Target Compliant Configuration of Conceptual Structural Features of Modular Product Platforms

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***Abstract*--Due to globalization as well as increasing competition and cost pressure business strategies extensively focus on individual products tailored to customer's needs. In order to meet this challenge, numerous companies structure their products and technologic solutions according to the design principles of modular product platforms. Therefore, the modular product platform approach of the automotive industry is often directly transferred on other industries, e.g. machinery and plant engineering. However, the attempt of simply transferring the automotive approach leads 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 boundary conditions and an individual target system for the modular product platform. The lack of target achievement consequently results from the missing alignment of the modular product platform to these circumstances.**

To resolve this situation by increasing the level of target achievement, this paper introduces a methodology for a target compliant configuration of Conceptual Structural Features in the early development phase of modular product platforms. By taking company-specific influencing factors as well as the individually pursued target system into account, the approach helps aligning a modular platform project to the company's individual overall situation.

I. INTRODUCTION

Due to wide range of pursued objectives, companies from different industries more and more frequently develop their products based on modular product platforms. Besides the conspicuous motivation of significant cost-saving opportunities in product development costs as well as production costs due to scale effects, the decision to develop a modular product platform might also be motivated by a higher flexibility of the product configuration and therefore a shorter time-to-market. Moreover, the different motivations as well as the individual objectives pursued are highly dependent on the situational context in which the company operates. In this regard, it is necessary to consider the exogenously given constraints of the company by the competitive environment.

Both from a scientific as well as from a practical perspective, existing approaches for the development of modular product platforms inadequately take these company specific objectives and constraints into account. As a result of that, companies in various industries and with completely different product types often try to just copy successful practices from other industries. A well-known example to create customized products while leveraging economies of scale is the modular platform strategy by the Volkswagen Group. The modular transverse matrix platform (MQB) of the Volkswagen Group serves as a basis for small as well as for middle class cars across all brands and variants. Whereas when it comes to commercial vehicles, companies try to derive different types of almost individually customizable driver cabins applying modular product platforms. Furthermore, companies in the rail vehicle industry establish modular product platforms due to heterogeneous customer requirements, a heavy pressure on prices and low production volumes. However, some companies in the machine tool industry are facing a higher product variety induced by individual customer needs, different customer groups and therefore heterogeneous market requirements. Obviously, the automotive industry faces different boundary conditions and external influencing factors than the rail vehicle industry or the machine tool industry. This inadequate individualization of a modular product platform is one of the main reasons for not achieving platform objectives, if at all clearly defined. In a representative study conducted by the Laboratory for Machine Tools and Production Engineering (WZL) among 120 companies in 2014 only 9% of the companies indicated that the objectives pursued by the introduction of a modular product platform were fully achieved [25].

Even though the basic principles, methods and practices of product modularization are well-known, many companies struggle to interpret and implement these concepts according to their specific needs. According to this, various scientific studies recognize and describe the relevance of different basic types of modular product platforms [10, 22, 24]. In fact, different approaches define reference models and name classifying features for modular product platforms [4, 32]. Although most authors claim that these reference models might also serve as a strategic guidance when introducing modular product systems they most likely fail to do so but only retrospectively classify modular product platforms. Moreover, the prospective use of the strategic awareness of an individually suitable modular product platform is not described so far [4].

To increase the level of target achievement a priori, this paper introduces a methodology for the individualization of a modular product platform approach in an early design stage. With regard to an individual configuration of differentiating features and their respective characteristics, the Modular Product Platform Structuring Concept (MPPSC) is introduced. This concept considers the exogenously given conditions as well as the individual target system of the modular system and therefore is characterized by context and target conformity.

II. RELEVANT TERMINOLOGY

The definition of a common terminology is necessary when it comes to modular product platforms as the understanding of certain terms in scientific works still varies. Furthermore, the perspective of structuring possibilities on a conceptual level needs to be introduced for a better understanding.

A. Modular product platform

Based on the definitions of SCHUH, FELDHUSEN ET AL., EHRLENSPIEL, RENNER and ARNOSCHT a *modular product platform* is characterized by a set of modules which can be either assembly groups or components. Based on standardized interfaces, modules can diversely be combined in order to derive a wide range of different product variants. Furthermore, the basic structure of modular product platforms is defined by constitutive features which make a fundamental contribution to the generation of commonalities [2, 10, 24, 27].

B. Early Stage of The Modular Product Platform Development Process

Even before the constructive modular design, it is necessary to analyze framework conditions and to define targets. In the context of modular product platform development the early stage describes a phase, which is characterized by a decision-making process based on very little information about the further development process as well as product features [31]. This stage is initiated with the product idea and the consequent initiation of the modular product platform development process and is terminated with a verified structuring concept.

C. 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. Moreover, all of the exogenous influencing factors affect the determination of the Conceptual Structural Feature's characteristics.

