METHODOLOGY FOR THE CONTEXTUAL DESIGN OF A MODULAR PRODUCT PLATFORM CONCEPT

Schuh, Günther; Riesener, Michael; Barg, Sebastian; Lauf, Hendrik
RWTH Aachen, Germany

Abstract

Due to increased competition and cost pressure in the globalized world, business strategies extensively focus on tailoring products to customer's needs. Hence, many companies are facing shorter product lifecycles, additional product development expenses and a wider product portfolio. Therefore, the modular product platform approach of the automotive industry is often directly transferred on other industries. However, a direct transfer of the automotive approach is likely to lead to missing targets and full potentials of a modular product platform. This circumstance is due to the overall situation of the applying company in terms of the company's exogenously given environment and an individual target system for the modular product platform. To meet the exogenous influencing factors as well as to increase the level of target achievement a priori, this paper introduces a methodology for the contextual design of a modular product platform concept in an early design stage. This concept adapts existing matching concepts and considers the given conditions as well as the targets and therefore is aligned to maximize the context and target conformity.

Keywords: Platform strategies, Product families, Product architecture, Design methodology, Design methods

Contact:
Sebastian Barg
RWTH Aachen
Innovation Management
Germany
S.Barg@wzl.rwth-aachen.de

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1 INTRODUCTION

The increasing competition due to the globalization leads companies to tailoring products to customer's needs. The main challenge for companies facing shorter product lifecycles, additional product development expenses and a wider product portfolio is to offer a certain portfolio which matches the individuality required by customers without losing control of their own product complexity. For example, in the automotive industry the number of products has doubled within the last 25 years while the product lifecycle of these products has shortened by 20%. This trend is expected to continue in various industries for the next several years Schuh (2015). Therefore, companies in various industries develop their products based on modular product platforms. A modular product platform consists of different modules with different sub-functions which are combined into products with varying main functions (Feldhusen and Grote, 2013). Besides the realization of significant cost savings due to standardization and scale effects, companies pursue other benefits, e.g. increasing product flexibility, shorter time-to-market or decreasing stocks. The realization of the individual target system in turn is dependent on the specific conceptual design of the modular product platform (Halstenberg *et al.*, 2015). One example for a successful implementation is the modular platform strategy by Volkswagen. The Modular Transverse Matrix (MQB) is used as a basis for small as well as for middle sized cars across different brands and product lines and ensures customizable products within a given configuration space while leveraging economies of scale. However, companies from other industry sectors are facing different exogenous circumstances such as low production volumes or products being engineered to a specific order. Hence, an identical methodological approach comparable to the automotive industry is not likely to be expedient due to varying circumstances as well as target systems. While the production volume of the plant engineering industry for example is much smaller, the customer requirements show a maximum of heterogeneity. In this context, Hansen *et al.* (2012) find that "*there is no one-fits-all when it comes to the tailoring of architecture initiatives to a specific situation of a company*". Especially the contextual circumstances of a modular product platform are not considered adequately in particular in early development stages. Thus, many companies often struggle to implement an existing methodological approach in their specific case of application which is further characterized by different influences from the corporate environment and the individually pursued objectives (Halstenberg *et al.*, 2015). In a representative study conducted by the Laboratory for Machine Tools and Production Engineering (WZL) in 2014 only 9% of 120 companies from various industries indicate that their objectives for the introduction of a modular product platform are achieved (Schuh, 2014). Even though the basic principles and alternative methods are well-known, many companies struggle to interpret and implement a specific conceptual approach according to their particular targets and constraints. Moreover, various scientific studies recognize the need for different conceptual basic types of a modular product platform (Vietor and Stechert, 2013; Ponn and Lindemann, 2011; Renner, 2007). Although different authors like Stechert (2010) or Braun *et al.* (2013) define reference models and name classifying attributes for modular product platforms, there is a lack of specific strategic guidance when conceptualizing a modular product platform in a given situation. Moreover, a prospective use of the strategic awareness of an individually suitable platform concept is not described yet (Braun *et al.*, 2013). To meet the exogenously given boundary conditions as well as to increase the level of target achievement a priori, this paper introduces a methodology for the contextual design of a modular product platform concept in an early design stage. This concept considers the given conditions as well as the targets and therefore is aligned to maximize the context and target conformity of the product platform. The presented methodology is adapting a matching concept to derive a suitable modular product platform concept for a given set of exogenously given influencing factors and an individually defined and weighted platform target system.

