INTERNATIONAL DESIGN CONFERENCE - DESIGN 2012
Dubrovnik - Croatia, May 21 - 24, 2012.

ENHANCED OBJECT-DRIVEN DESIGN (EOD) BASED ON PRODUCT PROPERTIES – FUNDAMENTALS AND IMPLEMENTATION IN THE ENGINEERING NETWORK CONCEPT

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Keywords: enhanced object, design by properties, view-based design, engineering network concept, product development process

1. Introduction

In the past 30 years of product development the range of product functions and with it also the extent of product and process complexity have increased dramatically. A life cycle-oriented product structure is a multidimensional network of requirements, functions, behaviour as well as development, testing and manufacturing structures. This network encompasses all disciplines involved in product development, all internal and external development and production sites as well as all manufacturing and assembly resources referring to the product plus the whole relevant product documentation. Unfortunately, all known systems and technologies for managing and representing product and process information prove to be insufficient, they suffer from restrictions and unsolved questions. Hence, especially persons involved in the product development process (PDP) feel overwhelmed by a massive complexity and information overload today. Furthermore, classical product development processes are at present still based mainly on CAD. Therefore, geometry is also part of the core of any Product Data/Lifecycle Management (PDM/PLM). However, modern industrial processes require support from computer-aided tools which by far exceed any classical information technology (IT) which focusses mainly on geometry. All these reasons lead to the current shortcomings and mid-term challenges:

- A permanently growing complexity of both product and related process information, which is often distributed across different legacy systems (ERP, CAD, FEM, CRM, PLM, etc). Today's systems provide only insufficient or selective solutions to meet this challenge. This results in a lack of transparency and persons involved in the PDP feel more and more overwhelmed.
- The question of consistency of the different kinds of product information – within the various branches of the processes, distributed over different locations and systems – is the source for unnecessary costs and avoidable efforts. Another aspect in this context are the deficiencies in interoperability between the various systems.
- Creativity and innovations of designers and engineers have to be in the focus of the product development process. Creativity has to be decoupled from previously dominant CAD representations and has to focus on customer-relevant product properties now. Knowledge about designing and developing the product with its defined properties and its processes has to be formalised so that it can be captured and transferred within the PDP and among the persons involved. However, adequate support from computer-aided tools is still insufficient.
- Customer-relevant product properties should have the highest priority. However, the management of special customer- or human-related property information is more or less missing in current information management systems. In parallel, also management, marketing,

engineering, economical properties etc. significant for the product and its success on the market have to be captured and must be assessable for controlling the PDP.

For these reasons, new innovative approaches and basic technologies for the federation and control of complex product and process information must be developed, in due consideration of the needs of all involved persons within the PDP.

Taking up the challenges from above, the approach of Enhanced Object-Driven Design (EOD) has been developed. EOD will constitute a formal frame for a product in the industrial PDP beginning in the conceptual phase including customer-related and design/engineering-specific product properties as well as product-related process information. Products or parts within their related processes are considered as Enhanced Objects (EO). The focus lies on the Description of an EO by its properties and their structure (including product functionalities), according to the "View" of the involved persons.

For pragmatic reasons, there are some restrictions to limit the scope of the here presented approach. The EOD approach does not claim to master all the industrial challenges and needs, neither existing ones nor those which can be expected to occur in the future. Furthermore, not all possible properties which for example belong to a complex product like a car can be taken into account. Only sets of properties are considered which are of interest with respect to special (industrial) problems, e.g. as they are given in property lists in automotive development which gain increasing importance.

Main intention of this paper is to present the key objectives and elements of the EOD approach as well as an example for a first usage of EOD in software development. So, in this paper the following Chapter 2 presents some important details of the EOD approach. In Chapter 3, an overview of the status of implementation of EOD in the Engineering Network concept is given. Chapter 4 concludes with a summary of work and gives an outlook on future research and work.

Remark: The authors are aware of that there are other approaches and concepts in Engineering design which show some analogies to EOD, such as concepts from M.M. Andreasen, V. Hubka/W.E. Eder, N.P. Suh or the CPM/PDD approach from Chr. Weber. However, these will not be discussed to limit the extent of this paper.

2. The approach of enhanced object-driven design

2.1 Background, motivation and objectives

The here presented approach bases on the following watching. Comparing CAx-related information to the various possible sets of product properties relevant for customers, designers, engineers, salesmen, or others, some similarities to Quantum Physics become apparent [Dankwort 2001]:

- In Physics, an object's state can be described by various pieces of information but never by only ONE set of information including ALL physical values of the system.
- Various different representations of a physical state are possible in parallel.
- The physical apparatus to perform an experiment and the experimenter – the observer – have to be considered as ONE system.

These three assumptions make up the foundation of the approach described in this paper. A product/ part will be considered by using a Description of the same including its properties, given by various Representations depending on the View of the customer or of the persons involved in the PDP. To define a product/part, special objects – *Enhanced Objects (EO)* – are used, with a special focus on the part/product-relevant properties. In accordance with the term Enhanced Object, the proposed approach is called *Enhanced Object-Driven Design (EOD)*. An Enhanced Object may be also an assembly of parts within its PDP. The possible Representations of an EO are necessary aids within the PDP, e.g. to set the granularity level of an EO according to a persons' View. A property of an EO in general is a specific piece of information linked to the EO. A person working in the PDP who is interacting with an EO with respect to the properties relevant to him, has to consider the property values. These may be numbers, figures, a word or a piece of text or many others. This focus on properties as the Description of a product and on its PDP is a new aspect of product handling within the PDP in a common view. More details about the different elements of the EOD approach you will find in Chapters 2.4 and 2.5.

Remark: In former publications the authors used the term "Engineering Objects" [Faisst and Dankwort 2004], [Faisst and Dankwort 2007] because they are working mainly in the engineering world. However, the scope of *this approach can be enhanced by extending it to other application fields such as emotional aspects (mutual intersection of human perception and objects), objects in urban development and others. For that reason, the more general term "Enhanced Object" is now being used.*

The initial motivation for the approach comes from experiences and results from former European research projects. The objective was to find a general theoretical basis for the advanced design methodology of *Engineering in Reverse (EiR)*, pragmatically developed in these projects. EiR combines the design methodologies of Design by Properties, Target-Driven Design and Intent-Driven Design, with a focus on customer-relevant properties.

