BROWNFIELD PROCESS FOR THE RATIONALISATION OF EXISTING PRODUCT VARIETY TOWARDS A MODULAR PRODUCT FAMILY

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Abstract

Modularisation, product platforms, product families and product configuration are efficient product structuring tactics for providing of product variants for customers. This paper studies how the design information related to designing of modular product family that supports product configuration can be structured and how to support defining of this kind of design information in a design situation in which existing product assortment should be rationalised towards a modular product family that supports product configuration. Research approach bases on literature review and empirical findings. Categorisation to five design information elements including partitioning logic, set of modules, interfaces, architecture and configuration knowledge is suggested. Existing methods consider partly or as different combinations these elements but considering of all of them is rare although all of them have been recognised as important. Thus a design method known as the Brownfield Process is introduced. Steps of the method are tested in industrial cases. As a conclusion we state that the method can be applied also to other cases in which rationalisation of existing product assortment is sought.

Keywords: Design methods, Product families, Product structuring, modularisation, Product architecture

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1 INTRODUCTION

One challenge for the companies is the cost effectiveness of offering product variants to customers. Product variety describes the number of different versions of a product offered by a firm at a single point in time (Ulrich and Eppinger, 2008). Modularisation, product platforms, product families and product configuration have been suggested as product development and product specification tactics which support offering of product variants for customers and enabling of benefits with commonality and design reuse such as cost savings for a company (Pine 1993; Victor and Boynton 1998, Juuti 2008, Pulkkinen 2007). Numerous approaches, tools, methods and suggestions have been presented in this field (Jiao et al., 2007; Gershenson et al., 2007; Daniilidis et al., 2011; Nomaguchi et al., 2012; Krause and Ripperda, 2013). Our focus is to study (1) how the design information related to designing of modular product family that supports product configuration can be structured and (2) how to support defining of this kind of design information in a design situation in which existing product assortment should be rationalised towards a modular product family that supports product configuration. Section 2 considers typical concepts in this field. Section 3 presents a method known as the Brownfield Process (the BfP) for designing of modular product families that support product configuration. Brownfield stands for the reusing of available assets and that there are limitations in designing because of existing solutions. The first version of the BfP was discussed in ICED11 paper (Lehtonen et al., 2011). Section 4 presents case studies and Section 5 includes summary and discussion.

2 LITERATURE REVIEW

Standardisation can be considered as enabler of modularisation. Standardisation of components includes replacing of multiple components by one component that can do the functions of all of them (Perera et al., 1999; Ulrich and Eppinger, 2008). Levels of standardisation include model specific, company specific and industry standard components and interfaces (Fujimoto, 2007). Interfaces are central role in modularisation. Modularisation aims to create variety for customers without forgetting commonality between module variants and properties that reduce complexity in the company's operations (Andreasen, 2011). As guiding principles for modularisation, considering of module drivers are suggested in making of product structuring decisions (Erixon, 1998). Modularisation includes defining of building blocks of product variants knowns as modules. A module has an assigned standard interface that enables the independence and interchangeability of the modules in the same place and the use of one module in several variant (Lehtonen, 2007). Component-sharing, component-swapping, cut-to-fit, bus, sectional and mix modularity are typically presented as types of interchangeability (Ulrich and Tung, 1991; Pine, 1993). Product architecture is also commonly discussed in modularisation. Product architecture describes the most important building blocks of the product and how they interact with each other through interfaces (Ulrich and Eppinger, 2008). There are integral and modular product architectures (Fujimoto, 2007). Modular architecture should include a minimum number of modules for creating the needed variety for customers because of cost factors (Andreasen, 2011). Designing of product platforms and product families are also solutions for increasing design reuse and enabling product variants. A platform is a set of core assets that are reused to achieve a competitive advantage (Kristjansson et al., 2004). Therefore research and development experiences are needed in defining of a product platform (Ulrich and Eppinger, 2008). Product platform enables launching of a modular product family with different product variants that corresponds to a set of market needs now and in predictable future (Lehtonen, 2007). Product configuration is understood as a systematic way to specify these variants for customers based on configuration knowledge (Pulkkinen, 2007; Hvam et al., 2008; Haug et al., 2012; Tiihonen, 2014).

