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NEW EXTENDED CONCEPT FOR THE USAGE OF ENGINEERING OBJECTS AND PRODUCT PROPERTIES IN THE VIRTUAL PRODUCT GENERATION PROCESS

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ABSTRACT

In this approach, a formalism is presented to overcome the geometrically preoccupied engineering thinking in the virtual product design process by concentration on processes of Engineering Objects. The Product Properties are the base of this Engineering Object understanding. It is distinguished between the description of an Engineering Object given by a set of its properties, which always are linked to the context and to the persons involved, and the representations of an Engineering Object, like a model, a picture, a drawing, a CAD file, or even the real physical part itself. Apart from the last, all other representations are only images/abstractions from the reality, which depend highly on the specially considered process step, that means on the "Context" and on the people involved in it.
The objective of the approach is to capture the product (in some granularity) together with the process and also together with the persons involved: the designer, the engineer, the manager, the end-user, the sales man, etc. This approach has the potential to support modern product development methodologies like Engineering in Reverse.
The proposed concept for the usage of Engineering Objects and Product Properties in the virtual product generation process will be developed and verified following the Aesthetic Design sub-process within a generalised product generation process. Concrete application examples will be presented. But the outlined basic ideas open the option for applications in various other fields of design.

Keywords: Engineering Objects, Product Properties, Engineering in Reverse, Virtual Product Generation Process, Product Design

1 INTRODUCTION

With the breakthrough of CA-techniques and -methods within the virtual product generation process there is an urgent need for a complete, integrated digital image of both the product and the related processes in the computer. From former days until now, CAD is the base for developing a product. Therefore, from the beginning there were urgent industrial needs for the exchange of the (geometric) CAD data between Engineering Design and NC, manufacturing, simulation etc. as well as archiving the CAD models for many years. Later on, the information for the description of the processes had to be included.

Today, we have to capture and to define in a holistic approach: The digital virtual product in a digital world within its complex processes – over the complete lifetime of the product with all aspects. A new holistic and integrated Product and Process Data/Information Model is mandatory, which should dynamically change with time and which has to capture:

- Product shape/geometry
- Functionalities of the product
- Structure of the product (assembled from components and concerning the functionalities)
- Properties of the product (and components) – target and actual
- Manufacturing and logistic as well as administrative concerns
- Process concerns, not only information, but also process control and optimisation

- Time dependency of the product itself within its life cycle
- Human aspects concerning all persons involved: Designers, engineers, Marketing, management, end-user, ...

The objectives of this approach are to fulfil these requirements but also to increase the efficiency in the industrial processes, and to the decrease the numbers of optimisation loops in the product development.

There is a need for a *formalisation* of the description of the product and the processes including product properties and functions as well as human aspects with the various personal and technical view points. Such a formal set of information may be the base for modelling and optimising the product within its complete life cycle and by that for future PLM systems. For this formal set of information we use the term *Engineering Object*.

Main goal of the approach is to improve both the product optimisation during the development concerning functionalities and consumer acceptance, but also to improve the related processes to optimise the classical four factors: *Time* to market, *Quality* of the product, *Costs* of development and manufacturing – and last not least – the *Innovations* for the product and for the related processes.

2 BACKGROUND AND MOTIVATION

2.1 Generalised Aesthetic Design Workflow

The proposed concept of Engineering Objects will be developed following the Aesthetic Design sub-process in a generalised product generation process (Figure 1) [1]. This sub-process is of high interest for the market position of a product – and also very familiar to the authors. The proposed concept will be verified by concrete application examples out of this kind of processes.

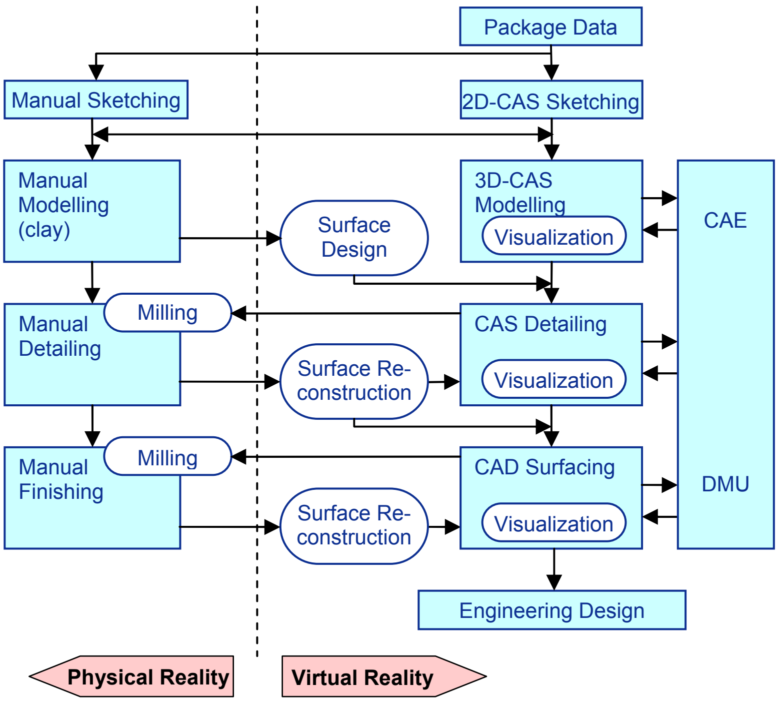


Figure 1. Generalized Aesthetic Design Workflow [1]

The Aesthetic Design process includes both work in CAS and on the physical model. Today, the creation of product shapes mainly is done with both techniques. Various optimisation loops of CAS modelling, visualizing, milling, manual modelling and surface reconstruction are done. If the stylists are content with their model (usually the physical one), it will not be altered anymore after the styling freeze and is then passed on to the CAD designers. These are cost and time intensive aspects of the Aesthetic Design process today.

