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AESTHETICS IN A FORMALISED REVERSE DESIGN PROCESS

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1. Introduction

In automotive industry, the product life cycle processes get more and more dominant over CAx functionalities. Therefore, it is of interest to determine the information necessary for running the processes successfully. Various topics have to be considered:

- The product itself with its properties and the functions of the product
- The *virtual product* within the computer including the product data model
- The design activities using CAx systems to define the product in its various representations
- The *process network* taking into account the parallelism of *process steps*

There are some difficulties to find a common, consistent view of all of these aspects. Reasons are:

- The virtual product is time depending
- Each process step depends not only on previous ones but also on subsequent phases
- The details of any process step depend on the person, engineer, user acting in it
- A general *product data model* usable from anybody in any process step at any time is a fiction

Today, all the knowledge about processes, product development (methodologies), relations between required functionalities, etc. is not captured in an organised, reproducible, recoverable, reusable way.
This paper presents an approach, which shows a formalism how to overcome the geometric determined engineering thinking in the virtual product design process by concentration on the relevant properties and functions of a product. As an example, the application of this approach on the concept of *Engineering in Reverse* and the realisation of it in a formal structure for *aesthetic products* is described.

2. Approach towards formalisation of process steps

By this approach, the complexity sketched above is reduced by using ideas of *Quantum Physics*: to concentrate only on aspects which are important for the activities of the actor within a *process step*.
Industrial development wants products to be modified and rendered more precisely in a less abstract way during the development process. But the description of the product is always in an abstract manner. Applying some physics ideas, the product/part can be considered as

"Engineering objects" which are in an *"Engineering State"*

at a given stage of the development process for Engineering objects.
The Engineering state (ES) is the "environment" of an Engineering object within a defined process phase and gives the position of an Engineering object within the process, that means, in relation to a special process operation (to be input or output of a process operator). It may be the initial state of a process step or the resulting state of a process step. This ES can contain Engineering objects, available

tools, services, constraints and requirements. The design process will bring an Engineering object from one ES to another, or will turn one Engineering object into another.
The Engineering object can be a complete product, a part or component part or even several elements in higher granularity.
The approach obeys the following logic. The process step is considered as:

"Input": An "Engineering object" in an initial "Engineering state"
"Process": An "Operator" acting on an "Engineering object"
"Output": An "Engineering object" in a resulting "Engineering state"

In Fig. 1 the components related to the product are the Engineering Objects.