3 PROPOSED METHOD

Figure 1 presents the main content of the BfP. This method aims to synthesize existing methodological suggestions and tools in this context where applicable. The BfP suggests partitioning logic (reasoning reasoning for the module division of a product family), set of modules (building blocks of product variants), interfaces (enabler of interchangeability and independence of modules), architecture (layout descriptions including modules and their interfaces) and configuration knowledge (knowledge that facilitates defining a customer variant from the product family) as the key design information elements. This categorisation is supported by findings from the literature and experiences in industrial setting in which key concepts of modular and configurable products have been studied. Synthesized methods in which all of these key concepts have been considered are rare. The BfP includes ten steps of which each step contributes to specific key design information elements. Using of the BfP may include iteration and customisation. If designers are not familiar with modular product family development, it is beneficial that expert in this field acts as a facilitator in each step. If not specified otherwise, every step can be started with a workshop in which goals, suggested tools and expected results are clarified to the design team.

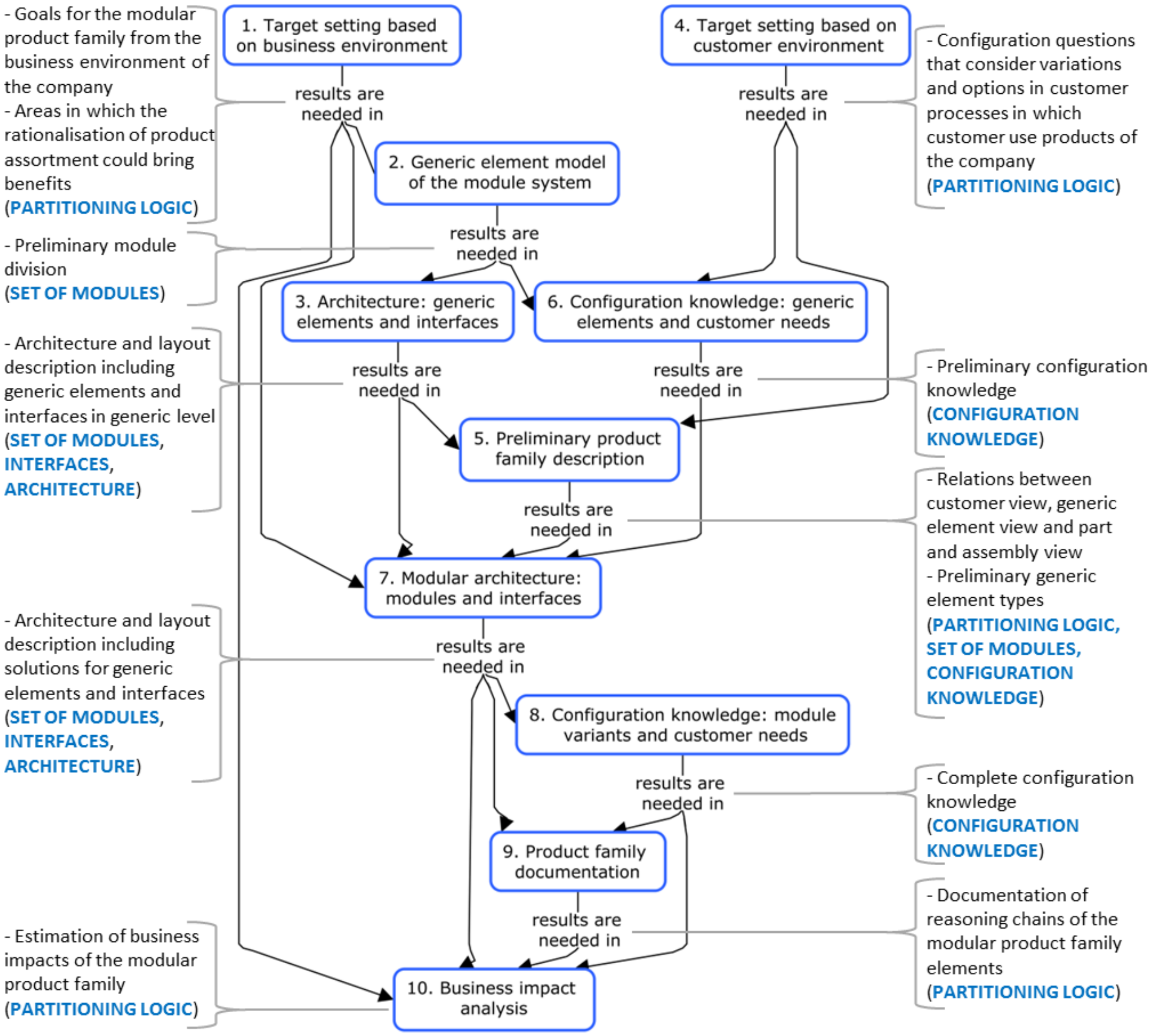

Figure 1. The Brownfield Process (the BfP).

