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ON THE CONTENT AND NATURE OF DESIGN OBJECTS IN DESIGNING

C. T. Hansen and M. M. Andreasen

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1. Introduction

In modern industrial product development it is very important for a company to focus the innovative efforts in order to develop products, which the potential customers and users recognize as being attractive and which result in a viable business case for the company. Traditionally the physical product has been seen as the core design object, but many different factors have made it necessary to expand this focus:

- Products have become multidisciplinary, i.e. there is a tendency to split designing up in disciplinary design tasks, each of which does not substitute a design object.
- Industry takes a total life concern, i.e. the situations and systems related to the product life phases have to be taken into account, appearing as things to be designed.
- The central role of the physical product is today mixed with important service and brand concerns of non-physical nature.
- The raison d'être of a product may be related to soft properties which cannot directly be related to the engineering of the product, but to other design objects.

These factors force us to make a revision of our mindset and design approach for properly capturing the interrelated set of design objects to be synthesised during the design activity.

Why do we propose articulation of 'design objects'? It appears that designing in industrial practice often is composed by multiple design objects. What are to be seen as design objects? Which properties of the 'ideal solution' should be allocated to what design objects? The product in itself or …? A distinction should be made between what is partial and what is a comprehensive and self-contained design object.

Different approaches have through the time been developed for answering what might be seen as a 'total life' approach; first of all Pugh's *'total design'-concept* [Hollins & Pugh 1990, Pugh 1991, Pugh 1996] where partial design activities are tied together and controlled by a product design specification. Pugh's idea is to let the engineering designer focus upon a totality of design aspects (all realisation-, life- and social/societal aspects) and bring them into a "complete" goal statement. However, a limitation of the concept is the narrow focus on the physical product as the design object.

The *product life approach* of designing has been developed by Olesen (1992), Mortensen (1999) and McAloone & Andreasen (2004), creating a theory of relations between product characteristics and characteristics and properties of product life systems. So here we see an expansion of the design object from being a physical product into a multiple set of life systems to be designed concurrently with the product.

A third approach has been opened by the authors of this article. Many important properties, important for the potential customer and to be understood and designed for by the designer, are actually not carried by the product in itself, but by activities and systems brought into relation with the product. A typical example of an important property is 'safe car', which in its formulation asks for single design object (the car), but which in its proper treatment in the design process needs explanation of the driver, the car operation, the maintenance, and the car in itself. The designer has to unfold these activities and see them as design objects, and what follows from this: designable objects.

The authors of this paper see a challenge to develop the idea of 'design objects' as a means to broaden engineering designers' understanding of what they are designing. Our aim is to deliver contributions to a totality of design concern, which can be seen as a productive mindset in contemporary product development. Thus, the objective of this research work is to create a better basis for innovative product development in industrial practice by embedding the idea of design objects into total design.

The structure of the paper is as follows: In section 2 we describe the total design approach in more detail, and in section 3 we make a brief description of product life thinking. In section 4 we propose 'design objects' seen as concrete 'to be designed objects', which the designer has to unfold in his imagination for being able to get a grip upon the product's behaviour and properties: we argue for the necessity of design objects, we describe the unfolding and utilization of a design object, and we discuss multiple design objects in the design process. In section 5 we discuss our research result. Finally, in section 6 we conclude.

2. The 'total design'-approach

In the early phases of a new product development project the design team is working in a situation of great uncertainty, where user needs or market opportunities, solution space and technological possibilities, design strategy and required resources are only vaguely comprehended. In this situation the idea of a 'total design process' is very intriguing. It is an attractive idea for a project leader to manage the design team's activities based on a holistic understanding of project status and alternative courses of actions. In this section we describe Pugh's total design concept [Hollins & Pugh 1990, Pugh 1991, Pugh 1996] and discuss its strength and limitation in relation to modern industrial product development and to more recent design methodology research.

Hollins and Pugh [1990] describe total design as "*a system for designing products up to the conceptual stage*." and "*it can be used for any manufactured product, not only engineering products*." The fundamental assumption behind Pugh's total design concept is that product development projects are carried through in large design teams. Hollins and Pugh write, "*large projects, such as the design of a car or a drilling platform …*" and "*design projects may have as many as 500 people taking part in the design process, and many of these may have contribution to make at any one time*." Such a large design team is seen as consisting of a series of radiating design circles. There is a main design circle with a product champion and managers, "*the managers meet in a design circle, as described, but then report back to their departments, which also operate as a design circle*." Thus, Hollins and Pugh state each design circle carries through *a partial design activity*, and the outcome of each partial design activity has to contribute to the product being developed.

