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# PRODUCT ARCHITECTURE DESIGN METHODOLOGY FOR DEVELOPING STANDARDIZED MODULES

**Thumm, Benjamin Roland; Göhlich, Dietmar**
Technische Universität Berlin, Germany

## Abstract

This paper provides a new approach based on "Product Architecture Drivers" (PA Drivers) as well as an overview of product variety and its relevance to product standardization. The target products for the approach are capital goods which are typically produced in low quantities. Those products are in general highly customized which leads to high product complexity.

A profound literature review of different types of variety, development processes and projects and a new definition for standardized product architectures is given. Most approaches consider modularization based on green field development. In this paper we investigate an approach applicable for brownfield product development.

For implementing new standardized modules into an existing product portfolio a suitable architecture has to be developed. A mapping between the future common product architecture, standardized modules and the product lines is given.

**Keywords**: Design Methodology, Product Architecture, Complexity, Modularization

**Contact**:
Benjamin Roland Thumm
Technische Universität Berlin
MPM
Germany
b.thumm@campus.tu-berlin.de

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# 1 INTRODUCTION

In recent years, customized products have gained importance for most industrial sectors. The wide product variety required by customers entails a strong increase in complexity due to the diversity of components. Therefore, a product structure needs to fulfil the different development requirements (Blees et al., 2009). The need to control the product complexity, faster time to market and decrease in cost leads to the quest for a robust and profitable product architecture. An effective concept to create customized products while keeping product cost down and quality high is a modular product strategy (Hanafy and Eimaraghy, 2013). Product standardization through modularization of products is an effective method for combining individual customer demands and low product costs, to offer products appropriate to the market (Dai and Scott, 2007). Modules have the capability to be swapped by others of different size or functionality to create variants (Gonzalez-Zugasti and Otto, 2000). However, according to Krause et.al (2013), major challenges arise from contradictory requirements and from balance compromises. To implement new standardized modules into an existing product portfolio, a suitable architecture has to be developed. This paper provides a new approach based on "Product Architecture Drivers" (PA Drivers) as well as an overview of product variety and its relevance to product standardization. The main distinguishing features of variety and the main objectives of variant management will be presented. For a better understanding of how variety grows, the main categories for development projects are identified and introduced. In addition, existing definitions of product architecture are supplemented by a new approach how to determine standardized product architecture. The information about the product variety, the different development projects and the methodology to define standardized product architecture are required to derive a new development approach for product architecture and standardized module concepts. Taking into account the different phases of a product development process, the following approach is focused on the conceptual design within a product development process. The target products for the approach are capital goods which are typically produced in low quantities. Those products are in general highly customized which leads to high product complexity.

# 2 LITERATURE REVIEW

In order to understand the increase of product complexity due to high product variance, a deeper understanding and distinction of product variety is necessary. To increase the customer benefit of products, the objective of variant management for controlling the internal and external variety gains more and more of importance (Frank, 2011). An overview of different aspects of product varieties is given below. In this context it is shown that the development process also affects product variety. Finally, the impact of product architecture on modularized products is discussed. The product-related variety within a company can be divided into two different types of variety: internal and external variety.

## 2.1 Internal Variety

The internal variety describes the variety of components, assemblies or processes occurring during the product creation process. It causes a high complexity and a lack of transparency within the procedures of the indirect operations and therefore it affects the overhead expenses. In total the internal variety will have a negative influence on the company and will lead to an increase of the production expenses. As long as the internal variety isn't driven by customer requirements but rather driven by the development itself, it has to be avoided (Bartuschat, 1995).

## 2.2 External Variety

The external variety describes the product variety which can be used by the customer. This variety can be identified by the customer and is driven by the market. The purpose is to fulfil customer requirements and to increase the product benefit. External variety is only useful if it doesn't exceed the market requirements (Bartuschat, 1995).