2 RELEVANT TERMINOLOGY

As the understanding of certain terms regarding the development of modular product platforms in scientific literature still varies, a definition of a common language and terminology is indispensable. Furthermore, the conceptual perspective of structuring opportunities for a modular product platform in terms of Conceptual Structuring Features (CSF) as well as the result of their distinct aggregation in terms of the Modular Product Platform Concept (MPPC) is introduced. The section closes with the introduction of the terms Matching Concept, Gestalt and Equifinality.

Modular Product Platform
A *Modular Product Platform* is defined by a set of modules which can either be assemblies or components. Based on standardized interfaces, these modules can be combined diversely in order to derive a certain range of product variants (Vietor and Stechert, 2013; Schuh *et al.*, 2016b).
Conceptual Structural Feature (CSF)
The type of a modular product platform concept is determined by distinct *Conceptual Structural Features* (Schuh *et al.*, 2016a). Hence, those features with respective characteristics represent the conceptual design opportunities for modular product platforms. Due to a certain level of abstraction, these features are applicable for various industries and provide guidance for the subsequent development of the modular product platform. The distinct characteristics are determined in the early design stage and their configuration results in the company-specific Modular Product Platform Concept (Schuh *et al.*, 2016b).
Modular Product Platform Concept (MPPC)
The *Modular Product Platform Concept* represents the overall strategic approach to achieve an optimum level of target conformity with a modular product platform. Therefore, the decision on a distinct configuration of a MPPC is dependent on the exogenously given boundary conditions and the individual target system of the platform approach. The MPPC is derived at an early design stage subsequent to the determination of the scope of products and precedent to the initiation of the development of specific modules (Schuh *et al.*, 2016b).
Exogenous Influencing Factor
The corporate environment with relevance to a modular product platform is described in exogenous influencing factors. In this context, the corporate environment with relevance to a modular product platform is characterized by all of those influencing factors that can neither be changed nor affected at all by the applying company (Schuh *et al.*, 2016a).
Matching Concept
The result of a *Matching Concept* is defined as "Fit", the degree of matching between two or more factors. The way this "Fit" is examined depends highly on external factors and there are various ways to define the "Fit" between the factors appropriately (Venkatraman, 1989; van de Ven and Drazin, 1985). Due to this vague definition, Matching Concepts are applied in multiple research areas with different solution approaches.
Gestalt
One opportunity for the examination of a matching or "Fit" from a multivariate perspective is the identification of *Gestalts* which are defined by a certain degree of internal coherence among a set of variables. Gestalts can be understood as recurring patterns of variables that are internally consistent. If a system is decomposed in multiple pairwise conditions, Gestalts cannot be identified. This leads to possible consistency conflicts during the development of structures (Venkatraman, 1989).
Equifinality
The term *Equifinality* implicates that there is more than one way of realizing a given outcome due to different trade-off relationships that cannot be fulfilled simultaneously. Following this, especially an optimum outcome can be realized by multiple solutions (van de Ven and Drazin, 1985).