D. Conceptual Structural Feature

The type of a modular product platform is determined by distinct *Conceptual Structural Features*. On the level of a modular product platform, FELDHUSEN ET AL. identify different aspects that affect the overall properties of the modular product platform [10]. In this context, PONN ET AL. also recognize the possibility to derive a variety of modular product platform approaches by combining the characteristics of the features structure, system demarcation and purity [22].

Hence, Conceptual Structural Features and their associated characteristics represent the different conceptual design possibilities when it comes to modular product platforms. The features are defined at a certain level of abstraction where they are applicable to all kinds of industries but still provide guidance for the subsequent development of a modular product platform. The characteristics of the Conceptual Structural Features have to be determined in an early stage of the modular product platform development process. As the result of combining the distinct features in their entirety the Modular Product Platform Structuring Concept (MPPSC) is defined.

E. Modular Product Platform Structuring Concept (MPPSC)

The *Modular Product Platform Structuring Concept* represents the overall strategic approach of how to achieve commonalities whilst maintaining an appropriate external level of differentiation under the influence of given boundary conditions. Therefore, the decision on a concrete configuration of a Modular Product Platform Structuring Concept is dependent on the business type, the product portfolio and the individual target system of the modular product platform. Hence, the Modular Product Platform Structuring Concept is well suited to adjust the development initiative in accordance to all of the relevant exogenous circumstances and individually targeted benefits. To take all these influences into account the configuration of the overall concept needs to be accomplished in the early phase of modular product platform development after the scope of products has been determined and before the development of modules and assembly groups is initiated.

III. RELATED WORK

When it comes to the development of modular product platforms on an operational level there are numerous methods in scientific research. Those methods for instance outline how modules can be derived from components or functions. However, due to the fact that most of the recently published methods address certain targets such as mass customization or reductions of development time their field of application is strictly limited to individual cases [13]. In the following section relevant approaches regarding influencing factors and pursued objectives of modular product platform initiatives on the one hand as well as approaches addressing related definitions of Conceptual Structural Features on the other hand are presented. This overview is essential to define a basis of context factors and objectives that have to be considered when characterizing the Conceptual Structural Features. In addition to that adjacent approaches that describe the necessity of overall customized modular product platforms are presented.

A. Relevant Exogenous Influencing Factors

HANSEN ET AL. state that *"there is no one-fits-all when it comes to the tailoring of architecture initiatives to a specific situation of a company"* [14]. Based on this hypothesis the authors outline external factors a company has to consider when setting up a product architecture. Some of the identified

factors are for instance the market launch and technology clock speed or the volume per variant. When reflecting their own work, the authors derive the need for a set of action-oriented solution recommendations that can be mapped to the identified external factors but miss out to do so [14].

GRESHAKE states, that the determination of a concrete modular product platform concept is dependent on the product portfolio, the industry, the company, the market cycle phase of the products and the corporate strategy [12]. Accordingly, a set of factors from the dimensions market, product and manufacturing represent the relevant framework of product architecture design.

KRISTJANSSON ET AL. identify the regarded industry and market as the two dimensions that determine relevant external influences which need to be considered when structuring a modular product platform on a strategic level [17]. When aligning the platform strategy the company needs to understand the market competition. That is why the authors recall Porter's Five Competitive Forces Model [23], which contains additional influencing factors for choosing a certain platform strategy [17].

B. Relevant Objectives

CAMERON ET AL. state that individually pursued objectives need to be considered when crafting a platform strategy at an early stage of development. Hence, the authors develop a framework of benefits commonly being anticipated when pursuing a platform strategy. This framework is defined by the dimensions of revenue benefits, cost savings and risk benefits. Subsequent aspects of these dimensions for example are entering niche markets and reduced time to market, shared development cost and production economies of scale as well as lower technology risk and higher production quality. Rather than attempting to realize as much as possible, CAMERON ET AL. expose that focusing on distinct benefits promises better results [6].

Moreover, BOWMAN suggests, that an effective planning of the modular product platform in the early stages of development is dependent on the definition of a distinct vector composed of the dimensions innovation, higher performance, lower customer costs, breadth and coverage. This vector of differentiation represents the pursued objectives to be achieved with the modular product platform [3].

C. Relevant Overall Approaches

ARNOSCHT describes a modular product platform design process which he divides into the three phases platform structure development, module development and product design. Regarding the platform structure development, the author proposes the definition of the target system and object range as the first step. However, this step insufficiently describes the definition of the target system in relation to the company's environment [2].

KLEISSL introduced a holistic design process for product classification systems with the affiliated operational and organizational structure. Therefore, the model is based on factors influencing the development process which, depending on the distinct characteristic implicate different rules for the design process. This approach aims at the development of a generally valid sector- and product-independent design process that is customized depending on the individual initial situation [15].

