An Approach Towards Considering Technical and Economic Aspects in Product Architecture Design

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Abstract

This work describes a general methodology for the analysis and design of product architectures. The methodology unifies two already existing methodologies, one focusing on technical aspects and another focusing on economic aspects, by considering both the technical and economic aspects.

The methodology proposed in this work is integrated in the chromosome model. The modelling is done in an object-oriented software environment.

Keywords:

Product architecture, product structuring, design methodology, design history, product modelling.

1 Introduction

This work aims to develop a methodology towards the analysis and design of *product architectures*. To start with we would like to define what product architectures are and why a methodology, and even a computer tool, are needed to create those.

A product architecture can be defined as the way in which the functional elements of a product are arranged into physical units and the way in which these units interact (Ulrich and Eppinger, 1994). So it is quite obvious that all products have some kind of architecture, even if it not necessarily have been considered during the design phase.

Many factors influence the choice of product architecture. The large amount of information, especially when designing complex products, makes it difficult to survey all important aspects. Therefore a methodology which helps to structure the information is needed.

Due to the large amount of information to be handled, it seems to be a great advantage to implement the methodology in a computerized environment. The information can then easily be captured and modified later on, if a re-design is needed.

The methodology, which is described in this paper, is a unification of two other methodologies dealing with product structuring; namely one which mainly consider the technical aspects (Pimmler and Eppinger, 1994) and another which mainly consider the economic aspects (Erixon et al., 1994). This unification is to be seen as a first step towards a holistic approach to product structuring.

Two types of product architectures can be recognised; modular and integrated architecture (Ulrich and Eppinger, 1994). A modular architecture includes a one-to-one mapping from the functional elements to the physical components, and specifies a de-coupled interface between components. An integral architecture includes a complex mapping from the functional elements to the physical components and coupled interface between components (Ulrich,1995),

2 The Product Architecture Design (PAD) Methodology

The goal of using the PAD methodology is to determine a product architecture, as good as possible, by clustering different organs (function carriers) to organisms, which are a group of organs showed in Figure 1. By doing the clustering the designer decides if an integral or modular architecture is created. The intention of the PAD methodology is to provide a support during the conceptual design phase and thereby, as early as possible, consider the product architecture.

The PAD methodology includes the following steps:

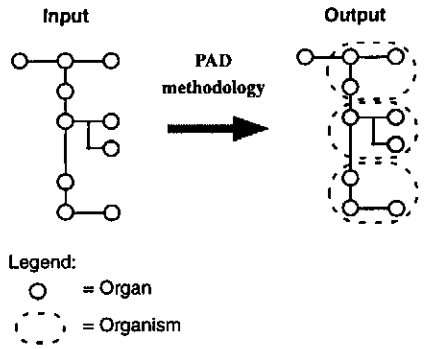

Figure 1: An organ structure where organisms have been created by clustering organs using the PAD methodology.

1. Establish an organ structure (Hubka and Eder, 1992), which is the input to the PAD methodology.
2. Investigate and score the interaction between different organs, considering the technical aspects; material, energy, information and spatial relationships (Pimmler and Eppinger, 1994).
3. Investigate and score the economic aspects for each organ in terms of e.g. carry over, variant design, manufacturing, upgrading and other aspects, for or against a modular design (Erixon and Östergren, 1993 and Erlandsson and von Yxkull, 1993).
4. Create a "Lanner-matrix", which is an Interaction Matrix (Pimmler and Eppinger, 1994) extended with the score of the economic aspects in the diagonal elements.
5. Generate alternative proposals for the product architecture by rearranging rows and columns in the matrix.

2.1 Establish an organ structure

The initial step is to establish an organ structure, which is a part of the chromosome model (Andreasen, 1992). A chromosome model is actually not necessarily needed to determine a product architecture, but as it is a strong theory for product modelling, we prefer to base our approach on a chromosome model.

2.2 Investigate the interaction between organ

The investigation of the interaction between organs is based on a methodology for the analysis of product design decompositions (Pimmler and Eppinger, 1994). After the organ structure is established the interactions between each organ are analysed and documented. Instead of organs Pimmler and Eppinger (1994) use the more general term elements, which can represents both organs and components. Pimmler and Eppinger propose four important types of interactions between elements to be analysed. These interaction types are as follows:

Spatial: A spatial-type interaction identifies needs for adjacency or orientation between two elements.

Energy: An energy-type interaction identifies needs for energy transfer between two elements.

Information: An information-type interaction identifies needs for information or signals exchange between two elements.

Material: A material-type interaction identifies needs for material exchange between two elements.