Remark: The term Engineering in Reverse (EiR) has been deliberately defined and used to distinguish EiR from "Reverse Engineering", which in Engineering design is used for surface reconstruction.

Now, the scope of application of the approach presented here has been extended. The vision of EOD aims not only at finding new solutions which reach far beyond industrial application of current EiR but also at providing a theoretical foundation for the development of new, innovative concepts and solutions (cf. Engineering Network concept, Chapter 3) for a better management of complexity in the product development process in the future. Hence, the key objectives of the EOD approach are:

- Enabling a product and process description fulfilling current and future industrial and customer-related requirements, in order to manage product and process complexity far better.
- Characterisation of products or parts by formally defined Enhanced Objects (EO).
- The Description of an EO by properties has to be distinguished from the Representation of an EO (like CAD).
- Support of Design by Properties with a special focus on customer-related properties. This also allows EiR and Target-Driven Design (use of properties as modelling tools within the PDP).
- Support of View-based design: An enhanced future-oriented design methodology supporting the View and the way of thinking of the people involved in the PDP.

2.2 Industrial basic process flow – trigger for the EOD approach

The basic process flow shown in Figure 1 clarifies the industrial relevance of EOD. The impact of later process steps on previous ones is obvious. There is no contradiction to classical thinking that follows the "cause-and-effect chain" in a continuous time progress. The overlapping of forward and backward information flow (feedback) is very important in process optimisation (e.g. "backward analysis" for process optimisation in industry). EOD also has to capture this request.

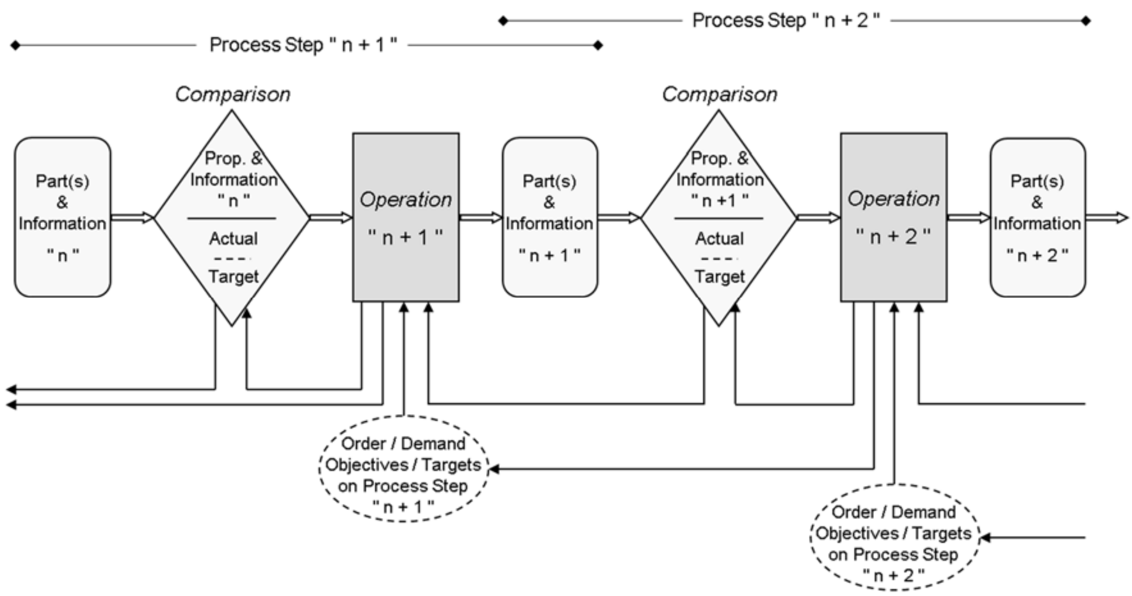

Figure 1. Basic process flow

General demands can be made on previous steps, but, to improve the actual running process step only impact on/from direct parallel running steps (from previous or on later ones) can be possible. In the EOD approach, the forward-backward aspects of a process flow will be supported.

Figure 2 shows a single basic *process step* in more detail. There are four main components:

- The initial part(s) – the Enhanced Object(s) – within its/their initial *Engineering State* with required (target) and actual property values. The Engineering State (ES) describes the context and environment of an EO during a certain position within the respective process step.
- The operation itself.
- The resulting Enhanced Object(s) within its/their resulting Engineering State with required (target) and actual property values.
- The order(s)/task(s) on the process step (from a superior point of view) as well as the demands on this step from subsequent or parallel process steps, and the demands from the considered process step on the other process steps respectively.