## 2.3 Product Variance and Product Standardization

The objective must be to decrease the internal variety while maintaining the external variety demanded by the market/customers (Franke et al., 2002). Therefore, product standardization through specification of maximum variety can only be successful if the company is market leader and generating cost advantages. Due to reduced product costs, standardization can be successful despite the limitation of flexible customer products. The reverse strategy to offer flexible products with a substantial cost surcharge may be possible for certain niche products. However, in order to master different market factors like piece numbers, market share, different market type, technology change, differentiation of customer requirements and flexibility, a meaningful combination of both strategies is required. The developers face several variety-drivers like component diversity, number of suppliers, wider variety, customer variety and the diversity of the product range (Engeln, 2008).

## 2.4 Development Projects

According to Meyer and Lehnerd (1997), three different types of development projects can be distinguished.

New basic development projects, also known as “greenfield development”, are projects which most of the modularization concepts are based on. In this type of project, the existing product architecture is questioned. New proposals for technical solutions are analyzed and can be developed (Göpfert, 2009).

Further development projects occur to improve existing product architecture. They are focused on increasing the quality or technical capacities. The relations of components and interfaces are not be questioned (Göpfert, 2009).

According to Göpfert (2009) there is a third project category called “Platform project”. This development is based on an existing product architecture with the aim of a fundamental change. The product architecture is modified while using present components and functions. The development is focused on adapting the relations of the components to set a basis for a new product series (Göpfert 2009). This is confirmed by Meyer and Lehnerd (1997): “A product platform is a set of subsystems and interfaces that form a common structure from which a stream of derivative products can be efficiently developed and produced”.

Another term for "Platform project" is called "Brownfield projects". The term brownfield project is mainly used in the IT industry for a new development which is based on prior works or products. Brownfield development is increasingly being used in many industries for reengineering existing products.

Further description of project types and categories are done by Wheelwright and Clark (1992). They speak of five types of development projects called R&D, Breakthrough, Platform, Derivative and Partnership. Those types differ in their role, requirements, resources and generate different results.

Most approaches consider modularization based on green field development. In this paper we investigate an approach applicable for brownfield product development.

## 2.5 Product Architecture

According to Koppenhagen (2004), product architecture describes the composition of components or assemblies to create a final product. The product architecture can be distinguished in two specific categories called *function structure* and *product structure*.

- The *function structure* describes the sub-functions of a product which are required to ensure the main product functions.
- *Product structure* compromises the physical product paraphrases which are used to describe the physical relationship between the different product components.

Contrary to the product architecture, the product structure merely describes the physical construction of a product and can be compared to the product architecture description (Blees, 2011). In contrast to Koppenhagen (2004), Ulrich (1995) defines product architecture by the functional structure, the product structure as well as the transformation between those two structures. The functional structures are not just the decomposition of the required functions into sub-functions but also their relations. By product structure, he understands the physical composition of components of a product.

There are also approaches to define a product architecture for product families. Jiao and Tseng (2000) use the three perspectives functional, behavioural and structural to do so. With their PFA (Product Family Architecture) methodology they describe an approach for developing a generic architecture to capture and utilize commonality and modelling the design process of a class of products (Jiao and Tseng, 2000).

We define product architecture on the basis of *product architecture drivers* (PA Drivers) which comprise the functional specifications, geometric parameters of modules and components which have significant impact on the internal and external variance of the product.

Examples for PA Drivers are technical dimensions, module arrangement or interface characteristics. The process of identifying appropriate PA Drivers is discussed in chapter 4.

## 3 PRODUCT

### 3.1 Product of scientific study

The chosen example for a capital good product is a Gas Insulated Switchgear (GIS). A GIS is part of an electric power system for high voltage. Switchgear in general is electric equipment intended to be connected to an electric circuit for the purpose of carrying out one or more of the following functions: protection, control, isolation, switching. Gas insulated switchgears are in particular metal-enclosed switchgear in which the insulation is obtained, at least partly, by an insulating gas other than air at atmospheric pressure. The main functional modules of GIS are: circuit breaker, busbar, disconnecting switch, earthing switch, current and voltage transformer, cable sealing end and control cubicle as shown in Figure 1. Substantial complexity arises due to very different customer requirements. Therefore the product requires a high adaptability to customer needs. The challenge is to develop a competitive, but at the same time extraordinarily variable product, which can only be achieved by modularization (Thumm et al., 2014).