MAGNUSSON ET AL. define the product platform strategy, the modularization approach as well as a combination of these two distinct conceptual opportunities to realize commonalities within different products while still satisfying the demand for a range of differentiated products. This empirically substantiated approach aims at the identification of market-given implications relevant to the derivation of a concrete product platform or modularization strategy. Based on the results of the study, the authors derive dependencies between the characteristics of contextual influencing factors and the different product platform strategies. Thereby, the characteristics of demand and the speed of environmental change are identified as the most relevant contingencies affecting the applicability of the concepts [18]. Although the approach hypothesizes that architectural concepts need to be designed dependent on contextual circumstances, it misses out on a sufficiently representative degree of detail in conceptual structuring opportunities when setting up a modular product platform.

HALSTENBERG ET AL. develop the Target-Oriented Modularization Method (TOMM) which assists the designer in defining a modular product architecture concept according to the pursued objectives [13]. Based on previously defined measures each of these generates a distinct product architecture concept. The determining measures have to be defined according to the individually pursued objectives. However, the substantial part of the method, a database with relationships between objectives and corresponding standard measures, is not part of the published approach [13].

Accordingly to TOMM, DAHMUS ET AL. develop a method to derive various product architectures as conceptual opportunities [7]. However, both approaches lack of a methodological evaluation and selection of the proposed modular product platform concepts. Whereas DAHMUS ET AL. do not discuss this step at all, HALSTENBERG ET AL. suggest a weighting of targets to enable an objective selection of a suitable architecture concept.

While most of the existing approaches only consider different overall modular product platform concepts this paper aims at the proactive configuration of distinct Conceptual Structural Features to derive different Modular Product Platform Structuring Concepts. The utilization of distinct Conceptual Structural Features to conceptualize modular product platform structures in accordance to the individual circumstances and pursued objectives is deemed as purposeful [4, 22, 32].

PONN ET AL. emphasize that choosing from different product platform concepts is dependent on the overall strategic framework. Therefore, the authors find three

Conceptual Structural Features with two characteristics each, resulting in theoretically eight different modular product platform concepts. Subsequently, PONN ET AL. exemplary compose four platform concepts out of the given set of structural features [22].

Similarly STECHERT derives eleven classifying features on a conceptual level for modular product platforms based on recent scientific research [32]. When setting up a modular product platform in the following, these features need to be proactively designed in dependence on development objectives and exogenous circumstances. However, not all of the composed features can be seen as Conceptual Structural Features.

IV. METHODOLOGY FOR TARGET COMPLIANT CONFIGURATION OF CONCEPTUAL STRUCTURAL FEATURES FOR MODULAR PRODUCT PLATFORMS

The overview of scientific approaches reveals that it is crucial to analyze the exogenous environment as well as the individually pursued target system of a modular product platform. However, a holistic approach to align the Conceptual Structural Features according to these dimensions is not existent yet. Hence, this paper's objective is to introduce an integrative methodology which enables the determination of a suitable configuration of the Conceptual Structural Features. Figure 1 illustrates the overall objective of the approach described in this paper.

As shown in Figure 1 the influences resulting from the corporate environment determine some of the conceptual structuring features. Subsequently, the leftover Conceptual Structural Features can be configured according to the individual target system, resulting in the Modular Product Platform Structuring Concept.

In order to increase the level of target achievement of the modular product platform, the configuration is highly dependent on the exogenous environment as well as the individually pursued platform target system. To achieve this, the main research question of this paper can be formulated as follows:

> *"How can the level of target achievement of a modular product platform be optimized a priori considering the exogenous environment by configuration of Conceptual Structural Features?"*

The conducted research in this paper can be described as applied research and therefore focusses on the derivation of a systematic target compliant configuration methodology of structure related features of a modular product platform. Based on an extensive literature review potential Conceptual Structural Features are extracted from diverse scientific approaches. The overall methodology introduced in the following basically consists of five steps which are summarized in Figure 2.

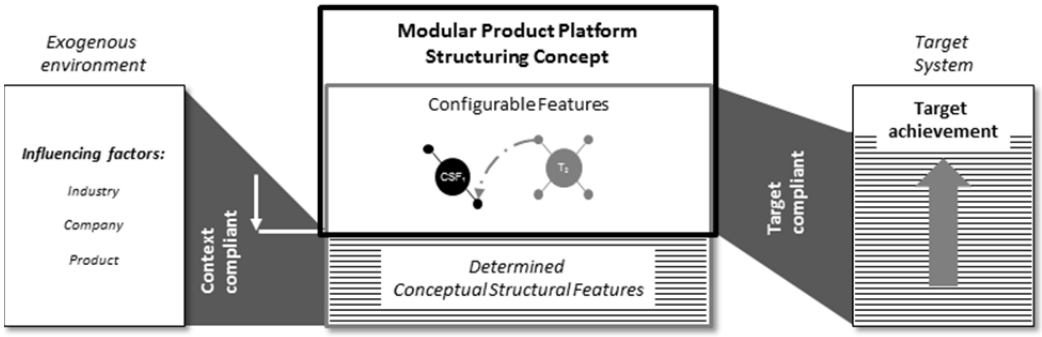

Figure 1: Context and target compliant configuration of a Modular Product Platform Structuring Concept

