Product structuring and Design Coordination

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Abstract

This paper presents a framework which serves as a basis for developing designer support in product structuring, taking into account considerations from various phases of the product life-cycle. The framework shows three relevant aspects of designer support: design activities, results of design activities, and coordination of design activities. The framework is applied to product structuring. Examples are provided to illustrate the framework.

Contents

1 Introduction

The Laboratory for Flexible Production Automation has a background in production engineering. Research at the Laboratory for FPA focuses on parts manufacturing and assembly processes, computer aided process planning (CAPP) for manufacturing and assembly, production control, and development of production equipment, in particular equipment for automated assembly. From this research the Laboratory for FPA has ventured in the field of Design For X (DFX).

The central issue in the DFX research of the Lab for FPA is generating methods and tools which provide the designer with the required knowledge to make correct decisions from other than functional viewpoints. One research project directed towards this goal focuses on the structuring of products [7][9]. Another research project focuses on the design of part relations [10]. In order to create designer support, an in-depth analysis of the design process is required.

In this contribution a framework will be presented, which serves as a basis for developing designer support in product structuring, considering a number of life-cycle aspects. Section 2 introduces the framework. The framework consists of three main elements, which will be discussed in more detail in the sections 3 to 5. Finally, section 6 presents conclusions.

2 A framework for designer support in product structuring

The required functionality of a product is the basic driver for the designer. The decomposition of a product can also be described using laws of functionality. In [6] for example a function oriented decomposition procedure for mechanical products is described. The basis of DFX is that functionality is not the only driver. Life-cycle aspects also put their constraints both on the design solutions and on the design process. In product structuring life-cycle considerations play a role as well. A design principle which illustrates this influence is: `isolate customer specific functions in modules, which are to be added to the product as late as possible`. DFX-related design activities are not restricted to certain phases of the design process; throughout the entire design process life-cycle considerations have to be regarded. The considerations are specific for the situation, *i.e.* the designer needs support in the problem he is solving at a certain moment.

The type of designer support the DFX research at the Laboratory for FPA aims at covers the issues mentioned above:

1. the support must enable the designer to optimize the product structure considering a number of different life-phases;
2. the designer must receive support from the early phases in design until all the details have been specified;
3. the support must be specific for the problem the designer is solving.

The framework presented in this contribution is directed towards this type of designer support. The framework shows three different aspects of designer support, see figure 1:

1. **results of design activities**: descriptions/models of the artefact;
2. **design activities**: activities which contribute to the generation of design results;
3. **coordination of design activities**: controlling the progress in design and allocation of resources.

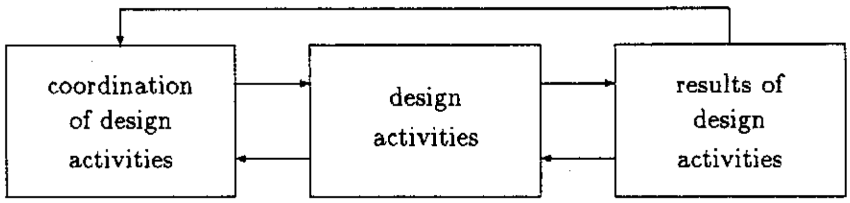

Figure 1: Overview of the framework for developing designer support

Research described in [1] also indicates that this distinction can be made. In the next sections the three elements of the framework will be discussed respectively. The discussion in this paper is restricted to product structuring, although it is believed that the framework can be applied to a larger range of design problems.

3 Results of design activities: product structures

In literature various definitions of the term product structure can be found. Two important elements of the definition of a product structure are:

1. a product structure is a description of the *contents of a product*: it describes out of which elements and relations between elements the product consists;
2. a product structure is *context dependent*: the various activities/disciplines within a company all have their own view on the structuring the product. It is therefore not possible to talk about **the** product structure; it is essential to define first *which elements* and *which relations* are regarded. During the development of a product a *collection* of structures is created.