3 STATE OF THE ART

Supporting the development process on an operational level, a wide range of methodologies is present in the scientific literature. Those methods for example focus on grouping components or functions into modules with cluster algorithms (Helmer *et al.*, 2010; Yu *et al.*, 2007). Since these methods address individual targets such as a reduction of development costs, the adaptability is limited (Halstenberg *et al.*, 2015). In order to resolve this dilemma, a modular product platform needs to be aligned with the exogenous influences and the individually pursued target system. Relevant work describing those factors is presented by Cameron and Crawley (2014), Hansen *et al.* (2012), Bowman (2006) and Kristjansson and Hans-Petter (2004). Since this paper is rather focused on the development of a methodology, adjacent fields of research are described in the following, presenting methodologies and frameworks that address the positioning within the dilemma of exogenous influences and pursued targets.
Considering modularization and product platform strategies as distinct conceptual opportunities to realize commonalities, Magnusson and Pasche (2014) evaluate the applicability of those concepts in a given context. Although the authors support the hypothesis that architectural concepts need to be

designed in accordance to the exogenously given context and the respective targets, the solution alternatives described do not sufficiently represent the range of conceptual alignment. Halstenberg *et al.* (2015) developed the Target-Oriented Modularization Method (TOMM) for the definition of a modular product architecture concept with respect to the pursued objectives. Similarly, Dahmus *et al.* (2001) presented a method for the selection of conceptual architectural opportunities. The critical step of both works is the evaluation and selection of a concept depending on a specific target. Only Halstenberg *et al.* (2015) solve this by weighting the targets to enable a selection of a target compliant architecture concept. While all of the mentioned approaches consider different overall alternative concepts such as modularization or product platforms, this paper addresses the approach of proactively designing a Modular Product Platform Concept based on the configuration of distinct Conceptual Structural Features which proof to be well suited to conceptualize modular product platforms (Braun *et al.*, 2013; Ponn and Lindemann, 2011; Stechert, 2010). Ponn and Lindemann (2011) as well as Vietor and Stechert (2013) outline possible features which need to be characterized in accordance with the exogenous circumstances and individual targets. With regard to the derivation of different types of modular product platforms there are scientific approaches to define a typology for modular products. Schuh (2012) and Ponn and Lindemann (2011) classify modular product platforms by individual characteristics. Combining distinct characteristics of relevant features enables the derivation of types (Dünnebacke, 2016). Meier (2007) identifies eight different product architecture types. MacCarthy *et al.* (2003) describes five basic architecture types defined by six features in different use cases applicable within the field of mass customization. One opportunity for the deviation of types is the statistical analysis which is represented by e.g. the cluster analysis (Kluge, 1999). Furthermore, types can be examined in logical analyses by use of common sense. Therefore, types can be defined by intuition or by a methodological approach that identifies certain values or combinations of values that seem appropriate for determining types by constructive typologization (Welter, 2006; Much, 1997). Two other possibilities are the relational typologization that establishes the relations of different existing types to define new ones (Nohl, 2013) or the typological reduction that mainly reduces the complexity of typologies by combining types systematically (Bailey, 1994).
Concluding, the need for a methodological approach addressing the challenge of aligning a Modular Product Platform Concept in accordance to the exogenous circumstances and individually pursued targets has been exposed by several authors. However, there is no methodological approach combining these three dimensions in one framework for the contextual design of a modular product platform.

4 METHODOLOGY DESIGN

The approaches mentioned above reveal that there is no methodology considering contextual circumstances and pursued targets when setting up the concept of a modular product platform. Hence, this paper introduces a methodology for the contextual design of a modular product platform concept. The overall research question can be formulated as follows:

> *"How can the contextual design of a modular product platform be defined using matching concepts?"*

The conducted research in this paper can be described as applied research and focusses on the development of a methodology for the contextual design of a modular product platform concept. Therefore, the methodology design takes the contingency theory as a basis. The contingency approach examines the connection of different exogenous factors in order to define the performance of a dependent variable, in this case the target system. In this paper, a matching methodology is adapted for the contextual design of a modular product platform. To identify existing matching methods, a wide literature research was conducted in various research areas, such as sociology, psychology, traffic management, health care, software development, algorithms and others. With respect to the scope of this paper, not all of the examined matching methodologies are presented in detail. In the following, the two approaches used for the design of this paper's methodology are introduced.
Inspired by the Fit-approach of van de Ven and Drazin (1985) in organizational research, Venkatraman (1989) further developed the idea of Fit by implementing six different ways of how Fit is interpreted and mathematically modulated in strategic research. For this paper, in particular "Fit as Gestalts" is of importance, which relies on the existence of Gestalts. The Fit of two sets of variables is evaluated by measuring the fit of the identified Gestalts in each set. Since this Fit-approach evaluates the Fit for multivariate perspectives without decomposing configurations of variables, this holistic consideration