3.1 Step 1: Target setting based on business environment

The first step includes defining business environment and areas in which rationalisation of the existing product variety could bring benefits. This step mainly contributes to partitioning logic. Two tools are suggested: cause-and-effect diagram about benefits with commonality and variability (Juuti, 2008) and Company Strategic Landscape (CSL) framework (Lehtonen, 2007). The cause-and-effect diagram shows the linkages between different benefits of products with commonality and variability. This diagram is suggested for ensuring the objectives in a situation in which a company has a strong belief about the benefits that are sought after with modular structures for product configuration. The CSL is a discussion and workshop oriented tool and is meant for cases in which the objectives of product development needs to be defined in more detail. The aim is to define explicitly processes such as product development process, order-delivery process and other life cycle phases, value chains the company wants to operate in and strategy and organisational aspects that influences structuring of products and to define key requirements to product structuring according to these viewpoints with the help of experts from the company.

3.2 Step 2: Generic element model of the module system

Preliminary module division known as generic element model is defined using the knowledge about the existing products. Thus this step contributes mainly to a set of modules of five key concepts. Generic elements are considered as abstract in product structuring because they don't present necessarily the final solutions of which product variants are made of. Generic elements can consist of sub-systems, function carriers, assemblies or even single parts. If generic elements are considered as function carriers, organ thinking as presented for example by Harlou (2006) is similar. Another example close to principles of the BfP is found in the research by Umeda et al. (2000) in which they noted alternative structure models for the product based on different business objectives. Defining of generic elements is started according to which entities the case company considers their products to consist of. If two or more proposals for generic elements have many similarities, defining of only one generic element should be considered. If elements that have much commonality with each other are approved as different generic elements, there is a risk that the product family will eventually include unnecessary variation. Completeness of the generic element model can be estimated based on the question: does the suggested generic element model represent all the products chosen for the rationalisation project or are there some areas missing?

3.3 Step 3: Architecture: generic elements and interfaces

This step aims to clarify generic elements which have interfaces with each other. Therefore the step contributes to a set of modules, interfaces and architecture. Architecture is considered as a description of a layout scheme of generic elements and interfaces between these elements. Defining of architecture is started by considering how generic elements are typically positioned in a product. Generic elements that have interfaces with each other have to be identified because that is a starting point in defining a modular architecture and thus important phase in modular product family development. Traditional office software can be used in this step as a support tool. Bruun et al. (2013) presents an example in which Microsoft Visio has been used in the drafting of product architecture and interfaces. They explain that this kind of description can be linked with product life cycle management systems by using additional applications. Bruun et al. also explain that it can be useful to keep some typical outline of an existing product as a background on which the architecture is drafted. Other illustrative examples of architecture descriptions can be found from Harlou (2006), Fujimoto (2007) and Eilmus et al. (2012). Generic organ diagram (Harlou, 2006) describes variant and optional organs and their interfaces in order to support identifying standard designs and architectures. Fujimoto (2007) presents modular architecture using a schematic in which modular components and interfaces are exemplified using rectangles and lines. Eilmus et al. (2012) suggest Module Interface Graph for visualising the variety of components and their connection flows. All of these examples are two dimensional. We suggest similar basic idea for architecture description. Types of interfaces are considered in Step 7.

