ASSESSMENT OF MODULAR PLATFORM POTENTIAL IN COMPLEX PRODUCT PORTFOLIOS OF MANUFACTURING COMPANIES

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Abstract

The globalized economy and the increasing trend of product individualization cause a rising amount of product variants to meet the customer's demands. An increasing number of companies develop new or adapt existing modular product platforms for their product portfolio as an approach in order to tackle these challenges. To improve the modular platform performance, it is crucial to define its structure in the early planning phase. This paper introduces a holistic approach that supports decision makers by offering transparency throughout the initial planning phase of the modular platform design determining appropriate products that suit on a common platform. The holistic method uses data analytics to describe the products within a portfolio and to detect similarities between customer requirements, functions and components. The introduced method analyses modular platform potential that is being evaluated in order to provide a detailed and profound prioritization of products in scope for the following platform design.

Keywords: Design methodology, Platform strategies, Decision making, Design engineering

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1 INTRODUCTION

Globalization and the increasing customer demands for individualisation force manufacturing companies to expand their product variety while keeping internal effort caused by rising complexity low. A promising concept to maximize commonalities and take advantage of economies of scale at the same time is product modularization using carry-over-parts (Schuh et al., 2006). To increase the performance of modular platforms both the product scope as well as the resulting number of modular platforms play a crucial role (De Weck et al., 2003). Independent from introducing or adapting modular product platforms, companies usually take upfront product platform decisions regarding the considered product scope solely based on expert intuition instead of systematic approaches. The sheer amount of product data associated with the products in the portfolio as well as the missing transparency regarding existing components and interfaces reinforce decision makers in this intuitive approach (Simpson et al. 2014). A recent study[1] conducted in preparation on this paper showed that nearly half of the surveyed companies start the design of modular platform products based on the intuitive definition of platform products. Also, only one third analyses the whole product portfolio before designing the platform whereas two thirds risk missing out potential platform synergy effects. Since the modular platform design is oriented on the defined product scope, a systematic analysis of the commonalities over the companies' product portfolio has fundamental importance within the planning of modular platforms. Hence, the lack of a structured approach hinders an optimal design of modular platforms which leads to suboptimal modularization results, as unused potentials remain. In order to increase the succesful introduction of a modular platform and to enhance the company´s profitability, this paper introduces a holistic approach for the determination of the optimal modular platform structure by the application of data mining techniques. The method focuses on the early planning phase within the platform development process and supports the identification of modular platform potential within the product portfolio.

2 RELATED WORK

The abundance of product platform literature has been illustrated by Simpson et al. (2014) as well as Otto et al. (2016). The research popularity of product platforms stems from its impact on companies' overall profitability by affecting product costs, product quality and time-to-market. Several studies deal with the optimal product platform design. Simpson et al. (1999) discuss methods of former product variety exploration and product family structuring such as the Product Platform Concept Exploration Method (PPCEM). The method provides tools to scale a platform concept into an appropriate family of products starting with overall design requirements and finishing in a product platform portfolio. Recent investigations aim at the efficiency enhancement of portfolio structuring methods. Some approaches tackle the problem from solely a technical perspective whereas others focus on the customer perspective. A frequently applied tool for determining product commonalities as it is introduced by Tucker et al. (2010) is the fuzzy c-means clustering. Moon et al. (2006) use data mining and fuzzy c-means clustering to support product family design. Association rule mining is used to develop rules related to the product functions. The development of association rules and clustering allow the identification of common functional features to determine homogeneous clusters, which represent possible modules for the modular platform structure. In contrast to that, Freeman et al. (2011) apply the pattern recognition technique of fuzzy clustering focusing component commonalties. The proposed method provides partition hierarchies of product commonalities represented by dendograms, which are supposed to be used to guide the optimization of product families. A quantitative method to determine the optimal number of platforms is developed by Seepersad et al. (2000) using the Decision Support Problem (DSP) and physical programming. The DSP technique is used to compromise between the attributes of a multi objective optimization problem. In the paper, the method focusses on the optimization of an absorption chiller product portfolio – highly customized products with low production volumes. Therefore, the method considers attributes like market demands, production cost and expected cycle time. After weighting these attributes, physical programming is used to compromise nine goals for the product platform design that can be summarized to: minimize average cost per product and minimize the

