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THE “OLD MASTERS” OF ENGINEERING DESIGN AND THE MODERN FORM DEVELOPMENT PROCESS OF AUTOMOBILES

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1. Introduction

The modern form development process of automobiles exterior design (called hereafter the development process in short) traditionally consists of the embodiment design phase (or system-level design phase) followed by the detail design phase. However, few changes have been made concerning the design process itself. Most of the existing methods are often structured around “concretization” of the product during the design process: an iterative refinement and improvement of the features of the product until production launch. Thus, the “Old Masters” way of working has been adapted to the different degrees of concretization of the product.
The term “Old Masters” is used to describe approaches from Gerhard Pahl and Wolfgang Beitz (Pahl & Beitz), Vladimir Hubka (Hubka), Eskild Tjalve (Tjalve), and Karlheinz Roth (Roth) which have a common characteristic approach based on working with principle solutions. From our point of view, the development process can be refined with a *designer-centered* approach. *Designer-centered* means here to focus to a larger extend on values and the cultural, the aesthetical and the emotional aspect of the design. This is because in the design of manufactured products the specialist activities of industrial design (in this context automotive design) and a wide range of engineering design techniques are brought together [Tovey 1992]. So, *designer-centered* approach also means to regard the tacit frames of an individual [Schön 1991] in context with his/her practice, cultural circumstances, methodology, etc.
Comparing of the “Old Masters” of engineering design and the modern form development of automobiles may lead to a better design process, ensuring in turn more time and cost effective activities and hopefully a better product quality. We also see a need for a research approach, which in our work, consists of a descriptive study of the form development at work. In this context, this paper discusses some important elements for form development from the “Old Masters.” In the following, we will present the background of study, case examples based on the development of “Excavators” by Tjalve’s [1976] and series of forms by morphing a “New Beetle to a BMW” by Chen et al. [2003] and finally a conclusion.

2. Background

2.1 The “Old Masters” of engineering design

Methods that describe the form development process are largely related to the product concretization process. Nevertheless, these methods often present elements that are oriented towards the designer’s knowledge and skills. An examination of these elements is the basis for this study.

One of the most detailed models of the form development process is described in Pahl & Beitz [1996]. They organize the embodiment design phase in 15 steps and the detail design phase in 5 steps. These steps logically encourage the practitioner to begin with the most important parts of the product ("the main function carriers") and to iteratively refine and improve the layouts and form designs until the final design is produced. The detail design phase deals partly with the finalization of the product details and controlling of standards, and partly with the integration of all the documentation for production and archiving. In order to help the designer, a checklist is added to the process. The designer is encouraged to check systematically for a number of factors that have to be taken into consideration during the process. Accumulated experiences and practices have led to the application of some basic rules as *simplicity, clarity* and *safety*. Pahl & Beitz emphasize the use of these rules and the use of these experiences and design practices at any step of the embodiment design and detail design phases.

Moreover, the design process is connected to a certain number of principles and guidelines that help the designer in dealing with specific aspects and related problems of the form design activity.

The theory of technical systems is central to Hubka's work [see Hubka & Eder 1982]. The procedural model of the design process is structured around the concretization of the technical system. The steps are similar to Pahl & Beitz process, even if detail design phase by Hubka's (e.g., establishment of tolerances and surface properties). The structural model of the design process [Hubka & Eder 1982] is the hierarchical decomposition of design activities. Below the level of the three main design phases (conceptual design, embodiment design, and detail design), the design activities are arranged in four levels, with respect to their complexity. Each activity of a lower level contributes to a higher – level activity. The first level, design operations, gathers all activities dedicated to the realization of the technical system, irrespective of the design phase. The second level contains the problem – solving process activities, and the third and fourth levels contain activities and actions that are independent of the design activity (e.g., "experiment" or "sketch"). The activities of each level are interdependent. Hubka has also dedicated a chapter to the designer describing what a designer *should* be, rather than describing the designer's actions and their consequences for the design process [Hubka & Eder 1982].

In Tjalve's [1976] Systematic Designs of Industrial Products, the phases of the form development process are denoted as system level design and detail design. The former focuses on the product architecture, while the latter focuses on actual details with regard to the embodiment and detailing of the product part. The system level design process guides a designer through the particular problem of product architecture.

Roth, in *Konstruieren mit Konstruktionskatalogen* [Roth 1989], regroups the form design phases into one single phase - detail design. Unlike the other approaches, the process is not divided between the conceptual design phase and the detail design phase. The designer may need to "jump" from one phase to another depending on his or her needs. Thus, a step is made towards the exploitation of the designer's skills and knowledge. The designer's degree of freedom is also emphasized. Instead of a process, two checklists are given, concerning general points and component design specification elements. As in Pahl & Beitz [1996] these are completed with a selection of principles and guidelines. The *simplicity* rule is also well-emphasized here as a designer role.