The design circles may be seen as identified foci of design tasks whatever they are related to sub-systems or important goal statements. Two mechanisms are seen as the controlling mechanisms for integrating the design circles' contributions and results into a totality: The design process model and the product design specification. Hollins and Pugh write, "*The main design flow is from market to selling but demonstrates iteration. The design activity model provides the framework to which the designed product must relate. In this and earlier research it has been found that the majority of design models show the same sequential core stages, and these are therefore considered to be axiomatic*." Thus, the idea with the design process model is to ensure that all the persons involved in the product development project understand the progress and know when to deliver their contributions and results.

With respect to the product design specification (PDS) Hollins and Pugh write, "*The product design specification gives 'breadth' to the design and must be a full and thorough written document which covers all aspects of design*. It is the most important part of the design process." Although the product design specification must be a full and thorough written document it is not static in content, "*Although the PDS must utilize the latest information available, it may have to include some assumptions which later may be discovered to be incorrect. The PDS must be continually updated in the light of improved information*." Thus, in Pugh's understanding it is important to identify all aspects of design and to formulate product design specifications prior to searching for solutions.

The strength and limitation of total design

The important strength of the total design concept is the articulation that the engineering designers working in a product development project are carrying through partial designs. The result of each partial design task is not an end in itself. The result has to contribute to the product in such a way that the product will be recognised as attractive by the potential customers and users, and result in a viable business case for the company.

Although this observation seems self-evident, its explicit articulation as a mindset element is very important in order to remember the overall design goal when working hard with challenging details, as Pugh's dedication indicates, "*To all those engineers who have contributed to exciting projects that have failed on the market*." [Hollins & Pugh 1990].

The limitations of total design are in our perspective related to Pugh's belief in the upfront formulation of the product design specification. According to Pugh it is important to write a product design specification based on an analysis of user needs and market demands before searching for solutions. However, several empirical studies make us question this understanding. Dorst and Cross [2001] emphasize the co-evolution of the problem space and solution space. The core of designing is to develop an understanding of a problem and an understanding of potential solutions, and based on this understanding the engineering designer has to identify a suitable match of a problem/solution pair. Thus, the design problem and the product design specification do not come first as a result of an analysis.

Another limitation is Pugh's focus upon the physical product as the design object. It is evident that an unfinished, unreliable product leads to a disaster, but to focus on the product is not enough; its raison d'être may rely on results of other design activities. Today we see examples in industrial practice where the physical product is only a part of the company's business case, e.g. the company Apple has introduced the iPod, which is a device to play music. When a customer has purchased an iPod, the customer is offered to buy music in form of digital files in Apple's internet store iTunes. Thus, iPod and iTunes are equal important elements of Apple's business case. Roozenburg and Eekels (1995) write,"*The material goal* [what concerns the product] *is not the only objective of product development; it is not even the most important one. Business economic goals (profit, profitability) and also social and ethical objectives play an important role*." The authors of this paper question the possibility and practicability of formulating such a wide set of goals in a product design specification document, but exactly this problem is the core of our concern on multiple design objects: There are other design objects than the product.

3. Product life thinking

In the last decade a worldwide public focus on potential ecological disasters, e.g. global warming, has forced industrial companies to be concerned about their products through the total product life cycle: manufacture, distribution, sales, use, maintenance, and disposal. During the design process both the product's functionality and its properties with respect to manufacture, distribution etc. are determined. Product life thinking is both an established theoretical area and widespread in industrial practice. The basic idea is to integrate the concerns for each product life phase into the design process in order to obtain an optimal fit. Basic theories and methods are called DfX, i.e. design for specific life phases X like purchasing, manufacture, assembly, etc.

Product life thinking brings relevant life phase activities and systems into the design process as design objects, which are considered for more or less basic re-design. Olesen (1992) has formulated a theory describing the so-called dispositional mechanisms between the product's characteristics and the characteristics and properties of the life phase activities, i.e. a general theory of all DfX areas.