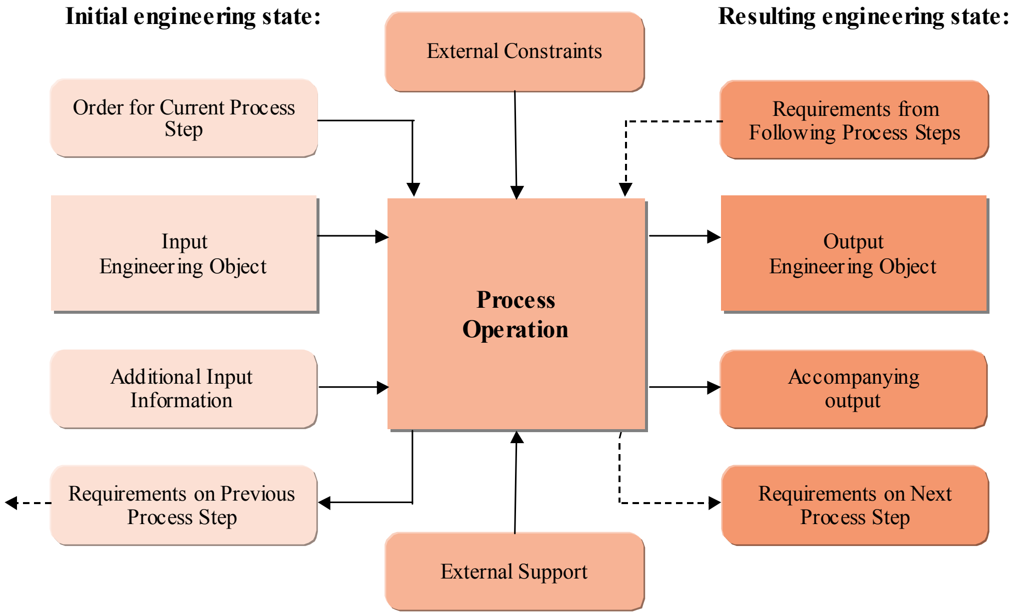

Figure 1. Basic process step

2.1 Engineering object

The difference of this approach to the common view is based on the following idea:
An *Engineering object* (EO) is ONLY given by the interdependency/interplay of it with the person dealing with, working with, judging this Engineering object: The user/designer/engineer, or - following the terminology of quantum mechanics – the so-called "*observer*".
From this point of view the EO has *no reality* when it is considered as a "stand-alone" object. As a consequence, the EO will be *described* by a set of its *properties*, which are of importance from the "observers" point of view.
In the CAD world, an EO is represented mainly as sets of geometric elements, e.g. Bézier surfaces or others. But alternatively it may be *represented* as a physical model (e.g. clay model) or in another way.
An Engineering Object is defined by:

- Identifier, name, administrative/logistic information
- User ("observer", that means the designer, engineer, customer, etc.)
- The purpose/the intended usage of this Engineering object; this kind of information depends on the point of view of the user/observer
- *"Description of EO"* =: {set of properties}, from the actors/observers/users point of view
- *"Representation"* (that may be a Bézier CAD model, or also a physical clay model, or only a (CAD) drawing, or a photo, or ...)

In short notation: $EO\ =:\ \mid Representation\ (a,\ b,\ c, ...),\ Properties\ (\alpha,\ \beta,\ \chi, ...)\ >$

We state that without the "actor/observer/user" the product data model has not any meaning [1].

2.2 Representation of an Engineering Object

The *representation* of an EO is a higher level of abstraction (abstract images of objects) in the formal structure of the product within the process. They are never the object itself but only a (more or less) theoretical model. The "reality" of such a model is not the reality of the object itself.
For the same EO, various different representations may be used depending on the view of the user and on the purpose within the process. The analogy to physics does not hold here: There is normally no mathematical formulation available in the sense of an element in an abstract mathematical space. Tools and methods do not belong to a representation but they are part of an operation on the representation.
The user/observer/designer has to decide on the evaluation/interpretation of a representation. The result of such an evaluation/interpretation are the properties of the EO, which are part of the description of an EO and which are needed for further use in the process.
A concrete and precise overview of important requirements and features for the representation of the EO you may find in [2,3].

2.3 Description of an Engineering object

The description of an EO can be given by a *set of properties*, which depends on the interaction of the user with the object by considering or working with its representation. Therefore, this set of properties depends on the representation and on the point of view of the "observer" and, in parallel, on the Engineering state within the special process element in the process network.
The properties we consider as the result of an Observation-/Measurement-/Testing-Operator working on a special representation:

Property = | *Observation-/ Measurement-/Testing Operator* | *Representation* >

Notice: These are not all properties relevant for an EO in a given ES with a special "observer".

In the description of products we distinguish between [2]:

- *"Direct Properties"* directly estimated out of the representation of a product, like:
  Values (with/without dimension); points, vectors, (continuous) value fields, vectors or vectors fields; curves, set of curves, etc.
- *"Derived properties"*, which can be:
  Reflection curves, calculated out of the geometric shape with an additional environment of light lines; the volume (e.g. of a skibox); the Eigen-frequency of a product (e.g. of a car body); and many other possibilities
- *"Add-on properties"*:
  For example attributes belonging to representation and set of properties (but not derived from the representation) like: "the part is zinc coated", the part is painted red, administrative properties

From another angle, we can distinguish between *Real properties* related to a concrete representation and *Target properties*, which normally are *requirements* on the product (or on a concrete representation) within the process life cycle. These last are the key of *Engineering in Reverse (EiR)* [4] as the fundamental concept of the two European projects FIORES and FIORES-II [1,5,6]. Both projects worked on the development of more advanced CAx tools. In the first project, the approach of surface refinement by means of target properties has been coped with. Whereas, FIORES-II has proposed a further step forward in the direction of the intent driven design approach. The consortium developed techniques to improve the styling workflow by capturing and preserving the intended aesthetic character of a product while modifying its shape due to the desired product properties.
The description of a complex part/product by a set of properties seems to be not applicable. But we have to consider that a process only runs successfully, if there is a agreement between the "client" and the "supplier" about the scope and the quality of the delivery. Normally *not all* properties relevant to any of all the "observers" are taken into account at the same time.

The field of *emotionally stated properties* are special occurrences of the above given properties. They will be considered in chapter 4.

2.4 Basic process step

A single process step can be broken down into basic process steps. Fig. 1 shows a possibility to represent such a basic process step in a general way. Additionally and different from the well known "Input – Process – Output" thinking mentioned above, the requirements between the process steps were added to both the "input" and the "output".