The strategies and the methods used by the "Old Masters" of engineering design in form development are based on the principle solution. Principle solution is a combination of working principles to fulfill the overall function with first indication of embodiment design [Pahl & Beitz 1996]. One of the well-known strategies related to the principle solution is the methods of quantified structure. According to Tjalve's [1976], the quantified structure brings us to a level in product synthesis where we can open solution space by varying the way to realize the solution (see also Figure 4). The quantified structure is a method of engineering design which uses variation to determine number or extent of element: to calculate or express the number, degree, or amount of element within a system or organization made up of interrelated parts functioning as a whole. However, the method of quantified structure does not encourage for aesthetics considerations related to subjective, emotional and qualitative form experiences.

2.2 Relevance of product semantics for form development in automotive design

From our point of view, supplements such as product semantics to the method of quantified structure are important for automotive design. Therefore, we will give a short introduction to aesthetics and to methods used to evaluate subjective, emotional and qualitative aspects of product design called semantics aspects.

Historically, aesthetics has been defined as the science of "sensuous knowledge," meaning the knowledge one obtains through the senses, in contrast to the knowledge one obtains through the mind, the subject of this science is beauty and ugliness [Monö 1997]. Moreover, a definition more commonly used in modern days is that "aesthetics deals with the nature of beauty, art and taste and with the creation and appreciation of beauty." Appreciation of aesthetic values of visual form is part of the science of perception psychology.

The perception of Gestalt is central in the appreciation of visual appearance in automotive design. Gestalt is an arrangement of parts which appears and functions as a whole that is more than the sum of its parts [Monö 1997]. The quality of the whole as being more than the sum of its parts' means that form, color, material structure are not introduced into the whole as isolated factors. A product can be seen as a kind of trinity within the limits of an economic/ecological circumference. In design work we can speak of a technical whole, an ergonomic whole and a communicative whole and still mean the same totality (see Figure 1).

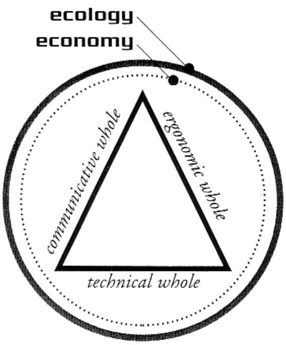

Figure 1. A product can be seen as a kind f trinity within the limits of an economic/ecological circumference [Source: Monö 1997]

In presenting a psychological view of aesthetics appreciation, it represents a mode of form perception, which is not determined by semantics interpretation.

There are several methods for the analysis of designer semantics interpretation [Wikström 2002]. The *semantics differential method* for the analysis of the meaning of objects; wherein the meaning of things is said to lie somewhere within a three dimensional semantics space. The position of the meaning of an object within the semantics space is determined through the evaluation of the object's grade of fulfillment of adjectives describing desired or non desired qualities. The evaluation is done using a Likert scale (see Table 1).

Table 1. Adjective pairs connected to a Likert scale and graded by designer x and z

Adjective	3	2	1	0	1	2	3	Antitheses
Good	x	z						Bad
Modern				x	z			Traditional
Feminine			x	z				Masculine
Stable				z		x		Unstable

The adjective pairs used in the Likert scale are categorized into evaluation, potency and activity factors through a factor analysis. These three factors constitute the axes of the three dimensional semantics space. The values given by the designer to each adjective on the Likert scale defines the product's position within the three dimensional semantics space. Placed in the semantics space, the product meaning can be compared with competing products' meanings, or with a concept of a product with the perfect meaning.

The *product semantics analysis* [Wikström 2002] is structured upon three of Monö's four semantics product functions; *identify, describe* and *express*. It is a tool for describe users' emotional and cognitive requirements for a product, and assessing whether these requirements have been met in products or product concepts. The quality of a product's semantics functions *to identify purpose and use* and *to describe function* can be measured by four parameters; intelligibility, response / handling time, correctness and insecurity.

For the analysis and evaluation of the quality of a products semantics function *to express*, the use of semantics word scales is suggested. These are similar to the ones used in semantics differential.

It seems that product semantics present relevant supplements to methods such as the quantified structure since it allows opening solution space related to quantitative and qualitative decision-making in the modern form development of automobiles.