1 Study conducted with 35 producing companies from different industries within the 2nd Complexity Management Congress held in November 2016, Aachen

expected cycle time for each absorption chiller type of the portfolio. Ben-Arieh (2009) uses a genetic algorithm for solving the so called multi-platform problem. Here, a platform is described as set of shared components among various products, whereas a product from a certain family can be produced using one of the developed platforms by adding or removing components. The main thesis within this context argues that a multi-platform is more appropriate for the optimization of the overall cost in comparison to single platforms. In the beginning, a genetic algorithm is applied to a single platform. Each time the genetic algorithm finishes, it is applied to one additional platform. When the problem is solved for the specific number of platforms, the methodology provides the number of platforms with the lowest overall costs. The increasing complexity of product portfolios and faster changing markets are requiring better performance of companies' system architects. Kissel (2014) provides a method to enhance working with such complex product portfolios. The method is capable to represent and manipulate complex structures by using graph algorithms. The approach systematically enhances transparency of complex portfolios and leads to an increase in effectiveness and efficiency regarding system architects work. Contrasting the consideration of algorithms, De Weck (2003) proposes a quantitative method to determine the optimal number of platforms focusing on cost and profit. Based on an estimated sales volume for a platform-based product, the whole sales volume of the product family is determined. Using the total cost of a product family (sum of variant cost and total investment cost) the profit for the whole product family is obtained. By varying the number of platforms, the maximum profit for the product family can be determined and thereby the optimal number of platforms. The literature review of Zhang (2015) outlines the demand for the effective development of successive product families. According to the myriad of academic and practitioners efforts, the topic is exploited on several stages. Nonetheless, there are still tremendous issues pertaining platforming and portfolio structuring. Focusing on new platform concepts like customer platforms, technology platforms, function-technology platform etc. is just one possibility to examine portfolio structuring from a new perspective.

Collectively observed, it is noticeable that the proposed methodologies mainly stem from a component commonality perspective. Existent literature lacks a systematic approach that addresses the early platform planning phase and combines the holistic multi-domain view on commonalities between products in three domains, the customer requirements domain, the functional domain as well as the technical domain. The joint commonality analysis on different domains as introduced within this paper allows the identification of modularization potentials as basis for the subsequent modular platform design.

3 METHOD FOR IDENTIFICATION OF MODULAR PLATFORM POTENTIAL IN COMPLEX PRODUCT PORTFOLIOS

Despite the fact that modular platforms help companies to tackle internal complexity while maintaining or increasing external product variety, the development and implementation of modular platforms is expensive and does not imply successful implementation without a previous strategic planning phase.

The introduced method for the identification of **modular platform potential in complex product portfolios** is based on product functions without restricting possible implementation solution and aims to fulfil the described pending issues. The approach is allocated in the early, strategic planning phase of the development and structuring process of a modular product platform. At this point, the developer determines most of the costs of the latter product development, the modules and components as well as its interfaces. By applying the method, important knowledge is externalized to assist the conception of effective frontloading for developing processes in accordance to lean development requirements (Schuh 2013). The approach follows the procedure of knowledge discovery from databases introduced by Fayyad et al. (1996). In a first step different sources are used to build a generic product description in three different domains based on domain-specific attributes and characteristics. This product description is used in the second step to identify commonalities based on a similarity using multidimensional scaling for the visualization in a two-dimensional scatterplot. The method is completed by the third step that analyzes the product portfolio in order to identify modular platform potentials. The result is a functions-oriented view of platform potential throughout the whole portfolio offering transparency for the design and structuring process.

3.1 Step 1 - Generic description of a product portfolio

Developing optimal modular platforms is an elaborate process especially with regard to complex product portfolios. The introduced method includes three steps in order to support developers gaining transparency by **describing products in three domains without restricting possible implementation solutions**. The basis for the approach is an analysis of product data such as customer requirements, functions and used components. In the first step the collected and consolidated data is used to describe the portfolio and its products in three domains: the market domain, the function domain and the technology domain. The market domain describes the external requirements that customers have regarding a certain product. The function domain defines the product functions that address identified customer requirements. A maximum of product functionality does not automatically result in higher customer satisfaction. The resulting structure of functions provides a profound basis when it comes to defining a specific module as it is resembled in the product structure. The product description is completed by the technology domain describing the product with regard to all components that are used to realize the existent functions. Different market requirements can be addressed by the same or different functions. Also, the same functions can be realized by different technical solutions.