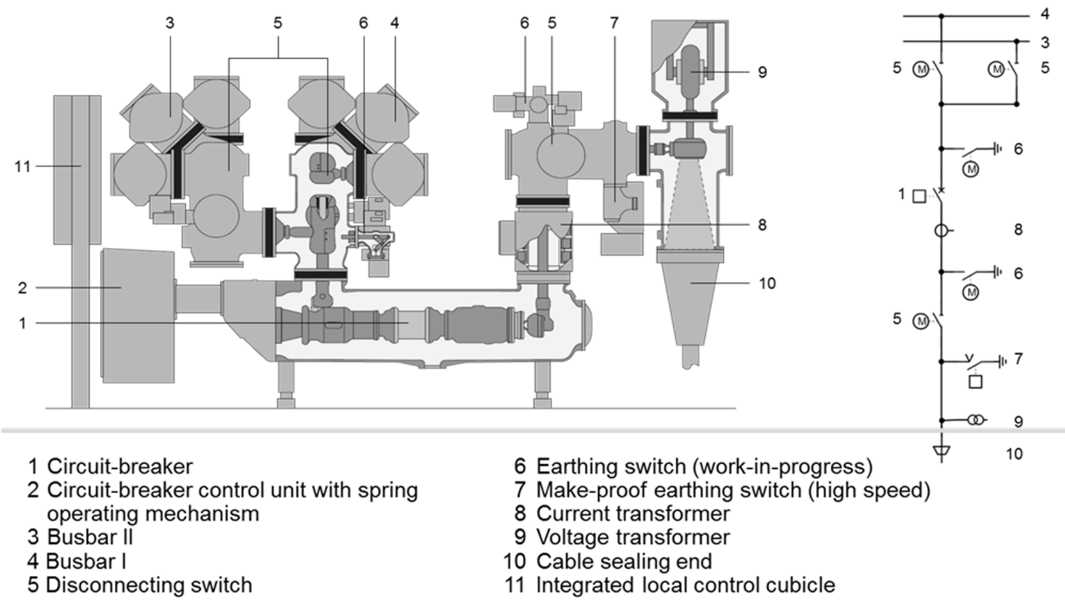


*Figure 1. SIEMENS Gas insulated switchgear with main functions (Thumm et al., 2014)*

Figure 2 shows a GIS module example including the interfaces to all directly connected modules. The module is a casted housing which is used in different variants within a GIS.

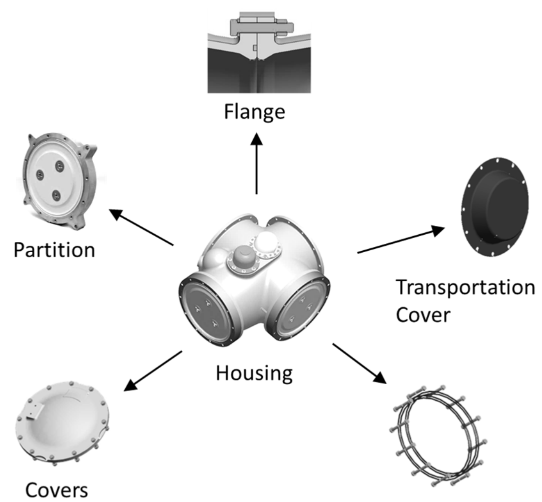


*Figure 2. Housing Module and its interfaces (Thumm et al., 2014)*

### 3.2 Initial Situation of Variance

At the beginning of the product standardization, a comprehensive investigation of the existing variance of the PA Drivers has to be carried out. Figure 3 shows an example of the PA Drivers which define the product architecture and the amount of variance. Due to the fact that the constantly increasing internal and external variety leads to higher complexity, it is important to understand the cause of it. Reasons for a variety rise can be historical or technical. It is therefore necessary to determine the existing PA Driver variance before reducing it.