This can be summarized into the following definition of product structure:

*A **product structure** is a context dependent description of the contents of a product.*

Figure 2 shows a number of structures that can be distinguished.

There are two important issues related to product structures, see figure 3. The first issue is the *generation* or *design aspect* of a product structure. In this case the product structures are regarded as the result of design activities. In creating a product structure, life-cycle considerations have to be taken into account. DFX research on the product structure level focuses on this issue. The second issue is the *information aspect* of product structures. In this case the product structure is viewed upon as a collection of product data (documentation). This aspect shows the product structure as a carrier of product data, like assembly drawings, assembly instructions, etc. The product data is used in various activities in the company, *e.g.* by the sales department (configuring a product for a specific customer), by design and engineering (*e.g.* re-use of design solutions, analysis of the design), activities related to the production of the product (CAPP, CAM, MRP), and after-sales activities.

structure	interpretation	elements	relations
functional hierarchy	hierarchy of functions fulfilled by the product	functions	consists-of
commercial (sales) structure	description of the families the assortment consists of, the primary functions within a family, including diversity (basic functions, variants, options)	families, primary functions	consists-of
relational model	assembly relations between material product elements	parts, groups of parts	connections
assembly hierarchy	hierarchy of parts and groups of parts, grouped in accordance with assembly sequence, it is a partial specification of the assembly sequence	parts, groups of parts (modules, sub-assemblies, clusters [3], etc.)	consists-of, assembly operations
service hierarchy	shows service parts and service modules, and their position in a dis-assembly tree	parts, groups of parts (service and non-service items)	consists-of, dis-assembly operations

Figure 2: Examples of product structures

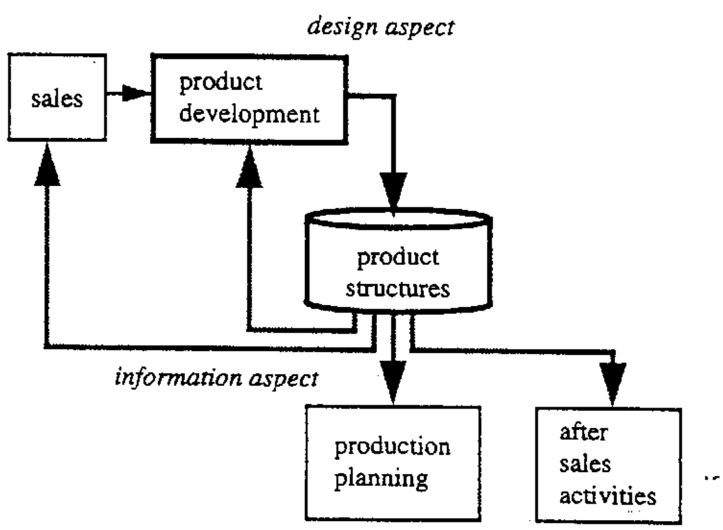

Figure 3: Design and information aspect of product structures

4 Design activities: structuring activities

The product structures are generated during design. The design activities which contribute to the generation of the product structures are referred to as **structuring activities**. Structuring activities are regarded as a subset of all design activities. The framework presented in section 2 suggests that it is possible to define a set of structuring activities independent from the sequence in which they will be executed. In general it can be stated that some of these structuring activities might be executed more than once during the design process, whereas others might not be executed at all. If a set of sequence independent structuring activities can be defined, a coordinating mechanism is required which controls when a certain activity can or must be carried out; this is discussed in section 5.

At present the set of structuring activities is under development. The approach taken to define them is investigating the relation between the measures that can be applied to express the properties of a design (*e.g.* assembly lead-time, assembly cost, (production) volume flexibility, service cost, etc.) and the parameters of the product structures that influence these measures (*e.g.* the number of sub-levels under the product or sub-assembly in the assembly hierarchy).

