10. SYMPOSIUM ”FERTIGUNGSGERECHTES KONSTRUIEREN”
SCHNAITTACH, 14. UND 15. OKTOBER 1999

CONTRIBUTION TO A THEORY OF DETAILED DESIGN

Niels Henrik Mortensen, Mogens Myrup Andreasen

Abstract

It has been recognised, that literature actually do not propose a theory of detailed design. In this paper a theory contribution is proposed, linking part design to organ design and allowing a type of functional reasoning. The proposed theory satisfies our need for explaining the nature of a part structure, for support of synthesis of part structure, i.e. detailed design, and our need for digital modelling of part structures.

The aim of this paper is to contribute to a design theory valid for detailed design. The proposal is based upon the theory’s ability to explain the nature of machine parts and assemblies, to support the synthesis of parts and to allow the modelling, especially digital modelling of a part structure. The contribution is based upon Theory of Technical Systems, Hubka [4] , and the Domain Theory, Andreasen [9].

This paper is based on a paper presented at ICED 99, Mortensen [9], but focus on the designers reasoning during part design.

1 Introduction

The majority of resources, like time and costs, consumed in industrial product development can be related to detailed design, i.e. the materialisation of machine parts (German Maschinenteile). Existing design theories based on a systems approach, e.g. Haberfellner [5] all have function, i.e. transformation from input to output or ability to deliver purposeful effects as the core concept. The units in a product which posses functions are the organs (German: Funktionsträgern). Because individual parts do not posses functions, one could argue that the design theories based on a systems approach are not valid for detailed design. As a consequence of missing theory for detailed design, there exists only sparse methods in design methodology supporting detailed design.

2 Characteristics and properties

In this section a distinction between the attributes defining the design, the attributes describing the behaviour and the attributes describing the human perception of a design is seeked for. As a super class description of the "things" which are designed, the term unit is used in this paper. Unit is a recursive term, thus a unit can be complex, e.g. a whole design or simple, e.g. a subassembly, a machine part or a surface. During designing at least three classes of units are synthesised: the design (which after production will be a product or a family of products), the life phase systems (production, transport, service, application etc.) and the so-called meetings, Olesen [7] between the product and the life phase systems. To model these three units four classes of design attributes seem relevant. These four classes of attributes may be named characteristics, inherent properties, relational properties and qualities.

Characteristics are a class of design attributes, that the designers can determine directly during design. Classes of characteristics for a design are: structure, form, dimension, surface quality and material, Hubka [4]. Inherent properties are a class of design attributes which describes the behaviour of a design or a life phase system. Examples of inherent properties are strength, stiffness, stability efficiency etc. The inherent properties are causal determined based on the design characteristics and the environment. Relational properties are design attributes which describes the behaviour of the so-called meetings between the design and the life phase system. Relational properties are causal determined based on the characteristics of the design, the life phase system characteristics and the meeting characteristics. Examples on relational properties are costs, throughput time, flexibility etc.

One might argue that all properties are relational in the sense, that all inherent properties depend on the design characteristics. However, the distinction between inherent properties and relational properties seems purposeful because in order to build in relevant relational properties both the design, the life phase systems and the meeting have to be explicitly and consciously designed, whereas the environment normally can not be designed but have to be taken in to consideration.

Quality, e.g. pride of ownership, can be contemplated as the stakeholders reaction on inherent and relational properties. This means that quality is not inherent the design, the life phase system or the meeting, thus determining quality requires a person observing and reacting. The main difference between properties and qualities is that design characteristics and properties are related in a causal way whereas there is no causality between properties and quality.

3 Constitutive and behavioural model viewpoints on designs

According to the Theory of Technical Systems, Hubka [4] and the Domain Theory, Andreasen [1] four model viewpoints on a design is necessary to explain constitutive and behavioural aspects: process, function, organ and part viewpoint. The four model viewpoints seems to be related to different units being synthesised: the meeting (process) and the design itself. Dividing the four viewpoints models into constitutive and behavioural models. The figure illustrate the attempt to create a parallel between the three model viewpoints, i.e. to identify a behavioural aspect of all these viewpoints. In section 5 we shall take a closer look on part behaviour.

