ericsson t68m mobile phone: the characteristic curve on the front of the phone. It can be argued that it is not possible to extract one single form element out of its context since the visual impression is determined by syntactic synergy. However, this example only aims at illustrating the general ideas of the methodology. A full analysis would have to consider the whole form design on all levels. As seen in Figure 4, the curve is part of the common design format of Ericsson mobile telephones. With small variations, the curve is present in all contemporary Ericsson phones.

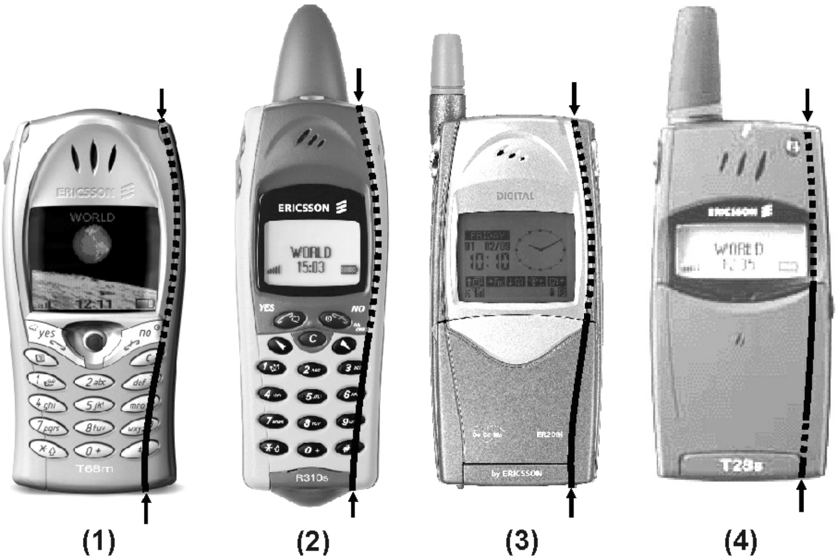

Figure 4. The studied styling feature, the characteristic curve of the Ericsson t68m mobile telephone (1), which is part of the common design format of the Ericsson product family of mobile telephones, including (2) R310s; (3) ER209i; and (4) T28s.

Step 1: Form functionality analysis

Is this a good form solution? The featured curve has become an important form element for identifying the product as an "Ericsson". From the perspective of relating the phone to other phones of the Ericsson range, it also serves its purpose. The treatment of the curve and the buttons carries a similar theme in phones (1) and (2); in the other phones (3)-(4) the curve is part of a lid. While its manifestation in phone (1) gives the impression of the curve being a split line between separate plastic parts, it is only a notch in the single piece front cover. Thus, the curve is merely an 'ornament'. The full potential of the idea has not been exploited and the rather 'immature' form idea still has undeveloped potential.

What does this form element do? What function does the curve have? An analysis of functional content according to the function classes of Table 1 reveals the following (Figure 5):

Internal (technical) functions:
None
The curve could potentially have e.g. a structural function, by serving as a split line between parts.

Ergonomic function:
None
The curve could potentially have e.g. a tactile or haptile function, enhancing use by form guidance.

Semantic function:
Identify brand
The curve has the function of identifying the phone as an "Ericsson".

Syntactic function:
Visually referring and connecting
The curve refers to the design format used in the phone as a whole and to the corresponding curves found in other phones, thereby 'strengthening' the format (by thematic repetition).

Visually connecting
The curve relates visually to the dynamic movement of curve D.

Visually uniting
The curve A-B is visually extended from point C to point A. The curve would otherwise have ended abruptly at point C (creating visual imbalance).
The segmentation of the curve, arising through the repeated interruption by the buttons of the keypad, is an example of the laws of gestalt perception: the segments of the curve are visually united according to the principle of 'the good curve'. As such, the segments of the curve are form entities.

Visually discerning
The surface E is enhanced by splitting it up into two separate surfaces, E1 and E2.
The buttons are enhanced by breaking curve A-B.
By segmenting curve A-B, the buttons are also allowed to unite surfaces E1 and E2.