of multivariate patterns is used in this paper for developing the overall methodology. The Person-Environment-Fit (PE-Fit) developed by Kristof-Brown and Jansen (2006) as the second approach with relevance to this paper is a multidimensional Fit-approach. Confronted with many different Person-Environment-Fit perspectives an appropriate framework that is able to consider results of different Fit perspectives is defined. This enables the derivation an overall result that relies on several supporting concepts regulating the interaction of the different Fit perspectives (Kristof-Brown and Jansen, 2006).

5 METHODOLOGY FOR THE CONTEXTUAL DESIGN OF A MODULAR PRODUCT PLATFORM CONCEPT

In the following, the formulated research question is addressed by a four-step methodology that supports the derivation of a contextual design of the modular product platform concept. First, conflicts in the initial situation will be identified and addressed to derive a vision for the methodology. Subsequently, the overall structure of the methodology will be explained. Finally, the four-step methodology is introduced step-by-step.

5.1 Analysis of the initial situation

Before describing the structure of the methodology, the initial situation has to be addressed. The methodology enables the user to derive an optimal configuration of the Conceptual Structural Features introduced by Schuh et al. (2016b). In this context, the optimal configuration depends on the weighted target system as well as the distinct contextual circumstances (see Figure 1). The figure shows exemplary variables of the situational context and the weighted target system as the two influencing dimensions. Furthermore, the seven Conceptual Structural Features building the MPPC are shown. At this point, it can already be noticed that there are two possible conflicts that may affect the results of the methodology. First, conflicts between influencing factors from both, context and target system need to be addressed. Second, the target system is both an influencing factor and defines the performance measurement. The resulting methodological complexity needs to be considered in the following.