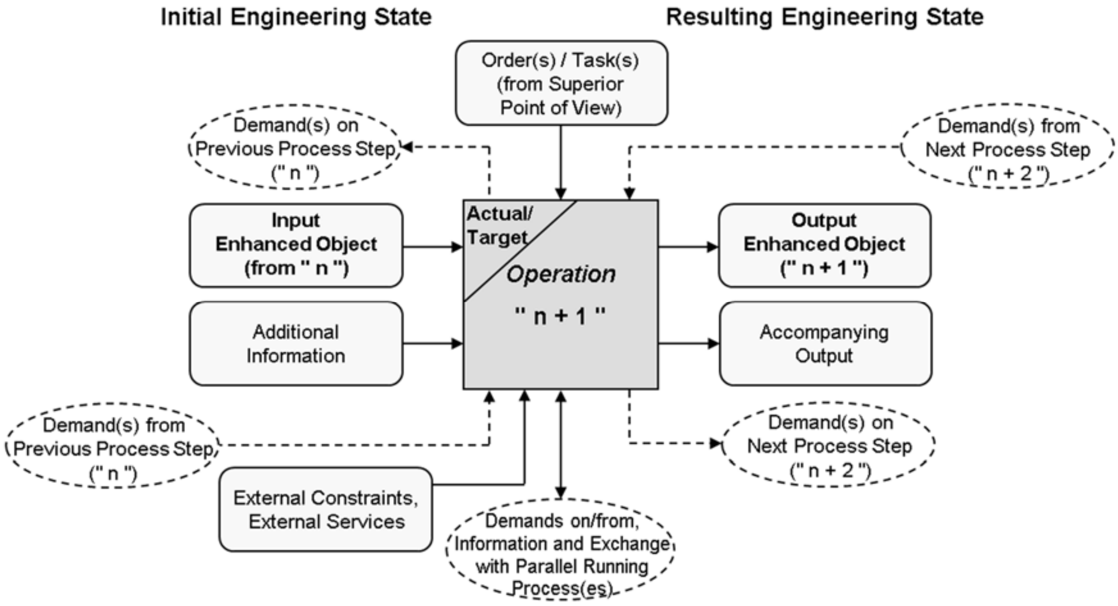

Figure 2. Basic process step

For an effective process flow, the comparison of actual and required (target) properties (that means the corresponding "values" of the respective properties) and also of actual property values of various development steps are of high relevance.

2.3 Central idea: enhanced objects within engineering states

A process step as given in Figure 2 takes a product/part – an Enhanced Object (EO) – from one Engineering State to another or modifies it - or both.

The *Engineering State* encompasses:

- The *Context* of an EO, which includes the position within the process (actual process step, preceding/succeeding ones). For a part/component: the position within an assembly with respect to other parts/components.
- The *Environment* of an EO, with external constraints and public and legal requirements, with available tools, services, energy, manpower, or, for a real product, the real world where the product is positioned or used.
- *External Orders/Tasks and Demands* from process control or other process steps – always concerning the View of involved persons: design or usage.
- A *Reference* to involved Enhanced Object(s).

The Engineering State is defined independently of the EO and is not to be a part thereof. Several EOs may belong to one ES. Therefore, the EOs may have a reference to various ES.

2.4 Definition of an enhanced object

An *Enhanced Object* either represents a complete product (e.g. a car) or a part, a component of a part or an assembly of parts (an assembly of several EOs) during its various development states within the life cycle. It includes its properties and its position within the processes (PDP, product usage process, etc.). Furthermore, an EO must always be linked to the people involved in developing or manufacturing the product/part, to those who are dealing and working with it, who judge or use it – such as designers, engineers, managers, end-users, or others. The involved person is called *Observer* or, keeping in mind that they are active persons in the process, *Actor*. These persons may be individuals or groups of persons with similar range of tasks, interests and/or education, or even an organisational unit within a company. These persons have, due to their responsibility, one or more special *View(s)* on the process and, by that, on the Enhanced Object. Due to these different Views of the involved persons, rather different product/part properties are of interest. Views are a basic part within the EOD approach (in the sense of ”View-based design/modelling”). Example: The senior manager responsible for a car has various Views, e.g. the View of business economics, the View of a stylist, the View of a marketing person, the View of a production engineer, and so on.

Two other important aspects of an EO are the *Description* of the EO given by a set of its *Properties* which are of importance from the Observer’s/Actor’s View, and the *Representation(s)* of an EO which may be 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 of the real product or part. A physical part, without any relation to an Observer/Actor is only a ”lifeless piece of material” without any meaning or function. An EO has no relevance in reality if it is considered as a ”stand-alone” object without any Observer/Actor or their View on it, or their interaction with it, respectively. It obtains its real status only through the Observer/Actor’s awareness of or interaction with the same. A certain CAD file for example needs an adequate CAD system and also a CAD designer who translates the information into the engineering world.

To assign a precise unique meaning to the introduced terms, an EO is defined by the following elements:

- The *Identifier*, a name (”ID”) with attributed administrative and logistic concerns (”AL”):
  A set of information, as used in classical information management.
- A *Reference* to its Engineering State (and by that to the process step).
- The *Observer(s)* or *Actor(s)*: One or several individuals or groups of similar persons involved in the process step.
- The *View(s)* of the Observer(s)/Actor(s).
- The *Description*: One or several sets of *Properties* relevant to the Observer(s)/Actor(s) or View(s) of the Observer(s)/Actor(s) respectively.
- The *Representation(s)* (none, one, or several) matching the Description and also depending on the Engineering State and the Observer(s)/Actor(s).
- The *Purpose*: The intended usage of the product – depending on the Observer(s)/Actor(s) and on the process step(s), also including related targets for properties and design intent.

A property of an EO is defined as a specific piece of *information* which is linked to the EO directly or indirectly and which an Observer/Actor needs for the assessment of the EO or in order to enter into an interaction, interdependency, interplay with the EO. Moreover, a property – respectively its value – can be a result of an interaction of the Observer/Actor with the EO. In the EOD approach properties also include product functionalities (cf. also Chapter 2.5 for more details about properties).

The time dependency of the Description and of the Representation(s) will be given through the modification (change) of the EO within the development process flow (by a reference to the respective corresponding Engineering State and by that to the particular process step within the process flow).

Figure 3 shows the structure of an Enhanced Object. An EO belongs to more than one process step, at least as an output of one (previous) step and as input for (one or more) (subsequent) process step(s).

