Proceedings of the WDK Workshop on
Product Structuring
June 22-23 1995
Delft University of Technology

Appendix A: Reprint of summarizing paper of the first WDK Workshop on Product Structuring

Summary of the key points of the WDK Workshop on Product Structuring

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1 Introduction

On June 22-23, 1995, the WDK Workshop on Product Structuring took place at the Delft University of Technology, The Netherlands. The workshop was co-organized by three institutes:

1. the Laboratory for Flexible Production Automation, Delft University of Technology, Delft, The Netherlands (hosting institute);
2. the Institute for Engineering Design, TU Denmark, Lyngby, Denmark;
3. the CAD Centre, University of Strathclyde, Glasgow, United Kingdom.

The workshop was organized under the umbrella of the WDK, Workshop Design-Konstruktion, an international society for the science of engineering design. WDK organizes the bi-annual International Conference on Engineering Design, and publishes books and readings in the field of engineering design.

In the invitation to the workshop, which was sent to people on a personal basis, product structuring was defined as the design activity which focuses on defining the elements and relations of a product. Around this central topic several issues were grouped, inspired by the background of the organizing institutes.

In total 23 people participated in the workshop. The group consisted of researchers from universities and research institutes from The Netherlands, United Kingdom, Denmark, Sweden and Germany. Moreover, a number of people from Dutch industry participated. During the workshop 14 presentations were scheduled, 7 on each day. Each presentation was ended by a discussion. Both days were finished with overall discussions, which were prepared by members of the organizing institutes during the workshop days.

This paper summarizes the main points raised during the workshop. They are taken from the written contributions, published in this proceedings, and from the presentations and discussions during the workshop. In the next sections the following issues are addressed:

Definition of product structure (section 2). This section is about the terminology, about understanding what a product structure really is. Other terms in use during the workshop are also discussed. Two main views centered around product structures appeared to exist. A product structure can be regarded as 1) a collection of data, resulting from design activities and as 2) a collection of data which is used by several activities in the company.

Product structuring as a design activity (section 3). Product structuring can be defined as the design activity focusing on the generation of (a) product structure(s). This section discusses various models of this design activity. Product structuring related to Design For X is also discussed.

Product structure as the carrier of product data (section 4). The product structure as a carrier of product related data is used in the various business processes within a company. This section discusses the users and their use of product structures.

In section 5 some conclusions are presented. The names in this paper refer to the (first) authors of the papers included in this proceedings. Although the intention of this paper is to create a summarizing overview, the view presented will undoubtly be subjective in certain parts. The authors apologize for not including those issues which are regarded important to incorporate by other participants to the workshop.

2 Definition of product structure

2.1 What is a product structure?

An important issue discussed during the workshop concerned terminology. Apart from the term "structure" other terms were used as well, such as decomposition, composition, configuration and product breakdown. This section summarizes the opinions on terminology.

Most authors define structure as *the elements of a product and the relations between the elements.* This definition of structure enables to define a set of structures for each product. Hence, to define a product structure, it is important to define *which* elements and relations are regarded. The type of elements which are often represented in a structure are functions and physical entities (parts or groups of parts). Relation types are input-output relations (between functions), hierarchical relations, connection relations and spatial relations (relative position of parts). Examples of these structures can be found in various papers. Each discipline within a company may have one or more views on the product, and may therefore need one or more different product structures.

Andreasen argues that a product can be described in four different domains: the product is a system of processes, functions, organs or parts. Andreasen shows that in each of the domains structure can be defined; structure is a *charactaristic* of each of the domains. A characteristic is a defining attribute of the product. There is only a limited number of characteristics: material, shape, dimension, tolerance, surface quality and structure. Herbertsson quotes Hubka, who distinguishes three types of product properties: basic properties, internal properties and external properties, see figure 1. The basic properties are the characteristics listed above, structure is one of the basic properties.