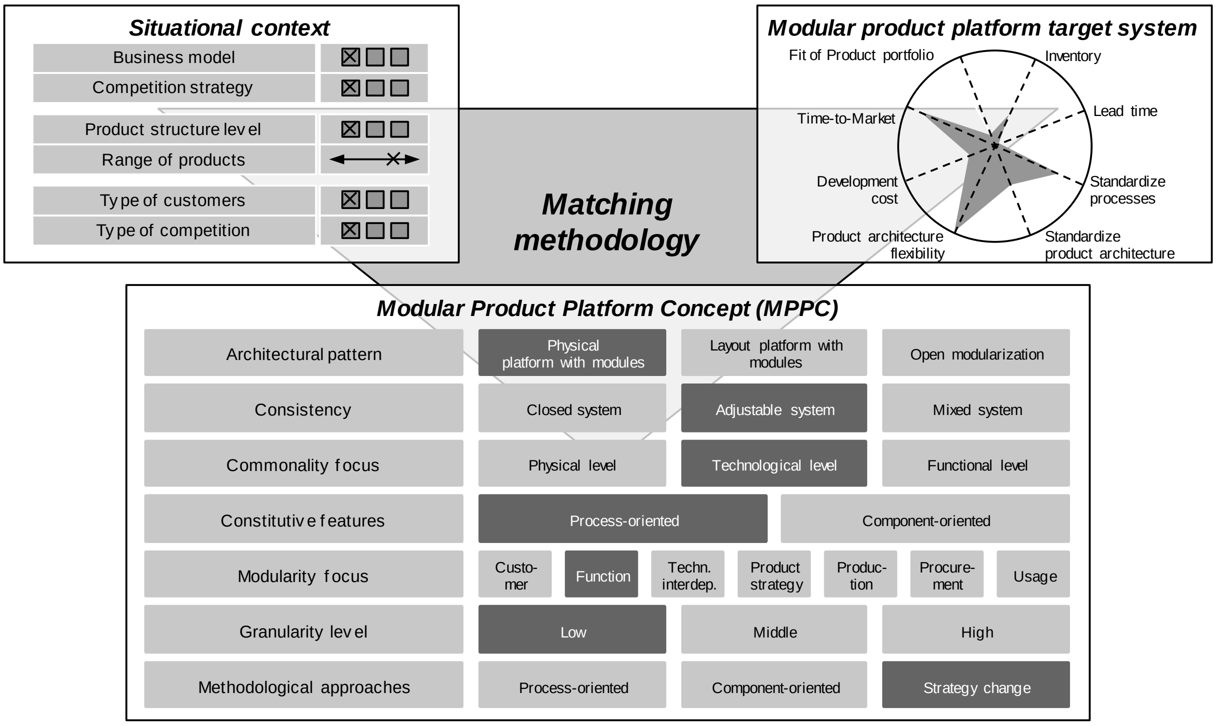

Figure 1. Initial situation for the development of the methodology (exemplary)

Resolving these emerging conflicts, two possible solutions may be applied. First the contextual factors and the target system may be considered both as influencing factors and the performance of a derived MPPC is measured by a universal performance index. Taking the extensively increasing number of input factors into account, the definition of a universal performance index does not seem likely to succeed. Hence, the solution may be the separation of the two influencing dimensions by integrating the target system into the overall matching concept in another way. In most matching methods the target for the optimization is formulated upfront and fixed even with volatile input. Since a multidimensional target system was not considered in any of the examined methods the multidimensional PE-Fit-Method is taken into consideration as an inspiration for structuring the overall approach of this paper's matching methodology. While the PE-Fit connects different Fit-Perspectives which already exist in the considered research area, the target system can be used in order to define new Fit-perspectives that have to be linked to derive an overall concept (Kristof-Brown and Jansen, 2006).

5.2 Overall structure of the methodology

In the following, the overall structure of the methodology is presented. The main structuring aspect is the separation of influences resulting from the contextual situation and from the target system. Hence, the target system is no longer considered as a direct influencing but as a regulating factor that defines the suitability of different matching-perspectives. In this context, every target dimension defines one matching-perspective that is separated from influences of other perspectives. It is called a perspective because the specific matchings only consider one extract, a target dimension, of the overall target system. When considering the target dimensions in isolation, individual part results can be derived. Therefore, the methodology will be structured into two major levels, the macro level and the micro level (see Figure 2).