2.2 Basic Process Steps

From a general view, in an industrial workflow within a given time window (or in overlapping time windows) exists a parallelism of different *process steps*, one in interaction with the other, sending requests and receiving the required input (Figure 2). So, "stand-alone" process steps are useless, they have always to be considered in relation/interaction with other parallel and/or preceding/subsequent design steps. Within such a time window, process steps cannot be regarded to be "first, second, or one following after the other". It is a kind of granularity of view to consider the various – more or less parallel – process steps as one. In a finer granularity, different process steps will be existent, one in interaction/interdependency with others, sending requests and receiving the required input (hopefully in the required way). In our approach we are not fixed on the straight forward sequential time flow.

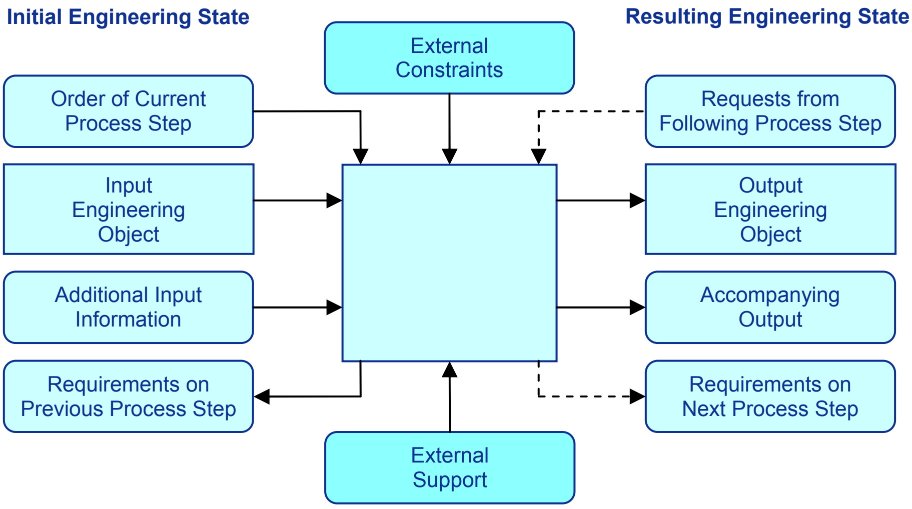


Figure 2. Single Process Step

For a better understanding, we will analyse a single process step as given in Fig. 2. It consists of four main components:

- The initial Engineering Object(s) within its initial Engineering State
- The process itself
- The final Engineering Object(s) within its final Engineering State
- The requests on the process step (from superior point of view) and the requests on this step from subsequent or parallel process steps, respectively the requests of the considered process step on the other process steps.

2.3 Engineering Objects

Within an *Engineering State (ES)* the product relevant object we call *Engineering Object (EO)* [2], [3]. The Engineering State defines the environment of the Engineering Object within a phase of the process under consideration. It will capture:

- The "Context", the position within the process (actual process step, preceding ones, succeeding ones)
- The "Environment", with external constraints and requirements, available tools, services, energy,…, but may be also with other Engineering Objects
- External orders/requests

The design process chain will bring an Engineering Object from one Engineering State to another, or will turn one Engineering Object into another: Decreasing (or keeping) abstractness, going more and more concrete.

Such an Engineering Object may be a complete product (i.e. a car), a part, a component of a part, an assembly of parts or even an assembly of several Engineering Objects of lower granularity and it will be considered to be partner in processes (product generation process, product usage process, etc.).

An Engineering Object represents the product/part during its life cycle in various development states, its properties, its position within the processes. Furthermore an Engineering Object must always be linked to the people involved in developing or manufacturing the product/part, dealing with, working with, judging, or using it, such as the user, the designer, the engineer, the manager, or others. In analogy to physics, these persons we call "Observer" or "Actor", keeping in mind, that she/he might be an active person.

As a consequence, for the Engineering Object we distinguish between the *description* of the Engineering Object given by a set of its properties which are of importance from the Observer's/Actor's point of view, and the *representations* of an Engineering Object, like the real physical part itself, or a model, a picture, a drawing, a CAD file, or others. Apart from the real physical part, all other representations are only images/abstractions from the reality.

The representations as images/abstractions of a product/part are of secondary importance: These images/abstractions depend highly on the special process step, that means on the Engineering State (the "Environment", the "Context") and on the people involved in it (the Observer/Actor). An Engineering Object cannot be considered only as a "stand-alone" object without an Observer/Actor: An Engineering Object is ONLY given by the interdependency/interplay of it with the person dealing with, working with, looking at, judging, or using this Engineering Object.

Concrete, real examples for Engineering Objects and Observer/Actor are given in Chapter 4.