Linking product life thinking to the concept of this paper, the basic idea is, that the stakeholders in each life phase activity, as operators or managers, may articulate what they perceive as ideal properties of their actual activity, and these properties shall be build into the a goal statement. Olesen calls activity related properties for universal virtues and points to patterns of product life oriented thinking. Olesen proposes, for the sake of making the product life related design objects concrete, that they are perceived and modelled as *meetings*, i.e. as activities in which product, life phase system, operators and stakeholders *meet* and something happens: manufacture, distribution, sales, use, maintenance and disposal. It is up to the designer to decide which of these meetings can be seen as well-established and reusable, and which shall be the object of a design activity. It might be a new way of maintenance requiring a diagnosis system and special tools or a new way of disposal requiring a new disposal system design. Because this area has been treated in several papers before, we will not go into more details.

4. Design objects unfolded in the designer's mind

The product focus argued by Pugh, but enriched by his very broad spectrum of product properties supported by the product design specification, - and the product life thinking and its basic laws identified by Olesen, are easily understood by the engineers operating in design. It fits to their engineering world and professionalism. But how to expand this world beyond what cannot be engineered? Dankwort and Faisst [2009] write, "*Modern industrial processes require support from computer aids going beyond classical CAD/CAM. Today, the geometrically preoccupied engineering thinking dominates the virtual product generation processes. The here proposed concept overcomes these limitations of CAD by introducing* Engineering Objects." So it seems we need more engineering objects, but as we shall see, also objects which are not of engineering nature.
The authors of this paper see it as a challenge to change engineers' view upon their design task and responsibilities (and truly obtain real multidisciplinary designing); by mastering the identification and unfolding of relevant design objects. We therefore formulate and attempt to answer the following three questions:

- What points to the necessity of (new) design objects?
- How to unfold and utilize a design object?
- How to bring multiple design objects into the design process?

We use *the term 'design object' to describe what the designers are designing, i.e. 'design objects' are the 'to be designed objects'*. Traditionally the physical product has been seen as the design object. However, in modern industrial product development and from a methodical point of view it is necessary to expand the focus in order to take product life activities, service and brand concerns, and other important, but soft and non-engineering, properties into account during the design process. Some of these factors are not necessarily carried by the physical product in itself, and then 'design objects' are relevant. The designer necessarily has to foresee and design 'design objects' for being able to judge these factors and properties and for supporting the product in its life.

4.1 Necessity of design objects

Designing is guided by a perception of a human or societal need to be satisfied and goal statements, articulating what behavioural properties the ideal solution shall carry. A central problem is therefore: Are we able to design, simulate or reason about the behavioural properties, when we look upon the actual design model or synthesis result in front of us?

> As an example let us think about an overhead projector's contrast on the screen. When we use an overhead projector we want it to create a picture on the screen with high contrast to ensure readability of text and illustrations. But what product properties do contrast depend upon? The overhead projector in itself do not carry contrast as a property; only when the user arranges the overhead projector and the screen right and uses the projector to show the transparencies, the audience can see the text and illustrations on the screen.
> However, some product properties contribute to obtaining a picture on the screen with high contrast: the contrast on the transparencies, the quality of the lenses, the accuracy of alignment of the lens system, the precision of the sharpness adjustment mechanism and its ability to keep position, and for some overhead projectors even vibrations from the cooling blower play a role.

We see here, that the use activity and "use system", i.e. the arrangement of overhead projector and screen ready for operation, are actually the carriers of the property, we focus upon. So the reasoning about a certain important property and identifying the proper – and composite – carrier of this property seems to be central in this example, and therefore the necessity to see the use situation as a design object is evident.

Let us imagine a product development project where some engineering designers are working in a design circle, which is responsible for maintenance of the product. The engineering designers have studied and discussed the product design specification, and they have identified the relevant constraints. Thus, they have a shared understanding of the design boundary. Since the engineering designers see the product as the design object, the synthesis activity encompasses the search for solutions, which posses the property 'easy to maintain'. A good solution is found by carrying through an evaluation, where each solution proposal is evaluated with respect to maintenance, and the best proposal is selected.

