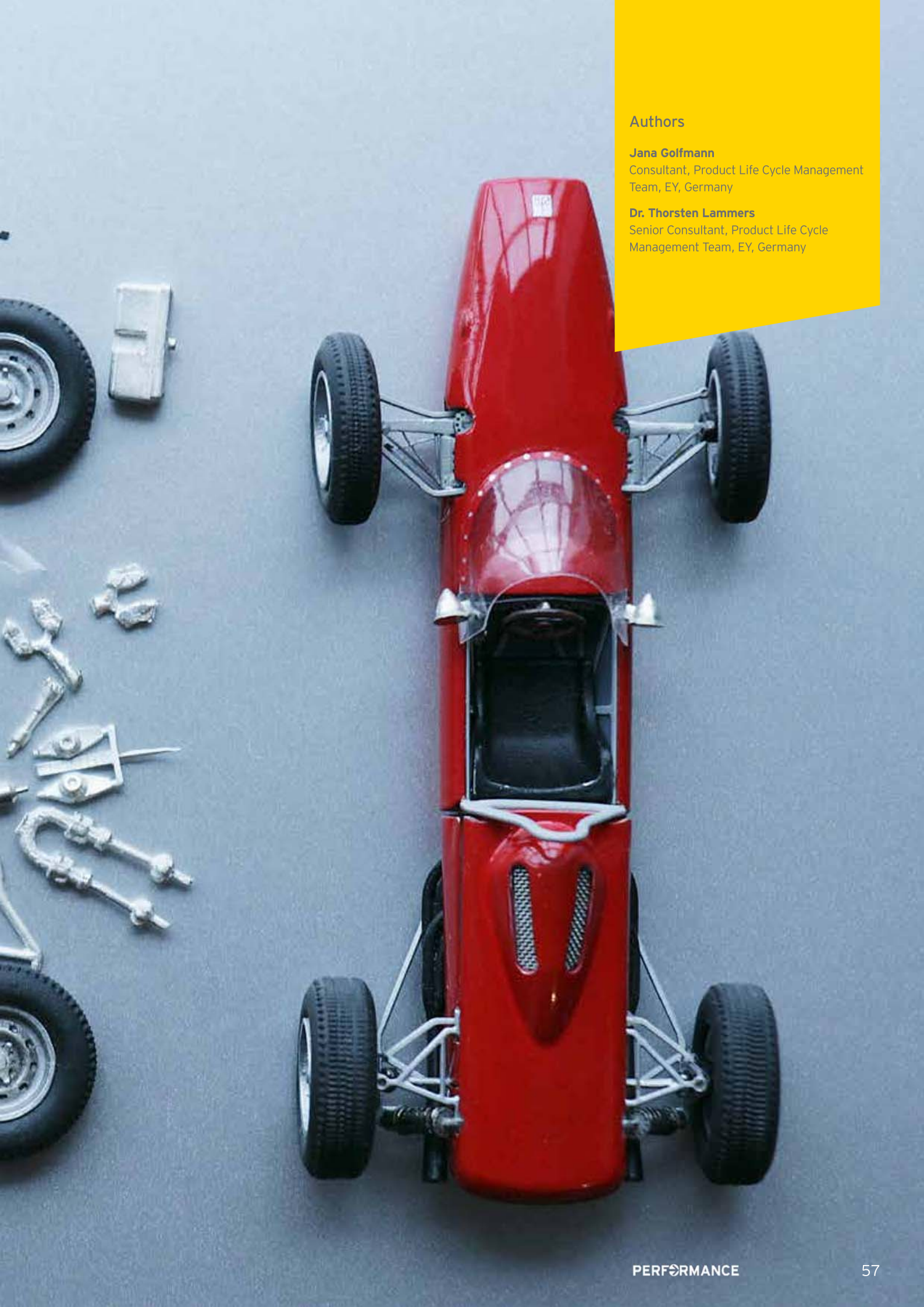


Modular product design: reducing complexity, increasing efficacy

In a global business environment, the increased individuality of customer demands adds external pressure for companies. On the other hand, growing competition creates the need for cost-cutting programs. The conflict between external variance and internal standardization can be solved by approaches such as modular product design. A proven four-phase approach that enables the modularization of product architectures is examined in this article.