Other authors also suggest that a product can be described in a number of domains. Erens distinguishes three domains: the functional domain, the technology domain and the physical domain. In each domain a structure can be defined. The structures described up to now are mainly used in design. Other disciplines, such as sales or assembly, have their own view on the product structure. A clear example is the product hierarchy, where the elements are physical parts and groups of parts. Sales is interested in a hierarchy which shows the functions certain parts,

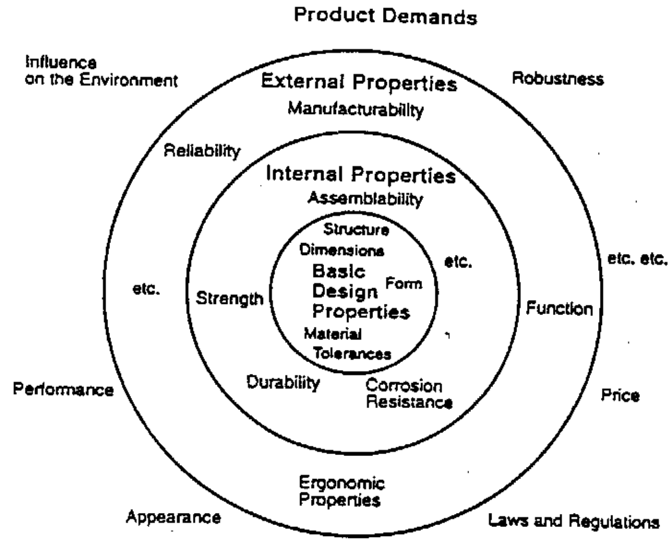

Figure 1: Structure is one of the basic properties (after Hubka, taken from Herbertsson)

or groups of parts, contribute to. Assembly is interested in a product hierarchy which represents (part of) the assembly sequence.

Apart from product structure, other terms were used during the workshop, which are related to product structure. The activity *configuring* is by various authors defined as the activity in which total solutions are composed out of known sub-solutions. In sales, this activity is more specifically referred to as *product configuration*. The sales department composes a product out of a given set of elements, to meet the demands from customers, see Hase and Boerstra. In design, configuration is referred to as *configuration design*, see Yu. In her work, Yu starts with a given set of elements which can be combined in pre-defined ways. Configuration to Hansen also has the meaning of creating an overall solution out of elements, but in Hansen's work the elements are not known in advance, but are synthesized as well. Obviously, configuring is closely related to *composition*. *Decomposition* is the opposite of composition: it is concerned with splitting up a totality into subs. Hansen describes a decompositon procedure in which functions are decomposed into sub-functions. Compositon and decomposition are closely related to hierarchical product structures. The term *product breakdown* is used by some authors to denote hierarchical structures.

In summary, the term product structure is a very general one; it covers other terms like decomposition, composition, configuration (read as nouns), product break-down, etc. In the same way, the activity product structuring also includes a range of activities like decomposition, composition and configuration (read as verbs).

2.2 Two main viewpoints on product structures

There are both creators and customers of the product related data represented in product structures. This indicates that there are two main aspects around product structuring, see figure 2. The first aspect concerns *creating product structures*. This is done by the design and/or engineering department. In designing structures, the designers have to cope with demands from the various life-cycle phases, often represented by departments within the company. In this way sales, production, service, etc. all have their requirements on product structures. This is treated in more detail in the next section. The other aspect of product structures is concerned with the *use of the product data described in product structures*. The various activities within a company all need their own data, and therefore often use specific structures. This is discussed in section 4.

Bikker, Boerstra and Janson confirm this distinction into two main aspects. Bikker discusses a model of the primary process within companies, see figure 3. The figure shows that during design, product data is created, stored in structures, taking into account requirements from sales,