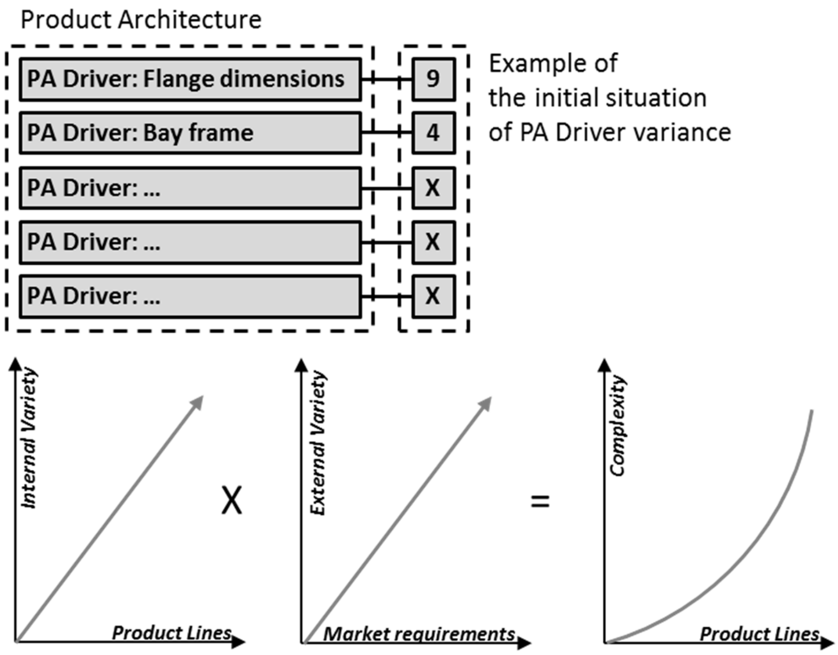


*Figure 3. Existence correlation between Architecture and Variance*

## 4 APPROACH

For implementing new standardized modules into an existing product portfolio, a suitable architecture has to be developed. A mapping between the future common product architecture, target products and standardized modules/components is also necessary (cf. Figure 4). It has to be ensured that the product architecture is suitable to all target products and enables the use of standardized modules and components. When developing a product architecture, the effects on the different products, modules and components have to be considered. Therefore it is essential to first develop a common architecture.