Now, let us imagine the design circle again. However, this time the engineering designers are not concerned with 'easy to maintain', instead they have decided to formulate their design task as 'an easy maintenance'. What does the product life activity 'maintenance' consist of? First of all there is *the product* to be maintained, but there is also *a human operator*, who is using some *tools or equipment* to carry through the *maintenance operations*. Thus, when the design circle decides to design 'an easy maintenance' they have access to a much broader set of design characteristics than just the product. They have access to *the product*, *the human operator* with his/her *training and instructions*, the *tools or equipment* (e.g. screwdrivers, hammer and/or PC), and the *sequence of maintenance operations* as relevant design characteristics. Thus, this broad set of design characteristics constitutes the design object in this second situation.

Figure 1 shows the design object in the two situations. In the first situation (A) the physical product is seen as the design object and the important property is 'easy to maintain'. In the second situation (B) the totality of product, human operator with training and instructions, tools or equipment and maintenance operations constitute the design object and the important property is 'an easy maintenance'.

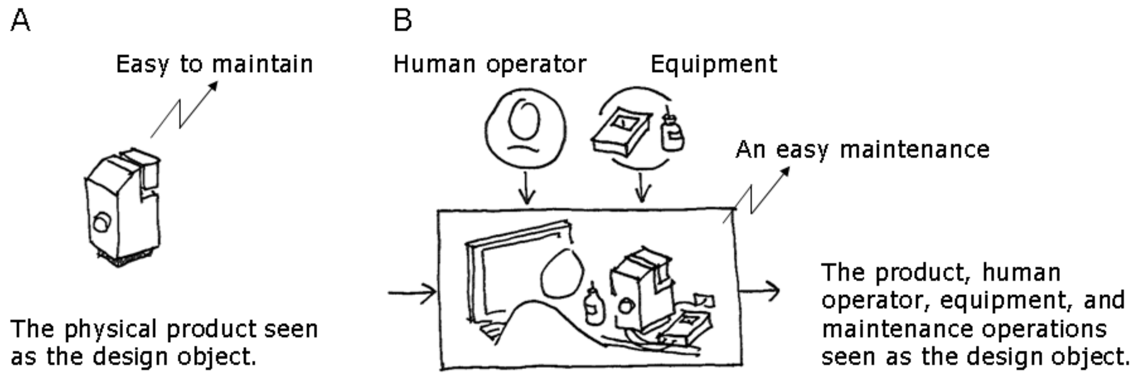

Figure 1. Two design situations with two different design objects

Seen from a product life perspective the example here is 'after the book': the engineering designers need to confront themselves with the composite design object (ideally seen), in this case to understand what really happens in maintenance operations, and to understand what is the meaning of 'an easy maintenance' in the eyes of the maintenance specialists, i.e. the human operator carrying through the maintenance and the maintenance manager.

In the first situation where the design object is narrowly limited to the physical product, the solution to be synthesised is *a technical solution*. In the second situation where the design object encompasses the product, the human actors, tools or equipment, and sequence of operations, the solution to be synthesised is *a socio-technical solution*.

When the design object is seen as a socio-technical solution we observe that it contains both characteristics of an engineering nature and characteristics of a non-engineering nature, e.g. training programmes and instructions. We believe that applying the concept of design objects consisting of product, human actors, tools or equipment, and sequence of operations in the design process increases the chance for synthesising better solutions.

In the example above we focused on maintenance, but of course maintenance is only one product life activity. In all product life activities, e.g. production, transport, sales, installation, use, maintenance, and disposal, we find the product, human actors (or stakeholders), e.g. production personnel, sales persons and potential customers, tools or equipment, e.g. production machines and shops for displaying the product, and operations or activities to be carried through.

4.2 Unfolding and utilizing a design object

Innovative and market conquering products are based upon smartness; to identify and utilize better, unique and realistic understanding of user needs and market demands than the competitors and to understand, where current approaches in-house may be the source of problems, see case below:

> Mira and Muñoz [2005] investigate the benefits of product and packaging integration through a case study in four industrial companies. One of the cases can be seen as a kind of worst case scenario in the sense that product and packaging redesign was not integrated and a good solution was missed.
>
> It is a Swedish company, it was founded more than 100 years ago, and it develops, manufactures, and markets petrol pumps. For many years the company's market was Sweden, and distribution of the pumps was performed by road and truck being a good and cheap solution. In the early 1990'ies after the breakdown of the Soviet Union the countries in Eastern Europe began to develop their economies, and new markets opened. The company decided to enter the new markets in Estonia, Lithuania, Russia, Ukraine, and Kazakhstan.
>
> The product is a 390 kg gasoline pump of 1.25 x 0.52 x 2.2 m, with a capacity between 40-130 liters/min. Mira and Muñoz write, "*This is the situation for* [the company], *but all these new situations have always new problems associated. Since the company did not have any previous experience of delivering pumps to these countries, they were unaware of the magnitude of loads and other environmental conditions facing the pumps during handling and transportation to the sites where they were to be installed. These problems originated several damages on the gasoline pumps during the distribution process (0.2 % of the pumps were damaged), thus some changes were demanded for the company to try to solve these problems and the subsequent damages*."
>
> In order to solve the problem with the damaged pumps the engineering designers focus narrowly on the pump, i.e. they consider the gasoline pump their design object. Mira and Muñoz write, "*The first idea the company had was to strengthen those parts of the pumps that were damaged. The reinforcements consisted of pieces of wood that are placed on the pump to support the sensitive parts of the pump. But this solution, even if it solved the damages, increased too much the cost of the pumps, and this increase was unacceptable for the company*." The outcome of this first idea caused reflection in the company, and Mira and Muñoz write, "*These circumstances and initial solution made the company learn an important lesson; an improved more effective load carrying package might be a cheaper and easier way of solving the problem*." Thus, we observe here a shift of focus from the gasoline pump to the package as a means to solve the problem with the damaged pumps. The company realizes that seeing *pump and package* as the design object in relation to distribution gives access to a better solution. Mira and Muñoz write, "*The action taken by the company was to enroll one of its engineering designers in a packaging design course and with this knowledge launch a new project to develop new pump packing that improves the properties of it. This reduction in costs and lead times is not available in a document but the company claims for its significance*." We see this case study as a piece of evidence to support the belief that applying our design object idea in the design process increases the chances of synthesizing better solutions.

Some design objects are of a socio-technical nature, i.e. consisting of product, relevant stakeholders, and tools or equipment and operations. For alternative socio-technical solutions, where the engineering designer has to take different stakeholder perspectives into account, it is not straightforward to evaluate which alternative is the best. Dorst [2006] formulates it as follows, "*For the solution to BE a solution at all it needs to be recognized as such in the contexts of all the relevant discourses (in practice this often means, first and foremost, that it should be acceptable to all the relevant stakeholders*.)" As a mental picture for unfolding relevant design objects one can reason on the nature of properties. Some properties seem to be carried by the product itself (like strength, reliability) and therefore do not lead to the definition of design objects; other properties are relational, it means that only when the engineering designer sees the product in relation to systems and/or activities they can be explained (like cost, which relates to both product and production system, and ease of use, which

relates to both user and product). Other properties again, e.g. brand identity, pride of ownership, style etc., are allocated to the product by different stakeholders and cannot be explained by looking only on the product.
From the gasoline pump and package case we see that there are some properties ‘close’ to the product, (e.g. weight of pump and capacity) actually measurable and easy to quantify and control by the engineering designer during the design process. But there are also other properties ‘distant’ from the product, but ‘close’ to the relevant stakeholders (damages on pumps during distribution) and the engineering designer has to take these 'distant' properties into account during the design process. Although these ‘distant’ properties cannot be directly controlled by manipulation and determination of the product’s characteristics, the engineering designer still has some options towards reaching an attractive, or at least acceptable, level of property value through the manipulation of characteristics belonging to tools or equipment, instructions, or sequence of operations, i.e. by manipulating the characteristics of a relevant and broad design object. Figure 2 illustrates the idea of ‘close’ and ‘distant’ properties based on the gasoline pump and package case. Some properties are ‘close’ to the product, e.g. capacity and weight. Other properties are ‘distant’, i.e. they are only indirectly (through other design objects or through stakeholders’ allocation) related to the product, e.g. ‘maintenance is easy’, ‘buying this brand’ or ‘Swedish design’.
Thus, to unfold and utilize a design object involves that the design team identify the broad set of characteristics of product, relevant stakeholders, tools or equipment, and sequence of operations or activities, and also identify the important ‘close’ and ‘distant’ properties. The identification of the broad set of characteristics opens for many excursions into the solution space. The identification of the important ‘close’ and ‘distant’ properties increases the chance of synthesizing a solution, which is acceptable and attractive to all relevant stakeholders.