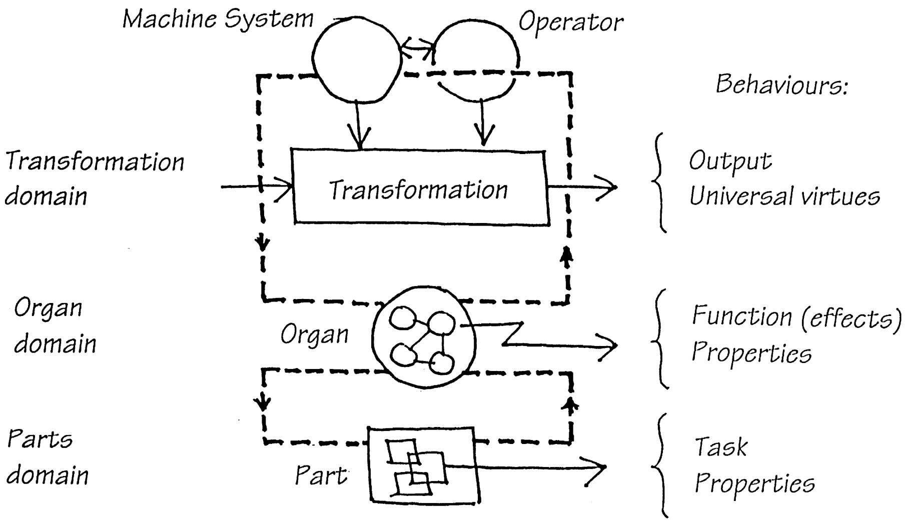

Figure 1: The Domain Theory, Andreasen [10]

The meetings as model unit: During design the meeting between the design and life phase systems are designed. A process plan can for example be seen as a constitutive description of the meeting between a design and a production system. The behaviour of the meetings can be contemplated as processes in the Domain Theory and the constitutive description of a meeting is designated a technology, cf. figure 1.

The design as model unit: According to the Theory of Technical Systems the design can be modelled from two constitutive viewpoints: organs and part viewpoint. The two constitutive viewpoints are necessary for explaining the behaviour of a design and the physical realisation. The organ models describe the units which posses functions, and the parts model describes the units which are a realised in a sequences of production processes, i.e. a process chain. The purposeful part of organ behaviour is designated functions, i.e. the ability to deliver purposeful effects. In Theory of Technical Systems there is not identified an explicit behaviour concept for parts. It seems necessary to do so in order to be able to specify the soll-behaviour of a part before synthesis and after synthesis to evaluate the ist-behaviour of parts. The behaviour and functions of parts is the topic for section 5.

4 Part constitution

When a part has been design it is defined by means of four classes of design characteristics: form, dimension, surface quality and material, Hubka [4]. The part design theory which is seeked for here shall not only be able to model the final results but also to describe the part in various stages "from 0 to 1", i.e. from the stage where no design characteristics have been determined to the stage where the part is completely defined. When designing a part there are the following types of influences:

- The part deliver wirk elements for one or more organs, i.e. when we “read” the part, and we may trace its wirk elements
- The part is materialised and serve duties during its life phases, i.e. the part has both causes and consequences from life phase meetings
- The part itself is defined by characteristics as introduced in section 2.

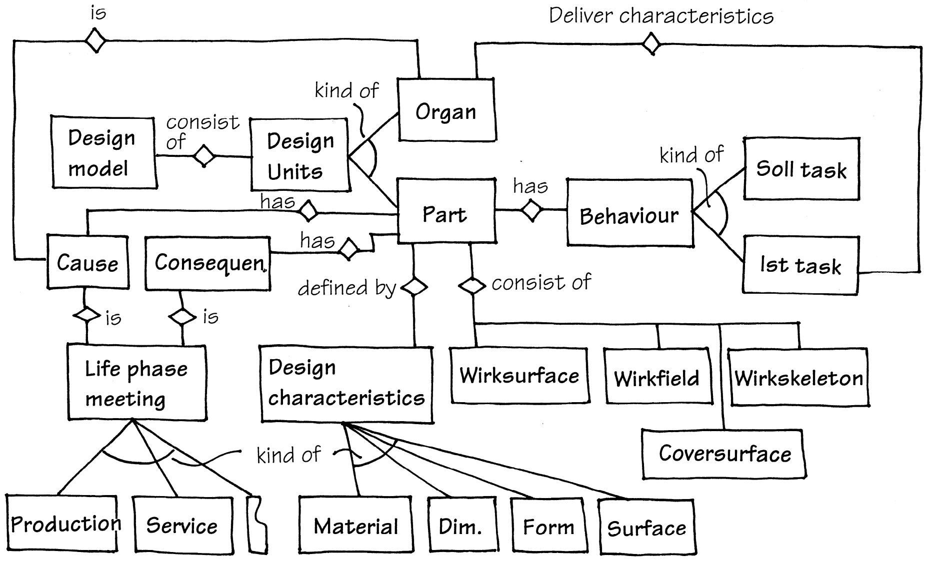

Figure 2: Part constitution

Ersoy [3] has in his efforts to create a theory of part design introduced the concept of wirk elements to define part, but has not decided on a necessary and sufficient number of wirk elements to define a part. In English wirk can be translated to mode of action. To underline the German origin and because mode of action surface, mode of action material etc. sounds awkward, the wirk concept is utilised here.