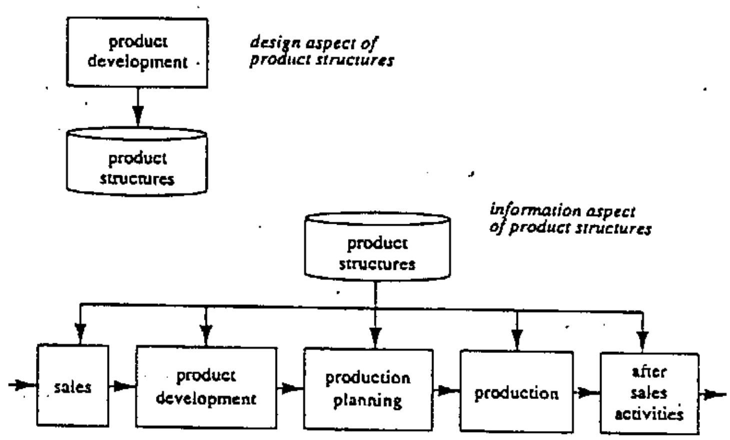

Figure 2: Two main views on product structures: creators and users (Tichem)

fabrication, assembly and use/service. This data is used in all these activities, but also in design itself. The latter aspect has to do with reuse of constructions. Boerstra distinguishes a product development traject and an order processing traject, see figure 4. In the product development traject product data is created, whereas the order processing traject uses the data. Janson makes the same distinction in a development and order processing and production traject, which he calls the off-line and on-line process respectively, see figure 5.

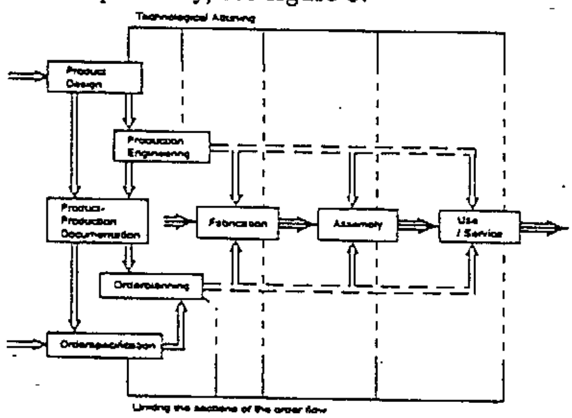

Figure 3: Model of the primary process (Bikker)

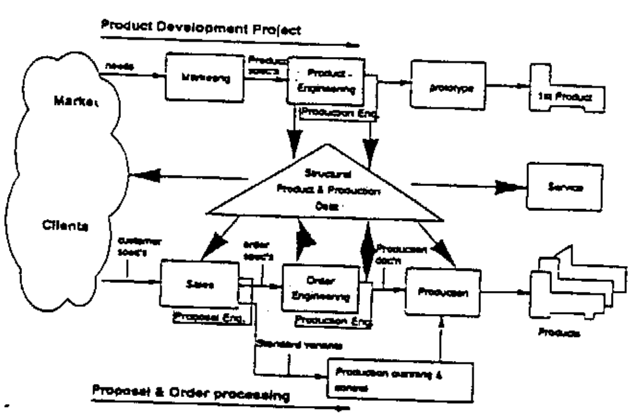

Figure 4: Product development and order processing traject (Boerstra)

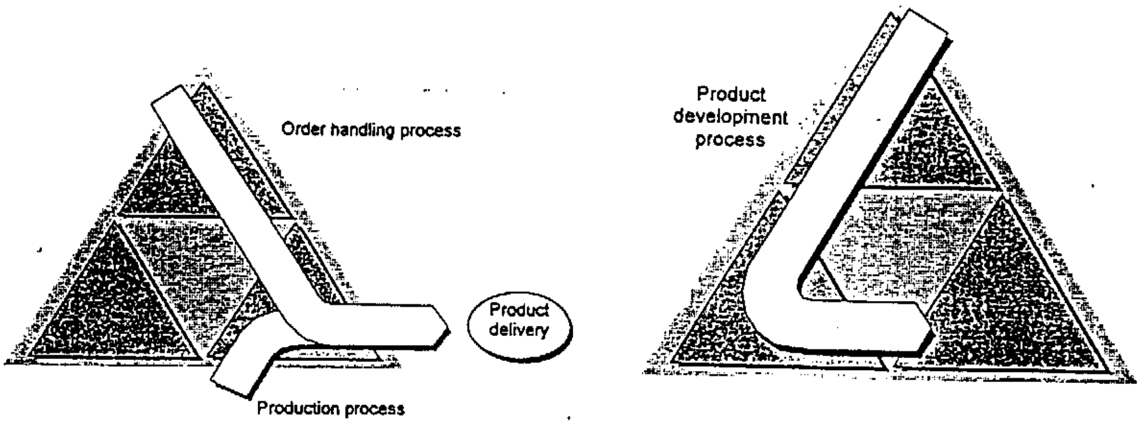

Figure 5: On-line and off-line process (Janson)