Chr. Weber presents another extended approach [4] for modelling products and product development processes, called "Characteristics-Properties Modelling" (CPM) and "Property-Driven Development" (PDD), respectively, which is in some points similar to our approach. The core of this CPM/PDD concept is the clear distinction between characteristics, which describe the structure and constituents of a product, and properties, which describe the product's behaviour. Within the approach, characteristics and properties as well as the relations between them form the base for product modelling.

Furthermore, in this context W. Gielingh's "Theory of Notions" has to be mentioned, which also shows analogies to our concept. Here, objects are described in terms of Notion chains (or Knowledge DNA), not as instances of classes. The Knowledge DNA contains Notions that can be interpreted either as properties of real world phenomena or as the intensional definition of object classes. It contains therefore the full semantics of object classes and enables CA applications to construct and reconstruct different views on the object. The Knowledge DNA itself remains view-independent [5], [6].

3 METHOD AND FORMALISATION

3.1 Objectives

The objectives which have to be fulfilled by this approach of Engineering Objects are

- to capture both shape/geometry and functionalities of products
- to capture both assembly structure and functionality structure
- to capture both product and processes
- to capture both human and engineering aspects:
  To treat both person (user/actor) and object (product) with its processes as ONE unit
- to take into account the targets and the wishes of the people involved in the
  product generation process (supporting "Engineering in Reverse" [1], [3] or similar methods)
- to control/optimise the product design workflow by product properties:
  No more by primary modification of CAD representations (geometry)
  => Target: To avoid optimisation loops with physical models
- to support holistic and integrated Product and Process Information Management (PPIM)

3.2 Formal Definition of an Engineering Object

We define an Engineering Object by

EO =: "Identifier": Name ("ID"), with attributed administrative/logistic concerns ("AL") -
a set of information.

"Engineering State": "Context": The position of the EO within the process (the actual
process step, the preceding, and the succeeding ones) and
in its "Environment", including "Orders", "Requests".

"Time dependency": of the "Engineering State": "Context" & "Environment":
The Position in the process – and –
the absolute or relative run time of a process step – and –
the time running during Input or/and Output of the process – and by that –
of the "Description" and of the "Representation(s)".

"Observer" or "Actor": The user, designer, engineer, customer, manager, or…
involved in the process or part of the process or using the product.

"Description" =: A set of "Properties" in a general sense,
depending on the "Engineering State" and
relevant to the "Context" and to the "Observer"/"Actor".

"Purpose": The intend in the initialisation of the process step and also in the usage
of the product –
depending on the "Observer"/"Actor" and of the process steps,
including also "targets" for properties and "design intent".

"Representation(s)" (one or more): also depending on the "Engineering State" and
the "Observer" / Actor" – and by that –
depending on the "Context": the properties relevant for this "Observer"/"Actor"
within the "Engineering State".

We write as following:

EO =: | ID, AL, , ES (Context, Environment), Observer/Actor, Description {Properties}, Purpose, Representation(s), Time dependencies >

Looking at the formalised structure of an Engineering Object, it can be noticed that the proposed formulation of an Engineering Object in an Engineering State with representation(s) and description by properties is also compliant to the feature definition [7] of the FEMEX working group [8].

To complete the definition we have to explain what are *properties* in this context. An overview will be given in the following chapter 3.3.

3.3 Rule of Product Properties in the EO Approach

The central idea of this approach lays in the definition of an *Engineering Object* with the differentiation between *description* of the Engineering Object as *a set of properties* on the base of the interaction between the *Observer/Actor* and the Engineering Object, and the *representation* of the Engineering Object as a subordinated item. The value of a special property in most cases will be estimated out of a representation.

3.3.1 Definition of Product Properties

A *property* of an Engineering Object, in a generalised view, is defined as an information linked to the Engineering Object, direct or indirect, which an Observer/Actor needs for getting in interaction with the Engineering Object, or which the Observer/Actor gets as a result of such an interaction with the Engineering Object. Every Observer/Actor has her/his own special set of properties of interest. The kind of these properties depends on the person and on the "Context"/"Environment" (process step, usage, ...).

In our concept, the description of products by properties is the key for the definition of Engineering Objects. The approach of properties includes also product functionalities.

Each property has three levels:

Generic level:	General description of the property, e.g. the terms "colour", "total length", ...
Target/Intention level:	Concrete statements / target values of the properties to be reached during the process, e.g. the requirements in the "package" of a car
Estimation level:	The measured, observed, or calculated values concerning identified properties due to a given representation (e.g. "Colour = Red", "total length = 4567 mm", "product character = very sporty", "maximum speed = 215 km/h", ...)

The description of an Engineering Object may include in parallel *target properties* and *estimated properties*. In some cases different representations of the same EO will lead to (slightly) different values of the same generic property. Here the observer/actor is asked to get consistency.

Property values can be given in an absolute scale – or – they can only be estimated relatively one in relation to another. They may be numbers (continuous or discrete) – or – geometric elements – or even – terms in a general sense. To have a common understanding concerning "terms" it is reasonable to find an agreement about them (may be in a *dictionary*). Methods of Artificial Intelligence (AI) may also be helpful (e.g. Case Based Reasoning – CBR).

3.3.2 Classification of Product Properties

We may distinguish between *Active properties,* which also include *product functionalities*, and *Passive properties*. Passive properties will cover "classical" product properties like product weight, dimensioning, petrol consume and many other.