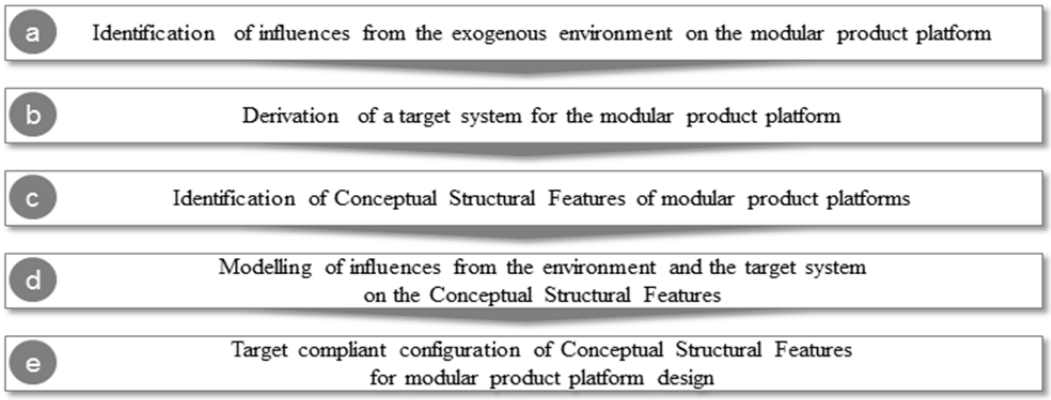

Figure 2: Methodology for a context and target compliant configuration of Conceptual Structural Features of modular product platforms

A. Identification of influences from the environment on the modular product platform

In the first step of the methodology the corporate environment with relevance to the modular product platform has to be defined. This step is crucial to derive implications for the configuration of the Conceptual Structural Features. For this purpose, the exogenous influencing factors of a manufacturing company are described in the form of features and respective characteristics. These features and characteristics need to be related to the decision making process on how to configure a suitable modular product platform for a given set of influences. To achieve the pursued objectives and meet a suitable compromise between standardization and differentiation from a business and customer perspective a context compliant structuring of the modular product platform is inevitable. However, besides the specific requirements of the industry the company operates in, the type of corporate business model has to be analyzed. Furthermore, restrictions arising from the considered product portfolio need to be taken into account. As all features are characterized as non-changeable from the company's point of view the later to be configured Modular Product Platform Structuring Concept needs to fulfill the so caused requirements.

For these reasons, the influencing factors are clustered in the subcategories industry, corporate type and considered product. Due to the restricted extent of this paper and focus on the description of the overall methodology, an extract of the factors will be stated below.

Besides others, the intended quantity of sold products must be taken into account regarding the industry. This factor is differentiated in the respective characteristics job shop production, batch production and mass production. The specification of this feature, for example, can affect the modular platform flexibility significantly.

With respect to the corporate type the existing business model has to be considered. The business model can be differentiated according to the various types of order processing. Therefore, it is necessary to determine whether the company operates in an engineer-to-order, a configure-to-order, an assemble-to-order or a make-to-stock business. This feature affects the degree of customer integration when it comes to the development of the intended modular product platform. When operating in a configure-to-order business for example, the customer can only influence the design of the final product within a given configuration space and in form of predefined modules. In contrast, companies running an engineer-to-order business, the customers might need to interact during development process and redesign product specifications several times in between.

By means of a systematic description of the corporate environment with relevance to the modular product platform, basic requirements concerning the configuration of the Conceptual Structural Features of the modular product platform can be derived. Besides meeting these requirements by a context compliant configuration in the first place, the pursued target system has to be considered too. It is crucial to the configuration that the pursued objectives are not contrary to the exogenous implications as they are given and may hardly be influenced or changed at all.

B. Derivation of a target system for the modular product platform

Nowadays, various companies are negligent of defining a weighted target system when it comes to modular product platform objectives. Most of them start the conception of a modular product platform project with undifferentiated objectives and merely focus on global objectives that only measure the overall company's success, e.g. in terms of general cost-cutting or increased competitive advantage. However, defining and communicating measurable objectives proves way more crucial. The Volkswagen Group, for example, subordinated four sub-goals to the overall objective of creating a competitive advantage with the platform strategy: increased profitability by reducing costs per unit, reduced complexity within the manufacturing system through harmonization of production flow, reduced development time and costs for new models due to standardization of components and improved control of the value creation chain by creating central standards.