All interactions can be quantified on a five-point scale from (-2) to (+2), there; score (-2) is detrimental, score (-1) is undesired, score (0) is indifferent, score (+1) is desired and score (+2) is required interaction. The scores are used in one the following stages there an extended Interaction Matrix, here called "Lanner-matrix", is created.

The goal of the investigation is both to quantify all four interaction types and give a verbal description of the interaction. The result shall be documented and have the content showed in Figure 2. While the documentation are written, also design history is created. Therefore, a function description of each organ is included, which will make it easier to capture the information in the future. The function descriptions are simply retrieved from the function domain in the chromosome model.

Organs:	**Load bar and Strap**		
Function: (Load bar)	The load bar carry the load from beneath.		
Function: (Strap)	The straps tighten the load to the load bar.		
Relationship:	The force in the straps results in a force which squeeze the load to the load bar.		
Score:	Spatial: +2 Information: 0	Energy: 0 Material: 0	

Figure 2: An example of documentation of the relationship between two organs; load bar and strap, from a roof rack (Lanner, 1995).

2.3 Investigate the economic aspects of the organs

The investigation of the economic aspects of the organs is based on a method by Erixon and

Östgren (Erixon and Östgren, 1993), called MFD (Modular Function Deployment). The first step using MFD is to treat each sub-functional solution, organ, like it was a separate module and analyse the relations to some certain *module criteria*. The relation can be expressed as; strong, medium or some relation between an organ and a module criterion, i.e. examine to what degree a n organ really have to be a module. The relations can be quantified by using numerical scores, there; (9) is strong, (3) is medium and (1) is some relation. In a MFD matrix all relations can be investigated, see Figure 3. In the figure a proposal for module criteria is also showed (Erixon et al., 1994).

Module criteria		Organs					
		Organ 1	Organ 2	Organ 3	Organ 4	Organ 5	Organ 6
Development	A) Carry over	1		3	3		9
	B) Technical development		9		1		
	C) Product plan		9	9	3	9	
Product variants	D) Different specification	3	3				9
	E) Styling part			1			
Manufacturing	F) Common unit	3			9	3	
	G) Process / Organisation					3	9
Quality	H) Testability		3	9	1		
Purchasing	I) Vendor exist		3	3	3		
After sales	J) Maintenance / service		9	9			
	K) Upgrading		9	9			3
	L) Recycling	3				1	

Figure 3: An example of a MFD-matrix adapted from Erixon and Östgren [3].

The MFD matrix gives a good picture of which organs that have one or more reasons to form modules (Erixon and Östgren, 1993). It also tells which of the organs that have the strongest motive of becoming modules.

2.4 Create a "Lanner-matrix"

Based on the scores of interaction between different organs and the scores of MFD we can now create a "Lanner-matrix", which is an extension of Pimmler and Eppinger's Integration Matrix (Pimmler and Eppinger, 1994).

The scores of interaction are placed in the nondiagonal elements. The scores from the MFD, which are the relations between organs and module criteria, are placed in the diagonal elements. See Figure 5.

In the "Lanner-matrix" information concerning both the technical and the economic aspects has been quantified. An advantage of that is that all information have been gathered into one matrix, on the other hand the matrix becomes quite cluttered. The way to get something out of the "Lanner-matrix" is to regard only the primary information at the initial step and then also consider the secondary information. How this is done is described in the next section.

2.5 Design a product architecture

The product architecture, or a suggestion of a product architecture, is designed by clustering organs into organisms (or chunks, using Pimmler and Eppinger's terminology). Before doing the clustering the rows and columns must be rearranged concerning only the primary information independent of other information. Which information is primary, depends upon the nature of the product being designed. For example when designing a mechanical transmission system, energy interactions might be of primary importance.

Let us now assume that the spatial interactions are of primary importance and rearrange the matrix established in Figure 4 independently of other information. The rearranging aims to amass high scores (+2) to the diagonal, which is essential for the clustering. The result of the rearranging and clustering can be seen in Figure 4.

	O2	O3	O1	O5	O4	O6
Organ 2 O2						
Organ 3 O3						
Organ 1 O1						
Organ 5 O5						
Organ 4 O4						
Organ 6 O6						

Figure 4: Clustering of organs regarding spatial interactions. For previous state see Figure 5.

This clustering results in the initial organisms as follow:

- **Organism 1** consists of organ 2, organ 3 and organ 1.
- **Organism 2** consists of organ 1, organ 5 and organ 4.
- **Organism 3** consists of organ 4 and organ 6.

