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Assembly Target specific Structuring of modular Product Families

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Abstract
The structuring of products is awarded the highest potentials for assembly effort reduction of variant product families. A research in corresponding literature in the field of engineering design shows deficits of the approaches regarding systematic applicability, consistency and validation of the proposed structuring measures. In this paper a methodical procedure is presented that intends the application of measures based on an analysis of the actual design for assembly targets. These measures are represented by a defined product model including chosen product attributes. Thereby, the impacts of the measures taken can directly be evaluated providing a validation of the initial design for assembly targets. The application to an exemplary product proves further potentials of the presented developed procedure regarding ergonomic application and significance of the results.

Keywords: Design for Assembly, Product Structuring, Modularity

Introduction

From a product costs point of view the life phase assembly is caught in dependent situation. Though a significant part of the costs incur in the assembly, it is in the development, where the majority of these costs are accounted [6]. In order to counter this constellation and develop the resulting potentials in the early product emergence process, diverse Design for Assembly (DfA) Methods and Tools were defined since the 1970s (see [1] for a detailed list of relevant literature). The DfA design guidelines can be divided into the main categories *Reduce*, *Standardise*, *Simplify* and *Structuring*. The corresponding DfA measures focus on the product aspects *structure*, *parts* and *interfaces* [13]. According to Andreasen, the application of DfA measures should concentrate on a product structural approach, since the expected effects are estimated to be higher compared to focus on part and interface design. Furthermore it can be state that the provided guidelines are only conditionally valid and might result in negative effects [2]. Therefore, product structuring measures need to be applied with simultaneous assessment of their specific impacts.

Background

A possibility for product structuring is the application of the Integrated PKT-Approach for Developing Modular Product Families. It contains various methodical units of design for variety and life phases modularization to support the creation of modular product structures at the level of conceptual design [11]. Due to the life phases focus, the approach provides the opportunity to consider any relevant requirements in product family definition.

The overall approach intends a separate analysis of the individual life phases, like product development, purchase, logistics, production, marketing and after sales. Therefore, idealised product structures are defined from each point of view. Subsequently, a compromising mutual product modularisation is agreed on. The following figure shows the general concept of the Integrated PKT Approach to serve external complexity by a lower amount of internal complexity applying different methodical units. One of the methodical units within the overall approach is the *Modularization for Assembly*, which specifically considers the aspect of assembly within product structure definition [7]. Further advancements in the development of this methodical unit are the topic of this paper.

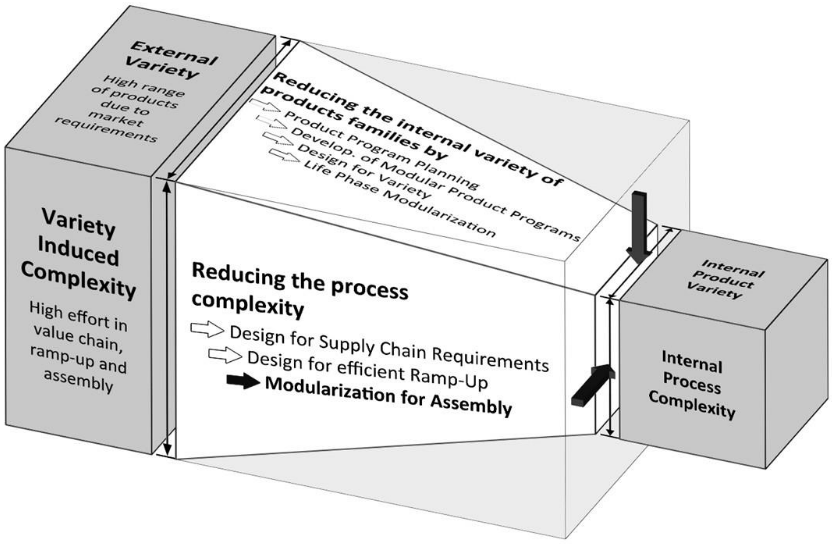

Figure 1. Integrated PKT-Approach for Developing Modular Product Families

State of the Art

For the elaboration of the methodical unit *Modularization for Assembly* the relevant literature is analysed for established methods on the field of product structuring. The investigation is thereby focussed on approaches, which explicitly consider the assembly. Then the use of the term product structure is clarified. Models for the graphical representation of assembly aspects within product structures are presented. The choice of methods described in the following paragraphs was characterised before as suitable for being a basis for the development of an assembly oriented procedure for product structuring.