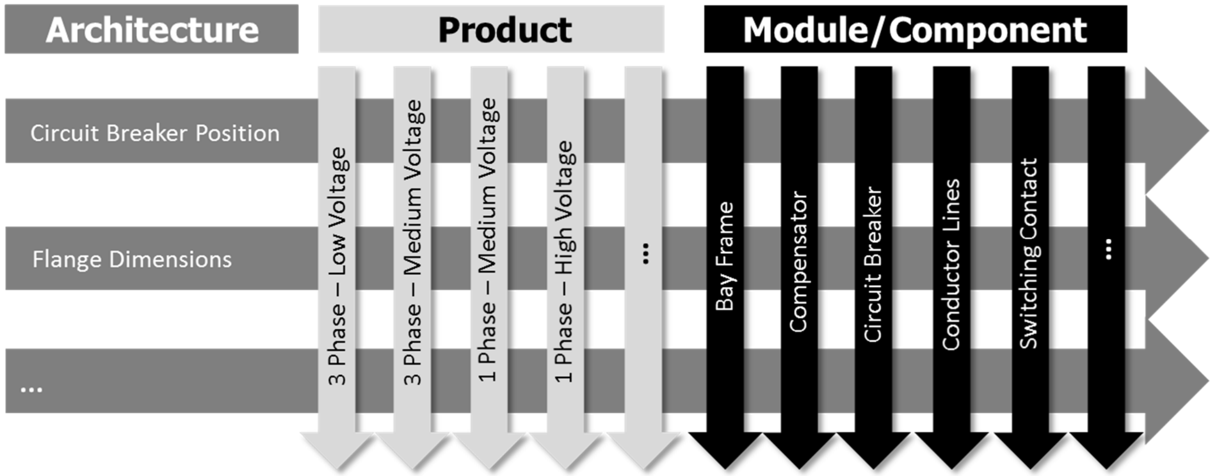


*Figure 4. Mapping Process Architecture-Product-Module/Component*

The following sections will introduce the architecture development process and the module development process for concepts. The two processes are a part of the "Conceptual Design" phase. Within the conceptual design phase, principle solutions (concepts) will be determined. According to Pahl et al. (2007), this can be achieved by abstracting the essential problems, establishing function structures, searching for suitable working principles and the combination of those principles into a working structure. Our new approach is focused on the "Conceptual Design" phase and the breakdown into two new phases. As shown in Figure 5, the architecture development phase is upstream to the module concept phase. The last phase in the lower figure is the embodiment design phase in which the designers are starting from concepts and where the construction structure of a technical system and the layout will be defined (Pahl et al., 2007).

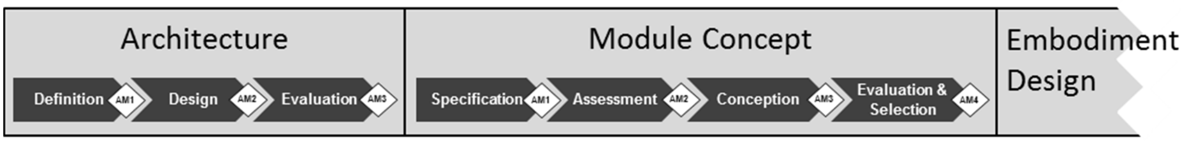


*Figure 5. Conceptual design phase for product standardization*

### 4.1 Product Architecture Driver (PA Driver) Development Process

In order to analyse the product architecture, a product portfolio investigation of the gas insulated switchgears products was conducted. The results showed that the product hierarchy contains parts which could be defined as PA Drivers. The preparation and analyses of the product portfolio which leads to the PA Drivers required three main perspectives:

1. Functional perspective (behavioral view): Represents the requirements of customers and leads to the main functional specifications

2. Performance perspective: Contains the functional specifications and technical feasibility which ensure the main technical parameter
3. Structural perspective: Includes the physical implementation and module/component structure

The first analysis showed how the variance occurred in the current product portfolio and why different specific technical solutions have been achieved. In a second step an additional product analysis was performed based on the specific product properties which could not be assigned to basic modules. The results exhibited that the identified modules had a main impact on the product layout and architecture itself.