The independent clustering is to be seen as preliminary. For determining the definitive clustering the earlier disregarded information must also be considered. The overlapping areas in Figure 4, covering organ 1 and organ 4, indicates

interface location between organisms. Here, the module criteria can play an important role, helping to decide to which organism an organ should belong to. If there is a conflict between module criteria in an organism, a split of the organism can be a solution. Even the scores of other interaction types, than the primary investigated, should be observed. A negative interaction score in an organism might require another clustering, or is at least a warning to the designer. Figure 6 shows all information after the initial clustering.

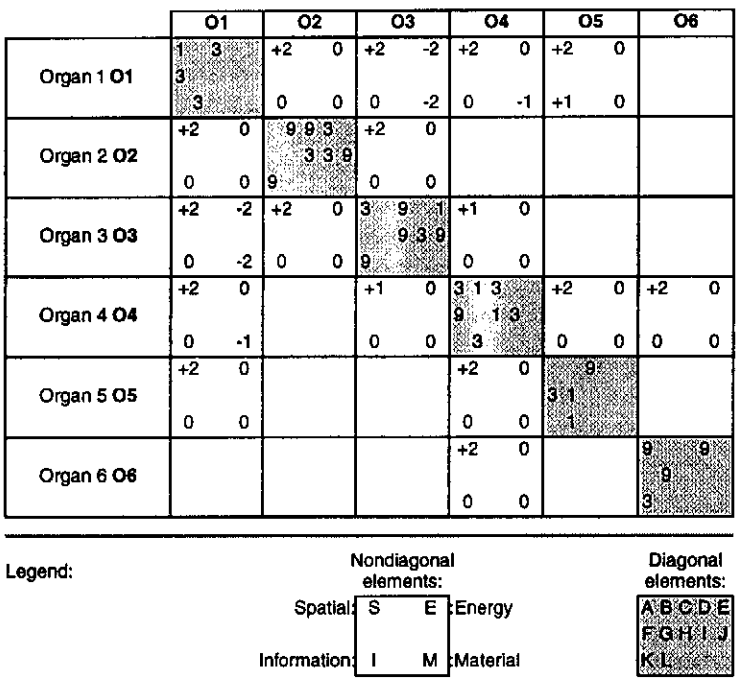

Figure 5: An example of a "Lanner-matrix". The position A to L in each diagonal element represents the module criteria, see Figure 3.

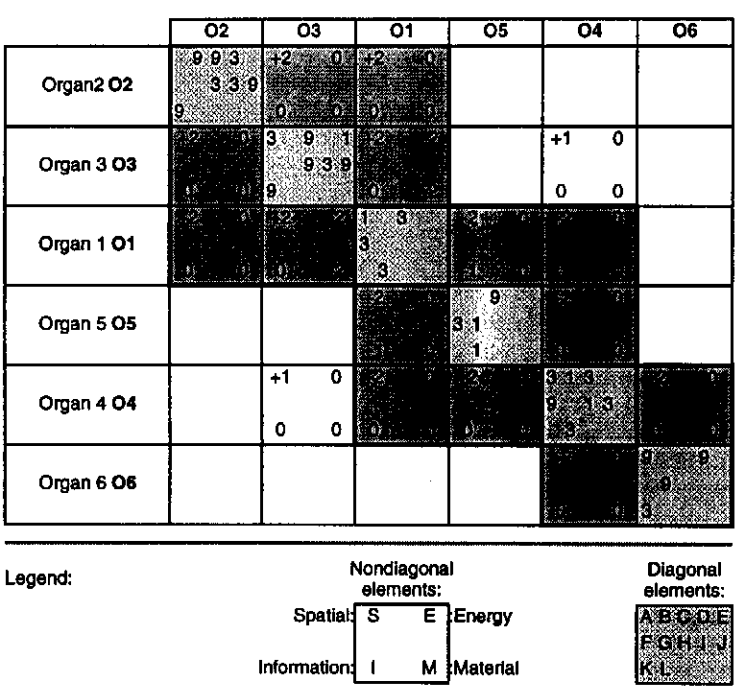

Figure 6: Clustered "Lanner-matrix".

The matrix in Figure 6 makes it possible to consider all interaction types and economic aspects in terms of module criteria. After this consideration a suggestion of the final clustering is stated as follows:

- **Organism 1** consists of organ 2 and organ 3. Organ 1 has been excluded due to the detrimental energy and material interaction to organ 3.
- **Organism 2** consists of organ 1, organ 5 and organ 4, (unchanged).
- **Organism 3** consists only of organ 6, due to the strong module criteria, which is a reason to make an organ to an autonomous organism.