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Introducing modular product architectures is a complex task and many industries do not have the resources and capabilities to modularize their product portfolio.

Any customer can have a car painted any color that he wants so long as it is black.”¹ With the goal of making cars more affordable, Henry Ford introduced the production assembly line of the Ford Model T in 1908. By applying a production system based on standardized processes, the costs per unit could be reduced significantly. If different colors had been offered, it would have meant a break in the assembly line, leading to longer lead times, the involvement of more staff, higher error rates and, ultimately, to higher costs. A century later, the global environment for manufacturing companies has changed significantly, bringing with it a new set

of challenges and risks. As a result of globalization, companies have to deal not only with increasing worldwide competition, but also with increasingly specific customer demands. While globalized markets force competing businesses to cut their costs, the demand for individuality leads to a higher variety of products being offered on the market as well as shorter product life cycles. The emerging conflict between internal cost pressure and the external need for product variety has become a strategic factor in today’s manufacturing world.²

Strategies that allow for both a greater variety of products and a manageable level of internal variety must be implemented in order to solve this conflict. Solution methodologies logically revolve around the product and its composition as the central elements of the conflict.

What are modular product architectures?

Modular product architectures are a proven concept and one of the key aspects of developing an integrated product life cycle management (PLM) strategy. They facilitate the standardization of product components while still allowing for a huge variety of products on the market.³

Products with modular architectures can be easily broken down into a number of standardized building blocks, which can be rearranged to create different configurations and variants. In this way, whole product families can be formed based on the same limited number of modules and the internal complexity can be kept to a viable level.⁴

The product architecture maps the functions of a product (the functional structure) to the physical components of the product (the product structure).⁵ The functional structure breaks down a product’s main function into a hierarchical network of subfunctions and, hence, translates customer requirements to a functional view for product engineering. Each function reflects the verbalization of a product task and is inherently abstract and solution-neutral. For example, the main function of a pocket flashlight could be “to emit light,” while two subfunctions could be “to create light” and “to store energy.” The product structure, on the other hand, reflects the hierarchical composition of the physical product components.

The benefits and risks of modular product architectures

The modularity of the product architecture is determined by the level of functional independence of the product components as well as by the level of interface standardization between different elements of the product structure. The more product components needed to fulfil a certain function and the more functions fulfilled by a certain product component, the more integral the product architecture will be.

On the contrary, biunique relations between functions and product components are characteristic of a modular product architecture. Product architectures can show any degree of modularity between these two theoretical extremes of full modularity and full integrality. The increased functional independence and