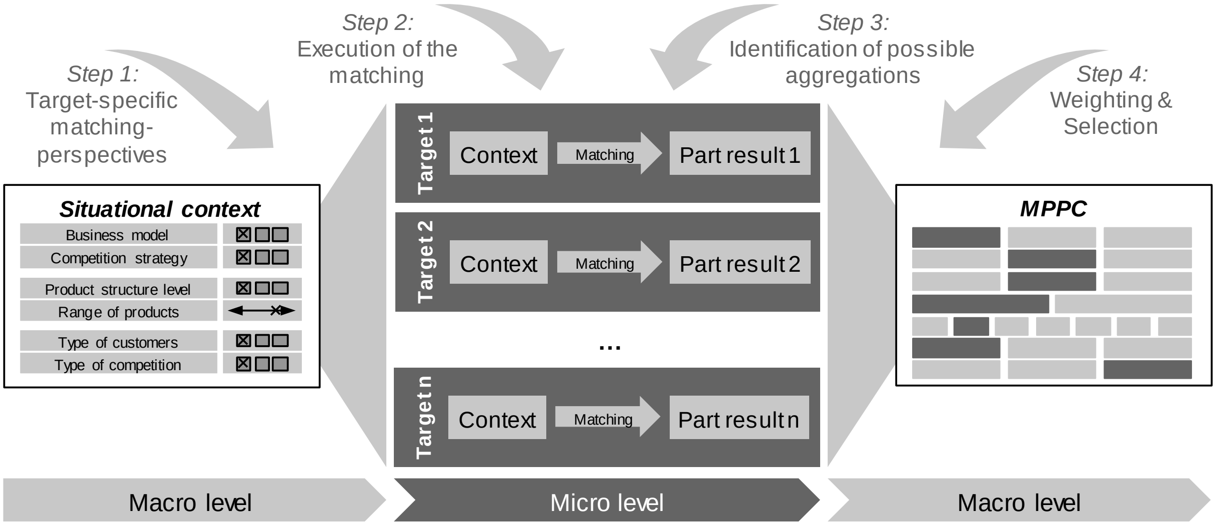

Figure 2. Overall structure of the matching methodology

The macro level decomposes the situational context and links the target specific matching-perspectives. The conceptualization of the methodology structure on the macro level is inspired by the multidimensional PE-Fit introduced by Kristof-Brown and Jansen (2006). Therefore, the main function of the macro-level is defined as the regulation of the subordinated matching-perspectives which deliver individual part results that again are combined in order to synthesize the optimum overall result for a given platform target system. In addition, the macro level facilitates the mapping of defined design rules for the Platform Concept.

The main element of this methodology, the matching of context and characteristics of Conceptual Structural Features, is conducted on the micro level and is separated from the restrictions and influences of the regulating target system. The matching is split into different isolated matching-perspectives which do not affect each other in any way and deliver individual results for each dimension of the target system. Each part result represents an optimal or nearly optimal Platform Concept for its associated target dimension. The conceptual inspiration for the operating principles of the matching-perspectives is the "Fit as Gestalts" concept developed by Venkatraman (1989).

5.3 Four-step methodology

The methodology to derive the contextual design of a Modular Product Platform Concept from the company's contextual situation and target system is structured into four major steps. On the micro level, the matching concept developed for this methodology is called "*Reduced Perspective Matching*" due to the suggestion of reducing the number of influencing factors and of Conceptual Structural Features. In the first step the relevant contextual features are allocated to the different target dimensions. Secondly, the matching is executed for each target dimension. Subsequently, step three identifies different possible aggregations of the part results from the target dimensions. The methodology ends with the selection of the optimal overall concept.

5.3.1 Derivation of target specific matching-perspectives dimensions

The **first step** is focused on the definition of different matching-perspectives which each address one target dimension. Furthermore, the contextual influencing factors are allocated to these dimensions on the macro level of the methodology. The contextual situation can be modelled by different factors that describe the Modular Product Platform's relevant circumstances. Conceivably, not all contextual factors may be relevant for every considered target dimension and one factor may be relevant for different target dimensions. For example, the target "shorten product development time" will be less customer orientated than "increasing product flexibility" and therefore the matching for "shorten product development time" may not consider many customer related contextual factors. This decomposition of the contextual situation is visualized with a Domain Mapping Matrix (e.g. Danilovic and Browning, 2007) and leads to reduced contextual models as well as better matching solutions as unnecessary input is no longer considered for the isolated targets. Hence, a company applying this methodology needs to specify its contextual situation and the objectives which should be pursued by the Modular Product Platform first. Subsequently, an isolated matching procedure is executed individually for every target dimension of the target system.

5.3.2 Matching appropriate Gestalts to every target dimension

The **second step** is the main element of the overall methodology. Applying the "Fit-as-Gestalts" approach of Venkatraman (1989) to the design of a Modular Product Platform Concept, the *Reduced Perspective Matching* is developed. This application leads to the implication that the possible solutions for every target dimension have to be fixed sets of variables which are defined as Gestalts. Since a Gestalt is characterized by inner consistency of the relevant features, not all combinations of distinct Conceptual Structural Features are suitable. For each target dimension a matching is conducted to derive multiple part results, the Gestalts. Therefore, each matching-perspective optimizes the relevant features of the MPPC for one isolated target dimension and takes its specific aspects into account. Hence, every target dimension only covers one single target which is addressed by one partial aspect of the Modular Product Platform. As a result, not all characteristics of a Conceptual Structural Feature are equally relevant for achieving a particular target. Analogous to the reduction of the relevant context aspects, the number of relevant Conceptual Structural Features may therefore also be reduced. Figure 3 shows the mapping of different possible Gestalt-alternatives, ranked by their performance for the specific target.