The *basic process step* given in Fig. 1 can be described with the following formalism:

< *Eng. Obj. A: Description i: Set of prop. i; Represent. j |*
| Process operator (depending on: functionality, ext. Requests) |
| Eng. Obj. B: Description k: Set of properties; Represent. l >

Requirements between process steps can be given in target properties with target property values. The *quality* of process steps can be stated by comparing target properties to resulting properties. Mandatory to do this is a metric, a similarity measure between two sets of property values.

3. Application of the approach on the Concept of Engineering in Reverse

Today, an industrial design workflow for aesthetic product shapes is based on a mixture of CA-techniques and manual work. This is realised with the concept of *Reverse Engineering*, where the determining shape is the result of manual optimisation on the physical model. Digitising and transferring the point clouds to CA-surfaces closes this break in the CA-process chain. This "sequential" workflow with many optimisation loops should be replaced by the concept of *Engineering in Reverse (EiR)*. Generally spoken, EiR stands for the process of generating a model according to its desired properties. There is usually no unique mapping between model and properties, so that the process in the end contains an optimization loop which refines the initial model until it is as close to the wanted properties as possible. There is not any longer a break when using CA- and physical models sequentially in a loop.

The *Engineering in Reverse (EiR)* approach follows this methodology: The *target properties* will be used to *control* the design of the product. The workflow is no more going from the beginning to the end but there is a direct impact from the future process steps on the actual ones.

To use the formalism from chapt. 2.1 and 2.4, the *target engineering status* has to be introduced.

The *target* is an Engineering object with (hopefully) clearly defined properties. But there is no representation available which is precisely consistent to this set of properties. That means that these target properties **α'** cannot be estimated out of the initial representation **a**.

In the EiR process the initial representation of the Engineering object has to be modified in such a way that the properties **β** resulting out of the modified representation **b** will fit or (normally) will be close to the target properties **α'**:

< *representation a; target properties α'| EiR operator |*
| new representation b; with properties β >

To estimate the quality of the result of the EiR process a quality operator **Q** will estimate the **DELTA** between the target properties **α'** and the resulting properties **β**, the EiR evaluation parameters.

< *(new) properties β; target properties α' | Quality Op. | EiR evaluation values* >
(Metric)

To realise this idea, the properties have to be formalised mathematically and a metric has to be found. This work is subject of further research and still in process.

The approach towards formalisation of process steps can also be applied to some other major design problems, e.g. features, design in Virtual Reality, product data, etc. [3].

4. Realisation of the approach in a formal structure for aesthetic products

The advantage of distinguishing between Engineering object, description by properties and representation becomes obvious by considering besides:

properties, which can be objectively estimated
(although the selection of properties which will be taken into account depends on the *user*)

and also

the *character* of aesthetically shaped products, that means properties capturing emotions.

This kind of properties belonging to the character of a product cannot be estimated by mathematical, engineering or measuring methods. It is obvious that the character of a product has no physical reality or even no "abstract" reality as an information technology data set. It is implicitly given in the shape of the product and depends on various factors such as the user/observer, his culture and his education, the environment of the observation and its history, company, corporate identity and more.
During FIORES-II questionnaires and person-to-person interviews with designers have been performed with the dual objective to

- identify those terms used during the styling activities to describe the aesthetic aspects of a product and those terms used in marketing to describe a product from an emotional point of view
- identify the main geometric elements on which designers act for characterising a product

It emerged that stylists use different languages when speaking with marketing people and when working at the definition of the digital model with surfacers. Three different languages were found, which are used when characterising/working at the aesthetics of a product shape:
Colloquial language:

- Used to describe the *Global character* of a product
- Terms depending on the cultural environment, the educational level etc. of the customer ("observer"), e.g. "a typical AUDI"

Marketing language (= "Language of trends"):

- Base for the representation of the *Emotional character* of a product (or parts of it)
- Terms to describe emotionally and individually the impressions the customer has of a product
- Terms related to emotional aspects, the Emotional character and other overall qualities which the final product has (or should have as objectives), e.g. emotional terms like "aggressive", “feminine”, "sporty", "masculine", etc. ("a sporty and elegant car")

Designer language:

- Terms used during the communication between stylists or between stylists and surfacers, to detail and precisely specify the *Aesthetic character* while working on the product model
- A restricted set of terms adopted by stylists, corresponding to shape properties, to provide instructions for modellers or surfacers about how elements have to be changed to enforce/modify a given/target character to fulfil marketing directives. E.g. "acceleration", "convexity", "crisp", "crown", "hollow", "lead in", "tension", etc.