Product structuring in DfA context

The characteristics of a product structure show a large impact on product properties, such as development time or lastly its economic success. The product structure on the other hand is influenced by technological and economic restrictions as well as strategic demands of its specific corporate environment. The product structuring targets from an assembly point of view concentrate on the aspects assembly effort reduction and ascertainment of the assembly share in product quality. To implement the measures for the definition of a product structure from an assembly point of view, different tools are at the developer’s disposal. The simplest way is the application of design guidelines. The therein proposed measures show a universal character and are provided as general information that needs to be adapted to the specific task by the user [1 and 13]. In order to support the practicability, the guidelines are thematically grouped and provided in catalogues.

An example for an approach, which broadens the view every product life phase is the Modular Function Deployment by Erixon. At first a decomposition of the product into its functions is conducted. Technical solutions are assigned to these functions. The actual product structuring is carried out by clustering of the resulting components on the basis of so called module drivers. In this approach, assembly aspects are considered with regard to the analysis of component specific processes. It is the aim to merge components into modules that go through the same processes, such as assembly operations or testing. The method is supported by the use of a Module Indication Matrix (MIM) [5]. According to the Integration Analysis Methodology by Pimmler/Eppinger modules are created with regard to the relations of their components. In this case, it is the special relations that are relevant for the assembly aspect. Components with a high degree of mutual relation are generally qualified for composing a module. The practical application is supported by the utilization of a Design Structure Matrix (DSM) [14].

Product structure representation

A differentiated set of information is obligatory to serve as basis for product structuring. On the one hand side, product attributes need to be provided, on which the measures are applied. On the other hand, systematic product information needs to deliver input for evaluation of the defined structure.

Jiao proposes an approach for a Generic Product and Process Structure for variety management. The product data can be represented by a bill of material, breaking down the product structure into assemblies, sub-assemblies, parts and raw material. In the case of a product platform consisting of multiple product variants, a generic product structure is derived [10]. For the actual representation of the product model, the five attributes of modular products commonality, combinability, function binding, interface standardisation and loose coupling defined by Salvador are used. Thereby, the possibility is provided to practicably act on the product structure [15].

Analysis and conclusion

The relevant methods for defining product structures designed for assembly can be divided into two main categories. In case of the holistic approaches, such as MFD and DSM, assembly requirements are only considered in an undifferentiated way. In contrast, the methods focussing on the assembly require a high level of information quality. For this reason, their application is actually limited to later phases of product evolvement. The guidelines applicable in earlier phases predominantly concentrate on the design of parts and interfaces. The provided design guidelines for product structuring remain on an unsystematic level. None of the methods provides a systematic evaluation procedure for the proof of a successful application of the proposed measures. It is a distinct system of design targets that is missing, which can be used for the selection of measures but also for the derivation of adequate evaluation criteria.

Conceptual Framework for Product Structuring

On the basis of the findings from the literature review, a procedure is proposed that provides a consistent relation of the four aspects, design targets, measures, product structure attributes and evaluation criteria as shown in Figure 2.

First step is the listing of general and specific targets for product structuring from the assembly point of view. On this basis relevant measures can be selected from a respective list. The actual structuring of the product is conducted by means of these measures. An adequate product model represents the characteristics of the structure and provides input for evaluation applying selected criteria. This concluding assessment delivers the validation of the initially listed design targets. With regard to a practical application of the proposed procedure the systematic set up of lists for each category is aspired.