In this paper we will focus only on Passive properties because of our application field *Aesthetic Design* (Active properties will be discussed in another paper).

Definition: *Passive properties* of an Engineering Object are properties for which the estimation of the property values will not modify the Engineering Object itself and by that also not the representation(s) of the Engineering Object or the Engineering State. The estimation of Passive properties values will not give a physical impact on or feed back to the Observer.

That does not mean, that the senses of an observer will not be appealed (eyes, ears, haptics).

For simplification, in the following the term *property is used for Passive properties*.

The distinction between *Objective properties* and *Subjective properties* seems to be of importance for Aesthetic Design, but analysing the applications of the Engineering Objects approach (Chapter 4) shows the cross linking of both.

3.4 Concept of Engineering in Reverse (EiR)

Generally spoken, Engineering in Reverse (EiR) stands for the computer-aided process of *generating/ modifying a product model* according to its desired *target properties* (*Design by Properties*), and the *control of the design workflow* of the product model by these target properties (*Target Driven Design*, usage of properties as "control handles","way of engineering thinking") [1], [3].

The concept of Engineering in Reverse follows this methodology: At the beginning of the process, requirements on the product (= to be achieved target properties) are defined and a target product model is modelled out of them. This target model must not be complete but can include relevant sub-ordinate targets only or leave out special target properties as well. There is usually no unique mapping between target model and properties, so that the process in the end contains an optimization loop which calculates and refines the "best solution" for the target product model within preset constraints (see Figure 3). At the end of the process, the final product model is that solution, which is as close as possible to the target product model (the desired target properties).

So, in case of EiR, the workflow is no more going only straight from the beginning to the end of the process but there is a direct impact from the target product model on the actual process steps at a time.

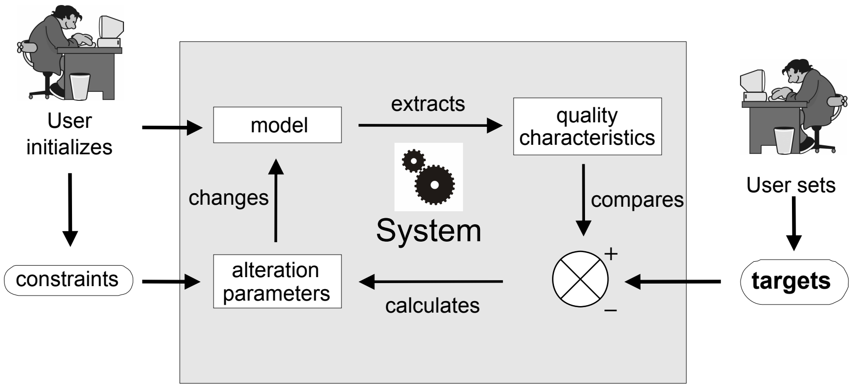


Figure 3. Principle of Engineering in Reverse (EiR) and Target Driven Design

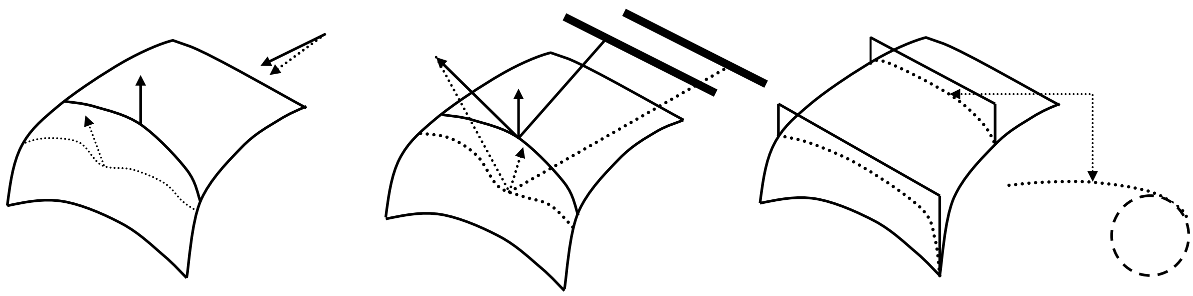
Engineering in Reverse was the fundamental concept of the two European projects FIORES and FIORES-II [9],[10]. Both projects worked on the development of advanced CAx software tools for the Aesthetic Design workflow. In the Aesthetic Design specific Engineering in Reverse concept of the FIORES projects, product properties are used as design tools. Therefore, the mathematical formalisation of properties is mandatory for Engineering in Reverse. Methods for the measurement of property values with a metric to compare property values are also imperative. Precondition for the estimation of values of a special property is the formalisation of this property to give a formal relation to the Engineering Object or to its representation. This specific approach of Engineering in Reverse can be extended to many large fields of design.

The general problem of estimating property values and to run target/actual value comparison is discussed for example in [11],[12].

3.5 Examples for Desired Target Properties in Aesthetic Design

From a Aesthetic Design specific point of view, Engineering in Reverse means NO Reverse Engineering (= no surface reconstruction!) but desired aesthetic target properties of a product defined by a designer/stylist are formalised and directly used as design and control parameters for free-form geometry or free-form modelling (in the sense of "Design by Properties" and "Target Driven Design").

Figure 4 shows several examples for desired target properties as they appear for example in aesthetic car body design.