Within each domain, attributes are used to characterize every product by specifying its appropriate characteristics (Schuh 2015). The data needs to be sifted and sharpened in order to generate a catalogue of attributes that can be used to describe the products considered in this exploration. Figure 1 shows exemplary the product function "Complete Safety Requirements" that addresses the market requirement "Safety Consciousness" and is realized through the technical component "Casing".

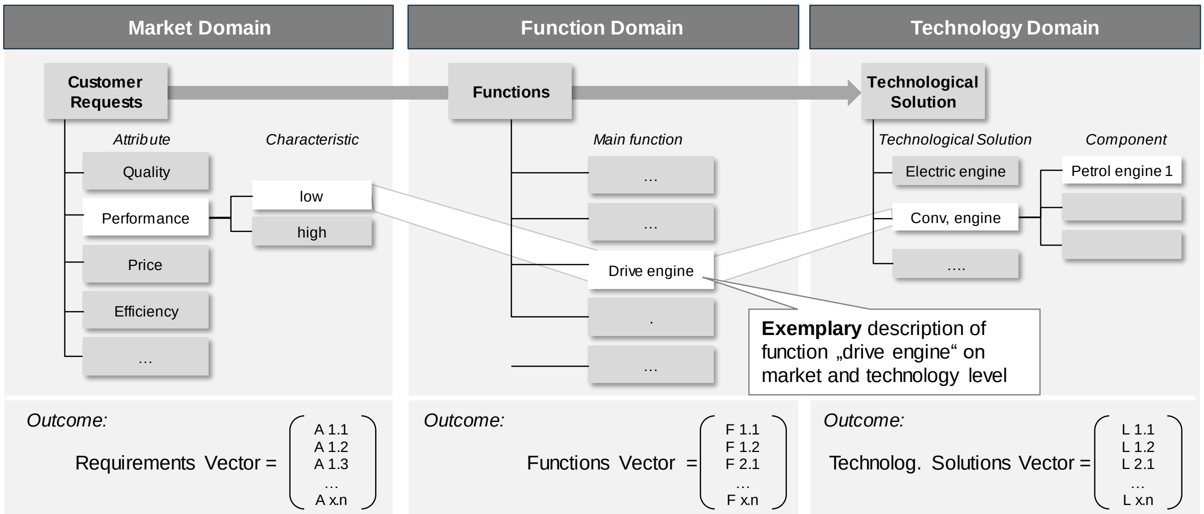

Figure 1. Derivation of product vectors based on a multi-domain product description

The generic multi-domain description of products results in corresponding vectors that help to describe products in different perspectives such as the requirements vector, the functions vector and the technical solutions vector. These vectors comprise a binary coding to list all the existing and not existing attributes of a product (a product with function A but without function B and function C would be coded as 1-0-0). Therefore, a product can be described by a nx1-vector, with n being the number of attributes for the respective domain. Following the idea of describing products by the use of attributes in the three domains, three generic structures are derived allowing the configuration of each portfolio product: (1) the generic requirements structure, (2) the generic functions structure as well as (3) the generic component structure. These generic structures describing products on different domains form the basis for the multi-domain analysis of commonalities between products which is described in the subsequent section. The example in Figure 1 shows the function "drive engine" for a car manufacturer including its respective market requirements and technology realization.

3.2 Step 2 - Visualization of the product portfolio

The second step analyses the commonalities between portfolio products in the three domains and introduces visual guidelines that help to identify modular platform potential. The combined multi-domain view on products offers important insights for the identification of potential. Based on the product portfolio matrices resulting from step 1 and the individual vectors of the three domains, a cluster analysis can be applied to deduce proximity matrices, as discussed in a prior paper of the author (Schuh 2015). Two individual products are considered to be similar if they show homogeneous attributes on the respective domains.

By the use of **multidimensional scaling, the proximity matrices of the products are transferred into a two-dimensional scatterplot**. The more homogeneous the attributes of different portfolio products are, the closer they are positioned in the scatterplot. The visualization is replenished with a cluster analysis that is conducted to create groups of objects with high conformity within and high heterogeneity between clusters (Backhaus 2016). Figure 2 shows the result of applying the two presented algorithms to a product portfolio matrix. Similar products are grouped into clusters pictured by circles around the included objects. The circles vary in size indicating the variance between the products within the respective cluster. The number of circles prefigures variance in the product portfolio itself. Some products cannot be assorted to a cluster due to their misfit in terms of heterogeneity. To support the handling and analytical visualization process, additional guidelines are introduced. Since the scatterplot, resulting from the multidimensional scaling does not provide assistance of any kind of orientation, two fictive reference products are introduced. Reference Product A is characterized by the absence of any attributes whereas reference Product B contains all possible attributes regarding the description as a vector. In the scatterplot, they form the extreme values along whose connection line the remaining products are classified. Arcs of circles are introduced around reference product B that divide the distance between the reference points to give an indication about the products complexity in terms of existent attributes.