3 Product structuring as a design activity

Product structures are created during design. This section discusses various aspects of the design activity *product structuring.* Two aspects are discussed in this section: general models of the activity product structuring, and product structuring related to Design For X.

3.1 General models of product structuring

If a product structure is defined as the elements and relations between the elements of a product, the activity product structuring can be defined as the *creation of elements and relations.* Obviously, product structuring takes place throughout the entire design process, from the early phases on until the final decisions are made. This is supported amongst others by Andreasen and Erens in their domain models of the design process. Besides structuring a product, the elements and relations have to be detailled. Andreasen states that it is impossible to design a product structure, without simultaneously regarding the geometric and other characteristics of elements and relations as well.

Some models for structuring were presented. Erens uses the productive reasoning model defined by March and Cross as a basic loop in the design process, consisting of the steps: decomposition, allocation, composition and validation, see figure 6. The loop can be applied between different domains, and on different levels of the product hierarchy.

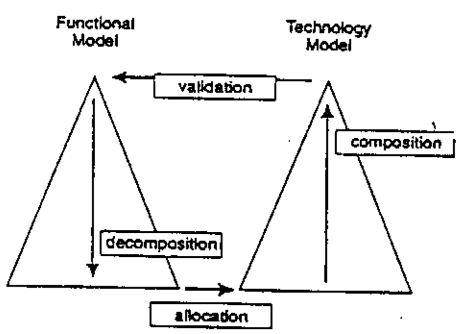

Figure 6: Productive reasoning model as a basic loop in design (Erens)

Hansen presented a phenomena model of function oriented decomposition. A phenomena model describes high level phenomena of the design activity. Hansen distinguishes two main directions of design activities, see figure 7. The first direction is referred to as synthesis: creating solutions for functions. The pattern of synthesis in Hansen's model follows the Function-Means principle: for a function, alternative solutions (means) are created, and the best one is selected. The second direction in Hansen's model shows decomposition and composition activities. Based on the chosen means, sub-functions are identified (decomposition), which again are the starting point for a new step into the synthesis direction. Parallel to this, specifications are broken down. The composition step in the model is the adjustment of the overall configuration, by incorporating the newly chosen means into the overall design.

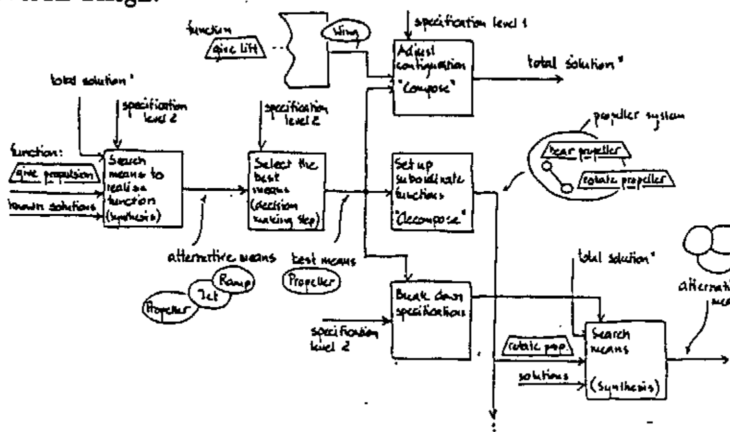

Figure 7: A function oriented decomposition procedure (Hansen)

A special type of product structuring is configuration design. In Hansen's model a configuration is a combination of solutions. Configuration design is defined by Yu as a combination problem: "configuration ...is the process of creating an arrangement from a given set of elements by defining the relationships between selected elements that satisfies the requirements and constraints". Yu's model of configuration design shows two activities: selection of elements and configuring the selected elements to configuration solutions, see figure 8. In her research, Yu is building a computer-based supporting tool for configuration design. In order to assist designers in configuration design, the set of elements and constraints on combining elements have to be defined.