Companies that define the overall as well as the subordinated objectives in terms of a target system deliberately are enabled to deduce a target compliant Modular Product Platform Structuring Concept. Accordingly, it is not purposeful to start the actual development process of the modular product platform if the target system of the platform development is not yet determined [10]. Even in the case of putative identical applications diversified target systems lead to different configurations of the platform structure. Therefore, during the early stage of development it is possible to align the Modular Product Platform Structuring Concept according to a company's individually weighted target system. Thus, the basis for an increased level of target achievement of the modular product platform is created during the early stage of the development initiative. Correspondingly, in this paper a target compliant Modular Product Platform Structuring Concept is defined as the proactive alignment of the structuring concept during the early stage of the development initiative according to a company's individually weighted target system.

To derive a weighted target system it is necessary to establish a hierarchy of feasible targets and sub-targets. In the context of a controlling system for modular product platforms VOGELS introduced a reference target system, which is supposed to serve as a basis for further considerations [34]. This target system is based on a broad literature research and summarizes the outcomes of various authors [9, 10, 11, 16, 24, 26, 29, 30, 33]. Accordingly, VOGELS defines four overall perspectives: the financial perspective, the market perspective, the value creation perspective and the architecture perspective.

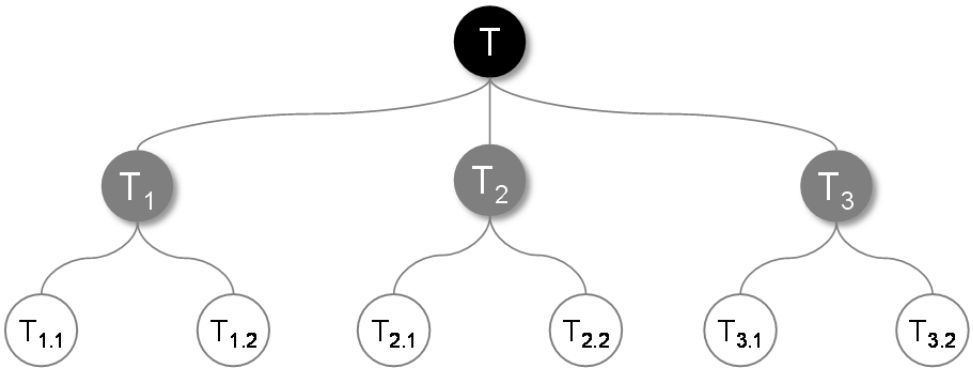

Figure 3: Hierarchization of main targets and sub-targets

From a financial perspective i.e. a higher turnover, an increased profitability, lower production costs and reduced development costs might be considered when setting up die individual target system. Regarding the market perspective relevant sub-targets are a better fit of the product program, a lower response time, an enhanced external quality as well as a higher sales volume. Considering the value creation perspective targets can be defined in terms of increased process standardization, an enhanced internal quality, reduced inventory and shorter lead times. With regard to the architectural perspective, possible sub-targets are a higher degree of standardization of the architecture as well as an increased flexibility of the product architecture. Since this variety of partially contrary targets is not achievable at the same time it is necessary to derive a specific hierarchization of the target system (see Figure 3).

To derive the weighting of sub-targets the method of pairwise comparisons is applied [19]. For the method of pairwise comparisons, each sub-target is matched head-to-head with each of the other sub-targets. Subsequently, a normalization of the evaluated sub-targets is conducted. Accordingly, the overall target system is made up of the sum of the weighted sub-targets. The weightings of the individually evaluated target system concurrently define the framework for the evaluation of the level of target achievement in the fifth step of the methodology.

C. Identification of Conceptual Structural Features of modular product platforms

Once the exogenous influencing factors and the individual target system have been derived it is necessary to identify differencing Conceptual Structural Features. The entirety of distinct conceptual structuring features results in the so-called "Modular Product Platform Structuring Concept" (MPPSC). By setting the various Conceptual Structural Features in accordance with their contribution to a context and target compliant modular platform structure in the fifth step of this methodology the resulting overall concept defines the general direction for the actual development process of modules, assemblies, components or standardized interfaces. Since the scope of this work does not involve the comprehensive assessment of all Conceptual Structural Features, some explanatory features will be listed in the following. An extensive discussion of all relevant Conceptual Structural Features will be in the focus of another paper in the future. From a methodical point of view the potential features were derived utilizing a trinomial approach which is shown in Figure 4.