Based on the analysis of various industrial design activities during FIORES-II, a structure for aesthetic products was found as shown in Fig. 2.
The main components are:

a) *Global Character* (G.C.) of a product shape:
Over-all impression of a complete product to a special customer or to a defined group of customers ("observers"). It is described by a customer depending subset of terms of the *Colloquial language*, e.g. "It's a typical AUDI".
In this case the complete product is an *Engineering object*, e.g. a special car model (AUDI S4, BMW 525, VW Golf IV, etc.).

b) *Emotional character* (E.C.) of aesthetic relevant parts of a product:
A special representation of the global character. The E.C. is described/expressed in terms of the *Marketing language* ("aggressive", “sporty", "masculine", etc.) to communicate the emotional impression of the customer.
Here, the aesthetic relevant parts of a product are the *Engineering objects*, e.g. the doors of a car, the side-silhouette of a car, etc.

c) *Aesthetic Character* (A.C.) of aesthetic relevant parts of a product:
A special representation of the global character. The A.C. is described, detailed, precisely defined and/or modified by using terms of the *Designer language* (while working on the product model) which are directly related to aesthetic relevant segments of geometric elements, so-called *Aesthetic relevant shape elements.*

d) Aesthetic relevant shape elements:
Aesthetic relevant shape elements are e.g. curves, sections relevant for the aesthetic feeling the stylist has about the shape. They are selected by the user/observer and evaluated by stylists/ designers with respect to the related terms of the *Designer language.*
The Aesthetic relevant shape elements of a product are also *Engineering objects*, e.g. character curves, reflection curves, shadow lines, (planar) sections, etc.

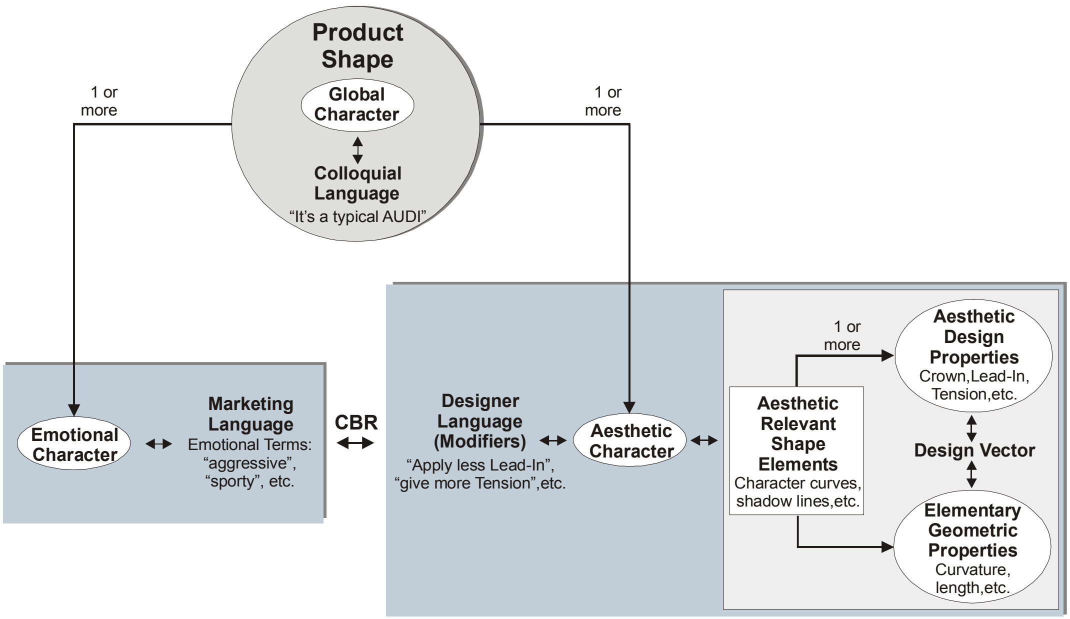

Figure 2. Components of the structure for aesthetic products

Aesthetic design properties are special terms of the *Designer language* (e.g. lead-in, tension, etc.), which are directly related to *Aesthetic relevant shape elements* while working on a product shape. They are the base of design functionalities ("Operators"), so-called *Modifiers*, acting on selected *Aesthetic relevant shape elements* to modify them, e.g. "apply less lead-in", "give more tension", etc. [7]:

Modifier = Operator on Aesthetic relevant shape element

e.g.: Operator "Tension" | Aesthetic relevant shape element > = Value

Elementary geometric properties are classical (differential or not) geometric terms derived from the *Aesthetic relevant shape elements* (e.g. curvature, length, saddle points, points of inflection, etc.). The related calculated values are the Elementary geometric properties values which represent parameters to describe an Aesthetic relevant shape element of a product in absolute values.