The **interpretation and analysis of the graphs** starts on the function domain aiming to find solution-neutral modular platform potential without restricting possible implementation solutions. Regarding functions, the clusters show the allocation of products with similar functions, which indicate application fields. The other two domains are taken into account to identify the addressed customer segments of a function and the ways the function is technologically realized.

A first connection between the three domains is realized through a strategic evaluation of the products in order to identify **products with constituent character for the modular platform**. Each product is evaluated in the customer and technology domain towards its significance. They are rated with individual scores in terms of current success, estimated development in the future and strategic accordance to the company. The score for each criterion allows a comparison of all products with the target to filter relevant products. A low score combined with high distances to other products indicates the exclusion from the planning process for the modular product platform. These products appear in Figure 2 as excluded products. Among the remaining relevant products, key products with constituent character for the modular platform are identified. The product with the minimal distance to all other cluster products, hence with the most commonalities, is a potential key product for the modular platform design. Due to its influence on the modular platform design, it is considered as potential **anchor product**. Besides the anchor product representing an orientation point for all products within one cluster, further key products representing boundaries have to be identified. Products located at the maximum distance to the anchor product fulfilling the necessary relevance criteria are referred to as **fellow products.**

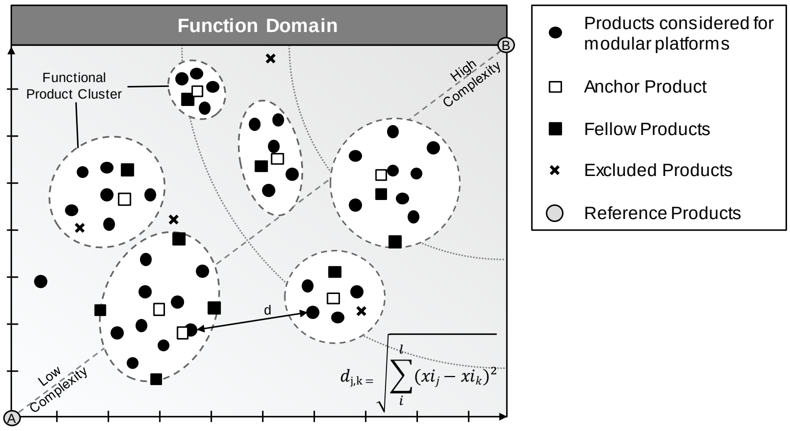

Figure 2. Implementation of visual guidelines and definition of anchor and fellow products.

Figure 2 shows a product portfolio in the function domain with indicated lead products, the anchor product and fellow products for the respective clusters. Anchor and fellow products are representative for the whole portfolio and considered for the identification of important key functions. These products serve as a starting point for the subsequent assessment of platform potential.
Linking the three domains leads to a profound understanding of the interconnections between requirements, functions and related technologies. The cross-linking between the domains is modelled by the use of axiomatic design introduced by Suh (1990,2001) and is input for the third step.

3.3 Step 3 - Assessment of modular platform potential

The third step deals with the assessment of the scatterplots in order to derive modular platform potential based on functional commonalities. The anchor and the fellow products serve as a starting point for the modularization process. **Due to the constituent character of the anchor product for the modular platform,** the functions of the anchor product form the basis for the following potential analysis. Functions can have structure relevance for the modular platform design due to the fact that they cause high direct and indirect cost and have strong geometric influence on the product shape. The identification of structure-relevant functions is not content of this paper and discussed in detail within a subsequent paper by the authors.
The assessment of modular platform potential starts with the detailed analysis of the functions scatterplot. Choosing a certain function as an element of the anchor product and highlighting products with the corresponding customer requirements and technical solutions as pictured in Figure 3, shows the arrangement of the products in the respective domains. This visualization emphasizes heterogeneities concerning technological solutions and different customer requirement groups addressed. Different patterns can result from this analysis: (1) homogeneity between considered products on all three domains shows that similar market requirements are addressed by similar functions, technology and even components. In this case, modular platform potential already has been realized. Another pattern can show (2) homogeneity between considered products on the market and functional domain, although differing technologies are used for the functions realization. In this case, it is obvious that e.g. historical development or a lack of human synchronization between product development processes caused inefficient variety showing potential for modularization. A third pattern is (3) homogeneity between products on the functional domain whereas they differ on the market and technology domain. In this case, the influence of technological harmonization on the satisfaction of respective customer requirements has to be analysed by the use of a sensitivity analysis. Figure 3 shows the heterogeneity regarding customer requirements (C2: low performance - 75kW; C4: high performance - 125kW) being addressed by one function (C: drive engine). In turn, the function is realized by three technologies (T2: petrol engine; T3: diesel engine; T4: electric engine).