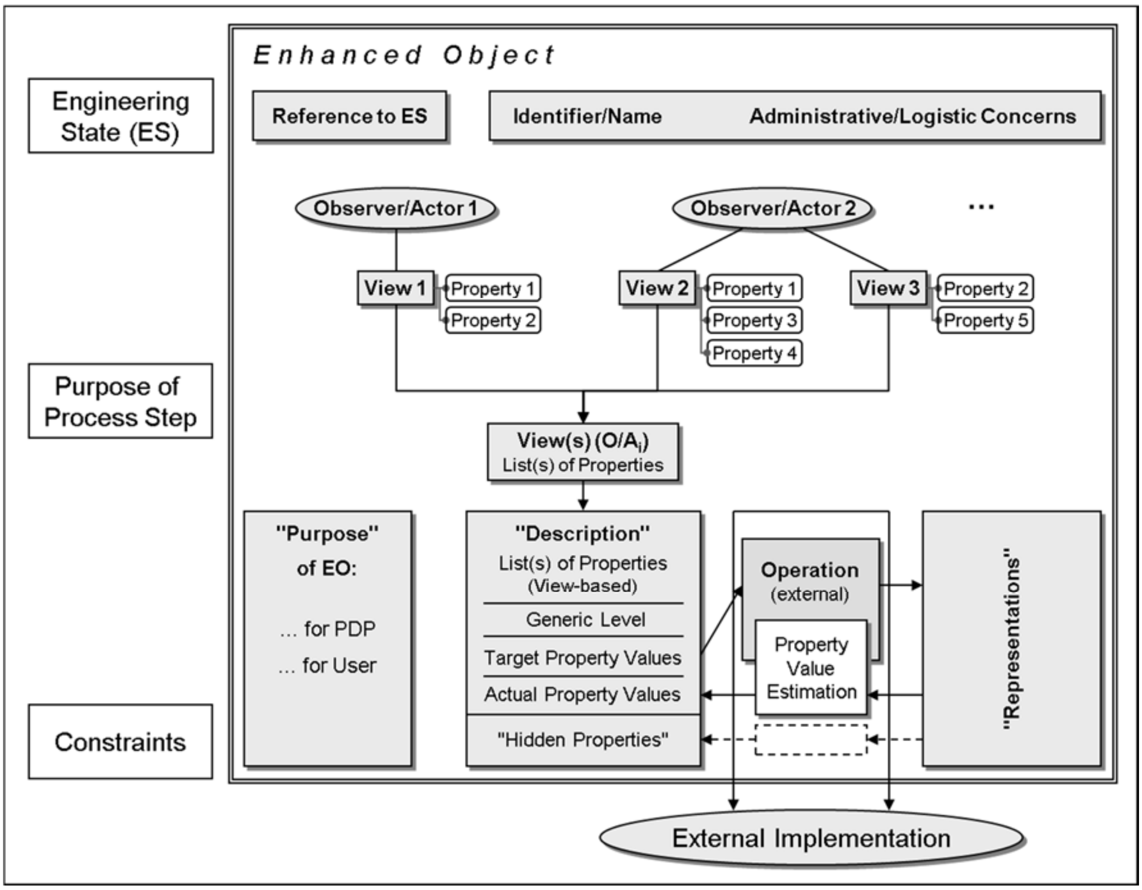

Figure 3. Structure of an enhanced object

Practical examples are given in Table 1:

Table 1. Examples for the different elements of an enhanced object

Enhanced Object	Automotive body shell	Air conditioning unit
Identifier	Part no., variant no., change status, date,…	(analogous)
Reference to ES	First design phase, 10 months before design freeze	Rough assembly, 10 months before design freeze
Observer/Actor	Stylist	Conceptual engineer
View of Observer/ Actor	Aesthetic quality of surfaces, effect of shape on other persons (perception)	Space management of rough assembly
Description	Customer relevant properties catalogue (subset) Product specific property catalogue (subset) Surface quality criteria: e.g. reflection curves	Draft dimensions of outer form of part
Purpose of EO within Process Step	Shape optimisation	Space occupancy in the assembly
Representations	Sketches, clay model, CAD file	Simple wooden model

The Description of an Enhanced Object corresponds to one or several sets of properties, relevant for the Observer/Actor. The term Representation is often understood as ”visual graphical representation”. In the EOD approach, this term is used in a broader sense, influenced by representation theory in physics: A Representation of an EO is a set of information independent of a carrier or coupled to a carrier, accessible by various methods like CAx, measurement and observation, or by physical impact. The results of such an access or interaction are resulting *property values*. The access to and/or the interaction with the Representation of an EO may also result in feedback to the Observer/Actor. The Description is of primary importance for the Observer/Actor. It is a motivation for his interaction with the EO and may be also its result. A Representation however is necessary for the process of interacting with the Enhanced Object. Representations are often – but not necessarily – concerned with geometry. A CAS or CAD model is one of several possible Representations and is therefore not *the* primary information about an EO within the engineering process network.

The granularity level of an EO (or the boundaries between EOs) depends on the Representation which is valid for an individual View of an Oberver/Actor on the product. According to the View of an Observer/Actor on a product, a certain Representation of the product is relevant for him, e.g. a picture of the complete product or CAD data of a part of it or even a sketch of a particular geometric curve. Therefore, the separation of EOs results from the Representations and not from the Views. Overlappings, e.g. logical combinations of EOs, are possible (but not in the sense of an assembly).

2.5 Description of enhanced objects by properties

The Description of an EO by properties raises the question whether a product can be completely described by an adequate set of properties. It is certainly possible for very simple products, such as standard parts like machine screws with a class list of characteristics in a parts catalogue. For a complex product, e.g. a car, a general set of properties that captures the interests of all persons who are or will be involved is not realistic. Although the structure of properties is rather complex, only a macro-structure will be given in this paper. Three levels may be considered for each property:

Generic level: General specification of the property. This level describes the *Type of property* (given by terms like e.g. colour, total length, proportion x:y, product character, and many others). Remark: An EO at generic level is compliant to the technical term ”Generic Component” as it is used in automotive product development.

Target/Intention level: Concrete statements / target values of the properties to be reached during the process are given. They describe the requirements in the package of a car (e.g. emission of CO_2 less than 130 g/km, etc.). This level describes the *Nominal property state*.

Estimation/Activity level: The measured, observed, or calculated values concerning identified properties due to a given Representation (e.g. colour = ”brilliant red”, total length = ”4567 mm”, product character = ”very sporty”, etc.). This level describes the *Current property state*.

A *Product Assembly* can be considered as a structure of EOs. In parallel, there are structures of properties and structures of functionalities. In EOD, the functionalities are considered to be a subset of more generally defined properties. Figure 4 shows a basic assembly structure of EOs.

The *Horizontal Property Dependencies* consider property dependencies within an EO or between several EOs on the same assembly level. An example may be the maximal angular momentum of an engine and the ability of the gearbox to handle such a high angular momentum.