In short notation, an *Aesthetic relevant shape element* is defined by a *Design vector* as following:

Set of (weighted) Aesthetic design properties	+	*parameters (values) of Elementary geometric properties*	+	*(CA-) representation*	:=	*Aesthetic relevant shape element*

The relations between the emotionally stated character of a product and technically, mathematically terms are also included in Fig. 2. To capture the *Emotional character* of a product and to link it with the *Aesthetic character* Case Based Reasoning (CBR) techniques are used. *Case Based Reasoning* is a field of Artificial Intelligence Research dealing with storing and using knowledge. It uses previous experiences (stored as *cases*) to solve new problems. This is done by retrieving similar experience via similar situations from these cases. Information is extracted by reusing the stored experience in the context of the new situation. To increase the knowledge database new experience is stored as new cases. The gain of information from a CBR database is done with the help of statistical methods [8].
In the annex, Table 1 gives a detailed summary of the realisation of the approach in a formal structure for aesthetic products as described above in chapt. 4. The table has been compiled with respect to the notation of chapt. 2 differentiating between *Engineering object*, *description* by properties and *representation*.

5. Results

In this paper, the practically evaluated and approved concept of Engineering in Reverse in Aesthetic Design is mapped on the formal approach of "observer/object/experiment" known from Quantum Mechanics. Various questions in product design can be handled by primarily considering properties. The classical approach dealing with CAD representations can be considered as a lower, abstract level with less general importance within the product life cycle. Properties in our generalised sense include requirements as a special view.

6. Key conclusions

For the product model we should have to differentiate between the description of the product which is related to the point of view of the engineer/observer/user – and – between representations of the product which depend closely to the special need in an actual process step. So we have to give up on the "GOD of Geometric Data structure". The approach is fully consistent to the definition of feature by FEMEX [9,10].
The concentration on the relevant properties and functions of the product (or process-intermediate product representations) brings the end-user or engineer into a more dominant position compared with the classical focus of CAD systems.
Therefore, standard thinking in Computer Aided Design focussing the CAD functionalities working on Geometry, is obsolete. New, modern and innovative design functions should have to work on properties.

References

[1] FIORES, "Formalisation and Integration of an Optimised Reverse Engineering Workflow" – Project of the European Community Brite Euram BE 96-3579, from 01/1997 – 12/1999, Coordinator RKK, University of Kaiserslautern, http://www.fiores.com.

[2] Dankwort C. W., Faißt K. G.: "Engineering in Reverse - A Holistic Extension of CAD", in: Papers of the workshop "New Trends in Engineering Design", Balatonfüred, Hungary, pp. 91-94, June 27-28, 2003.

[3] Dankwort C. W.: "Reality in Design", in Kimura F., Ohtaka A.(eds.): Proceedings of the "4th. Workshop on Current CAx-Problems", Nov. 13th. - 15th. 2000, Shizouka, Sanbi Printing Co., Ltd 2001.

[4] Dankwort C.W., Podehl G.: "FIORES – ein europäisches Projekt für neue Arbeitsweisen im Aesthetic Design", VDI-Berichte 1398, "Entwicklungen im Karosseriebau", S. 177, 1998.

[5] Dankwort C.W., Podehl G.: "A New Aesthetic Design Workflow – Results from the European Project FIORES", in P. Brunet, C. Hoffmann, D. Roller (Eds): "CAD Tools and Algorithms for Product Design", Springer-Verlag, 2000.

[6] FIORES-II, "Character Preservation and Modelling in Aesthetic and Engineering Design" – Project of the European Community Growth No. GRD1-1999-10785, from 04/2000 – 03/2003 , Coordinator RKK, University

of Kaiserslautern & think3, Bologna/Aix-en-Provence. The consortium consisted of 3 groups of partners from 6 European countries: industrial companies (BMW, Eiger, Formtech, Pininfarina, Saab, Alessi), software enterprises (CAxOPEN, think3, Samtech, UDK) and research institutes (LPC-CNRS, IMATI-CNR, PULV, University of Kaiserslautern), http://www.fiores.com.