A part can be contemplated as an elementary materialised unit, which is realised in a sequence of production processes without assembly processes. Figure 2 shows an entity-relationship model of a part. Seen from a constitutive viewpoint the part consists of wirk surfaces, cover surfaces, wirk field and wirk skeleton. A wirk surface is a surface which contributes to realisation of an organ an thereby its function. The wirk field is the "glue" which keeps the surfaces together. Cover surfaces are free surfaces, Tjalve [8] that do not directly have functional contribution. These surfaces are free in the sense that they can be changed without changing the functional contribution to organs. A skeleton is a spatial reference system, which carries the relations between surfaces and material fields. The super system parts are assemblies. A part has a reason and a consequence. The reason for a part is an organ and the consequence is sequence of production processes or other meetings during the design life.

5 Definition of part behaviour

There are at least two possibilities for defining the functionality of a part:

1. Parts can be contemplated as units which creates organ characteristics, e.g. dimensions, tolerances, material field with correct spatial and wirk relations.
2. Parts can be contemplated as units which only posses internal properties, Hubka [4], e.g. strength, stiffness, corrosion properties.

Both concepts seems to be relevant for parts. The purpose of a part can only be validated by the contribution to creation of organ characteristics and a precondition for being able to deliver organ characteristics is that the part posses relevant internal properties. Therefor it seems appropriate to work with two type of behaviours for parts, i.e. function and internal properties even though it appears paradoxical that the ability to deliver organ characteristics is contemplated as behaviour.

To make it explicit that organ and part behaviour by nature is very different it has in concert with Andreasen been chosen to designate part behaviour, part task. A part tasks can be defined as follows: A part’s task is by me means of design characteristics to deliver correct organ characteristics, thus correct organ functions are created. Figure 3 shows an example of tasks for parts in a hole puncher contributing to a punching organ which determines the properties of the holes in a sheet of paper.

6 Explaining synthesis of parts

A consequence of the design characteristics defining a part, three elementary classes of synthesis patterns can be described: concretisation, detailing, decomposition/composition. Concretisation is the process where more characteristics are gradually determined.

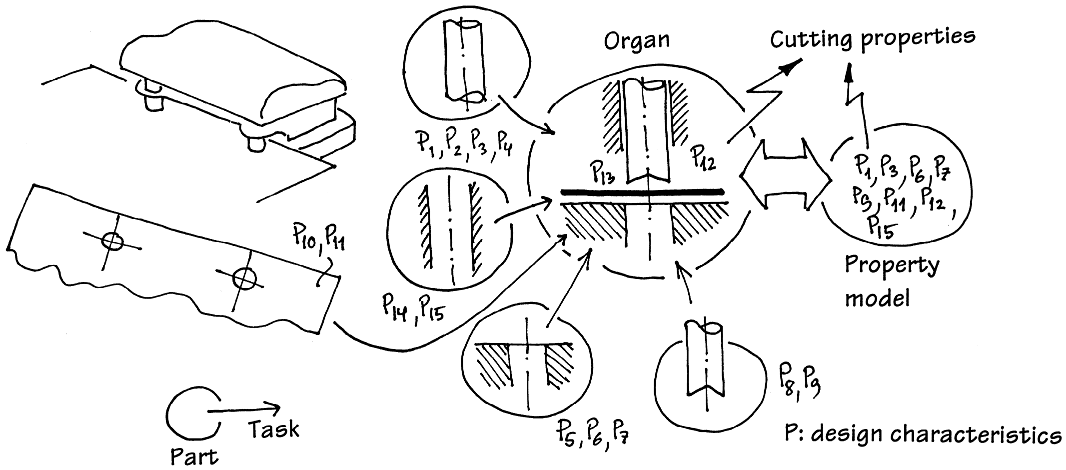

Figure 3: Part tasks

Detailing is a process where more parts or part units (wirksurfaces, wirkfield etc.) are determined. Composition is the process where more part units are integrated to an entirety and decomposition is a process where a part is decomposed into more parts, e.g. governed by the choice of assembly method. More complex synthesis operations are choice of Bauweise, superimposing organ structures in a part structure and opportunistic synthesis, which will be explained further.