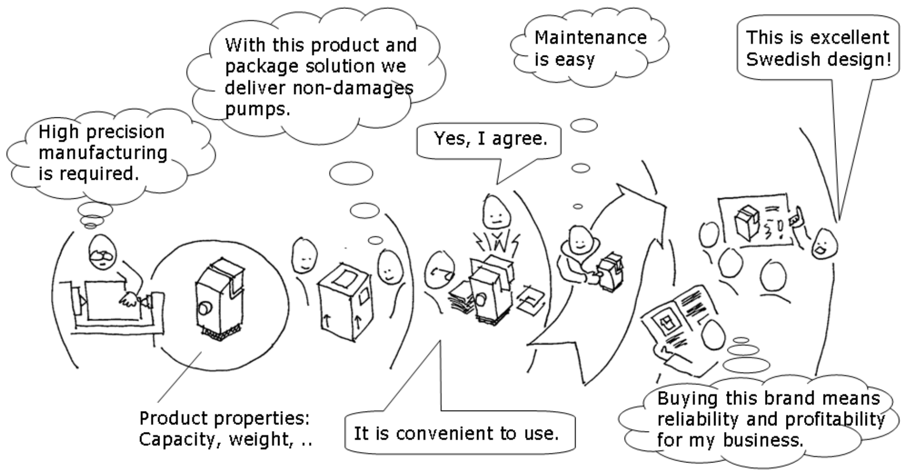

Figure 2. The different stakeholder perspectives broaden the spectrum of properties into ‘close’ properties and ‘distant’ properties

4.3 Multiple design objects in the design process

One of the main messages of this paper is that we have to treat goal statements properly. The risk is that designers by a shallow imagination make themselves content with the solution, without proper understanding of the stakeholders’ perceptions of value and ideal solution. The following example shows the necessity of unfolding a complex understanding and concern for being able to bring insight into the goal statement “high safety”.

When designing a car obviously safety is an issue. A car’s safety property is a composed property depending upon the driver’s ability and attitude, the car’s drive properties, and the car’s safety equipment, e.g. brakes, collision damping properties, activation and operation of airbags, and windows’ cleaning. Thus, when potential customers ask for “high safety” the automotive company has to recognize that this customer statement is not very distinct. The sales department might like to have special safety features, e.g. eight airbags compared to the competitor’s car model having only six, the engineering designers have to follow regulations form many countries at the same time, and the economy department may warn about high costs. In order to handle this safety issue we claim that there is a need for a good 'safety model', i.e. a model which can help to clarify: How is this car's safety to be composed? How good is it in different characteristic situations and for different stakeholders? What trade-off are the members of the 'safety' design team forced to make? Figure 3 shows many elements of such a 'safety model'.

We observe that a sufficient and comprehensive safety specification has to be composed: some specification statements are giving criteria like "high energy absorption", some specification statements are pointing to product characteristics "eight airbags", "tubular empowerment in doors", and some specification statements are pointing to stakeholder behaviour "encourage the driver and passengers to use seat belts".

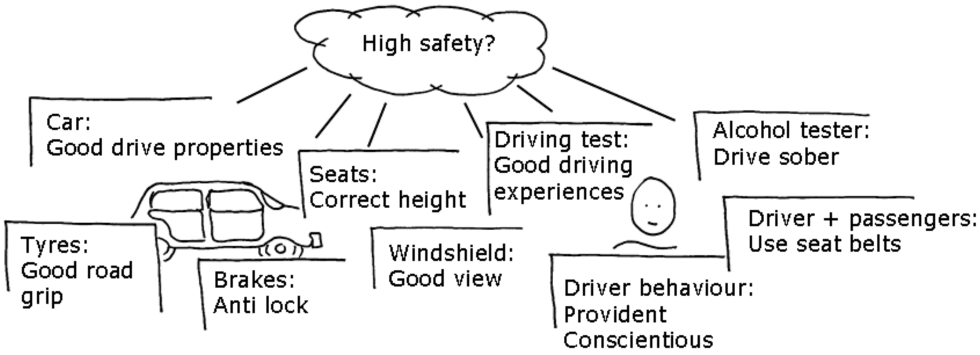

Figure 3. The customer statement "high safety" points to a very composed design object having both 'close' and 'distant' properties

To formulate sufficient and comprehensive product design specifications based on solely an analysis of user needs and market demands is not possible. The design team has to make excursions into the solution space and develop a "safety model". Thus, the core question is how to choose to solve the safety issue. When the designers have created some attractive "safety concept solution" proposals, it is the right time to start formulating specification statements. It is an illusion to specify first and search for solutions afterwards.