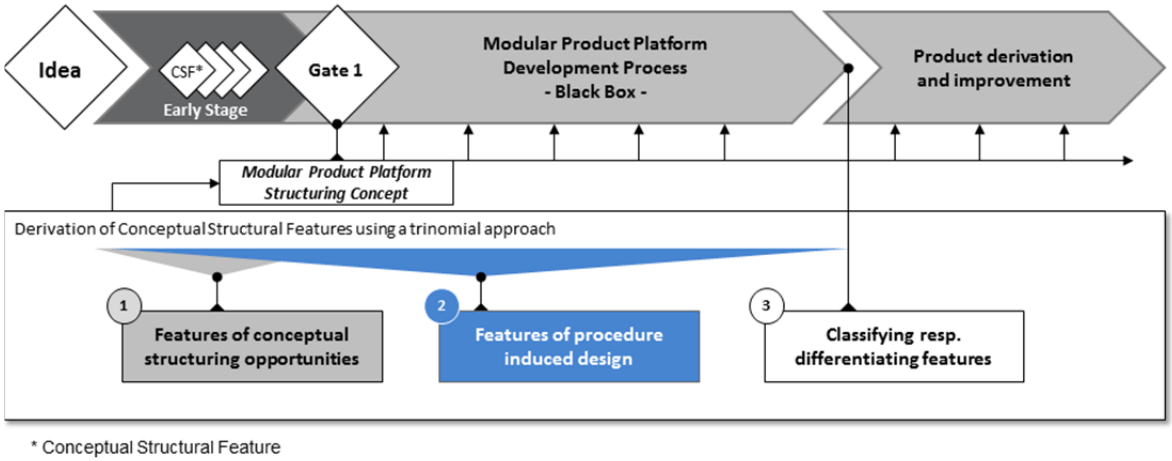

Figure 4: Derivation of Conceptual Structural Features using a trinomial approach

In addition to Conceptual Structural Features derived from conceptual opportunities regarding a modular product platform in the early development phase as well as classifying respectively differentiating structural features from a retrospective point of view, some of the features were derived from the various corresponding process models described in the scientific literature.

The conceptual opportunities for modular product platforms are derived from existing sequences of modularity and platform development processes. These opportunities can be understood as strategic decisions that essentially characterize the process design in the product development context [28]. Since modular product platforms are applied in differentially characterized industries, there is no universally valid sequence of activities and decisions in platform development process models though [20].

However, some of these conceptual decisions can be mapped to the conceptual level and in this way impact the overall modular product platform. Some process models ask the user to decide upon the actual proceeding during the product platform development and thereby offer alternative methods or workflows. Precisely these alternatives were analyzed regarding their impact on the conceptual structuring of the modular product platform. In case of a given impact Conceptual Structural Features of procedure induced design are derived.

As described before, some approaches focus on the development of descriptive classification models that retrospectively describe existing modular product platforms [4, 32]. To derive additional Conceptual Structural Features, these classifying features have been examined whether they can equally be used as proactively used Conceptual Structural Features when setting up a new modular product platform.

In order to define a structured set of consolidated non-overlapping features from the total number of over 30 singularly identified potential Conceptual Structural Features the approach of a Static Design Structure Matrix was applied [5]. Based on informational dependencies between the potential features, coherent clusters have been derived. These clusters contain several potential features which in turn were consolidated to discrete Conceptual Structural Features with respective characteristics. In the following, examples for the clusters that contain features regarding the determination of constituent features, the modular setup, the structural implementation as well as the procedural approach are presented.

Regarding the determination of constituent features, the methodological approach can be exemplified. Two fundamentally different *Methodological Approaches* can be pursued when defining a set of constitutive features. Since the chosen approach significantly impacts the design of the modular product platform on a conceptual level, the Methodological Approach is defined as one of the Conceptual Structural Features. The characteristics of this feature are represented by the process-oriented approach and the component-oriented approach [32]. In a later stage of the methodology, the suitability of either approach is evaluated by means of individually pursued targets.

Besides others, the modular setup is exemplified by means of the *Granularity Level* of modules. Defining the granularity level of a modular product platform has major implications on the whole product and platform life cycle [20]. Different authors made relevant contributions to the granularity level of a modular product platform [1, 9, 16]. While ALGEDDAWY ET AL. and ERICSSON ET AL. elaborate an ideal number of modules and an optimum granularity level using case studies, KOHLHASE describes a more generic approach regarding the granularity level. This approach differentiates modular product platforms according to the inherent complexity of modules and introduces the characteristics "Modular System with layout element", "Modular System with standard elements" and "Modular System with functional units" [16].

With respect to this paper the presented generic characteristics shall be understood as indicatory values representing an increase (modular system with layout elements) or a decrease (modular systems with functional units) of the granularity level (see Figure 5).

When it comes to the structural implementation the pattern from which the different product variants are derived, is defined by the feature *Architectural Pattern*. Similarly to DELLANOI, this paper defines the characteristics of the architectural pattern as the three generic patterns "Physical Platform with Modules", "Layout Platform with Modules" and "Open Modularization" (see Figure 6).