Choice of Bauweise: Jakobsen [6] has identified the interplay between choice of production method, form and material. The three characteristics can not be chosen independently and there does not seem to exist a certain sequence in which the characteristics are chosen. The decisions are concerned with the entirety and afterwards the feasibility of form, material and production methods are controlled. The entirety might be named a Bauweise, Andreasen [2]. A Bauweise is a known and proven solution where form, material and production method is chosen.

Superimposing organ structures in a part structure: An important difference between an organ structure and a part structure is that a design can be modelled as organs from different viewpoints whereas the part structure seems to be unambiguously defined. When a design is modelled based on solid state mechanics theory the organ model consist of beams, column, plates etc. When a design is modelled based on vibration theory, the organ model consist of masses, dampers, springs etc. These patterns seem to be valid also for other property theories. The part model is from a task point of view completely defined when the design characteristics: structure, form, material, material and surface quality are determined, Hubka [4]. The design of a part can therefor be seen as superimposing different organ models into a part model, i.e. it is decided which wirk surfaces and wirk fields that shall belong to each part.

Opportunistic synthesis: In this pattern the designer uses already existing surfaces and wirkfields for establishing other tasks of for a part. This means that the same part normally delivers several tasks. Opportunistic synthesis means to utilise existing units of a part as basis for realisation of other tasks.

7 Conclusions

The paper has identified a need for distinguishing between two types of functionality of designs, functionality of organs and functionality of parts. It is proposed that a part functionality is defined as the ability to deliver corrects organ characteristics. It has been proposed that a part can be contemplated as consisting of wirk surfaces, cover surfaces, wirk fields and wirk skeletons. A consequence of this is that a part can be gradually determined, thus it is a step towards identification of a part concept. Identification of a part functionality contributes to the domain theory, thus a complete functional reasoning pattern from individual parts to the purpose of a machine is possible, i.e. parts deliver tasks to organs which deliver functions to the meeting, thus a process of an operand is completed.

References

[1] Andreasen, M.M.: Machine Design Methods Based on a Systematic Approach - Con tribution to a Design Theory, Diss., [In Danish], Department of Machine Design, Lund Institute of Technology, Sweden, 1980.

[2] Andreasen, M.M.: A Sketch for a Baweise Theory, Proceedings of WDK Workshop Fertigungsgerechtes Konstruieren, Universität Erlangen-Nürnberg, Erlangen, Germany 1992

[3] Ersoy, M: Wirkfläche und Wirkraum. Ausgangselemente zum ermitteln der Gestalt beim rechnergestützten konstruieren, Diss, TU Braunschweig, 1975

[4] Hubka, V. & Eder, W.E.: Theory of Technical Systems, Springer-Verlag. Berlin, 1988.

[5] Haberfellner, R et al: Systems Engineering, Verlag Industrielle Organisation, Zürich 1995

[6] Jakobsen, K.: The Interrelation between Product Shape, Material, and Production Method, proceedings of ICED 1991, Heurista, Zürich 1991

[7] Olesen, J et al: Design for Environment (Danish: Miljørigtig konstruktion, UMIP-udvikling af miljørigtige industriprodukter), Dansk Industri 1996

[8] Tjalve, E.: A Short Course in Industrial Design, Newnes-Butterworth, London 1979

[9] Mortensen, N.H.: Function Concepts for Machine Parts – contribution to a Theory of Detailed Design, Proceedings of ICED 99 (U. Lindemann et al editors), Technical University of Munich, Germany 1999

[10] Andreasen, M.M.: Conceptual Design Capture, Proceedings of Engineering Design Conference'98, Brunel University, 1998

Assistant Prof. Niels Henrik Mortensen
Technical University of Denmark
Department of Control and Engineering Design
Building 358
Phone: +45 45 25 62 75
Fax: + 45 45 88 14 51
E-mail: nhm@iks.dtu.dk

Prof. Mogens Myrup Andreasen
Technical University of Denmark
Department of Control and Engineering Design
Building 358
Phone: +45 45 25 62 58
Fax: + 45 45 88 14 51
E-mail: myrup@iks.dtu.dk