3.4 Step 4: Target setting based on customer environment

Studying of the customer environment is important if the company wants to change its operating mode from project delivery with delivery specific solutions to configurable product delivery with predefined modular solutions and common architecture. Understanding about customer requirements needs to be up to date because defining of the most suitable product variant for the customer is based on answering questions which describe the main customer requirements from variation perspective. If all of the requirements cannot be described formally, the part which these requirements relate to could be left outside the systematic configuration, thus being partly configurable structure (Juuti, 2008). This step contributes mainly to partitioning logic of the product family because actual configuration knowledge is not defined in this step yet. The BfP includes a presumption that the very basic requirements that products must fulfil are well known within the company and the need to focus on these is low. Defining of traditional requirement list as suggested by Pahl and Beitz (1996) is not necessarily suitable for designing of modular product family that enables product configuration if the requirement list does not reveal reasons for why different product variants would be needed. The starting point in analysing the customer environment is to define processes of customers in which they use the products of the company and to focus on variability issues. The focus is to define generic process steps and segmentation based on customer processes. This includes alternative parameters and options that have an effect on the content of modular product family. It is important to define preferred ways how customers are working with products and philosophies that may cause the need for different products.

3.5 Step 5: Preliminary product family description

A preliminary product family description is defined by focusing on customer requirements causing the need for variants, generic elements and related existing parts and assemblies and defining links between these viewpoints. This step has similarities with Product Family Master Plan (Harlou, 2006) in which combining of customer, engineering and part view is highlighted. The purpose of the step is to facilitate discussions among designers about possibilities to add more commonality to the existing products and to define number of variants needed for fulfilment of each customer need. Thus this step contributes mainly to partitioning logic, set of modules and configuration knowledge. Each customer need from variability viewpoint is linked to a generic element that it relates to. If there are generic elements which have no relations to customer needs related to variability, these generic elements have good potential for standardisation. Generic elements to which several customer requirements are related are a challenge for rationalisation of existing product assortment. The extent of part assortment in the existing products and possibilities for standardisation of parts or assemblies are also considered by defining the relations between the generic elements and parts and assemblies. Studying relations between different views can be an eye-opener if current products do not include lots of commonalities and there exist many solutions for almost same kind of need. Every variant part or assembly should have a reasoning chain to a specific customer need that explains why there needs to be variation. Parts and assemblies should be organised according to which generic elements they are related to. This helps in making of an overview regarding existing products and their commonalities and also regarding complexity of the whole product assortment. This step supports recognising of different product structuring tactics which are discussed more in Step 7.

3.6 Step 6: Configuration knowledge: generic elements and customer needs

Preliminary configuration knowledge describes relations between generic elements and customer requirements causing the variety need. Later on in Step 8, more detailed configuration knowledge is defined using actual solutions for generic elements by using same principles as in this step. We suggest the K-Matrix (Bongulielmi et al., 2001) as a supporting tool for this step. The original K-Matrix is a configuration matrix in which relations between the technical view and the customer view are defined. In the BfP, technical view includes a collection of generic elements. Because the technical view is not defined in detail in this step of the BfP, more diverse types of relations are used than in the original K-Matrix. There can be at least four types of relations between technical and customer view: (1) customer need excludes a generic element option, (2) customer need might have an effect on the generic element option, (3) the generic element option is needed to realise customer need and (4) customer need does not affect the generic element option. This kind of knowledge supports defining of final solutions to generic elements. Separate modelling of configuration knowledge is also considered beneficial in the implementation of configurator software for the defining of product specifications in the sales-delivery process (Haug et al., 2012).