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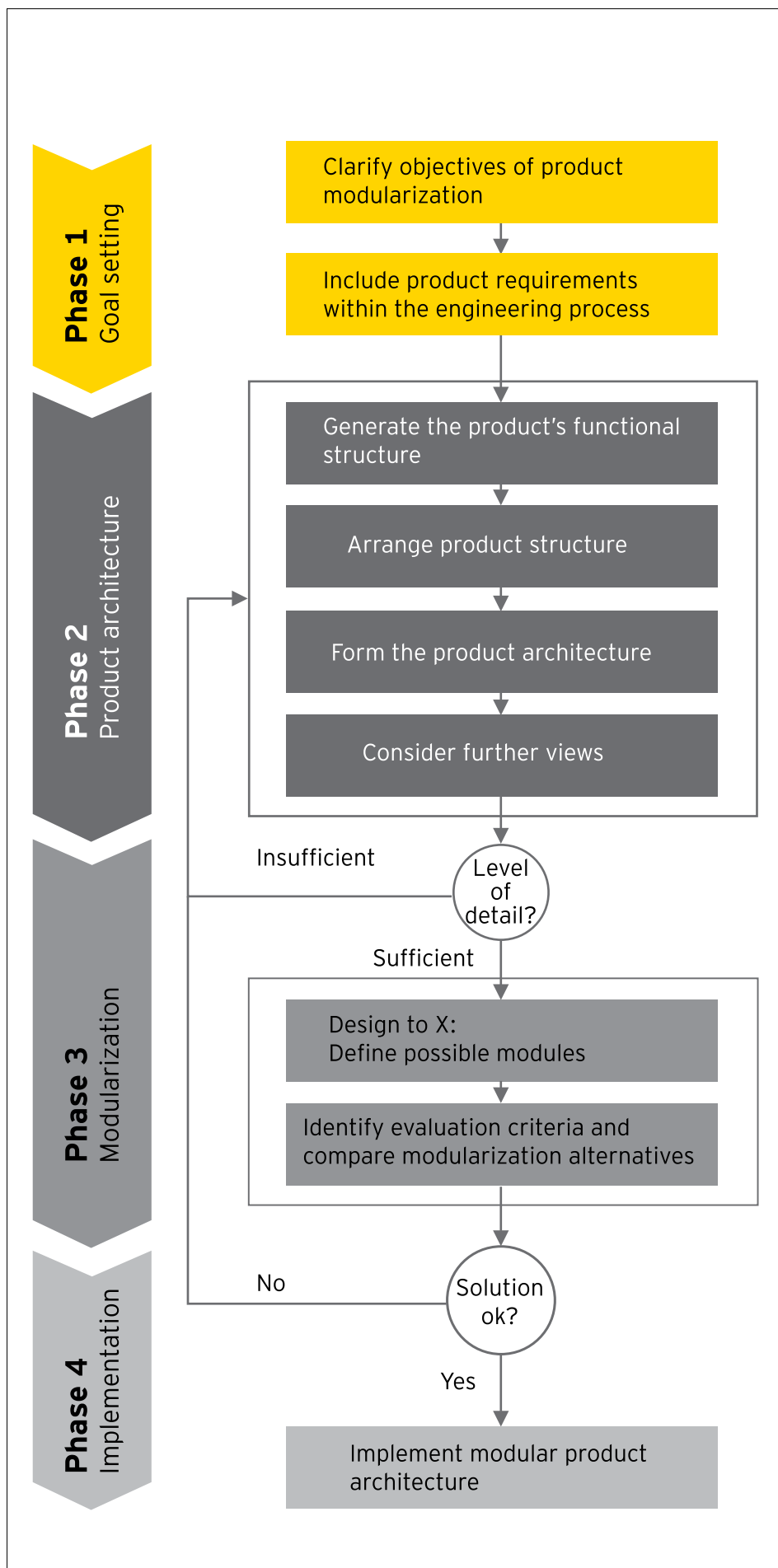
Figure 1. The four phases of the modular product architecture approach

standardization of interfaces in modular product architectures creates multiple benefits for the manufacturer. These include reduced complexity and increased interchangeability in engineering, a lower rate of production errors and reduced component variety in manufacturing.

Despite these multifaceted advantages, potential risks, such as high implementation costs and product-specific technical restrictions, should be analyzed. The risks also provide good reason to pursue an optimal rather than maximal degree of modularity, depending on the individual characteristics of the focal company.⁶

A four-phased approach for the modularization of product architectures

Defining the modules within the engineering department can provide benefits across all the phases of a product's life. The implications for engineering are manifold and require the integration of many different departments.⁷ To support engineering-heavy industries, we have developed a comprehensive and resource-friendly method, based on previous approaches, that enables the modularization of product architectures in four phases⁸ (see Figure 1).



The benefits to the manufacturer include reduced complexity and increased interchangeability in engineering, a lower rate of production errors and reduced component variety in manufacturing.