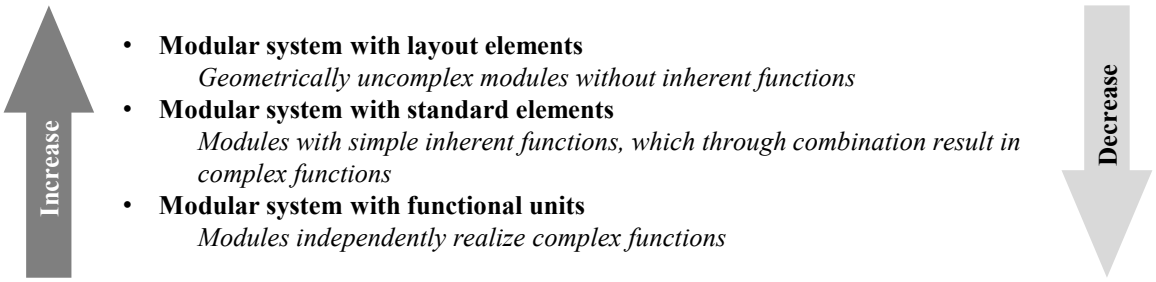

Figure 5: Granularity Level of Modules

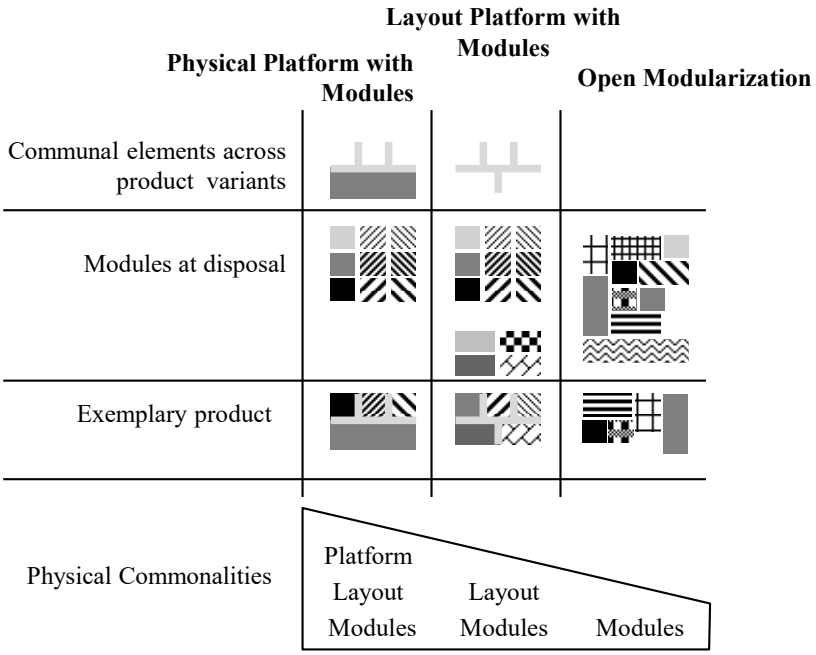

Figure 6: Architectural Pattern [8]

Whereas physical platforms with modules are suitable to enhance the communal physical platform and individualize the derived product variants by a set of inter-changeable modules, layout platforms used to standardize the arrangement of modules in terms of the layout across a range of product variants. In contrast, open modularization can be used to cover a vast range of product variants through versatile combinability of modules.

The entirety of the identified Conceptual Structural Features needs to be analyzed in terms of their dependency on influences from the exogenous environment as well as the individual target system, which defines the fourth step of the methodology.

D. Modelling of influences from the environment and the target system on the Conceptual Structural Features

As described before, the distinct characteristics of Conceptual Structural Features define the direction for all further coming development stages of the modular product platform when aligning them to the situational context of a company as well as the individual target system of the modular product platform. Therefore, the influences from the corporate environment and the individually weighted target system on the Conceptual Structural Features have to be modeled.

For this purpose, the graph theory, the heuristic screening method and the respective description of the dependencies within consistency matrices are applied. The data base is built up on an extensive literature research, on the evaluation of case studies of industrial application as well as on the results of an empirical study.

Exemplary influences can be described using the *Architectural Pattern* (see step 3). In the case of complex products with hierarchic product structures and considerable freedom in design, Layout Platforms proof to be suitable [21]. Moreover, both Physical Platforms with Modules as well as Layout Platforms allow the integration of the customer in the product configuration by choosing from a variety of given modules. In contrast, with Open Modularization the customer can be integrated during the process of defining customized product concepts. Besides these product related contingencies, the pursued level of commonality has to be considered when determining the pattern for the modular product platform.

Figure 7 schematically shows the influences on Conceptual Structural Features.

Besides the exogenous influencing factors described in the first step of the methodology the individually weighted sub-targets derived in the second step affect the determination of a context and target compliant feature's characteristic. Moreover, it proves crucial to consider that the influences and effects may contradict themselves. Thus, no trivial determination of the feature's characteristics is possible.

In order to solve this challenge of contradictory influences, the Conceptual Structural Feature's characteristics are being determined according to the configuration logic as described in the following fifth step of the methodology. This type of structural approach constitutes the basis for a context and target compliant configuration of the Conceptual Structural Features, which collectively result in the Modular Product Platform Structuring Concept (MPPSC).