(A) Shadow curves (B) Reflection curves (C) (Curvatures of) plane sections

EO = Part of front hood
Description: Property A: Shadow curve with defined vector v
Property B: Reflection curve with defined light conditions x
Property C: Plane section with given intersection plane y

Target Property value: Curve itself with special curve behaviour due to stylist's intent
Actual Property value: Curve calculated out of (e.g.) NURBS representation of front hood

Figure 4. Examples of Target Properties in Aesthetic Design [9]

4 EXAMPLES FOR THE APPLICATION OF THE APPROACH OF ENGINEERING OBJECTS AND PRODUCT PROPERTIES

In the following, different exemplary scenarios are presented which demonstrate how the approach for the usage of Engineering Objects and product properties can be practically used.

4.1 Realisation of the EO Approach in a Formal Structure for the Emotional Perception of Aesthetic Products

First, the proposed approach for the usage of Engineering Objects and product properties will be realised in a formal structure for the perception of aesthetic products as it is typical within an Aesthetic Design sub-process.

The advantage of differentiating 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 *Aesthetic Character* of a product cannot be estimated by mathematical, engineering or measuring methods. It is obvious that the Aesthetic 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.

The *Aesthetic Character (AC)* represents the designer's idea and goal: the *design intent*. It refers to the *Corporate Identity* of a company and is related to *emotions* of consumers. The emotional description and technical specification of the Aesthetic Character is done by *verbal expressions*. Further, the Aesthetic Character can be mapped on aesthetic relevant geometrical elements (CAD curves) which act as carriers of the AC, so-called *Aesthetic Properties (AP)* (e.g. reflection curves, silhouette lines, …), and their corresponding characteristic mathematical values, so-called *Geometric Properties (GP)* (points, curves with length, curvature, …) [2].

During the European project FIORES-II it emerged that designers/stylists use different languages when speaking with marketing people and when working with surfacers at the definition of the digital product model. Three different languages were found which are used when characterising/working at the aesthetics of a product shape [2], [13]:

- *Colloquial Language (CL)*: A customer depending (cultural environment, education level, …) subset of terms used to describe the *Global Character (GC)* (overall impression) of a product (e.g. "a typical Ferrari", …)
- *Marketing Language (ML)* (emotional): Terms used to emotionally and individually describe the emotional perception of the Aesthetic Character of a product (e.g. "an *elegant* and *sporty* car", ...)
- *Designer Language (DL)* (technical): Special terms used by designers/stylists to detail and precisely specify the Aesthetic Character while working on a product model (e.g. "an *accelerated* curve", "give more *tension*", ...)

Based on the analysis of various industrial design activities, Table 1 gives a detailed summary of the realisation of the Engineering Object approach in a formal structure for the perception of aesthetic products as described above. The table shows an exemplary section of the multi-level structure (different levels of granularity) and has been compiled with respect to the notation of chapt. 2 and 3 differentiating between *Engineering Object*, *description by properties* and *representation*.

Table 1. Extract of the Formal Structure for the Emotional Perception of Aesthetic Products

Engineering Object	***Aesthetic Perception by "Observer"***	***Explanation***	***Description***	***Representation***
The whole product - or - aesthetic relevant parts (1 or more) of the product, which are typically for the product family. E.g.: front hood of a car, side view of the windows, doors of a car, side-silhouette of a car, …	*Global Character (GC)* (of the product or of selected product parts)	Over-all impression of product parts to a special customer – or to a defined group of customers ("observers").	Name of the product part. Customer ("observer") depending subset of terms of the representation with subjective (individual) weights.	Well defined set of terms of *Colloquial Language* (fixed list) ⇨ filter on that list
	Aesthetic Character (AC) (special representation of the Global character)	AC is 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
		AC is *represented* by aesthetic relevant parts/segments of geometric elements, so-called *Aesthetic Properties* (1 or more, selected by user/observer). AC is 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 Properties	Terms of Designer Language related to aesthetic relevant segments of geometric elements := *Aesthetic Properties.*	Geometric representation: ⇨ CAD: Bézier, curve on surface, standalone curves, … ⇨ Clay model ⇨ Curve on photo ⇨ …

⋮

Example: Emotional Perception of an Aesthetic Product

Figure 5 shows the break-down from Global Character to Geometric Properties for the emotional perception of an aesthetic product (here: a Ferrari):

(1) The Global Character GC of the product shape gives an over-all impression of the complete car (= Engineering Object EO) to a special customer (= Observer). The customer describes his impression of the car by a subset of terms of the Colloquial Language CL (= set of properties), e.g. "Wow, it is a typical Ferrari!".

(2) The Global Character is directly linked with the emotional perception of the Aesthetic Character AC which causes feelings at the customer (= Observer) while looking at the complete car or parts of it (= EO). The customer expresses his emotions in terms of the Marketing Language ML (= set of properties), e.g. "I am impressed. It's really a strong, dynamic and sporty car", or "front end and hood look really aggressive", etc.