[7] Dankwort C. W., Faißt K. G.: "FIORES-II - CAD im Spannungsfeld zwischen Ästhetik und Design: ein Hilfsmittel zur Bewahrung des Produktcharakters im Entwicklungsprozess", in: VDI-Berichte Nr. 1674, pp. 31-48, zur Tagung "Entwicklungen im Karosseriebau", Hamburg 7.-8. Mai 2002.

[8] CBR-Web, http://www.cbr-web.org.

[9] FEMEX: Working Group "Feature Modelling Experts" organised by J. Ovtcharova, 1995-1997.

[10] Weber, C.: What is a Feature and What is its Use? - Results of FEMEX Working Group, in Proceedings of 29th International Symposium on Automotive Technology and Automation 1996 (ISATA 96), pp. 109-116.

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ANNEX:

Table 1. Formal structure for aesthetic products

Engineering object	***Aesthetic perception***	***Explanation***	***Description***	***Representation***
Complete product (e.g. a concrete AUDI S4)	Global character (of the product)	Over-all impression of the product to a special customer – or to a defined group of customers ("observer")	Customer ("observer") depending subset of terms of the representation - in some cases: with subjective (individual) weights - properties more generally (vague) Other possibility: Characterisation of product by special/ typical aesthetic relevant parts of the product	Well defined set of terms out of the *Colloquial language* "It's a typical AUDI"
Aesthetic relevant parts (1 or more) of a product, which are typically for the kind of product. E.g.: front hood of a car, side view of the windows, the doors of a car, the side-silhouette of a car,…	Global character (G.C.) (of selected product parts)	Over-all impression of product parts to a special customer – or to a defined group of customers ("observer")	Name of the product part Customer ("observer") depending subset of terms of the representation with subjective (individual) weights	Well defined set of terms out of the *Colloquial language*
	Emotional character (E.C.) (special representation of the Global character)	Described/expressed in terms of the *Marketing language*, to communicate the emotional impression of the customer	Name of the product and of the product part Customer ("observer") depending subset of terms of the representation with subjective (individual) weights	Well defined set of terms of *Marketing language* (fixed list) ⇨ filter on that list
	Aesthetic character (A.C.) (special representation of the Global character)	A.C. is *represented* by aesthetic relevant segments of geometric elements, so-called *Aesthetic relevant shape elements* (1 or more, selected by user/observer) A.C. is *described*, detailed, precisely defined and/or modified by using terms of the *Designer language* (while working on the product model) which are *directly related* to the *Aesthetic relevant shape elements*	Terms of Designer language := *Aesthetic design properties* related to Aesthetic relevant segments of geometric elements := *Aesthetic relevant shape elements*	Geometric representation: ⇨ CAD: Bézier, curve on surface, standalone curves,… ⇨ Clay model ⇨ Curve on photo

Engineering object	***Perception***	***Explanation***	***Description***	***Representation***
	Aesthetic perception (of the aesthetic relevant shape elements)	Terms of the *Designer language* which are directly related to *Aesthetic relevant shape elements* => *Aesthetic design properties* *Aesthetic design properties* terms are the base of design functionalities ("Operator"), so-called *Modifiers*, acting on *Aesthetic relevant shape elements* to modify them	Special term of *Designer language* := *Aesthetic Design property*	Fixed set of terms of *Designer language*: Acceleration, convexity, crisp, crown, hollow, lead in, tension, etc.
Aesthetic relevant shape elements	Elementary geometric properties (of the aesthetic relevant shape elements)	Properties of product shapes. Classical (differential or not) geometric terms derived from the *Aesthetic relevant shape elements*, e.g. curvature, length, saddle points, points of inflection, etc. The related calculated values are the *Elementary geometric properties* values	*Elementary geometric property*: Value (curvature, max curvature, length, number of saddle points, etc.)	Geometric representation: CAD-curve, -surface, etc. + algorithms
	Aggregation of Aesthetic Design properties + Elementary geometric properties	Aesthetic relevant segments (1 or more) of geometric elements: Points, curves, sections relevant for the aesthetic feeling the stylist has about the shape => *Aesthetic relevant shape elements* *Selected* by user/observer, *evaluated* by stylists/designers with respect to the selected terms of *Designer language* Parameters describing an *Aesthetic relevant shape element* in absolute values are expressed by *Elementary geometric properties* values	Set of (weighted) *Aesthetic design properties* + parameters (values) of *Elementary geometric properties* := *Aesthetic relevant shape element* => *Design vector* E.g.: {Lead-In = 0.5, Tension = 1.2} + parameters	Geometric representation: Character curves, reflection curves, shadow lines, (planar) sections, etc.