The *Vertical Property Dependencies* connect EOs across different assembly levels:

- The influence of properties from parts/components on properties of a component/product on a higher assembly level.
- NEW properties evolve of assembled products or components (in Figure 4: property β of EO A) without any direct root in the property structure of the assembled parts. These properties (including functionalities) of the final product are relevant for the final user (customer). They are influenced by the properties of the components/basic parts in a very complex way which is often only known to a few very skilled engineers due to their vast experience.

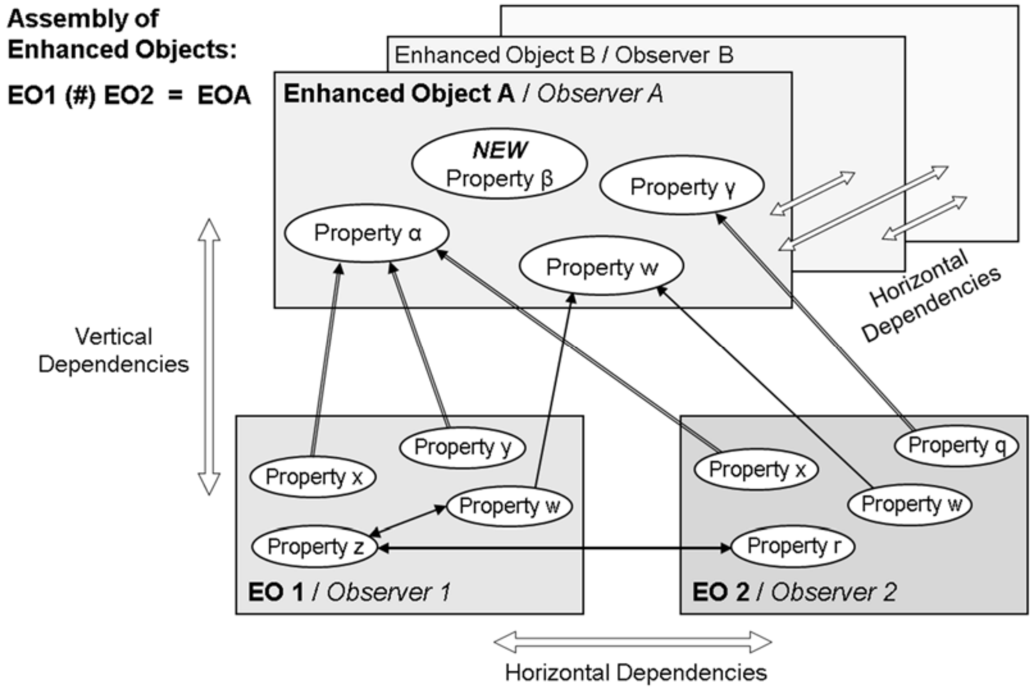

Figure 4. EO/property structure and dependencies/relations

A supplementary classification of properties from the Observer's/Actor's viewpoint on properties distinguishes between:

- *Objective Properties*: Values of objective properties are measurable. They can be estimated based on engineering fields (e.g. length, weight, maximal power of an engine, colour according to a standardised colour classification). Their property values are independent from the individual Observer; but it depends on the Observer's point of view whether a special property belongs to the Description of the EO.
- *Subjective Properties*: The estimation of values of subjective properties depends on the View of an individual Observer. Disturbing noises emitted by a product in operation may belong to this kind of properties, even though the level of noise can be measured as well as its frequency spectrum. In this case, the (property) noise therefore also has an objective level. The result of such an estimation is a Description, not precisely reproducible but usable for comparisons.

In Aesthetic Design, so-called *Emotional State Properties* belong to the group of subjective properties.

A further classification of properties from the viewpoint of interaction with an EO differentiates between:

- *Passive Properties*: The values of such properties can be estimated without any impact on or modification of the EO or change of the EO's position in the corresponding ES (e.g. the length of a part).
- *Active Properties*: To get values of active properties, a dynamic interaction with the Actor/ Observer is necessary (e.g. the directional stability of a car while driving). Product *functionalities* will be considered as active properties. In reality, a functionality of a complex product may be a combination of several passive properties and several active properties, e.g. the "feeling of safety" while driving, or the "sensitivity of a car" while driving at crosswind, etc.

The estimation of property values is of high importance for controlling the various processes. The following different levels have to be distinguished:

On the *Generic Property Level*, not only the type of property values is of importance but also the significance/relevance for the person involved (and for the considered process step).

On the *Target Property Level*, one differentiates between *design target* (must have values/set values) and *design intent* (not quantified objectives for the product supposed to be achieved by the design).

On the *Estimation/Activity Level*, the property values can be given directly within an EO and/or are derived from it (such as the present market price of a product) as a value currently valid for the EO.

The property values can be estimated by technical or physical measurement or calculation or observation of the product/part/component or its Representation (e.g. measure a distance in a drawing). For non-quantifiable properties the result of property estimation may be expressed in terms describing the impression/observation of an Observer. In the Description of an EO, the set of properties may list – depending on the situation – both target property values and actual property values in parallel.

3. Enhanced object-driven design towards application in IT

EOD mainly follows the industrial workflow but the approach shows possibilities also for the extension of current product and process information technology. The implementation of the ideas of EOD in new innovative concepts for the development of a new extended information management systems would be most advantageous for application processes. However, there are some unsolved questions concerning IT implementation. A primary objective must be to capture Enhanced Objects and Engineering States together with the related engineering process steps. Implementation in CAS/CAD systems, especially for EiR, demands the solution of problems in methodology and algorithms but is less challenging concerning information management.