Phase 1. Goal setting

Clarify the objectives of product modularization

Modularity can be used as a measure to support technical requirements and strategic objectives. In phase 1, the main priority is to identify the company's individual aims for pursuing modularization. Company-wide support needs to be generated for the creation of universal and sustainable modules. Top management should actively encourage and be committed to the modularization efforts.

Include product requirements within the engineering process

Companies focus on exceptional technologies to give their product a unique selling proposition. However, such technologies do not automatically guarantee market success and, in many cases, these products end up as "shelf-warmers." Often, the reason for this is an incomplete clarification of the product requirements. Therefore, the focus of the second step of our method is to create a list of product requirements that reflect customer needs and for which the market dynamics should also be considered.

Phase 2. Product architecture

Generate the product's functional structure

In the first step of the second phase, it is necessary to determine the functions and subfunctions of the product while meeting the requirements from phase 1. To achieve this, a functional decomposition must be undertaken.

On the first functional level, the overall function of the product will be defined. On the second level, we determine the subfunctional structure, expressed by a certain number of partial functions. The logical interrelation between these subfunctions provides the functional structure of the technical system. The functional breakdown is then used to define the technical solutions.

The development of the functional structure should be executed in interdisciplinary teams, and we work closely with the client during this phase. The process should be repeated and empirically processed until a valid and accepted functional structure is created.

Arrange the product structure as a hierarchical composition of the physical product components

The functional decomposition shows that each subfunction may have several practical solutions. The next step is to determine the relationships between the technical specifications and the subsystems.

In this step, the product components and assembly should be arranged in a hierarchical form in order to more easily visualize the entire product. The creation of the product structure can either be done as a workshop or prepared with bills of material, CAD drawings or other structural documents.

Again, we work closely with the client during this phase, as the benefit

of developing it together is that a much better understanding of the strengths and weaknesses of the products is achieved.

Connect the functional and product structures to form the product architecture

The combination of the functional and product structures makes up the product architecture, which is the basis for further modularization steps. We define the architecture of a product as the "scheme by which the function of a product is allocated to physical components."¹⁰ Establishing the product architecture not only involves arranging functional elements and mapping them to physical components, but also the specification of the interfaces among interacting components. In order to capture the structure of the product architecture, we use the IT tool METUS®.