3.7 Step 7: Modular architecture: modules and interfaces

Step 7 focuses on defining of standard and variable section of the product family, defining of part sets for generic elements and clarifying the overall architecture of modular product family and defining of interfaces. When considering the five key design information elements, this step contributes to set of modules, interfaces and architecture. If variation needs from customer perspective are not related to a generic element, the element is good candidate for standard element that is common for different variants. A part set for standard element is selected or re-designed based on the existing part sets. Designing a single standard solution for a given set of different needs might be possible but this kind of element can be too expensive because of excessive adaptation possibilities and performance. If a single standard solution is not reasonable for realizing the variation need, a set of interchangeable modules which are standardized within a company should be considered. Standardized variant options can be considered also as fully-configurable elements. If a reasonable number of standardized modules cannot be defined for a generic element that needs to consider different variety requirements, dividing the generic element or changing the generic element division or modifying existing part-sets or assemblies is needed. If restructuring of generic element does not help in recognising standardization possibilities, the element is considered as one of a kind element. Designing of re-usable modules for business areas which have low sales potential is not reasonable if designing of these kinds of product elements is more complex and costs more than designing of one of a kind element for each rare case. The aim is to avoid one of a kind elements since designing of those can be expensive. If standard, configurable and one of kind elements exist, we define the whole modular product family as partly configurable. A reasonable number of parts is affected for instance by the variety of customer needs the same product family would have to fulfil, possibilities, skills and resources for recognition of commonalities from existing solutions and standardization of part sets. In reducing unnecessary parts, recognition of commonalities and realisation of the same kinds of solutions with fewer physical solutions is aimed at. There is a possibility that the generic element must be divided if certain sections of its related part sets could be standardised but the element would also have to consider the variation. Thus this generic element would be divided into standard and variable elements and redesigned accordingly. Tools and approaches for designing of new solutions and finding of new ideas are listed in for example by Pahl and Beitz (1996). If generic elements are divided into smaller entities because of variation needs and possibilities for better standardisation, number of interfaces to be managed increases if elements that could be standardised cannot be combined with other standardised elements to form a single larger standard element. In considering of overall architecture, recognition of interfaces is important because they enable interchangeability and independence of the modules. The BfP is open for different interface definitions. Interfaces can be defined from several perspectives such as spatial, structural, geometry, material, energy, signal, and information (Avak, 2006; Sosa et al., 2007; Rahmani and Thomson, 2009). Fujimoto (2007) presents that there are three kinds of interfaces: model specific, company specific and industrial standard interfaces. Categorisation to non-standard interfaces, closed standard interfaces and open standard interfaces and also to frozen and unstable can be also found (Cabigiosu et al., 2013). Unstable means that interface can be substituted with another standard interface. According to Fixson (2006), different modularity types (Ulrich and Tung, 1991; Pine, 1993) can be also understood as different interface types. Defining of boundaries for the product that the variation should not exceed can be also helpful in order to manage spreading of variety in products in which space is a critical design criterion (Holmqvist, 2004). Harlou (2006) explains that each company should clarify ownership of the product elements and interfaces in order to prevent deteriorating of the modular architecture during the time frame and losing the benefits of reuse.

3.8 Step 8: Configuration knowledge: module variants and customer needs

The complete configuration knowledge is defined by adding solutions that generic elements include to the same kind of matrix discussed in Step 6. Subsequently relations between solutions of each generic element and customer needs are defined using the same kind of notation as in Step 6 but at this phase the configuration knowledge should be definitive.

3.9 Step 9: Product family documentation

After modules are defined in Step 7, design reasoning path of each generic element is described separately including name of the product family in question, generic elements it includes, solution principles for each generic element and type of each solution (standard, modular with variants or one of a kind element) and variation needs from customer perspective. Aim of the documentation is to support in understanding and discussing the structure of the product family and to support future updating of the modular product family in a company.

3.10 Step 10: Business impact analysis

As an outline for this paper, only basics of the business impact analysis are presented. Evaluating the results of the product development is important for clarifying how well the objectives are met with the designed modular product family and if this rationalized product assortment could be competitive from business perspective. Business impact analysis is supported by a model that describes relations between key design information elements, encouraging guiding principles and mechanisms for product rationalisation and generic steps of manufacturing industry. Guiding principles for modularisation and product family development have similarities with for example the module drivers presented by Erixon (1998) and mechanisms by Fixson (2006). The business impact analysis is facilitated by a supporting tool that suggests a set of questions to be answered focusing on guiding principles and their effects to process and life cycle steps. Answers are given by focusing on decades of money (thousands, tens of thousands, hundreds of thousands etc.) because analysis with definitive values can be difficult because there might not be accurate information available. The time period under review should be long enough so that the estimating of effects related to the later life cycle phases such as possible product revisions could also be estimated. The largest decades are the most important when the results of analysis are discussed. If business effects of some guiding principles are impossible to estimate this can be considered also as a result explaining that some topics are not well-enough known.