From a pragmatic point of view, the identification of an EO is one main point for future implementation. IT methods have to capture the EO's identity including information such as an identifier, administrative and logistic information, or a revision state. Structural information – like the relations of EOs in various Engineering States at certain process steps, the assembly structure of EOs, their corresponding Description(s) by sets of properties and the Representations as well as the relations in between – is of high complexity. The structural information has to include also a generalised structure of Observers/Actors and a structure of Views (like a general concept of various ”viewpoints” which act as View filters for each of the Observers/Actors). The information about property structure and property values is an IT challenge concerning the identification of an EO. In addition, a information management system also has to manage the interdependencies and relations of EOs and their properties in assembly structures. Here not only the ”facts” have to be handled, but also the background, i.e. the engineering and algorithmic relations. This goes beyond ”classical” information management. Known examples of EO ⇔ property interdependencies have to be stored along with all information available, even if the background mechanisms of the relations are not known analytically.

In the following, a brief overview shows the status of implementation of the EOD approach within the Engineering Network concept which has been developed as part of already finished and actual running research projects.

3.1 Implementation of the EOD approach in the engineering network concept

The globalisation along the value chain, the need to continuously support the various phases of the product life cycle, the increasing importance of mechatronics, the continuous growth of embedded software and networked systems, etc. leads to an increasing product and process complexity. Because of globalisation, business units are nowadays scattered all over the world. The ability of a company's IT systems to integrate and to federate distributed product data and related processes as well as the administrative management of a large number of product variants are hence decisive factors for success, survival and competitiveness of a company. Although recent PDM systems and PLM solutions deliver first answers to these challenges, their use in practice is still limited.

To directly address the issues described above, the *Engineering Network concept* has been developed in the context of different research projects. The conceptual foundations for the concept have been laid in [Mogo Nem 2011]. On the basis of these results, a new generation of information management systems can be developed in the future, paving the way for a better control of product and process complexity and a more cost-effective management of product data and business processes.

EOD is embedded and used in the Engineering Network concept. However, when applying/using EOD in the context of IT/software development we will speak of *Enhanced Object-Driven Modelling (EOM)* to clearly differentiate between the worlds of Engineering design and software development/ implementation with regard to the usage of EOs. This distinction is also necessary because the usage of EOs in software development requires some IT-specific adaptions of the original EOD approach. The same applies to some other items defined in the EOD approach.

The *Engineering Network (EN)* consists of a new enhanced and flexible object-oriented meta-model and an appropriate framework for the modelling, structuring and provision of collaborative and integrated multi-disciplinary product data and engineering process models. The Engineering Network concept aims at reducing complexity by offering a flexible multidisciplinary information federation backbone and thus reducing the efforts and costs for implementing and customising PLM solutions. Moreover, the EN concept supports the mapping of data into data management systems [Mogo Nem et al. 2008], [Eigner and Mogo Nem 2009]. Product data models and engineering process models derived from the EN meta-model provide user-specific Views [Eigner et al. 2010] as well as flexible and variable development processes.

At the current state of the development, the formal frame of the EOD approach has been implemented to a large extent within the Engineering Network concept. A prototypical implementation of the data model and a first draft of the Engineering Network framework have been carried out. However, to realise EOD technically the viewpoint had to be changed from an Engineering design point-of-view to a computer science point-of-view. This posed some problems, because the functionality from the perspective of Engineering design should remain the same, but at the same time a technically clean implementation structure should be used. Figures 5 and 6 illustrate the different perspectives. In Figure 5, the structure of an product example with EOs, Views, properties and representations and the relations in between is shown from an Engineering design perspective. A special product, a car, is represented on top-level by an EO-1 with different Views on it (engineering design, marketing, CAA-design) and the corresponding sets of properties and Representations. Its assemblies, parts, particular elements, etc. are represented by further directly related, subordinated EOs (via “structure” nodes). The granularity level of each EO depends on the View of the involved person (Observer/Actor). A special feature in this context is that the properties and the product structure are attached below the Views. This makes sense from an Engineering Design perspective, but in reality and also on implementing-level there are no Views between product and subordinated parts, elements etc.

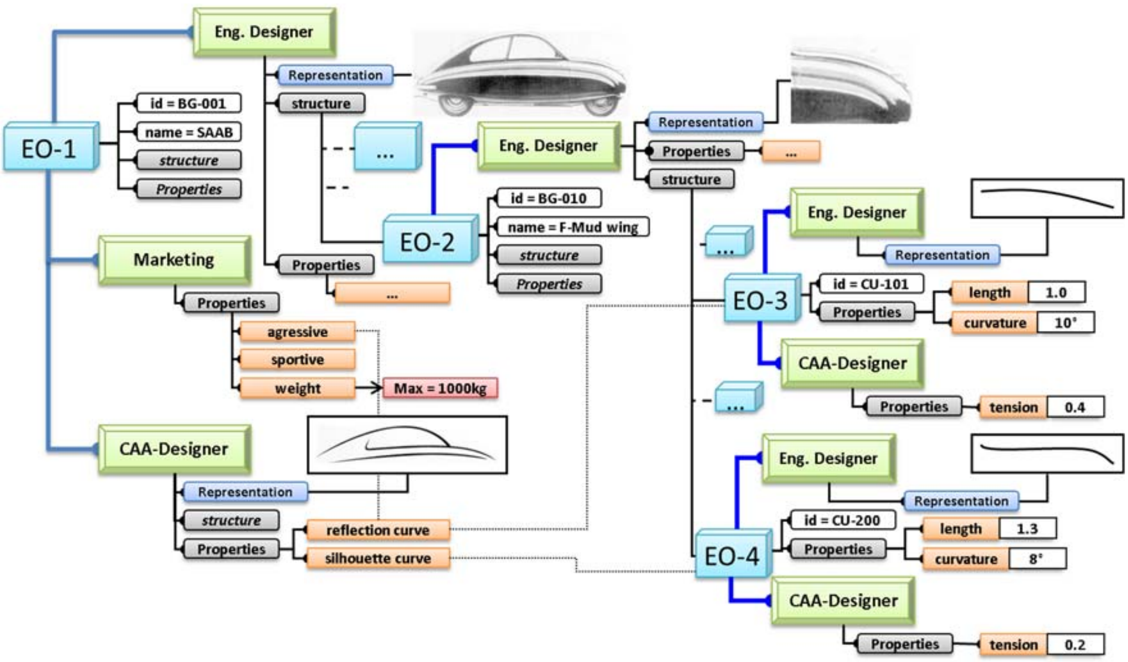

Figure 5. EO/property structure: Example from automotive aesthetic design (engineering design perspective) [Modeno]