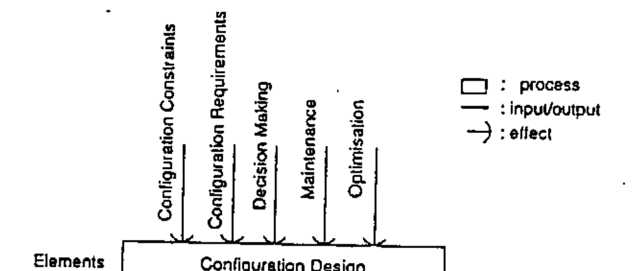

Figure 8: Model of configuration design (Yu)

MacCallum defines the design process by investigating the data created in design. During design different models are used, created, changed, etc. The sequence of models addressed during design is called a Product Information Breakdown Structure (PIBS). Behind each model in the PIBS design activities can be positioned.

3.2 Structuring and Design For X

Andreasen makes a distinction between a correct configuration and a good structure. A correct configuration is a structure of solutions which suits the purpose of the product (the needs, the functions). A good structure points at the issue of optimizing with respect to life cycle properties. This is referred to as Design For X (DFX) on product structure level.

DFX on structure level implies that elements and relations are not only defined based on functional requirements, but that the various life-cycle phases control the design as well. In this context, Andreasen states that "to the functional determined structure other structural principles may be added for specific purposes". Obviously, in one design, a number of superimposed structuring principles may be found. Designers should be supported in DFX. Tichem describes a framework for designer support, which aims not only at supporting decision making, but also at supporting in the navigation of the designer. This requires a coordination mechanism, which task would amongst others be to indicate the relevant life-cycle issues during design.

During the workshop two classes of structuring principles were mainly discussed: structuring principles for assembly and structuring principles for dealing with diversity. For assembly, structuring principles are relatively well known and understood. Examples are *integrate parts*, *design a stacked construction*, *design a good base component*, and *create modules*.

Diversity is an aspect of a product familiy: it defines the size of the product familiy, the variants that can be offered to the market. The main issue is to control diversity. Diversity implies that for one function several solutions exist, due to varying demands/specifications on the function. Erens describes that for the type of products he is looking at, mechatronic products, for one function several technologies can be used, and for one technology several hardware solutions.

The general idea in managing diversity is to create a large variety volume with the smallest possible structure volume, *i.e.* with the minimum of elements creating the maximum number of variants. Herbertsson explained the difference between modular design and integrated design by describing the relation between functional structures and structures of function carriers, see figure 9. Structuring principles for managing diversity aim amongst others at creating modular

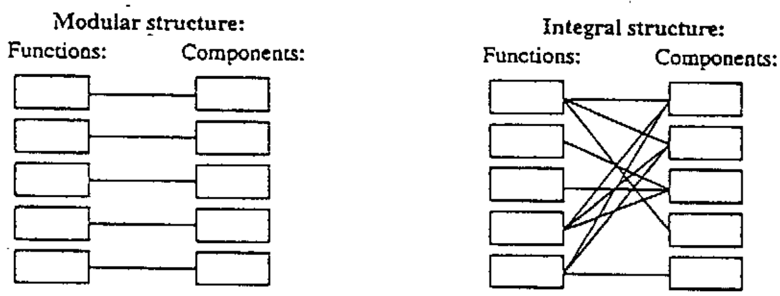

Figure 9: Modular versus integrated design (Herbertsson)

designs and standardization of elements (on sub-assembly/module level and on part level) etc.