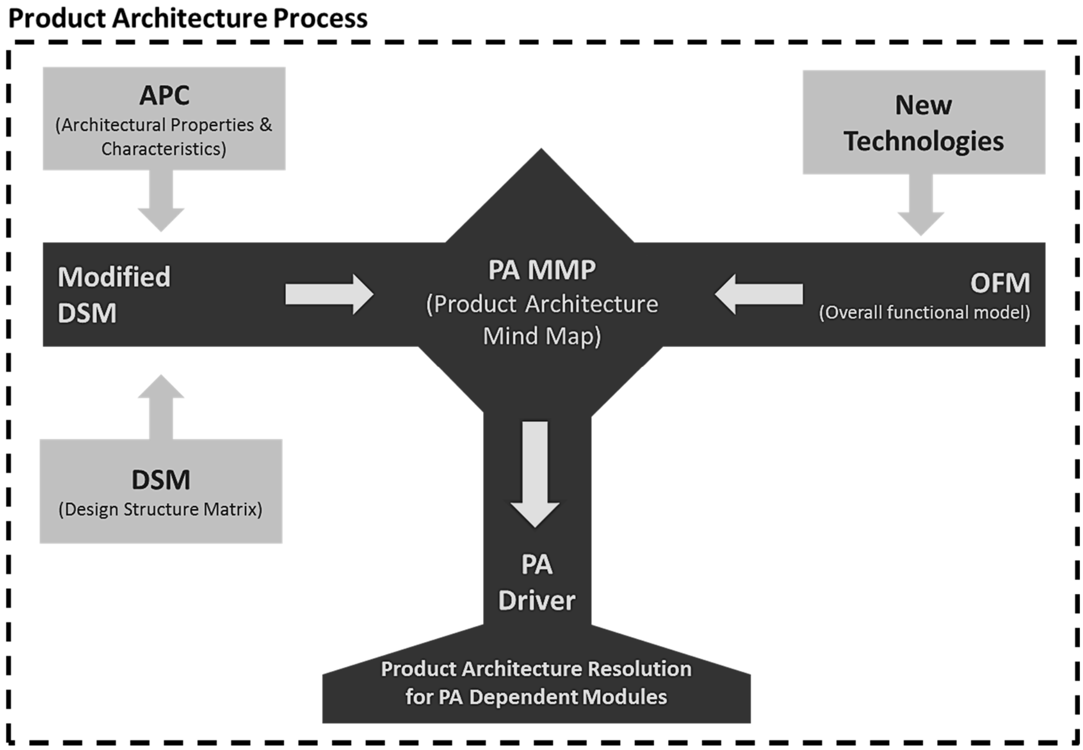


*Figure 6. Complete PA Driver Process (Thumm et al., 2014)*

As described before, the architecture is determined by the PA Drivers. They are also required for the PA dependent modules and necessary for the concept development. It is therefore essential to pre-investigate and determined those PA Drivers. The product architecture process shown in Figure 6 helps to define the number of attributes, characteristics and variety of PA Drivers. The PA Drivers are a prerequisite for developing standardized highly PA dependent module concepts. The module characteristics and interfaces are mainly affected by the PA Driver. After finishing the PA Drivers, the highly PA dependent module concepts can be developed and implemented in the modular product design. In this phase, a detailed elaboration of the highly PA dependent modules happens. Pahl et al. (2007) call it "Embodiment Design" phase. The phase is based on concepts and determines the construction structure (overall layout) of a product including the technical and economic criteria (Pahl et al., 2007). A possible example related to our product of investigation could be flange dimensions. This PA Driver does have a major impact on several interfaces, influences physical parameters and helps to produce a rough dimensional layout. The milestones including their tasks which have to be processed are shown in Figure 7.

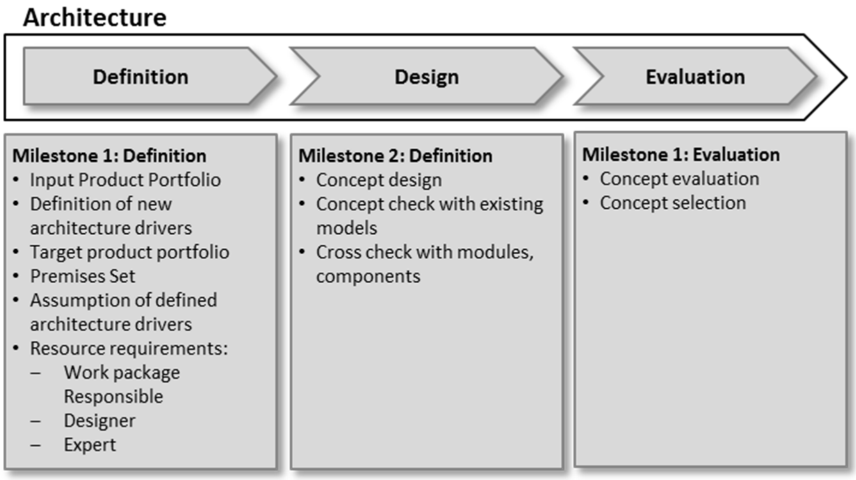


*Figure 7. Architecture Process*

## 4.2 Module development process for concepts

The process to investigate and determine a module concept consists of five Milestones: specification, assessment, conception, evaluation and selection. Those milestones include certain tasks which have to be fulfilled to investigate standardized module concepts. Within the process, important information about the target product portfolio, existing solutions and their history as well as future modules will be compiled. The concept development defines the number of attributes, characteristics and varieties of a standardized module which are required for a subsequent development. The actual module development happens in the phases embodiment design and detail design (Pahl et al., 2007). Those phases contain product planning, design, tool manufacturing, initial sample testing and product approval (Feldhusen, 2013). The following milestones in Figure 8 cover the main tasks which are crucial for the concept development.