As mentioned earlier we see the co-evolution of problem space and solution space as a fundamental aspect of designing. It means that relevant, important design objects cannot all be identified beforehand, but demands a flexible, explorative and iterative design process. A central problem in designing is therefore design coordination, it means balancing and focusing upon proper design objects and bringing the results of their synthetisation and utilization into a solution with integrity. Figure 4 shows a speculative example of unfolding design objects.

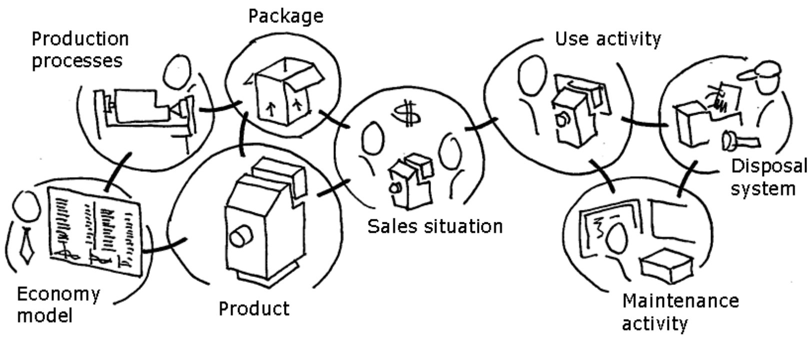

Figure 4. A chain of design objects linked to the product with stakeholders, preferences, and 'close' and 'distant' properties

5. Discussion

Most design models and procedures described in literature and used in practice, e.g. Cooper's stage gate model, are based upon the gradual determination of the physical product as the backbone. Other aspects to be analysed or synthesised are then "glued" to this backbone in a logical structure, based upon more or less strong causalities. An example is Andreasen & Hein's model Integrated Product Development, where activities related to need/market/sales and to production are positioned concurrently to the product synthesis.

The presentation above shows, that there are necessary expansions to how such design models seemingly force us to focus upon one or a few prescribed design objects, which call for additional design objects:

- Product life phase activities and systems.
- Product related deliverables as packaging, maintenance, etc.
- Objects carrying aspect or properties related to the product.

The last type is the most difficult one, because the way the product, stakeholders, activities and other systems are interrelated and by their interaction or behaviour create the actual aspect or property does not have a general nature. It depends on the actual, individual life destiny of the product – which is future at the time of designing!

The justifications for unfolding the complexity of more design objects are multiple. Engineering designers attempt to create an unlucky, too limited delimitation of their design task so that it fits to their professional background. Non-engineering aspect of products brought to the market may be decisive for the success and need their place in the design process. Realistic considerations on product aspects and properties cause for establishing good models of what might carry these aspects and properties. The authors of this paper have only found sparse notices and argumentation for design object expansion in the literature. However, we do not believe the phenomenon is neglected or unknown; we believe the authors keep their descriptions of designing simple for pedagogical reasons. Our reasoning in the article is based upon observations of engineering students' design activities, especially when it comes to realistic and demanding master projects, and is based upon our research work on a general understanding of a theory of properties: how to formulate goals, how to reason about properties during the design process, how to model design objects and how to evaluate.

6. Implication and conclusion

The most interesting implication of design object expansion is to bring a proper understanding to students and practitioners: what to tell them? The topic raises the dilemma: How to maintain the design activity simple, transparent and tractable and at the same time establish activities and creating results of multiple object-related concerns?

We see the topic as an important part of 'design staging', i.e. the activity to identify, planning, bring in resources, coordinating and motivations the actors, - just like directing a novice or staging a play. The problem with design object expansions is that so little can be based upon past experiences. What is important, necessary and must not be forgotten is related to individual, actual aspects of the new product to be designed.

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Claus Thorp Hansen, PhD
Associate Professor
Technical University of Denmark (DTU)
Department of Management Engineering
Section of Engineering Design & Product Development
Building 426, Produktionstorvet
DK-2800 Kongens Lyngby, Denmark
Telephone: +45 4525 6273
Email: ctha@man.dtu.dk
URL: http://www.kp.man.dtu.dk/