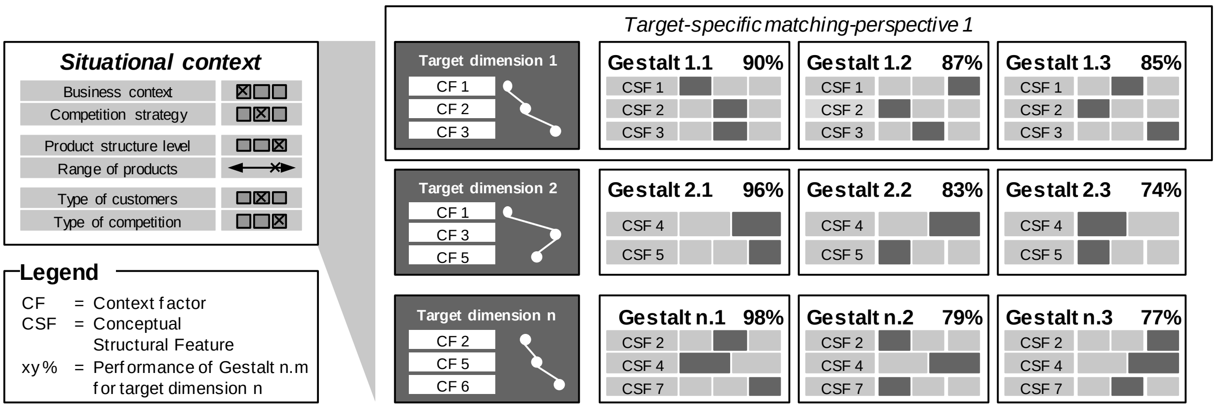

Figure 3. Mapping of different Gestalts to each target dimension (exemplary)

After identifying the Gestalt-alternatives per target specific matching-perspective, each Gestalt is rated by its degree of fulfillment for the isolated target, which in turn defines the performance index of the particular Gestalt. Gestalt 1.1 for example achieves the specific target dimension 1 by 90%. Following the assumptions of the matching methodology the performance of each Gestalt for a particular target is dependent on the interaction effects between the context and the Gestalt itself. The exact degrees of target fulfilment are calculated separately. There are different approaches that may be appropriate for this, for example an analytic examination of the Gestalts or an empirical study. The definition and execution of such a method is ongoing work at the Laboratory for Machine Tools (WZL) of RWTH Aachen University. The next step deals with merging the Gestalts in order to synthesize an overall MPPC.

5.3.3 Identification of possible Modular Product Platform Concepts

The **third step** focuses on the identification of possible Modular Product Platform Concepts and is allocated to the macro level of the methodology. In this context, there are restrictions which prevent the selection of every imaginable combination of Gestalts from different target dimensions to derive an overall MPPC. For the design of this overall MPPC one Gestalt from every matching-perspective has to be picked. Due to the fact, that Gestalts of different target dimensions share conceptual features, these need to show the same characteristics in order to be combined to a platform concept. Following this, Gestalts connected with different values for the same Conceptual Structural Feature exclude each other from the selection for an overall Platform Concept. The result of this step is a number of possible combinations of different Gestalts from the Matching-Perspectives. Each combination represents one possible overall MPPC solution. In the following, one of these solutions has to be selected.

5.3.4 Selection of an optimal platform concept

In the **fourth step** a suitable Modular Product Platform Concept needs to be derived from the identified overall MPPC alternatives. In order to evaluate different overall Platform Concepts, the weighting of the different target dimensions needs to be taken into account. As shown before, each target dimension is matched in isolation and different Gestalts are mapped to these target dimensions. Each Gestalt is evaluated by a performance value indicating the suitability of this specific Gestalt for the target dimension. All features that are not covered by a Gestalt do not have any significant influence on the fulfilment of the specific target. Hence, an overall concept is defined by the sum of its Gestalts which achieve the particular targets by a certain degree. In conclusion, a Modular Product Platform Concept fulfils a certain target dimension according to the fulfilment of the respective Gestalt. Therefore, the expected fulfilment of the whole target system can be derived from the selection of the Gestalts or the selection of a combination of certain Gestalts. In order to calculate the degree of the target system fulfilment of a platform concept, the weighting of the target dimensions is considered. For target i in a target system with n targets the relative weighting w_{r_i} can be derived from the absolute weightings w_{a_1} to w_{a_n} by Equation (1):