Visually balancing
The curve places the buttons firmly onto surface E by their unification of surfaces E1 and E2 and motivates the positioning of the buttons, creating balance in the visual composition. Without the curve, the buttons would have a tendency to 'float around' on surface E.

It should be noted that this functional analysis is only illustrative and does not aim at being complete. Other, or additional, functions may very well be identified. The aim is to show the types of functions associated with visual form elements.

Figure 5. The characteristic curve A-B of the Ericsson t68m mobile phone.

Step 2: Form development

The analysis of form functionality indicated that the curve serves several syntactic functions. The apparent lack of other classes of functionality, however, suggests that there are unexploited opportunities for form development, which are waiting to be investigated. These opportunities can be explored by further idea generation, with the aim of finding means for the "missing" functions.

In Figure 6, alternative solutions for the studied curve are illustrated. The main characteristic of all new alternatives is that they each fulfill one or more functions belonging to function classes not represented in the current design.

Alternative 1: A structural function has been added. The notch has the additional function of connecting to separate parts.

Alternative 2: Ergonomic and semantic functionality has been added. The 'trench' provides tactile guidance to the user for orientation on the keypad. It also adds a more powerful expression to the phone by the dynamically curved surfaces.

Alternative 3: Has properties similar to Alternative 2, but a form with other syntactic characteristics.

Alternative 4: The notch has been eliminated completely and replaced by a 'ridge' form of the buttons. The ergonomic functionality is similar to Alternatives 2 and 3. Semantically and syntactically, it has other properties.

The example serves to illustrate that functional reasoning presents a feasible approach for form development. The method can be applied on detailed and overall levels of product design, and in several stages of the form design process.

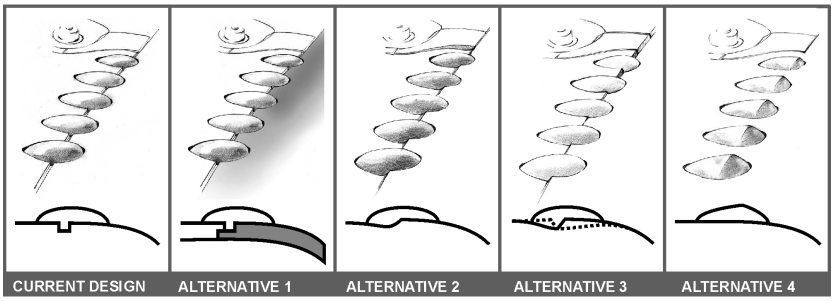

Figure 6. Alternative solutions for the characteristic curve of the Ericsson t68m. Each concept is illustrated by a free-hand sketch (top) and a cross-section view (bottom).

Method for design format handling

Design formats provide an approach towards modeling of styling aspects in product design (Warell and Nåbo, 2000; 2001b). Design formats can be used to describe styling features and principles of products, what is commonly referred to as the “form language” of a design.

Methodical procedure

Design format handling includes several tools usable for the purposes of analysis, assessment, specification, and synthesis of product styling. The different procedures are described in the following.

Descriptive design format analysis and assessment

A company or design team that wishes to achieve a greater understanding of the appearance of its products can do so by analyzing form content and composition in a single product, a product family, or a product generation series. In all cases, the first step in creating a descriptive design format is the examination of product styling features, i.e. visual form and compositional solutions.

Design format analysis of a single product

In order to analyze the design format of a single product, the product form must be broken down into visual ingredients such as form elements, gestalts, form entities, physical components, etc. The way the decomposition of the form into visual ingredients is done varies from case to case, depending on styling features and component structure. The basic procedure includes the following steps.