In order to find a solution for the described issues from above, a structure as shown in Figure 6 has been developed. In contrast to attaching the EO's properties below the Views, both Views and properties are directly attached to the EOs and the Views include a reference to the corresponding EO's properties. This structure is navigated from an EO to its Views and then on to the corresponding properties. Additionally, View-specific properties have been added which enable the aggregation and storage of View-specific, EO-independent information (such as View ID, View-specific access control lists, etc.). Furthermore, the EOs maintain direct relationships with each other. Thus, the implementation is closer to a real product structure, but it lacks the ability to be navigated in the same way as an Engineering design perspective demands. To enable an Engineering design perspective compatible object navigation, the visualising software has to add some kind of virtual dummy nodes beneath the Views that serve in the same way as the "structure" nodes from Figure 5. Such a node exists if there is at least one EO on the next lower level of the product structure that has the same type of View as the actual View. The dummy node holds a link to the next lower level in the product structure and by this it allows an Engineering design perspective compatible object navigation.

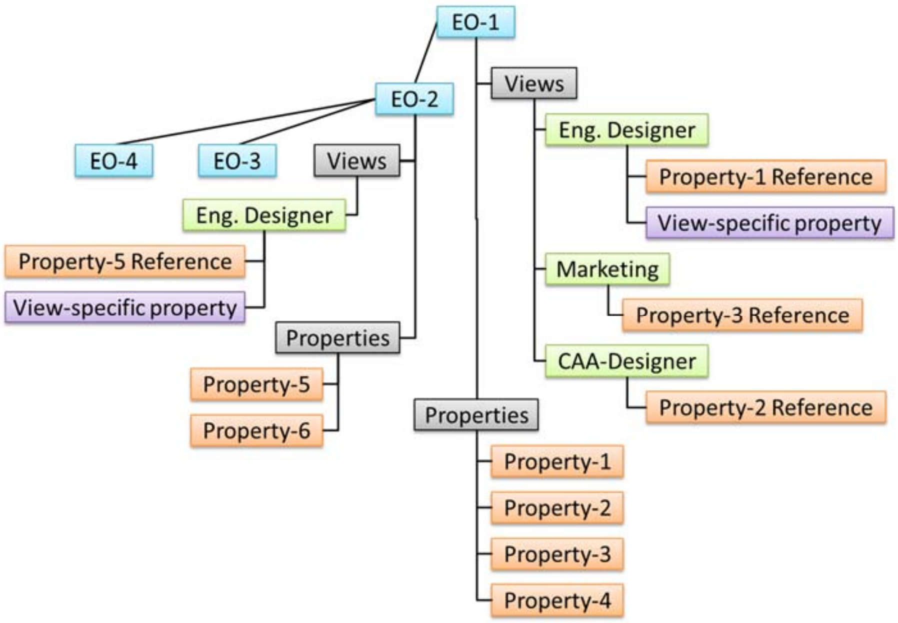

Figure 6. EO/property structure: Example from an implementation perspective

In general, the Engineering Network concept is based on two core components:

- *Enhanced Object component*: EOs are used for the modelling of product-related information and allow a user-specific, individual presentation of the data. Today different models are used for this purpose. Different disciplines (software, electronics, mechanics) have various different models. Some of them are defined in ISO 10303 (STEP). An EO is a virtual object which is fed by information from models of various globally distributed systems. The position of the "Viewer" determines which information is included. For this purpose, the EO component includes and offers "Viewpoints" which are linked by different "Views" to the virtual EO. By taking a "Viewpoint", a real object is created which holds and presents real data. Furthermore, an EO has properties which carry the specific values of the EO. The EO has interdependencies/relations to other EOs. Relations can be of types EO ⇔ EO, EO ⇔ Property, EO ⇔ View, View ⇔ View and Property ⇔ Property. The Property ⇔ Property relations are fully programmable and offer the possibility to attach algorithms, methods, etc. to them (e.g. to execute operations such as transformation, calculation, check, etc.). This for example allows an automatic update functionality by which a value change of the source property is automatically transfered to and/or compared with related properties (within definied and valid constraints. Exceeding the constraints has to stop the process). In addition, this enables also the application of Engineering in Reverse or Target-Driven Design, respectively.

- *Engineering Process component*: Engineering Processes (EP) are used to model the business processes associated with the EOs. In the EN concept, the assumption is made that there is a strong correlation between a product and its associated processes. Thus, the EO is the processes' data context. According to the concept of object orientation, a process is defined as a dynamic behaviour of an object. In EN, processes are therefore mapped to object methods and reside in the EOs. EPs can access other EOs by traversing the relationships between EOs. Thereby a process can change not only its own EO but also related EOs. In the context of Engineering design, EPs serve for capturing the various design processes and mapping them onto some formal and executable structure. According to the final execution of these structures further research is needed.

The following Figure 7 gives an overview of the core part of the Engineering Network architecture – the EN Federation Backbone Layer. The federation layer consists of several parts. First, there are the import and export interfaces that connect the layer with its own data store and external datasources. Second, the Engineering Network core module consisting of (a) the EN meta-model which can be customized and (b) the instantiated customized model that stores the concrete data according to the customization structure. The third part are the interfaces that enable access to the federated objects via an open SOA and a native .NET interface. Middleware or end-user clients can be docked on top of this federation layer. Within the EN meta-model, the meta-class EO-Type is used for modelling and specifying an EO. EO-Type also supports the modelling of an EO's Views with the meta-class View-Type. Relationships between several EO-Types are also supported in the meta-model. The Engineering Processes associated with an EO-Type are defined by the meta-class EP-Type.