4 CASE STUDIES

Steps of the BfP have been applied in two cases that focused on sheet metal processing equipment (Case A) and conveyor solutions (Case B). The main results of Case A were discussed in paper by Lehtonen et al. (2011) although the method was organised differently in the paper. That paper covered applying of Steps 1,2,4,5,7,8 and 9 as categorised in this paper. In Case A, preliminary architecture was also modelled (Step 3) using traditional office software as suggested in Section 3.3 in order to create a common understanding of the architecture. Step 6 was not done in the case because earlier considerations of relations between customer requirements and generic elements done in Step 5 were considered sufficient. Case A included also a business impact analysis. Because a completely new product family was not designed, estimated savings on materials and components were moderate. Impacts were higher in terms of operational costs for the company. In certain cost topics, it was evaluated that costs could even be reduced by 40 %. Based on the analysis, the repayment time for the product family development project was also calculated. This estimation for the design project was seen as positive and thus the project was continued towards concretising. Case B included applying of Steps 1,2,4 and 6. Figure 2 summarises how the results looked like by applying suggestions given in Section 3. Section 5.1 discusses the results more.

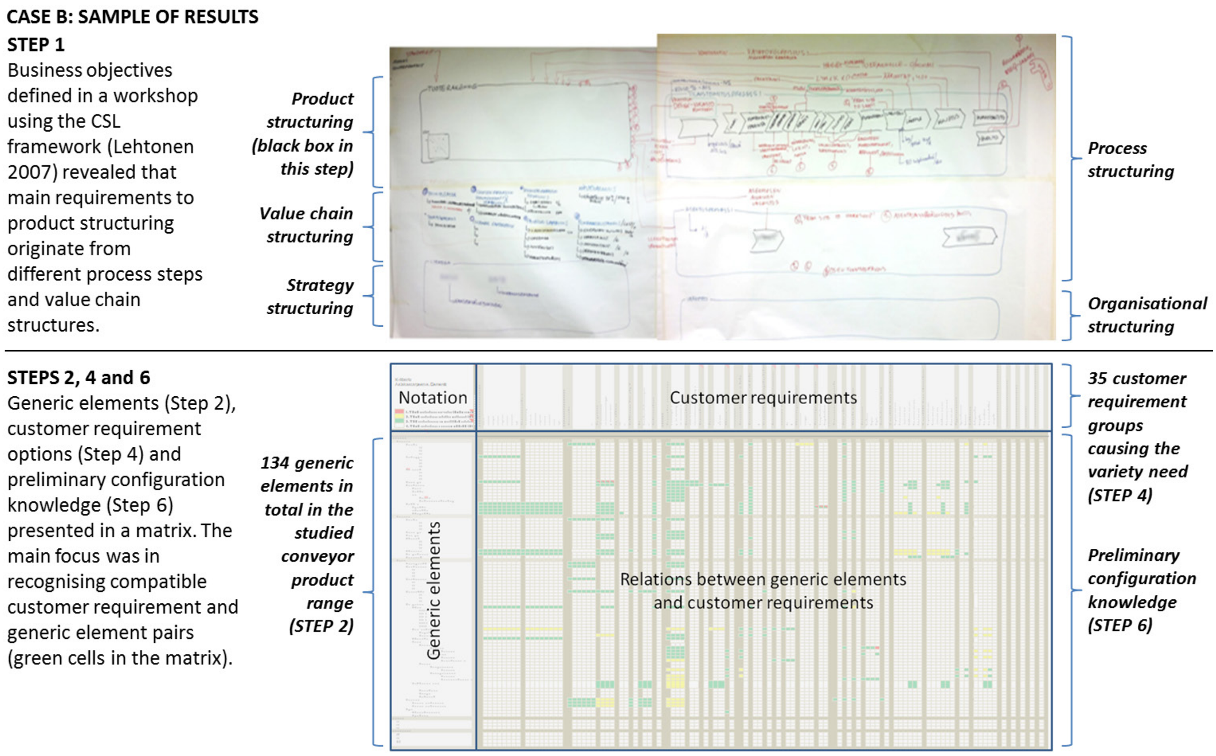

Figure 2. Illustration of the main results of Case B. These results were achieved based on methodological and tool suggestions explained in Section 3.