1. Identify main physical components or subsystems of the product. For a vacuum cleaner, these can be the top cover, chassis, wheels, handle, etc.
2. The physical components are recorded in writing or by sketches, in the left column of a format assessment matrix (Figure 7).
3. Identify styling features of the product form, such as form elements, material treatment, colors, graphics, surfaces, form meetings, curves, symmetries, form relations, composition and balance principles, etc. These styling features represent ingredients of the design format of the product.
4. Record the identified styling features, in writing or by sketches, in the top row of the format assessment matrix.
5. For each physical part (or subsystem) of the product, the styling feature can be illustrated by e.g. a free-hand sketch, highlighting the use of the styling principle in each part. In Figure 7, the form elements in the top cover of the vacuum cleaner 'carrying' the styling feature are reinforced. The relative degree of visual coupling with each identified styling feature of the design format is assessed with the help of scores on a two-point scale; one point indicates a weak relation (an unfilled circle), two points indicate a strong relation (a filled circle). The form design of one physical component can carry form elements corresponding to several styling features.
6. The procedure is repeated for each physical component or subsystem until all relations are considered.
7. The scores in the rows of the format matrix are added, yielding a figure in the right column, which represents the visual relation of each physical component to the design format of the product.
8. The scores in the columns of the format matrix are added, yielding a figure in the bottom row which indicates the degree to which each styling feature is represented across the form solutions of the parts of the product, i.e. how "strong" the design format of the product is.

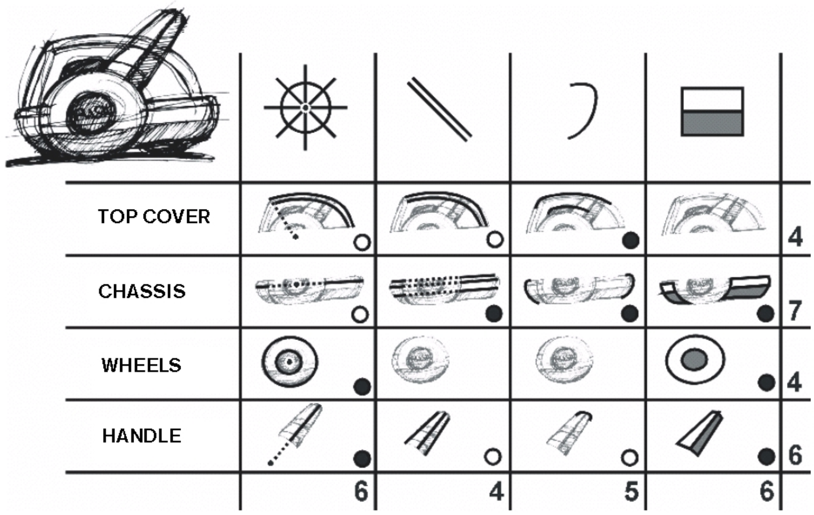

Figure 7. Descriptive design format analysis and assessment of a single product. Sketch material courtesy of Electrolux Home Products Operations (Sweden) AB.

The assessment obtained by the format analysis method can give the designer and design team a new perspective on the styling content of the product's form design. The format analysis makes it evident what styling features are present in the design. The assessment by scoring indicates to what degree different styling features are represented in the design, if any form ingredients need to be visually strengthened or suppressed, if important form elements need to be enhanced, etc. By the analysis method, a design format can be established and defined for use in the form development of new products.

Design format analysis of a product family

The format analysis procedure for a product family is very similar to that of a single product. The main difference is that the styling features are analyzed on a higher 'macro' level, where significant ingredients on a more general form entity and form element level are considered, i.e. those elements which are significant for identifying product family characteristics. The procedure includes the following steps.

1. Significant form elements, compositional principles, colors, materials, etc. are recorded for each product of the product range. Figure 8 shows the analysis of a selection of products included in a product family of electronic consumer products.
2. The contents of the design format of the product family are described in the top row of the table.
3. For each product, the presence of styling features represented in the design format is indicated. By assigning a value to indicate the degree of

similarity with styling features of the other products in a product-for-product manner, it is possible to assess the degree to which each product conforms to the common design format of the product family.

4. The values are summed up horizontally (rows), representing the typicality of each product in relation to the product family; and vertically (columns), indicating the representation of each styling feature across the form design of the product family.