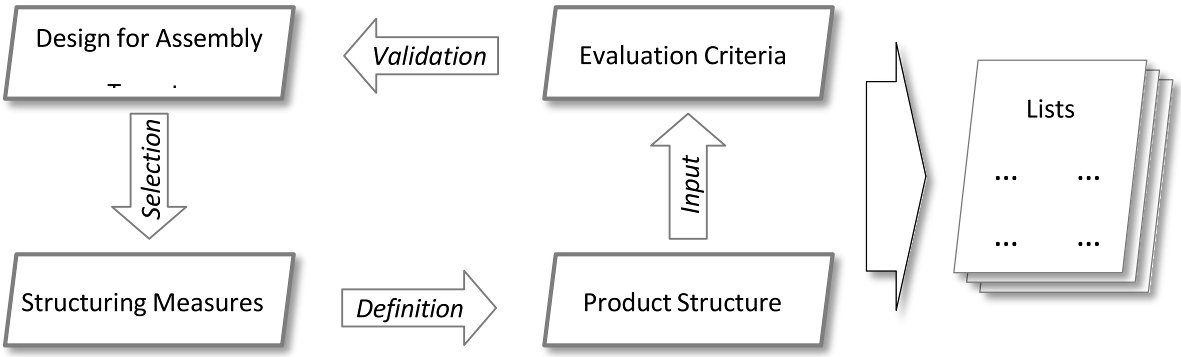

Figure 2. Methodical Approach for Product Structuring from Assembly Point of View

Concept Elaboration

The listing of the individual elements of each category is the basis for the elaboration of the procedure. The input is extracted from the relevant literature. During the investigation it was asserted that, especially in the case of targets and measures, confusions of the terminology occurs. While one author assigns a statement to the group of assembly targets, another author's comparable statement is assigned to the group of measures. The lists described in the following make the attempt for a non-redundant differentiation into the particular categories. These lists do not make claim of being complete. In terms of the proposed methodical procedure, an amendment of the lists is both possible and even requested at any time.

Design for Assembly Targets

Next to the fulfilment of technical functions, the economic implementation is general objective of the product designing activities. A design target is therefore the enhancement of the economical properties of a product [9]. This economical aspect needs to be included in the formulation of assembly targets. The target describes the advancement of a specific property state. So the five general Design for Assembly targets *Lead Time Reduction*, *Assembly Cost Reduction*, *Increase of Profitability*, *Increase of Productivity* and *Maintain Product Quality* can be stated. Based on this list of targets, structuring measures are selected that determine the properties of the product.

Product structuring measures

In general, measures support the meeting of the respective requirements in terms of economic efficiency. They should be treated as proposals in the sense of thought and creativity provoking impulses. Analogous to the DfA targets category, this aspect should be considered in the respective formulation of each element of the product structuring measures list.

The superior measures for product structuring correspond to the general DfA principles *Reduce*, *Unify* and *Simplify*. Therefrom specific measures are derived, which are the definition of *sub-assemblies*, implementation of *integral design*, *aggregation and unification of interfaces*, application of *common and standards elements* and *postponement* of the product differentiation point. The intended effects are the simplification and parallelisation of assembly operations, the reduction of components. A high degree of utilization, economies of scale, simplified assembly system and lower resulting investments for the assembly system.

Product structure representation
The product structure attributes represent the relevant product information from an assembly point of view compared to a product model. For a general overview of the product the *Module Interface Graph (MIG)* displays the modules as well as their interfaces and provides information about variety and part numbers [3]. This graphical product model is enhanced by *assembly relevant information*. In case of the components or modules the dimensions (weight and size) as well as the suitability as base part and capability for communal treatment are added. The interfaces are additionally characterised by the specific joining principle, the stability of the resulting compound and their capability for commonality.

Key figures/evaluation criteria
The entity of product attributes determines the product properties. These properties are directly related to the economic characteristics of a product which were initially defined as the actual design for assembly targets. The criteria for evaluation can be divided into two groups. For a *qualitative* evaluation, the oppositional effects of pairs of criteria are analysed. For example, the increase of components within a module reduces the number of joining operations but impedes the module handling. For a *quantitative* evaluation, the use of key figures is proposed. The following key figures have direct relation to assembly properties: *Interface Complexity* by Boothroyd [4], *Module Coupling Independence* by Blees [3], *Lead Time* by Erixon [5], *Total Constant Commonality Index* by Wacker/Trevelen [16], *Primary-Secondary-Factor* by Lotter [12] and the own defined *Degree of Parallelisability* [7].