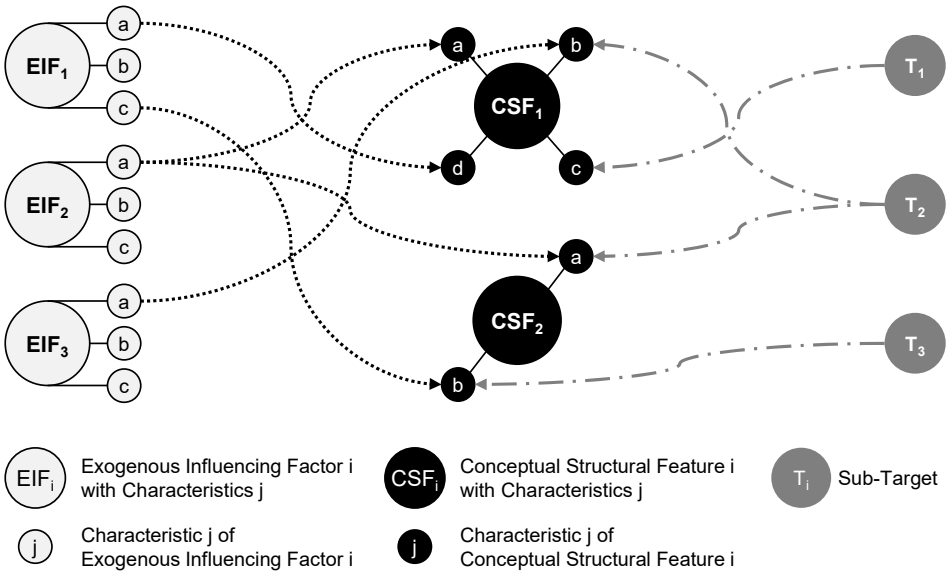

Figure 7: Schematic modelling of the influences on Conceptual Structural Features

E. Target compliant configuration of Conceptual Structural Features for modular product platform design

The last step of the methodology pursues a context and target compliant configuration of the identified Conceptual Structural Features in order to derive the Modular Product Platform Structuring Concept. This step is crucial to achieve an optimization of the level of target achievement of the modular product platform. The level of target achievement is made up of the sum of the weighted contributions to the target achievement of the sub-goals that were defined in step two. The differentiated configuration of a modular product platform consequently results in a varying contribution to the level of target achievement.

In order to achieve a higher degree of target achievement, the contribution of each feature to all sub-targets must be evaluated while considered in isolation. This contribution is evaluated applying the pairwise comparison method. Subsequently, a linear optimization model is used to maximize the level of target achievement by determining the optimal characteristic for all of the leftover Conceptual Structural Features.

For example, focusing on the flexibility of the modular product platform contributes to the target achievement of increased flexibility of the product architecture. However, this runs contrary to the target of lower production costs as the effects of economies of scale decrease the smaller the batches.

In order to achieve a consistent Modular Product Platform Structuring Concept by designing with configuration methods a set of rules describing requirements and restrictions in the various combinations regarding the interaction of features and characteristics is indispensable [15]. However, the fundamental requirements derived from the exogenously given influences have to be considered initially. Once all of the Conceptual Structural Features determined by these influences have been fixated with the corresponding distinct characteristic, the theoretical solution space of configuration possibilities is minimized.

By reducing the potential solution space in the first place, the complexity of the decision model for the configuration in terms of the linear optimization model decreases significantly.

V. CONCLUSION

As formulated in the derived main research question, the objective of this paper was the development of a methodology for the identification of a context and target compliant configuration of Conceptual Structural Features in terms of a Modular Product Platform Structuring Concept. Therefore, a methodology consisting of five steps was introduced. After defining the relevant terminology such as the Conceptual Structural Feature and the Modular Product Platform Structuring Concept (MPPSC) related scientific approaches were presented and critically reflected. An important step of the methodology is the derivation of the features that need to be considered when configuring a modular product platform structure. With regard to this, a trinomial research approach was introduced. Using examples for the identified Conceptual Structural Features these five steps were described in the following. This methodology provides a significant contribution to the user by supporting the determination of a context and target compliant configuration of the Conceptual Structural Features of a modular product platform. Consequently, this leads to a higher level of target achievement by means of an increased suitability of the modular product platform to a company's overall situation and the individually pursued objectives.

Moreover, the paper's outcomes are relevant to users from various industries as the presented methodology enables both, a proactive use in terms of the individual alignment of the modular product platform as well as a comparison of existing modular product platforms. Hence, a cross-industry discussion and best practice sharing on a comparable basis is facilitated. Regarding the needs for further research it can be stated, that the methodology needs further detailing, especially by a detailed description of the configuration algorithm to derive the Modular Product Platform Structuring Concept. Therefore, a further detailing of the Conceptual Structural Features as well as the configuration model represents the content of other publications, which emphasizes future research. Finally, case studies in different industries will be conducted to validate the diverse configurations of a modular product platform structure.

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