$$w_{r_i} = \frac{w_{a_i}}{\sum_{k=1}^{n} w_{a_k}} \tag{1}$$

In a next step the overall target compliance or overall Fit "$OA - Fit$" can be derived from the Fit values by the following Equation (2):

$$OA - \mathrm{F}it = \sum_{i=1}^{n} Fit_i * w_{r_i} \tag{2}$$

For each of the alternative overall Modular Product Platform Concepts identified in the previous step, a Fit-value representing the target system fulfilment can be calculated. The evaluation of the different MPPC alternatives shows the degree of fit between the concept and the company's situational context and defined target system. The Modular Product Platform Concept with the highest matching degree is chosen to fit the individual needs the best.

6 CONCLUSION

This paper introduced a methodology that connects the situational context and the target system of a company with the conceptual design of a modular product platform which in turn gives direction to the subsequent development process. The novel methodology enables its user to adapt their MPPC in an early development phase to their contextual situation and defined target system in order to achieve a higher degree of target fulfilment for their Modular Product Platforms.

After the definition of the relevant terminology and a review of adjacent fields of research a methodology adapting existing matching methods from other research areas was presented. By introducing the macro and micro level, a separate integration of the influences of both the situational context and the target system is realized. The methodology's key element is the multidimensionality of the matching between the context and the platform concept that is determined by the target system. It is structured into four major steps: the formulation of the contextual model, the matching of all possible solutions for the different target dimensions, the identification of all possible combinations of Gestalts and the selection of the best fitting overall solution in terms of a suitable MPPC.

The methodology developed in this paper enables a company to derive a MPPC based on the contextual situation and the defined weighted target system. Especially when deciding on the concept of the modular product platform in order to derive suitable tools and methods for the development itself, companies can derive a conceptual design that directs subsequent development for a specific use case. As companies should rather align their platform concept to given constraints than just transfer a successful practice, the innovative contribution of the presented results is to be seen in the overall methodological approach which is relevant to users from various industries.

Future research related to this work is suggested on empirically validating the hypothesis that the performance of a MPPC is dependent on the situational circumstances and the predefined target system. One option for testing this would be applying this methodology inversely to verify the real performance of existing Modular Product Platforms in industry which in turn is part of current work at the author's research institute. Further opportunities for future research address the identification of Gestalts and the evaluation of the performance values for these Gestalts in different contextual situations. To derive the fulfilment degrees of targets for the evaluation of Gestalts there are different approaches. First, existing Modular Product Platform Concepts and the associated contextual situations can be examined. Measuring the performance of the MPPC itself and the improvements after the development, conclusions can be drawn that deliver indications for the relationships between performance and interaction of context and the MPPC. Furthermore, statistical approaches using data of existing Modular Product Platforms, their contextual situation and performance on different targets is of relevance. Finally, the relevant factors for the target dimensions on input and output side need to be elaborated. Since this approach follows the understanding of different Fit-Perspectives of the Person-Environment-Fit and therefore assumes that only few variables of the context and the Conceptual Structural Features are relevant for each target dimension, the relevance of the factors for different target dimensions has to be evaluated in order to test the applicability of this methodology.

The methodology elaborated in this paper combines different matching concepts and transfers the conceptual framework of the contingency theory onto the contextual design of MPPCs. Moreover, it enables both, a proactive use of the methodology in terms of the individual alignment of the modular product platform concept as well as a comparison of existing modular product platforms using it as a classification concept. Hence, a cross-industry discussion on a comparable basis is facilitated.

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