Methodical synthesis
The practical implementation of the procedure requires the utilisation of a methodical tool. The application of measures and thereby definition of the product structure as well as the deduction of information for assessment and validation needs to be ergonomically supported.

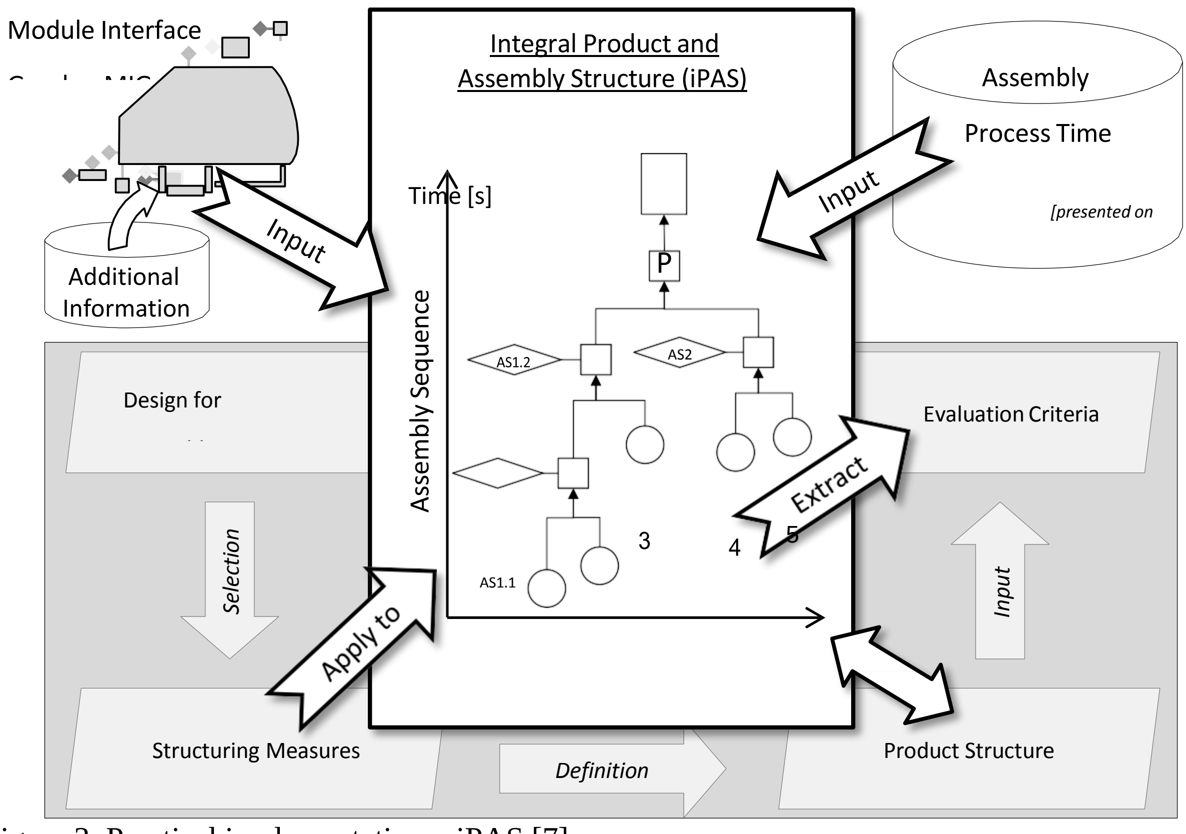

Figure 3. Practical implementation – iPAS [7]

Therefore, the application of the integral Product and Assembly Structure iPAS is proposed. The iPAS, shown in the centre of Figure 3, represents the product structure and its related assembly process in a single diagram. Thereby, the impact of structuring measures on the process can directly be demonstrated [7]. The Module Interface Graph in combination with the additional assembly relevant information delivers the necessary input. The application of structuring measures is conducted within the graphical chart. Relevant product structure attributes can be extracted from the iPAS in order to provide data for the evaluation. By means of the optional integration of an approach for assembly time estimation, it is possible to additionally enhance the accuracy of the evaluation [8]. The finally defined product structure can directly be transferred back to the overall PKT Approach without any difficulties.