2.3 The modern form development process of automobiles

The use of the method of quantified structure is an important element in the modern form development processes. However, today the development of technology enables form creation to be expanded to various perspectives like different aspects of aesthetics. One of the latest methods of the modern form development process of automobiles based on the aesthetical dimension is the use of morphing techniques, which can be considered as an enlargement and merging of the "Old Masters" methods with insights from cognitive psychology and the arts with the goal to open solutions space. The uses of morphing techniques can solve certain aspects of problem-solving within the frame of the form development process. The word "morphing" comes from the compound word *Metamorphosis* of Greek origin. *Metamorphosis* is composed by two words - *meta* and *morphosis* which means the changing way in form of structure. We commonly apply the word morphing as an abbreviation of *metamorphosis* [Chen & Parent 1989]. Morphing usually indicates a special effect on transformation between two images applied in movies or animations. It is most commonly applied in cross-fading techniques to achieve the transformation of one thing into another in films. For acquiring smooth distortion in the morphing process, marking the appropriate corresponding points and vectors between target images is essential.

The shape creation method called shape averaging is used in the development of automobiles. Shape averaging could produce a series of novel shapes between two typical shapes representing different meanings. It is hypothesized that the average results are useful for predicting trends in form, or for extracting stereotypes from a group of related shapes. The technique can be used to create new forms by blending general features of existing unrelated shapes. The algorithms of shape averaging could extract the mean, median and mode forms from the average shape [Chen & Parent 1989]. Figure 2, shows the blending results between car shape and teardrop shape at different weighted averaging ratios.

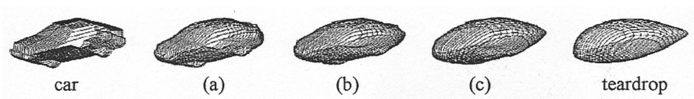

Figure 2. Weighted averaging shapes from a car and the teardrop shape under rations of (a) 70/30, (b) 50/50, and (c) 30/70 [Source: Chen and Parent 1989]

For understanding how product shapes evoke affective responses, Chen et al. [2003] conducted a survey to evaluate the affective characteristics of each of the product shapes related to the product semantics analysis above. Semantics itself describe users' emotional and cognitive requirements for a product, and assessing whether these requirements have been met in products pr product concepts [Wikström 2002].

A perceptual map of automobile shapes was constructed for further study of relationship between automobile shapes and the affective responses. Nineteen representative automobiles and seven adjectives were chosen for analyses. Using a multidimensional scaling program (MDPREF), they constructed the perceptual map. They also used a preference – mapping program (PREFMAP) to determine the location of the vector corresponding to each adjective in the perceptual map, Figure 3.

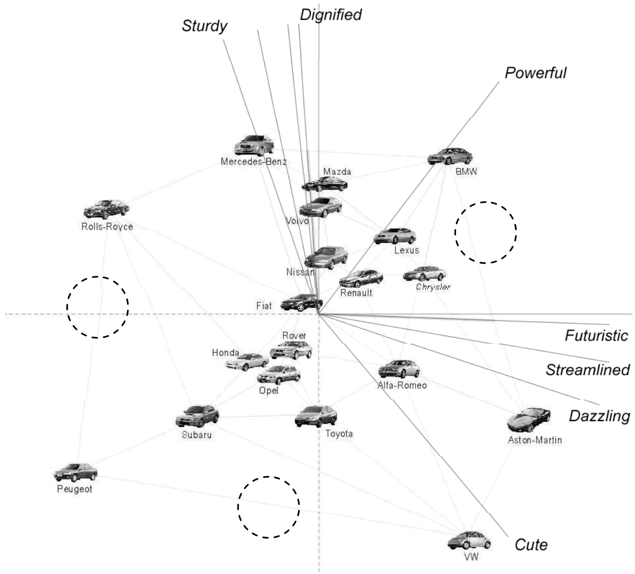

Figure 3. Perceptual map of 19 representative automobiles and 7 representative adjectives [Source: Chen et al. 2003]

In the perceptual map, if two adjectives look similar, then the position of these two aspects will be closer. On the other hand, if two adjectives look dissimilar, the corresponding points will be further away from each other. Observing the perceptual space of nineteen automobiles and seven adjectives, the researchers found that there are many empty spaces (indicated by dotted circular lines). How can we fill up the map and predict the unknown new form at a specific position?

The values determined out of perceptual mapping, such as futuristic, streamlined, dazzling, etc. should form the variables for the morphing technique.