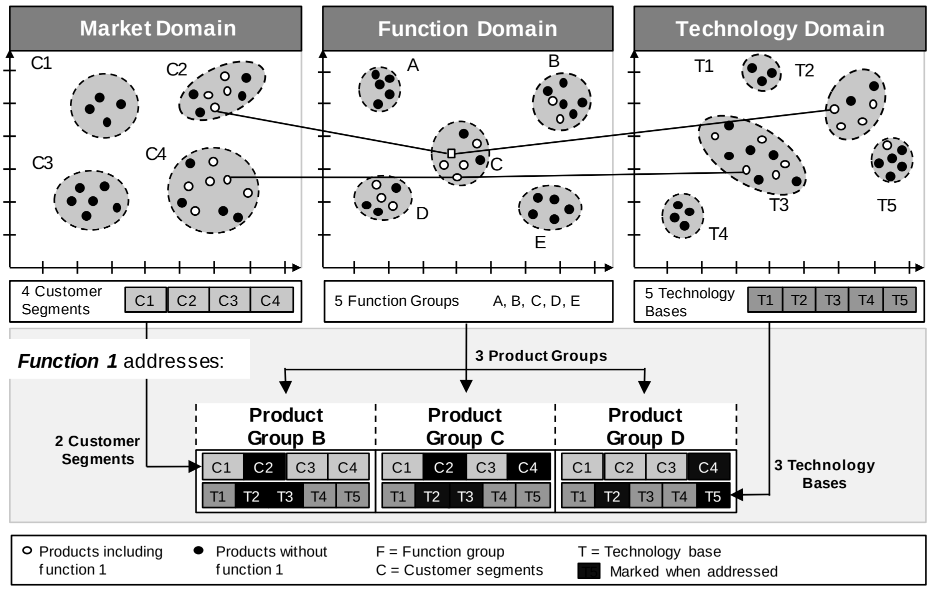

Figure 3. Analysis of inter-domain connections for structure-relevant functions

The **interconnections between the domains** are depicted in Figure 3. For each structure-relevant function, respective products containing this function can be identified and mapped to the market and technology domain. This allows a revealing interpretation of the function's modular platform potential and exposes **similarities between functions as well as clusters**. The connections and similarities are mapped in a matrix in the bottom part of Figure 3. The same function might be realized through different technological solutions offering potential to standardize. But different customer segments might require different technologies. Every structure-relevant function needs to be assessed with regard to modular platform potential and its required variety. A whole portfolio combines an abundance of structure-relevant functions complicating the modularization planning. In order to overcome this difficulty, a modular platform potential index is introduced.

The modular platform potential (PPI) evaluates structure-relevant functions of lead products based on defined criteria. The overview presented in Figure 3 results from the axiomatic design that connects all three domains and offers detailed information. It allows a first assumption about the functions' importance for the platform structuring by showing the addressed clusters within the different domains. In Figure 4, the range of an exemplary structure-relevant function is directly indicated through the connected product groups. Addressed customer segments as well as the technology bases that realize a certain function are mapped to the product groups and hence, to the products. The PPI builds upon this visualization and quantifies the connections and similarities.