(3) Now, from a more technical point of view, let us assume that a designer or stylist (= Observer) is working at the car body shell or the outer skin of a part (= EO). At this stage, there is a mapping of the Aesthetic Character on the Aesthetic Properties AP. By keeping his emotional perception of the Aesthetic Character in his mind, the designer/stylist is detailing and precisely specifying the Aesthetic Character by acting on specific aesthetic relevant geometrical elements, the Aesthetic Properties (e.g. reflection curves, shadow curves, …) and by using special terms of the Designer Language DL which are directly related to these Aesthetic Properties, e.g. "the curve must be more *accelerated*, it needs to have more *tension*". In that case, the set of properties consists of both the Aesthetic Properties and the corresponding terms of Designer Language.

(4) A person from CAGD (Computer Aided Geometric Design) or an engineer (= Observer) wants to change the Aesthetic Character of a part by giving "more tension" to a special CAD curve (= EO) or by "defining a new target curve B (parallel to curve C)". He can do this by working on/with the Geometric Properties GP of the corresponding curve which are the characteristic mathematical values extracted from it, e.g. length, curvature, number and position of inflection points, etc. Here, the set of properties is defined by the Geometric Properties.

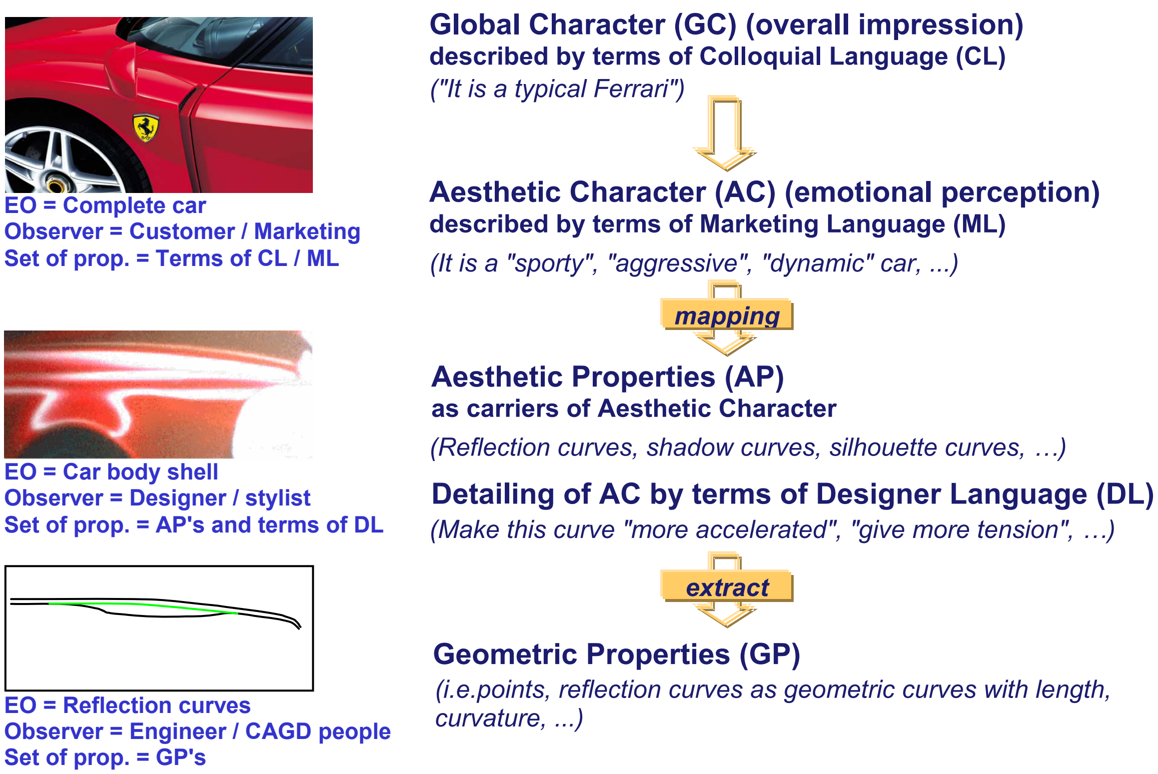


Figure 5. Example "Emotional Perception of an Aesthetic Product"

The following Table 2 gives the corresponding formal structure for the example from above.

Table 2. Formal Structure for the Example "Emotional Perception of an Aesthetic Product"

Engineering Object	***Aesthetic Perception by "Observer"***	***Explanation***	***Description***	***Representation***
Complete Car	Global Character Observer: Customer	Properties: Colloquial Language: "Wow, it is a typical Ferrari!"		Car itself - or – painted clay model - or - photo-realistic CA-model
Car body shell - or - Outer skin of a part	Aesthetic Character Observer: Customer	Properties: Marketing Language: "strong", "dynamic", "aggressive", …	Target properties: "Make it more aggressive"	Car itself - or – painted clay model - or - photo-realistic CA-model
	Aesthetic Character Observer: Designer, Stylist	Properties: Aesthetic Properties: Reflection curves, shadow curves, … Designer Language: "acceleration", "lead-in", "tension", …	Target properties: "The curve must be more accelerated, it needs to have more tension"	CAD-representation of curves. Estimated out of surfaces: (e.g. represented as NURBS surfaces)
Aesthetic relevant CAD-curves	Observer: CAGD people, engineer, surfacer, …	Properties: Geometric Properties: Curvature, length, number and position of inflection points, ...	Target properties: "Give curve A more tension", "Define new target curve B (parallel to curve C)"	(e.g.) NURBS representation

4.2 Mapping of Formal EO Approach on Concept of EiR

The target of a designer is an Engineering Object with clearly defined properties. But at the beginning there is no representation available which is precisely consistent to this set of target properties $\boldsymbol{\alpha}^T$. That means that these target properties $\boldsymbol{\alpha}^T$ cannot be estimated out of the initial representation $\boldsymbol{a}$.