By analyzing the outcome of the assessment, the company can take steps towards defining and further developing the form content of their products.

Design format analysis of a product generation series

The analysis of design format across different generations of products can provide valuable information to designers regarding the use of styling features over time. The format analysis procedure for product generation series is very similar to that of a product family, the main difference being that styling features are assessed across generations instead of across members of a product family. Therefore, the procedure will not be further described here.

Design formats as a prescriptive method for specification and synthesis

Design format modeling can also be used for prescriptive purposes, as a method for specification and synthesis. Starting from the establishment of a design format for a specific product, a product family, or a generation of products, a general design format for new products of the company can be developed. This design format can be used as a specification for the styling of new products. Furthermore, several design formats representing different alternatives in terms of form language can be developed, which gives the design function of the company the opportunity to systematically do research into, and cultivate, several form language alternatives during early pre-design stages or as a continuous design development activity.

During form design development, design formats can be used to direct design development activities by working as a template for form design. During the sketching process, starting from a fully or partially defined design format, the design format is developed alongside with the emerging product form, in an evolutionary process (Warell and Nåbo, 2001a). New form ideas arising during sketching add styling ingredients to the format, which consequently develops and ‘grows’ in content. The process of form design and design format evolution is in that respect similar to the continuous development of the design specification of a product during product development.

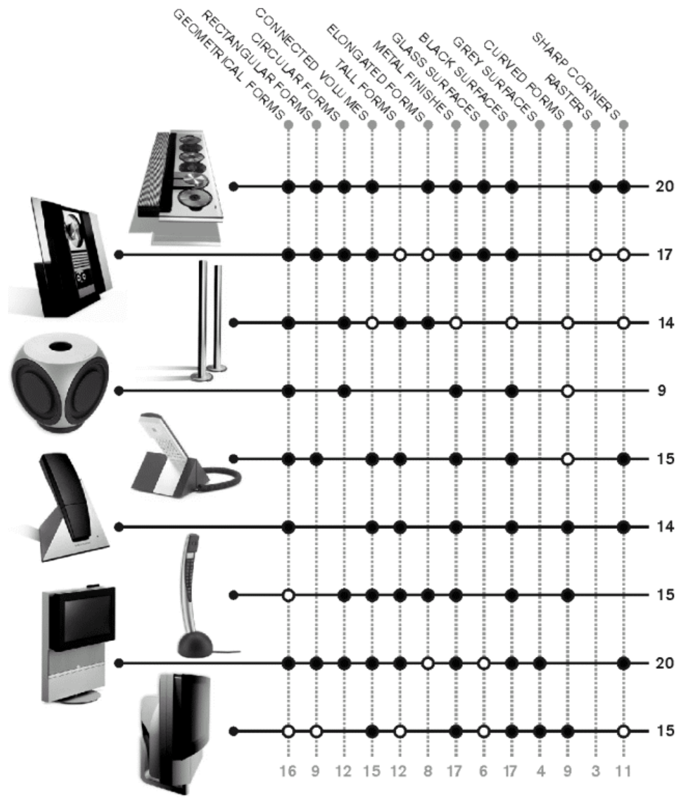

Figure 8. Descriptive design format analysis and assessment of a product family. Selection of products from Bang & Olufsen. Filled circle indicates a strong relation (two points), unfilled circle a weak relation (one point) to the common design format of the product family.

7. CONCLUSIONS

In the article, three main methods addressing issues of analysis, description and evaluation of visual form design have been presented. The methods provide ways of approaching aspects of visual product form and appearance and the handling of such issues in relation to technical aspects of the product. The methods can also assist in making form design a less subjective process. By externalizing and formalizing styling issues, the understanding of form can be enhanced within the form design discipline as well as between disciplines. Designers, design teams, or the company can apply the methods to increase the understanding of content and function of the visual product form, and its relation to other products in product families or with the competition. The achieved knowledge can be used for defining and specifying visual form design of new products and to develop the appearance of products for the future.

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