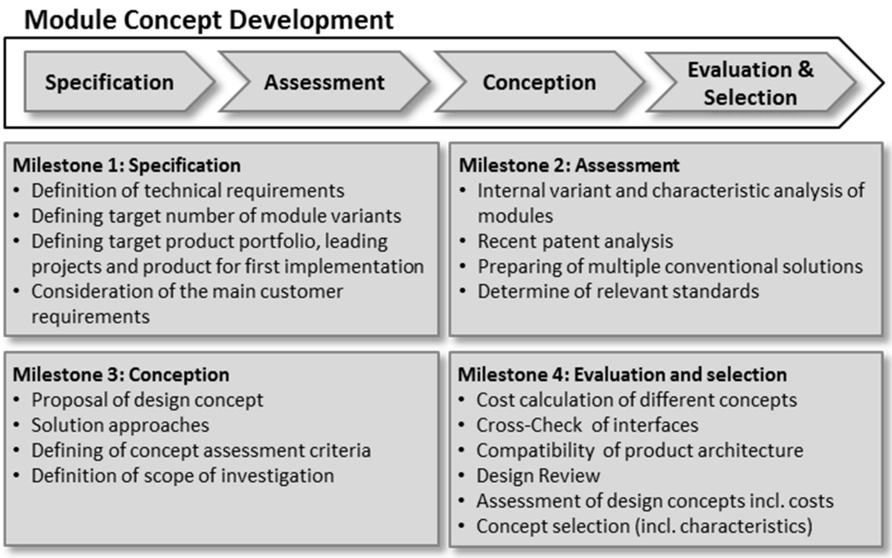


*Figure 8. Module Concept Development Process*

The modules themselves can be distinguished in two types. Highly product architecture dependent modules (Highly *PA* Dependent Modules) which require finished PA Drivers as an input and are strictly depending on the product architecture. Those modules have to be developed subsequent to the PA Drivers. A practical example referring to the previous PA Driver example could be a bulkhead. It is directly affected by the parameters and characteristics of the PA Driver "flange". Modules which can be independently developed are called *slightly PA dependent m*odules. Those modules are not directly affected by product architectural changes and conversely have no significant impact on the product layout or structure. They can be independently developed and integrated in the embodiment design phase using the same concept development process. A good example for a PA Slightly Dependent Module is a drive unit. Performance requirements, interfaces and dimensions could be independently defined for this module.

### 4.3 Architecture and Module Concept Development within the Product Development

The characteristics and specifications of PA Drivers define the product architecture and have to be developed within the architecture phase. The development of the slightly PA dependent modules can be started simultaneously. The second concept phase called "Module Concept" provides a process for the module concept development. PA Highly Dependent Modules are the essential part of this phase. The concepts for those modules will be subsequently developed after PA Drivers and parallel to the PA Slightly Dependent Modules. An illustration of the overall process is given in Figure 9.