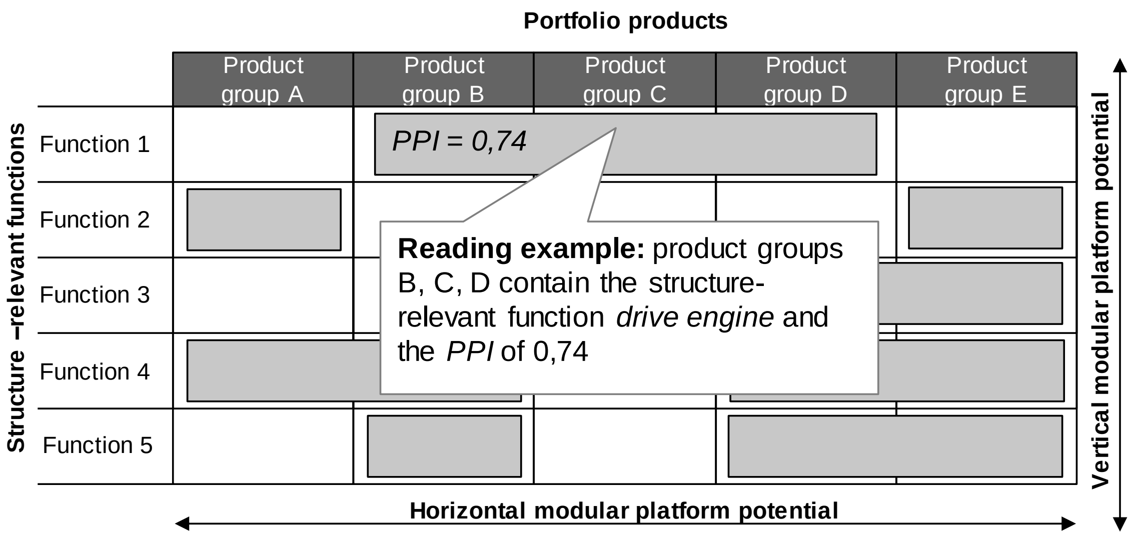

Figure 4. Assessment of modular product platform potential

The PPI evaluates the platform potential in order to gain transparency in the early planning phase. The **share of clusters in the three domains** that are directly addressed by the indicated structure-relevant function contribute to the formula as well as **the total product units**. The resulting grades allow a comparison to other functions and foster the interpretation process. They can be used to identify either horizontal potential regarding the product groups where the structure relevant functions are used or vertical potential with the focus on the number of structure-relevant functions that are important for the design. A function with a high grade indicates a large number of involved products and therefore might offer horizontal platform potential. The standardization and modularization of a widespread function can bring extensive benefits through the reduction of internal complexity. Potential for standardization is precisely shown in the visualization and evaluated through the PPI. Furthermore it is possible to identify vertical platform potentials. Since the presented overview in Figure 4 shows the impact of each function, vertical similarities within and between product groups can easily be determined. Hence, the Mapping Matrix offers a detailed view of both vertical and horizontal platform potentials. The PPI uses this information to provide a well-founded evaluation and prioritization of functions that should be considered in the platform structuring and development process.

The introduced method supports the entire design planning process for modular product platforms by the systematic assessment of existent potential. The application of data mining techniques to converts data of a given portfolio into an extensive portfolio visualization on three different domains. An analysis of the interconnections between the domains highlights structure-relevant functions that reveal hidden and visible modular platform potentials. The PPI evaluates the functions' platform potentials and offers extensive help for the process of the modular platform development.

4 CONCLUSION

To tackle the dichotomy between economies of scale and economies of scope, companies make use of product modularization and carry-over-parts. This paper introduces a holistic approach that supports developers and decision makers in the early, strategic planning phase of a modular platform by gaining transparency and offering a toolset for the systematic identification and assessment of modular platform potential. A generic product description in three domains without restricting possible implementation solutions enables a revealing visualization of the product portfolio that includes the developer in the analytical process. On the basis of a proximity matrices and product clusters, lead products with structure-relevant functions are identified which form the basis for the potential assessment. An introduced platform potential index ranks the potential of different functions suggesting highly relevant functions and standardization potential. The introduced index is further elaborated and will be discussed in detail within a subsequent paper.

5 FUTURE RESEARCH

Future research focuses on the detailed derivation of anchor and fellow products by the definition of further criteria. Also, the determination of the structure-relevant functions is considered by further research papers. Another research field is the development of an generic algorithm-aided approach that builds up on the introduced method and examines the composition of products for each identified modular platform potential. It has been shown that the number of product variants highly influences the successful implementation of a modular platform. By accomplishing this challenge combined with the identification of structure-relevant product functions and its platform potential deduction presented in this approach, a consistent way of structuring modular platforms that supports developers in the early, strategic planning phase is introduced.

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