3 Computer Implementation of the PAD methodology

For easy use of the PAD methodology it has been implemented in a computerized process and product modelling tool. The software being used is called METIS Base (NCR METIS ED&D, 1995) and is an object-oriented software with a graphic user interface. This software have been used earlier at our department when modelling extensions of the chromosome model (Malmqvist, 1995).

In the implementation different object types have been defined, such as *function*, *organ* and *component*. Each type has their own set of properties, e.g. all module criteria for the *organ* type. Objects can be connected to each other by a relationship. Different types of relationships have been defined, e.g. *interaction* which describes the interaction between organs by a set of properties. The properties for the *interaction* type are the scores of the four interaction types and a verbal description. An example of the implementation in the organ domain can be seen in Figure 7.

We have also implemented some methods in METIS which automatically create reports of relevant information. One method reports the interaction between organs in a similar way as showed in Figure 2. Another method compose a "Lanner-matrix" comparable with Figure 5. The development and implementation of methods have been based on case study of a compass saw.

4 Future work

The computer implementation has to be further developed. Today the rearranging of the "Lanner-matrix" is not included the implementation.

To improve the PAD methodology an industrial case study is planned. The case is about gear boxes to trucks and the aim is to point out strengths and weaknesses of the PAD methodology and to get feed back from designers.

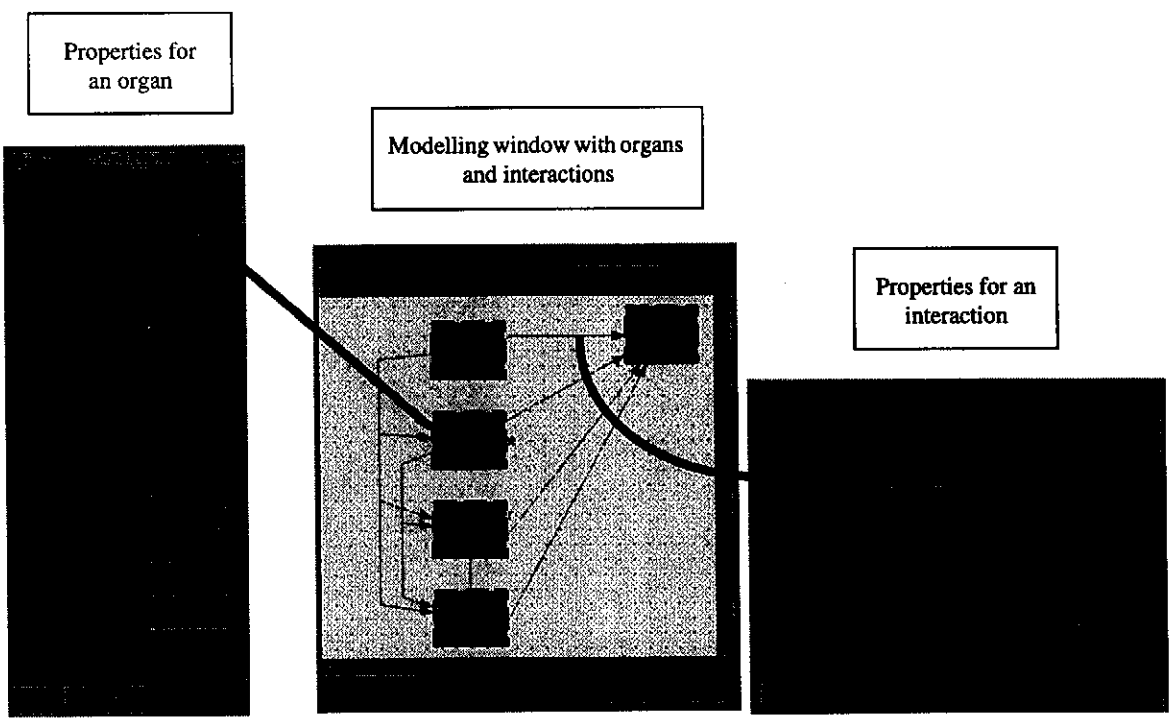

Figure 7: A part of an organ structure.

5 Conclusions

In this work we have proposed a unification of two methodologies dealing with product structuring. This gives an opportunity to consider both technical and economic aspects at the same time. Although designing product architectures is a demanding task, the designer will be aware of the consequences of the choice of one architecture or another when using the PAD methodology. The time it takes to practise the PAD methodology will hopefully be saved in the future, then the information once documented can be of use when doing a re-design.

The implementation in METIS simplifies the use of the PAD methodology and is time saving because of the automatically generated reports. It is also necessary to store the information in some kind of database if one want to easily retrieve the information in the future.

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