Bikker discusses the issue of the Customer Order Entry Point (COEP) and the Order Specification Entry Point (OSEP). COEP is the point where an order penetrates the hardware flow, activities in the realization traject after the COEP are specific for a customer. In the same way, the OSEP specifies which part of engineering is done independent of a customer, and which part is done after order entry (customer specific engineering). A company must decide on the position of COEP and OSEP, based on considerations like the degree of innovation, the frequency of innovation steps, and sales volume. The product structure should be designed in accordance with the desired position for OSEP/COEP combination.

4 Product structure as the carrier of product data

This section deals with the second main aspect related to product structure: product structure as carrier of product related data. During design, an enormous amount of information about the product is created. In some way this should be captured. This requires the development of suitable information structures, and the development and implementation of information processing systems. Murdoch discusses a framework which enables the indexing, storage and capture of product related and design process related information. He argues that all product related date must be stored, not just physical entities, but functional entities and life-cycle related information as well.

The users of product related data can be found in the entire company's process chain: order acceptance and sales, design and engineering, production, and after sales activities. During the workshop, mainly use of product structures in order acceptance and sales and in design and engineering was discussed.

Product configuration is an activity within the sales department. It is concerned with composing a product for a specific customer, based on the customer demands and on a set of available elements out which the product must be composed. Boerstra and Hase discuss this topic. It is essential to each company which markets families of products. Product configurators support the sales department in this activity. Boerstra argues that the type of supporting tool depends on the complexity of the product family, where complexity is defined in terms of the number of variants, the number of parameters needed to select a specific variant, and the number of cross-influences between configuration rules. Paper-based product configurators are suitable for low-complexity families, whereas computer-based product configurators are a necessity for high-complexity product families. Hase describes an object oriented data base system for product configuration. Each product configurator has configuration rules stored. These rules are cumbersome to input to a product configurator, and must be updated every now and then because of changes in the product family. Automatic derivation of configuration rules from design decisions would be advantageous.

In engineering, reuse of former designs is a clear objective for many companies. The design department therefore needs information systems, not necessarily computer-based, which support in reuse of former designs. A prerequisite for such a supporting system is the fast retrieval of data.

5 Concluding remarks

This paper summarizes the main statements on product structuring, taken from the written contributions in this proceedings and from the presentations and discussions during the workshop.

A product structure is defined as the elements and relations a product consists of. For each product a set of related structures can be defined. Two aspects aspects centered around product structure can be distinguished: creation of strucyures in design, and use of structures in all company processes. In designing good product structures, requirements from the life-cycle phases have to be considered. Some models of structuring products are presented. It was concluded that understanding of the activity product structuring is not complete, which opens possibilities for further research. Product structure regarded as the carrier of product related date calls for frameworks to capture all relevant product information and for information systems which enable to process the product data.

Appendix B: List of people to whom this invitation was sent

In case you are missing people on this list of whom you think they can give a valuable contribution to the workshop, please contact us.

M.M. Andreasen	Department of Control and Engineering Design, TU Denmark, DK
C.T. Hansen	Department of Control and Engineering Design, TU Denmark, DK
N.H. Mortensen	Department of Control and Engineering Design, TU Denmark, DK
H. Bikker	Industrial Organisation and Management, TU Delft, NL
W.F. Bronsvoort	Computer Graphics and CAD/CAM Group, TU Delft, NL
W. van Holland	Computer Graphics and CAD/CAM Group, TU Delft, NL
F.W. Jansen	Computer Graphics and CAD/CAM Group, TU Delft, NL
H.J.J. Kals	Design & Production, UT/Lab for Production Engineering, TU Delft, NL
P. de Ruwe	Industrial Design Engineering, TU Delft, NL
T. Storm	Lab for Production Engineering, TU Delft, NL
M. Tichem	Lab for Production Engineering, TU Delft, NL
K. v.d. Werff	Mechanical Engineering Design, TU Delft, NL
M.A. Willemse	Lab for Production Engineering, TU Delft, NL
J. Bowen	Computer Science Department, UCC, IRL
F.J Erens	Industrial Eng. and Managament Science, TU Eindhoven, NL
H.M.H. Hegge	Industrial Eng. and Management Science, TU Eindhoven, NL
J.C. Wortmann	Industrial Eng. and Management Science, TU Eindhoven, NL
K.J. MacCallum	CAD Centre, University of Strathclyde, Glasgow, UK
A.H.B. Duffy	CAD Centre, University of Strathclyde, Glasgow, UK
B. Yu	CAD Centre, University of Strathclyde, Glasgow, UK
L.T.M. Blessing	Engineering Design Centre, University of Cambridge, UK
T. Murdoch	Engineering Design Centre, University of Cambridge, UK
G. Hird	Lucas Engineering and Systems, Shirley Solihull, UK
M. Simon	Lucas Engineering and Systems, Shirley Solihull, UK
G. Erixon	KTH, Stockholm, S
J. Herbertsson	Linköping University, Linköping, S
L. Janson	IVF, Linköping, S
H. Birkhofer	Technische Hochschule Darmstadt, D
D. Fischer	Fraunhofer-Inst. für Arbeitswirtschaft und Organisation, Stuttgart, D