The application of the measures within the iPAS tool is conducted in the sense of the design guidelines. Therefore, a set of idealised product structure patterns that are displayed in the iPAS representation way is provided. These patterns are classified as right or wrong or an advice for modification is proposed. It is the aim to provide simplified examples the user needs to apply to the actual product structure. The iPAS is therefore to be regarded as a tool for supporting the creative activities of the designer in the sense of a basis for visualisation and discussion of assembly aspects in the product structure.

The following figure shows the example of such an idealised pattern. In this case, the initial product structure, displayed on the left side, contains two variant components (#2 and #3) leading to variant processes displayed by grey boxes. The first proposed strategy is to postpone the product differentiation point by grouping the variant components into one module. The second strategy is to achieve a component or interface design, which enables communal processes.

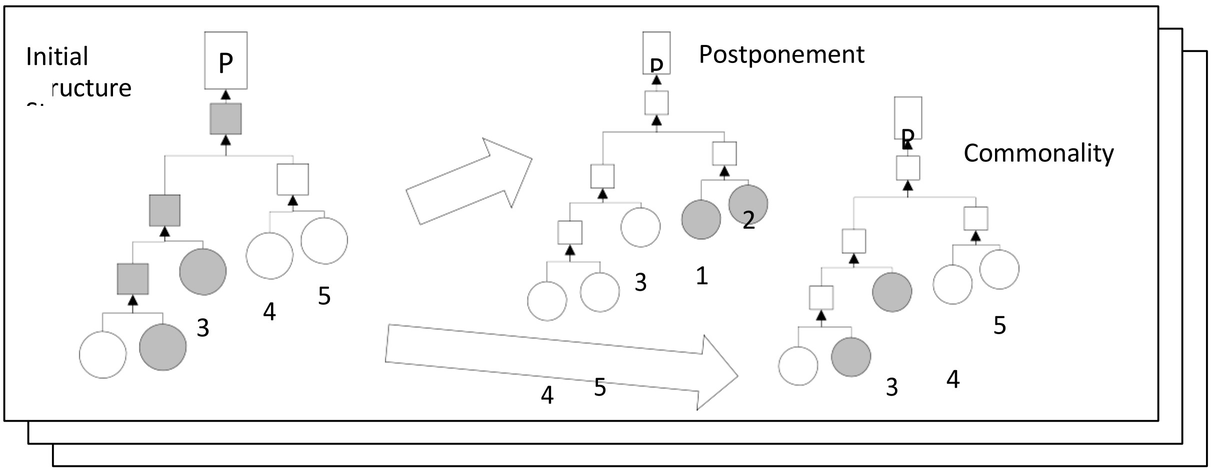

Figure 4. Idealised patterns in iPAS representation for product structuring measures

Case Study

The developed procedure is applied in terms of a case study. A computer mouse is used as exemplary product. The initial product structure and assembly sequence are displayed in the iPAS in the figure below. The resulting shape of the iPAS points towards three applicable modifications on the structure. The affected components are marked in the iPAS on the left side and the Module Interface Graph (MIG) on the lower right side of figure 5.

- Measure I proposes an integral design of the housing (OG) and the buttons (PMT's). The iPAS shows the close relation of the components. For this reason, the modules are candidates for integral design. The actual feasibility of the proposed modification needs to be verified by further individual investigations.

- Measure II identifies candidates for the postponement of variant components by grouping electrical elements into one module (BA, PL, KA, AK, FU). In the initial product structure these components represent an extensive part in the variety differentiation. The individual sequential mounting of each component leads to high assembly efforts. By the use of a single module assembly tasks can be shifted into pre-assembly reducing lead time in final assembly.
- Measure III defines the component PL as suitable as base part for the prior defined module. This modification is necessary to facilitate the pre-assembly of a module and facilitate its installation in final assembly.