In the Engineering in Reverse process the initial representation $\boldsymbol{a}$ of the Engineering Object has to be modified in such a way that the properties $\boldsymbol{\beta}$ resulting out of the modified representation $\boldsymbol{b}$ will fit or (normally) will be close to the target properties $\boldsymbol{\alpha}^T$.

Classically the impact on the initial representation $\boldsymbol{a}$ is done by the operating designer. In Engineering in Reverse there run optimisation algorithms which directly work on the representation to minimise the DELTA between the target properties $\boldsymbol{\alpha}^T$ and the actual properties $\boldsymbol{\beta}$ estimated out of the step by step modified representation while the optimisation process is running.

To realise this idea the following questions have to be solved:

- the properties have to be formalised mathematically
- the relation between properties and representations has to be formalised mathematically
- a metric has to be found: A quality operator $\boldsymbol{Q}$, by which the DELTA between $\boldsymbol{\alpha}^T$ and $\boldsymbol{\beta}$ can be estimated
- Algorithms have to be developed to modify the representation due to the DELTA for further minimisation

For special problems there are solutions available, but generally this work is subject of huge further research and still in process.

Example Application Scenarios for Engineering in Reverse in the Aesthetic Design Workflow

In the following are illustrated two examples of application scenarios of the Aesthetic Design workflow, which show how the formal Engineering Objects approach can be applied on the concept of Engineering in Reverse.

Working procedure 1: Change of product‘s Aesthetic Character by defining target terms of Marketing Language (= target properties).

The procedure is as following:

- The designer/stylist defines/selects aesthetic relevant curves (Aesthetic Properties) which act as carriers of the Aesthetic Character and which – from his opinion – should be changed in order to change the complete Aesthetic Character of the product
- He applies so-called *Modifiers* on the curves. Modifiers are special modelling tools for curves which allow the modification of product shapes in terms of the Designer Language [12], [13]. The Modifiers directly act on the selected Aesthetic Property curves
  => Intuitive push-pull tools for curve manipulation
- The designer/stylist stops with curve manipulation when he thinks that the new Aesthetic Character of the product is reached: now the target curves are defined
- The CAD system calculates the new corresponding surface(s)