B. Hase	Fraunhofer-Inst. für Arbeitswirtschaft und Organisation, Stuttgart, D
H. Meerkamm	Universität Erlangen, D
V. Weinbrenner	Lehrstuhl für Konstruktion im Maschinenbau, TU München, D

A. Kleingeld	TNO Product Centre, NL
W. van de Vegte	TNO Product Centre, NL
M. Boerstra	Stork Demtec, NL
S. van de Bosch	Stork Demtec, NL
M. Oud	Stork Demtec, NL
P. van den Hamer	Philips Research, NL
M.P.M. van Loon	Philips Research, NL
A.A.M. Ranke	Philips CFT, NL
G.H. Tuinzaad	TNO Metaalinstituut, NL
G. Vaessen	Océ, NL
W. Verhofstadt	Océ, NL

Appendix C: Description of the organising institutes and WDK organisation

The Laboratory for Production Engineering, Delft University of Technology

The Laboratory for Production Engineering is active in production engineering research. The Laboratory concentrates on research in the field of parts manufacturing and assembly processes, and process planning for parts manufacturing and assembly. In the latter field, CAPP systems (Computer Aided Process Planning) both for parts manufacturing and assembly were developed. From this background the Laboratory has migrated into the field of design for manufacturing and assembly. The aim of this research is to develop methods and tools for designer support in DFX, where the present focus is on parts manufacturing, assembly, and service.

The Department of Control and Engineering Design, Technical University of Denmark

The Engineering Design part of this department has a 25 years background in research and education on problem solving, engineering design and product development. The origin of the research is design methodology, but the marriage to the Institute of Product Development (IPU), a consulting company situated at the university, has created a highly praxis oriented approach. Together with IPU a theory basis for product development was created and research areas like DFA, DFM, DFQ, DFC, and DFEnv were taken up. Today one of the major research areas is the development of a "designers workbench", based on a product model concept, masters or case based knowledge and with abilities in functional and conceptual design. The design methodological background of product decomposition receives great interest within the institute.

The CAD Centre, University of strathclyde

For over a decade the CAD centre has focused on the application of Artificial Intelligence techniques to supporting engineering design. The long term goal is to develop a fully integrated computing environment which supports design and its management based on computational theory of design. In the mid-80's they originated the concept and developed a long term research strategy towards the realisation of an Intelligent Design Assistant (IDA) which would act as a colleague to a designer, providiing guidance, learning from past design experiences, carrying out semi and fully automated design tasks, explaining its reasoning and in essence complementing the designer's natural skills, thus leaving the ultimate decision making, control and responsibility with the designer. The CAD Centre is amongst others involved in projects on configuration management, reuse and product modelling.

WDK: Workshop Design-Konstruktion

WDK (Workshop Design-Konstruktion) is an international association for design research and education, conducted by V. Hubka in Zürich, founded 1980. WDK organises the biannual ICED conferences (International Conference on Engineering Design), and the WDK-expert groups organise workshops. WDK also publishes books on design science and education.