In this paper only a few examples of structuring activities will be described. For a more elaborate overview of the structuring activities that can be distinguished the reader is referred to [9].

I. Definition of diversity that will be offered.
Today's market is amongst others characterized by an increased demand of diversity: customers want a product tailored to their wishes. Companies faced with this demand attack the problem in two ways: increasing the flexibility of the production processes and (simultaneously) reducing the need for flexibility of the production process by proper product design [2]. Especially structuring a product has a great influence.

One of the questions the designers are faced with is: must all diversity demanded really be offered? Some of the variants wished by the market will probably be sold in small volumes. However, in general each variant that will be offered leads to cost, amongst others engineering effort. The amount of diversity to be offered therefore is a balance of the desired market share and cost due to the diversity.

An example can be found in [11]. The main functon of the product considered in the case was *showing visual information*, which was chosen to be fulfilled by a monitor. The different market segments the company aimed at required different sizes of the monitor. However, some of the variants identified would lead to problems in engineering, and/or would only contribute to a small portion of the market share. This was reason for the company to limit the range of variants to be offered, thus optimizing the overall company result.

II. Assembly lead-time considerations.
The lead-time in assembly is one measure to be considered during the development of the product. The lead-time in assembly is one of the factors contributing to the delivery time, *i.e.* the time between the moment of ordering a product and receiving the ordered product.

For each group of parts in the assembly hierarchy the question must be answered whether it is necessary to make a decomposition step because of assembly lead-time considerations. The lead-time is amongst others determined by the number of assembly operations, and parallellism in assembly. If the lead-time constraint is not met, one of the options is to define sub-assemblies which can be assembled in parallel.

III. Sub-assemblies due to accesibility constraints.
During product design sub-assemblies are created for various reasons, one being lead-time considerations (see previous example). Sometimes, however, the sub-assembly is not the result of

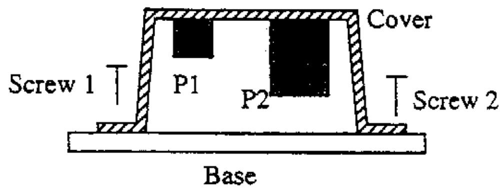

Figure 4: The cover, P1 and P2 form a sub-assembly because of accessibility constraints

a consciously taken decision to create it, but rather the consequence of a number of synthesis steps (a chosen concept, a chosen geometry). These choices sometimes lead to a special type of sub-assembly: a group of parts which is to be pre-assembled before it can be added to the base assembly, *because of accessibility constraints*, see figure 4.

This situation always leads to extra cost in assembly: it is a disturbance of the pure serial assembly sequence, leading to extra operations and sometimes to extra equipment cost (fixtures). Especially in the case of automated assembly it is quite likely that a special fixture and a special gripper for handling are required.

If such a situation occurs the designer must be confronted with the consequences. An estimation of the extra cost due to extra assembly and handling operations and due to extra assembly equipment provides this information. In this way the designer receives an indication of the necessity to change the situation.

IV. Choice of manufacturing and assembly process.
Structuring the product proceeds until the smallest product items are identified: the individual parts, which cannot be decomposed by dis-assembly operations without destruction. The decomposition of the lowest level sub-assembly into individual parts is not only determined by functionality (required relative motion, shape of the parts), but also by possibilities and limitations of manufacturing and assembly processes. Pure DFA (Design For Assembly) is directed towards part count minimization, which is indeed the optimum for the assembly process. However, part integration might lead to increased complexity of the individual parts, thus increasing the manufacturing cost. This increase in manufacturing cost might exceed the reduction of asembly cost.

An example can be found in a case study on a product from Bang & Olufsen, a CD-loading system [8]. The initial design of the base plate of this product specified the production of a number of individual parts by cutting processes, followed by assembly of these components on a sheet metal base part. During the design it appeared that assembly cost would be unacceptably high. In a redesign step injection moulding was selected as an alternative process. In terms of the assembly hierarchy, this decision had a great impact; the number of parts the base plate assembly consisted of was greatly reduced.