5 SUMMARY AND DISCUSSION

5.1 Summary of the results

The BfP is based on separating of partitioning logic, set of modules, interfaces, architecture and configuration knowledge as key design information elements (answer to research question 1) that facilitate understanding about designing of a modular product family that supports product configuration. The method includes ten steps that support defining of design information related to the five key design information elements based on existing product assortment of a company. The BfP is an answer to research question 2. The methodological suggestions of the BfP are kept in generic level because the aim is that the method could be applied to different cases. The emphasis was to suggest good practices found from the literature that facilitate designing of modular architecture and product family that supports product configuration. Thus many of the approaches, methodological suggestions and tools of the BfP are validated separately already in earlier publications. Presumption is that design organization is able to define its business and customer environment and has knowledge about the products they have designed, produced and sold to customers. These kinds of capabilities are important in decision making related to viewpoints that were not considered in the method. Defining of modular architecture including set of modules and their interfaces (Step 7 of the BfP) is probably the most demanding step of the method. This step results in a product family structure that either enables or prevents fulfilling of business objectives. Another challenging step is to estimate business impacts of the modular product family (Step 10 of the BfP) it can be difficult to evaluate all of the effects that may occur during the life cycle. Steps of the method were used in industrial cases in which objective were to rationalise existing product range. In Case A, the most of steps were used as described in Figure 1 and rationalised product assortment and business goals were achieved. Prior to applying the BfP, the company had failed several times in their modularisation projects. This was discussed mostly in earlier paper by Lehtonen et al. (2011) although the content of the steps were presented differently. After applying the BfP, the company started to develop another product range by using the same principles on its own. Case B focused on the front end steps of the method. This case was successful for validating steps and approaches that were not discussed in Case A. All of the steps such as Step 7 were not applied in Case B. Partially applying the method does not necessarily lead to a realisation of the main objective as in Case B if existing knowledge and results related to these steps and key design information elements are not sufficient. Thus commitment and investments to product development is highlighted in order to reach the objective.

5.2 Discussion

Design methods of modular product families in which all of the suggested key design information elements are highlighted are rare. The importance of these elements has often been recognised separately or in smaller sets. For example Erixon (1998) and Eilmus et al. (2012) focus well on defining module content but these methods do not focus on product configuration aspects as much as the BfP. Presenting of partitioning logic (reasoning for a certain module division according to a specific business and customer context) as a separate key engineering concept in this field can be also considered as a new contribution. The BfP is primarily meant for rationalisation of existing product assortment. Innovations are mentioned often to increase competitiveness and enable new business but the designing of a completely new product is rare in the manufacturing industry because of several risks as for example Pugh (1996) has presented. Consequently we state that the BfP is noteworthy. Gericke and Blessing (2012) mention that design processes typically do not represent the creative process sufficiently. This is also one weakness of the BfP. The method does not remove the need for trial and error, which is a typical property of traditional design processes. The integration of creative tools and methods such as presented by Pahl and Beitz (1996) could be helpful in redesign activities. Results of applying the BfP does not necessarily present model solutions of mass customization in its purest form. This is because it might not be possible to define only standard and fully-configurable product elements but customer specific solutions are also needed because of complex customer and business environment. Jump from a paradigm to another needs competence, commitment and investments. Hubka and Eder (1996) explain that a method can be a strictly algorithmic or strictly regulated procedure, heuristic instruction (relatively flexible procedure) or relatively fuzzy instruction without clear references (a quite free procedure where only main principles work as guidance). The

BfP includes characteristics of heuristic and fuzzy instructions. The method cannot be considered as a strict procedure because of given suggestions and tools.

We state that the BfP follows method-like characteristics according to Newell (1983) which are discussed below. The BfP in itself cannot define the best solution in a design situation but it provides suggestions and guidance about what should be developed and defined in each step. The BfP aims to present a specific way to proceed including different steps in the designing of a modular product family that supports product configuration. The aim of the BfP is that by following the steps, possibilities for defining a rationalised product assortment increases. The BfP includes generic sub-goals and sub-plans. The name of each step aims to describe the result of the step. Steps contribute to the suggested key design information elements (partitioning logic, set of modules, interfaces, architecture and configuration knowledge) in designing of a modular product family that supports product configuration. The BfP does not define exactly how these sub-goals can be achieved in every different case, but the process aims to provide generic suggestions and tools that may help in the realisation of these sub-goals. Use of the BfP (whether the method is used or not) can be estimated by comparing the existing design information related to product family development and the suggested main results of each step. The aim in the description of BfP has been to define the results of each step, including what these results look like and to which other steps the results of a specific step relate to.

5.3 Future work

Future work includes defining maturity stages or characteristics to each key design information element in order to support analysing the current state of product assortment in each case. Future work will also focus on how to find the most promising product range in which largest benefits could be achieved by product development. Lastly, future work will include defining the business impact model and tool further.

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