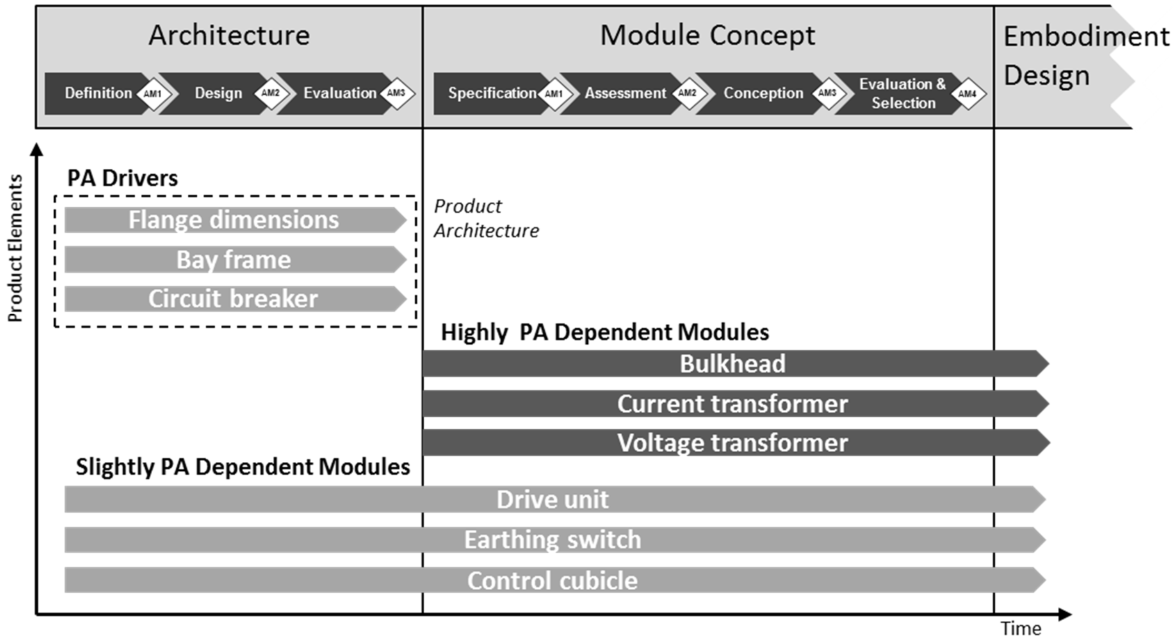


*Figure 9. Overall Process of PA Drivers and PA Independent and Dependent Modules*

The reduction of PA Driver and module variety will lead to a reduced complexity. This is accomplished by standardizing main dimensions, key functions and concepts. The interaction between the PA Drivers and modules will progressively reduce the variety. Figure 10 presents the funnel shaped decrease of complexity.

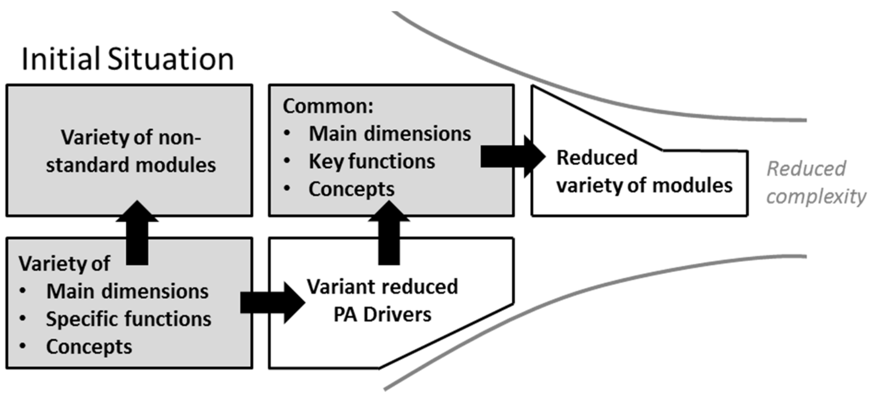


*Figure 10. Reduction of complexity through standardization*

## 5 CONCLUSION AND FURTHER WORK

Our goal was to develop standardized module concepts in a brownfield environment. The approach presented in this paper is based on PA Drivers which lead to a suitable product architecture. Therefore, the concept phase of product development has been divided into architecture and module concept phase. The mapping and interaction between Modules, PA Drivers and the development process could be validated.

Due to restricted resources, an implementation scenario for the detailed development of new standardized modules is required. Clusters of modules and PA Drivers which have to be implemented into existing products could be determined by a modified design structure matrix. Some of the required input could be gained by analysing the basic project management parameters of product development and the correlation between the PA Drivers and modules. An approach comprising the information of the design structure matrix and other project parameters could be used to find the ideal implementation scenario.

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