5 Coordination of structuring activities

The Laboratory for Flexible Production Automation participates in an Esprit-funded working group, called CIMDEV. This working group consists of a number of sub-groups, one being the Design Coordination group, consisting of:

- the CAD Centre, University of Strathclyde, Glasgow, United Kingdom;
- the Department of Computer Science, University College Cork, Cork, Ireland;
- the Institute for Engineering Design, TU Denmark, Lyngby, Denmark;
- the Laboratory for Flexible Production Automation, TU Delft, Delft, The Netherlands.

The field of research defined by this group is referred to as *Design Coordination*. Design coordination can be defined as [5]: *a high level concept of the planning, scheduling, representation, decision-making and control of product development with respect to time, tasks, resources and design aspects.* The hypothesis of the Design Coordination group is that in providing (computer based) support in design coordination, the design process will improve, leading to better products. Some results of the Design Coordination group are described in [5][4][1].

Design coordination covers a wide range of issues. Relevant to the work described in this paper is the sequencing and control aspect of design activities. Sequencing of design activities involves determining the sequence in which design activities are carried out. Control involves commanding the execution of design activities. The set of structuring activities defined in section 4 was sequence independent; a coordinating mechanism is therefore required to control the execution of the activities.

This assumes that it is possible to define procedural knowledge, which specifies when (i.e.in which situation) which activity must be carried out. This knowledge can be stored in what is referred to as **coordination patterns**. The coordination patterns have the form of *trigger* → (= followed by) *action*.

In section 4 some examples of structuring activities were discussed. The coordination patterns for these examples will be presented here.

I: definition of diversity that will be offered
Identification of a primary/customer function which is subject to diversity → define the range of variants for this function

II: assembly lead-time considerations
Identification of a group of parts (product, sub-assembly) → check lead-time constraint, give guidance to designer
or: *Change in number of sub-levels (below or over a certain threshold value) → check lead-time constraint, give guidance to designer*

III: sub-assemblies due to accessibility constraints
Identification of such a situation → compute consequences and give guidance to designer

IV: choice of manufacturing and assembly process
Group of individual parts → check possibilities for integration, compute consequences of integration

This separation of coordination of design activities from the execution of design activities makes the sequence of executing structuring activities very dynamic, in contrast to many descriptions of the design process in the design methodology, which sometimes tend to suggest - or are sometimes *interpreted* to suggest - a more or less sequential approach to design.

Structuring activities are sometimes carried out without having complete information. The coordination mechanism plays a role here as well. As soon as the missing information becomes available, the designer must return to the earlier decision, and verify whether the decision was correct or not. As an example: a decomposition step in the assembly hierarchy might be based on an estimation of the number of parts. If the part count appears later on to differ much from the original estimation, it might be necessary to reconsider the decision taken earlier.

In this section design coordination on the level of design activities is discussed. It should be noted that design coordination as treated by the Design Coordination group covers a much larger range of activities. Coordination of activities on development project level is an example of an aspect which is not dealt with in the research described in this paper, but which certainly belongs to the interest area of Design Coordination as a whole.

6 Conclusions

In this paper a framework which serves as a basis for developing support for structuring products considering multiple life-cycle phases has been presented. The framework consists of three main elements, a collection of structures, a set of structuring activties, and a set of coordination patterns.

Future work will include the definition of structuring activities and coordination patterns, including a practical verification.