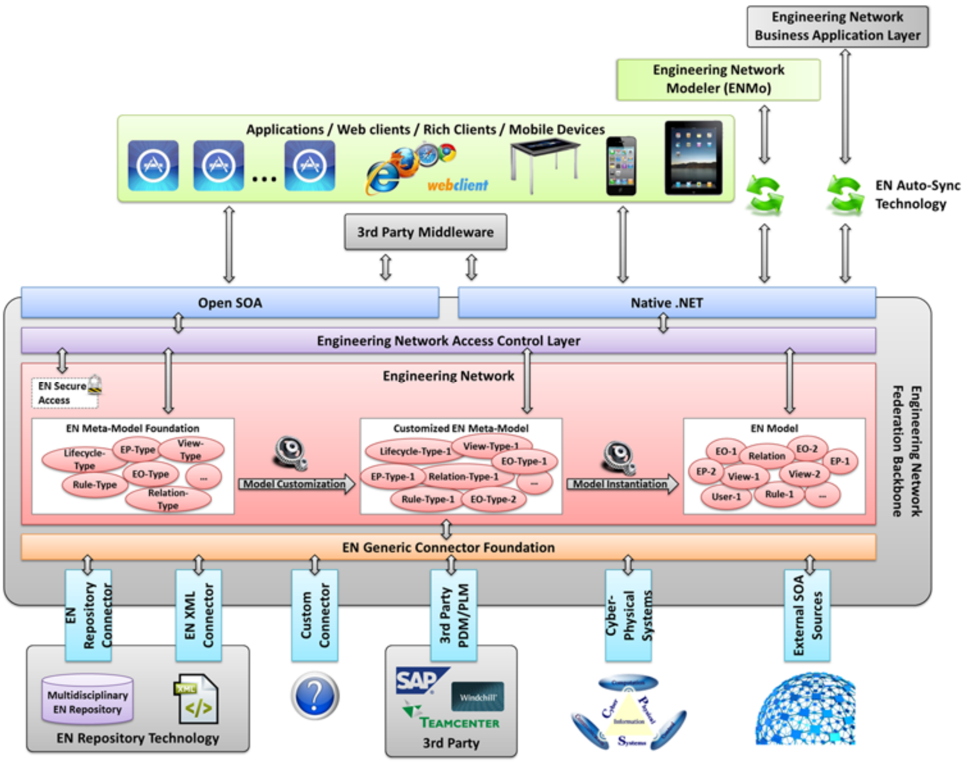

Figure 7. Engineering network federation backbone layer

For the realisation of the EN meta-model, the Microsoft .Net platform with C# as implementation language has been chosen. To store the data of the meta-model the Aras Innovator PLM software is used. More details about the EN concept can also be found in [Mogo Nem 2011].

The further development of the Engineering Network concept including EOD/EOM is the topic of several ongoing and future research and development projects. Within these projects, for example the relations between processes and EOs are studied regarding structural changes of a product (and corresponding EOs) and their effects to both inactive and running processes. Furthermore, research includes also aspects like how to interrelate properties with each other, e.g. how to connect properties of EOs from new additional product parts which are defined later during the process flow with properties of existing EOs from the early stages of the product development process.

4. Conclusions and outlook

The EOD approach presented here can be considered as a basis for efficiently capturing and managing product- and process-relevant information in Engineering design, thereby also including the persons involved, the so-called Observers/Actors. In the early stages of a PDP, the wishes and requirements of the final customer are the root of the process. Therefore, the conceptual phase – with definition of the target product properties and target functionalities (= requirements) – is based on the customers' wishes and needs. The way engineers think is influenced by the knowledge of these properties and their realisation. EOD allows the handling of product properties and therefore the industrial processes can be managed in a way that is closer to the initial interests and intentions of designers/engineers and customers. For this purpose, the approach introduces Enhanced Objects with a Description by a set of properties and with Representation(s), both depending on the Observer/Actor.

The authors would like to stress that the EOD approach is not a new design theory but describes new, engineer-oriented and customer-oriented ideas, fundamentals and methods for a better support of the engineer's target-oriented thinking. Hereby, one focus also lies on the support of Engineering in Reverse. Additionally, a key objective of the EOD approach is the improvement of handling and controlling the increasing complexity of modern products and their processes.

The discussion of the EOD approach leads to general research fields: description of industrial products and parts by properties and their corresponding integration in an industrial workflows. The multiplicity of parts and their related properties requires significant structuring and formalisation as a basis for controlling the dependencies between the various properties on the different assembly levels. As a consequence some extensions of classical information managment structures to include process control are obvious. Furthermore, there is a close relation to ”ontology” in computer science – not to be confused with the philosophic term ”ontology” (R. Goeckel, 1613).

The formalisation of properties including building a metric is the precondition for supporting process control, change and decision management, and also for Engineering in Reverse. It has already been solved for some special applications in Aesthetic Design. Therefore, there is the justified hope that the challenges concerning other applications fields also may be solved.

IT implementation of the formal frame of the EOD approach has been carried out by embedding EOs as well as the suppert of Design by Properties and View-based design in the Engineering Network concept. The EN concept provides a new enhanced and flexible object-oriented meta-model and an appropriate framework. This is a basis for the development of new innovative and extended solutions for a better management of complex product and process information in the future. Further, the EN concept provides the ability to capture and to reproduce the interdependencies and relations between EOs, Views and properties. This also supports to manage complexity in product development far better and helps to make the network of information much more transparent. The work on the EN concept is still in progress.

There are also interesting analogies between the EOD approach and Aristotle's ”substances” and its attribute ”categories” mentioned in his ”Categories” and ”Metaphysics” (384–322 B.C.) – this asks for future research as it goes beyond the scope of the industrially oriented approach presented here.

Although the EOD approach is based on experiences and results from former research projects and industry, further research is needed to solve open questions. E.g. the study of the relations between properties, and especially when they belong to different EOs, is subject of further research. Concrete use cases from industry have to be run and analysed to improve the concept and to validate its efficiency and functioning. Some possible applications of EOD are already in the course of being researched. Further, some expansions of the EOD approach to non-engineering fields are under discussion.

For some years now, the industrial importance of product description by properties has been strongly increasing. Therefore, the authors believe that there is a good chance for both EOD approach and Engineering Network concept to achieve broad industrial implementation because they represent new innovative solutions to the management of increasing industrial needs.

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