This can be done by developing an algorithm that works on the characteristics of the gestalt such as X, Y, and Z. Reverting to the "Old Masters," the method of quantified structure is also an important element in the modern form development processes. However, semantics should have been more emphasized and acknowledged as a valuable asset complementary to the quantified structure approach in the generation of the overall design. A frequently used method in the modern form development process of automobiles based is the use of morphing techniques, which can be considered as a valuable tool to enlarge and integrate the "Old Masters" methods with insights from cognitive psychology and the arts. This integration should also enlarge the already opened solutions space. Similarly to the quantified structure approach, a semantic algorithm should be developed to create new forms based on values out of perceptual mapping. The following case example shows a quantified

structure approach according to the practice of the "Old Masters" as well as the modern form development approach based on morphing techniques. The example does not show a direct connection between use of quantified structure method and morphing to facilitate modern form development.
However, this does not mean that the use of quantified structure is irrelevant in the modern form development process of automobiles. The modern form development addresses the need and future possibility of adapting the method of quantifying engineering structures to a semantic-based form generating structure. This form generating structure should enlarge the solution space and bring us to a level in product synthesis where we can move from one principle solution to another solution related to form development.

3. Case examples

This section describes how the strategies and the methods of quantified structure are used by the "Old Masters" of engineering design and modern form development of automobiles. The "Old Masters" of engineering design considered form development in design based on quantified structure that enables us to realize principle solutions. It is based on the variation of relative arrangement - number and dimensions. Tjalve [1976] and Hubka & Eder [1982] stated that quantified structure is used from two points of view.

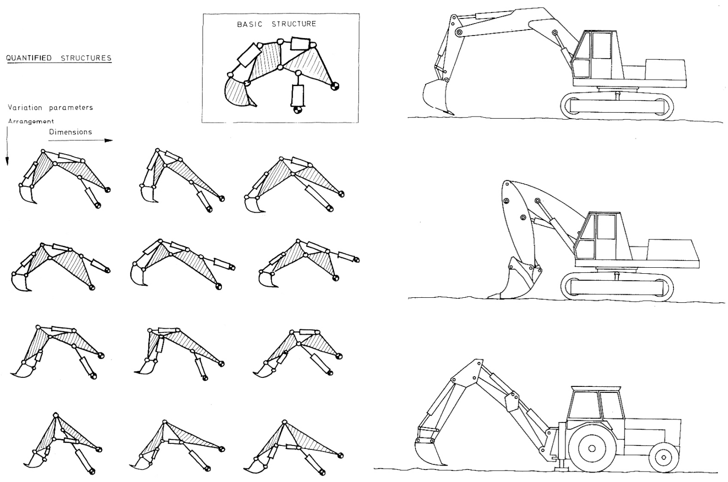

Figure 4. Quantified structures for an excavator [Source: Tjalve 1976]

They differ between the elements in which the functional connection can either be included or not. If these functional connections are ignored, the structure variation method gives a number of suggestions for a very rough construction of the product. If the functional connections are included, we get a definite further development of the basic structure, with the aim of optimizing and specifying the parameters involved. Figure 4 shows some quantified structures for an excavator and demonstrate how three of these are employed in existing excavators.
The functional connection between the most important elements is expressed in the basic structure, most often in some sort of sketch showing the principle of the design, where commonly accepted symbols for known elements (machine, hydraulic, pneumatic, electric symbol, etc) are used.
As long as this sketch expresses the basic structure, it is exempted from any definite dimension of form. However, it may be the starting point for a series of quantified structures built on the structure variation method with the relative arrangements and dimensions as parameters for each separate element in the basic structure.

Table 2. The modern form development of automobiles based on quantified structure using morphing techniques [Source: Chen et al. 2003]

Products					
Adjectives	Cute	1	0	1	Powerful

In modern form development process of automobiles, the use of quantified structure is still significant. The modern form development brings us to a level in product synthesis where we can move from one principle solution to another solution related to aesthetics.
This is illustrated in Table 2 with a series of shapes that has been obtained by morphing a New Beetle to a BMW [Chen et al. 2003]. A series of new shapes that smoothly interpolate among shapes have been generated by using image morphing techniques. We can see that the path of distribution of the interpolated shapes provides image of how emotional characteristics change in responses to varying shapes. The uses of morphing techniques make the overall form uncover the solutions in relation to the aesthetical form and the solution principle form in parallel.

4. Conclusions

This paper hopes to provide a better understanding about the possibilities and limitations of the “Old Masters” of engineering design for modern form development of automobiles. We found that the “Old Masters” of engineering design consider form development in design based on quantified structure while in the modern form development process of automobiles is additionally related to aesthetics in a broader understanding including product semantics. Thus, the interpretation of the quantified structure approach and product semantic analysis and their connection seems to be appropriate as a result of study. In the product synthesis, design approaches from the two parties are similar as far as the development allows us to move gradually from one solution to another. Future research should investigate the possibility of developing a semantics algorithm to develop a similar structure for “opening the solution space,” similar to the quantified structure approach.

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