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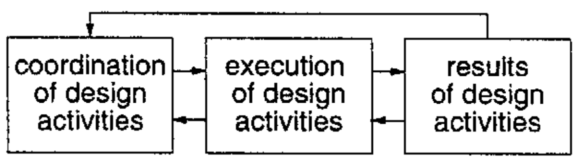
Contents

1. Framework for designer support

- DFX (Design For X) on level of product structure
- type of support:

  a. a number of life-cycle phases (assembly, parts manufacturing, service)
  b. support entire design process
  c. support specific for design problem at hand

- framework: basis for developing support



2. Product structures

- a **product structure** is a

context dependent description

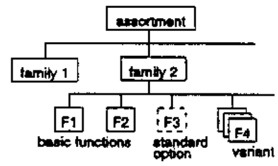
of the **contents** of a product

different disciplines/ activities

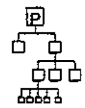
elements and relations the product consists of

- a few examples

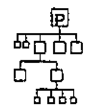
commercial structure



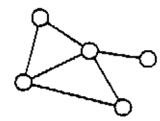
functional hierarchy



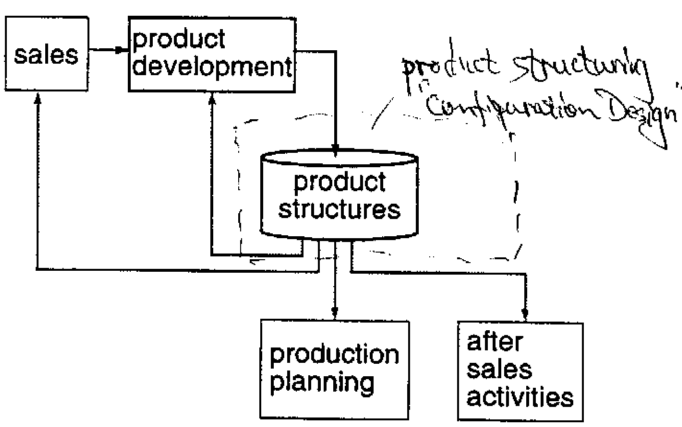
assembly hierarchy



relational model (liaison graph)



- 2 aspects of product structures
  - result of design activity
  - carrier of product data



3. Structuring activities

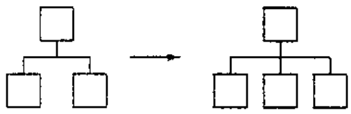
- design activities which contribute to the generation of product strucures
- a set of structuring activities, independent from the sequence of execution

- example I

Assembly lead-time

reduction of assembly lead-time amongst others by increasing parallelism in assembly

implies definition of sub-assemblies

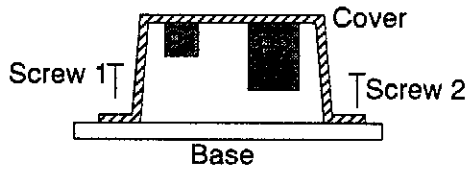


- example II

sub-assembly because of accessibility constraints

leads to extra cost due to extra operations and equipment

designer must be confronted with situation

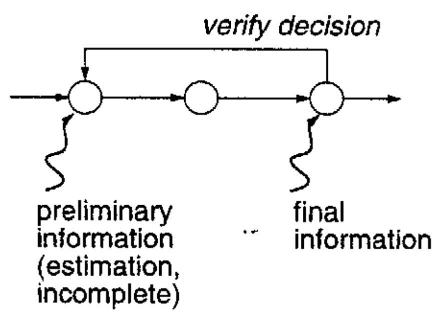


4. Coordination of activities

- Design Coordination:
  a high level concept of the planning, scheduling, representation, decision-making and control of product development with respect to time, tasks, resources and design aspects
- computer based support for coordination of design activities will improve the design process

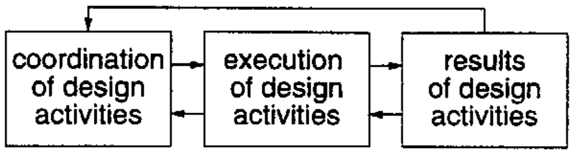
- coordination patterns:
  trigger ⟶ *action*

- decision making with incomplete information



Summary

- framework



- future work: definition of set of structuring activities and coordination patterns
- practical verification
- towards supporting tools