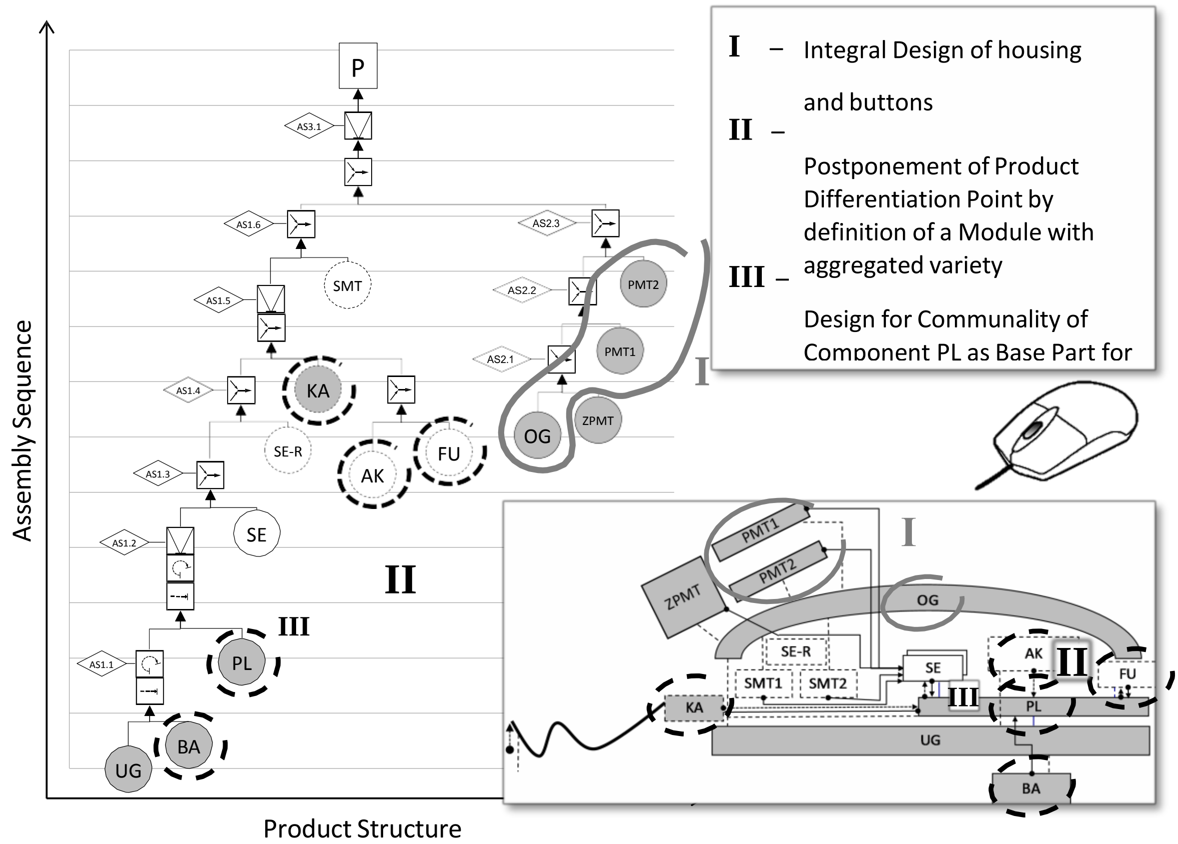

Figure 5. Case Study – three exemplary measures for product structuring

Conclusion and Outlook

The procedure presented in this paper describes a methodical approach for the structuring of products on the basis of defined Design for Assembly targets. The use of a specific product model representation is the core element for the application of structuring measures as well as the direct evaluation of their impacts. Based on this methodical framework, the concept elaboration is conducted by the setting up of lists for the elements of the four main categories targets, measures, product structure attributes and evaluation criteria.

For the practical implementation the utilisation of an integral representation model for product structure and assembly process (iPAS) is proposed. The application with an exemplary product shows proof of the expected potentials for product development. On the one hand side, a consistent product structure definition is possible providing basis for general concept assessment and preparation of the decision making process. On the other hand, the extensive supporting character for creative activities is shown. The graphical representation reveals the structural and process related connections within the product. The application of measures can be performed intuitively and their impacts are directly pointed out. In terms of future elaboration of the approach the formulation of further idealised patterns as well as their validation by applying to more extensive product families is scheduled.

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