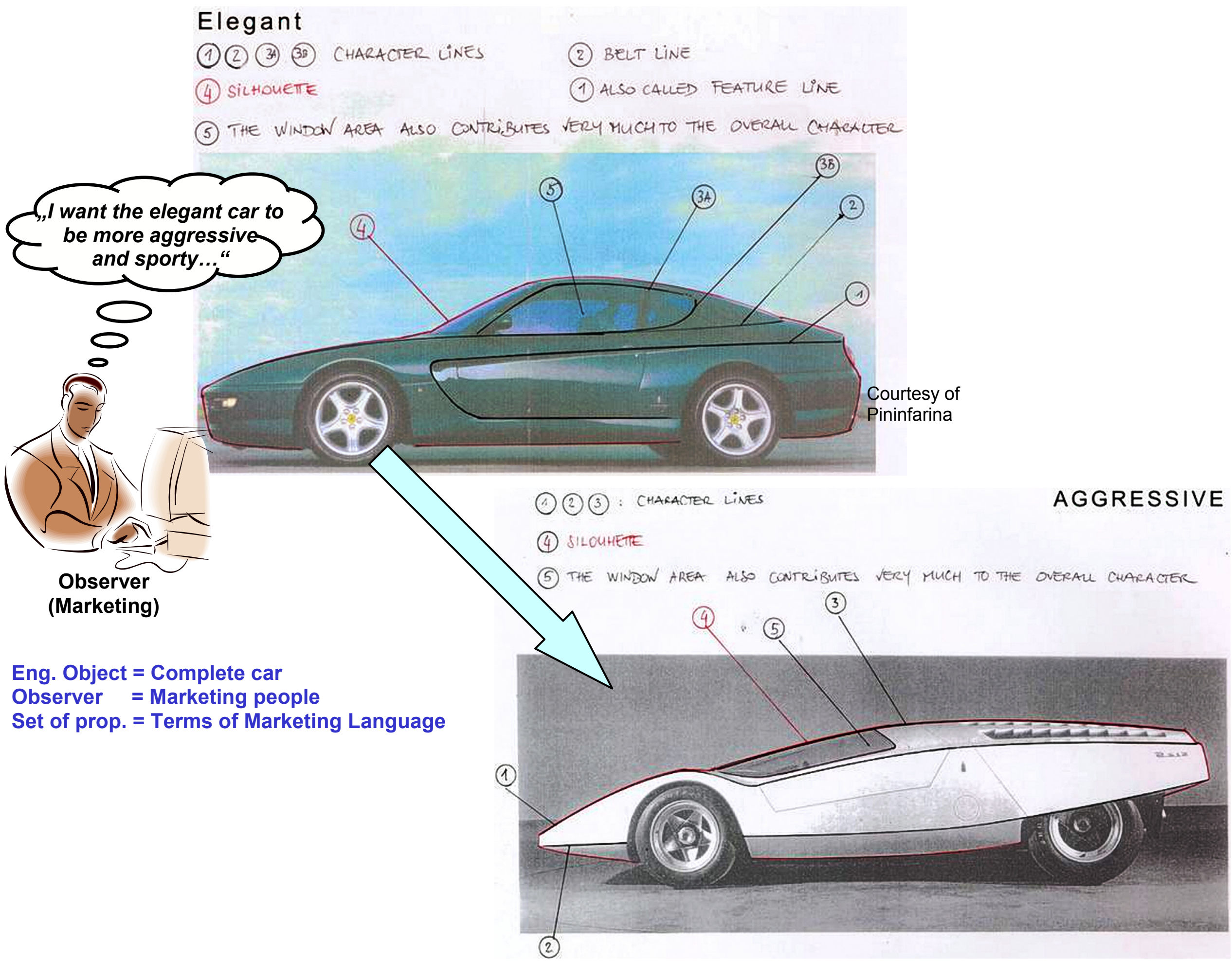


Figure 6. Change of Aesthetic Character by Defining Target Terms of the Marketing Language

Note: The modifier tools mentioned above, which have been developed during FIORES-II project, in the meantime, built on an Engineering in Reverse and Target Driven Design approach, have been implemented in a commercial software from think3 company [14].

Working procedure 2: Shape modification by defining/specifying target reflection curves (= target properties). Starting point is a CAD model with visualised surface properties, in this case simulated reflection curves ("highlights") on a CAD surface.

The procedure is as following:

- Select not-satisfying curve A
- Define new target curve B (parallel to curve C)
- The CAD system calculates the new corresponding surface

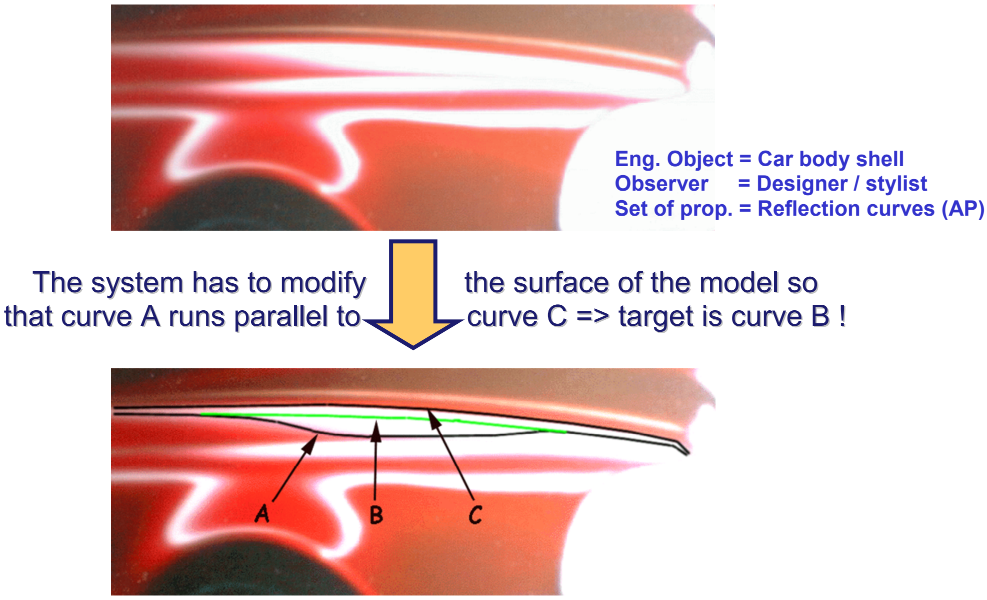


Figure 7. Shape Modification by Defining/Specifying Target Reflection Curves

5 RESULTS AND SUMMARY

A formalism for the usage of Engineering Objects and product properties including both the *product* and the *processes* was developed to overcome the geometrically preoccupied engineering thinking in the virtual product generation process. In this approach, the differentiation between *description* of an Engineering Object by properties and *representation* of an Engineering Object is the base of an alternative understanding of design. The description by properties includes product functions as well as, imperatively, the relations to the persons involved and the context. Further, this concept also considers non-technical aspects (even emotional ones) as well as human communication aspects. By regarding the target properties of a product also the wishes and intents of the customer are included. Therefore this concept also supports the increase of marketing acceptance of the product.

Beside the application areas described in this paper, the concept can also be projected on various other fields such as: Feature technology, Design in Virtual Reality / Virtual Engineering, extension of current Product Data Model / Data Exchange approaches (IGES, VDAFS, STEP, and others), extension of Knowledge Based Design (like CBR) on product development, enlargement of multi-criterial optimisation on complex product design problems, and others. Some of this visions are sketched out in [15].

This new concept could be a base for a new *holistic and integrated Product and Process Information Model* for future PLM systems which are not that CA-dominated as previous ones.

6 KEY CONCLUSIONS

For efficiency in the industrial processes the decreasing of the numbers of the optimisation loops has to be supported by this approach. Therefore with this approach we want to find a way to improve both the product optimisation during the development concerning functionalities and consumer acceptance, but also to improve the related processes to optimise the classical four factors: *Time* to market, *Quality* of the product, *Costs* of development and manufacturing – and last not least – the *Innovations* within the product and within the processes.

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