Consider further views

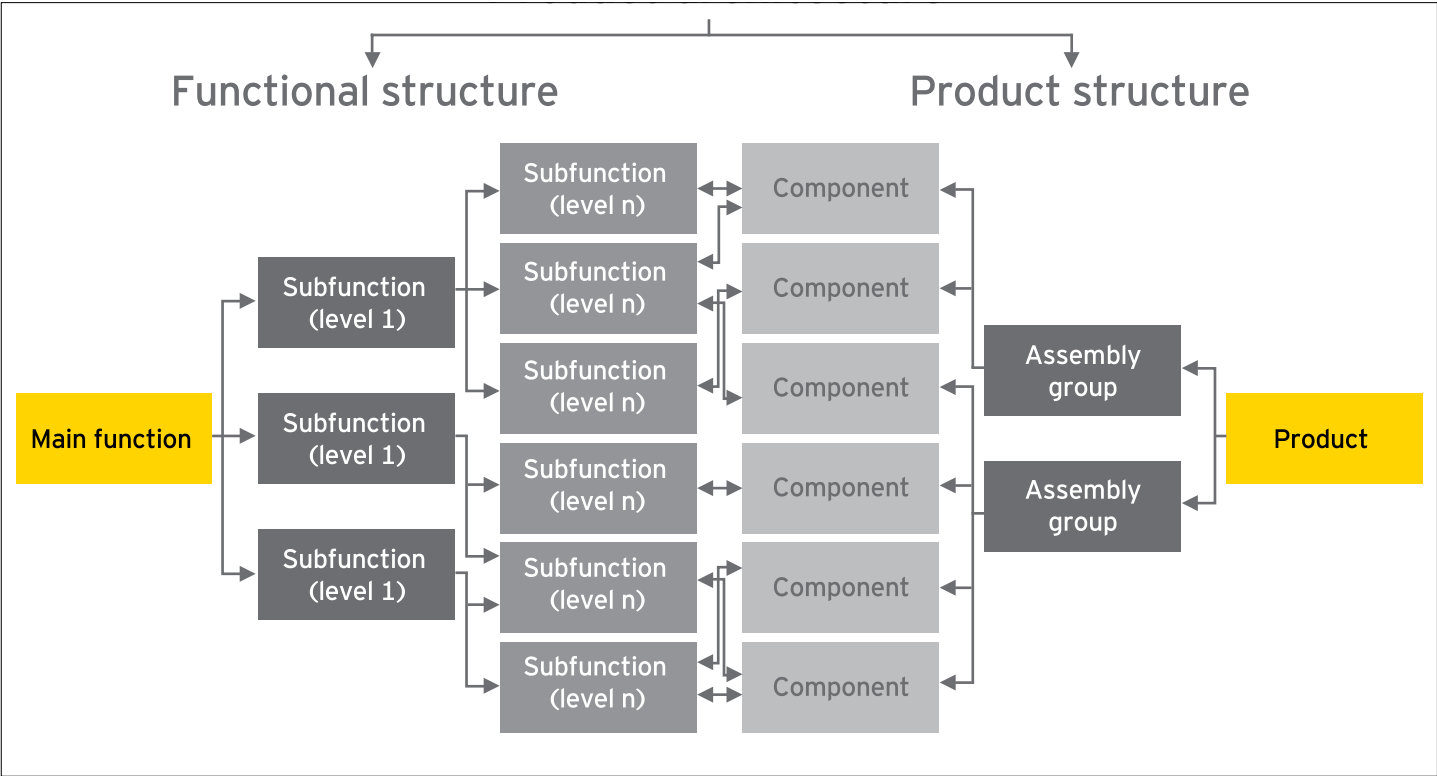
Beyond the functional perspective, further product characteristics need to be considered to generate diverse perspectives on the product structure. An example would be the identification of variant drivers and values that have an effect on different product components in order to generate a variant perspective on modularization.

For example, the variant driver "water-resistance" with its values "yes" and "no" could cause the existence of two different variants of a flashlight's battery cover. To consider the internal and external variance, it is essential to include the product configuration and sales departments. Further perspectives on the product structure could be derived from supplier, sales or cost considerations. The

10. K. Ulrich, "The role of product architecture in the manufacturing firm," Research Policy, 24, 1995.



Figure 2. How the product architecture is structured



One major opportunity to reduce costs is the standardization of production and assembly equipment.

selection and prioritization of these diverse perspectives depend on the modularization objectives.

Phase 3. Modularization

Design to X: define possible modules

The next step after determining the existing product architecture is to optimize the product. Information gained from the different perspectives (functions, variants, suppliers, etc.) can be used to define new modules.

In most cases, the newly built modules are designed to standardize product components and assembly groups for a product. One major opportunity to reduce costs is the standardization of production and assembly equipment. In the case where firms have different production facilities, the standardization of production and assembly equipment with universal and sustainable modules could constitute a significant limitation of independence for each respective factory.

Identify evaluation criteria and compare the modularization alternatives

In the next step, the developed modularization alternatives need to be evaluated according to their impacts. The successful implementation of our method makes use of the connectivity between the individual perspectives. The consideration of isolated perspectives within product development is helpful for specific applications (for example, functional modeling in early development phases).

However, managing the overall

connectivity is of major importance for product modularization. For this reason, the way in which the key influencing factors on the product components cross-link needs to be closely documented, as this allows a full evaluation of each architecture alternative.

To carry out a full assessment of a modular product architecture, the implementation costs need to be estimated. In addition, the modification costs induced by changing requirements, which affect the product structure, need to be anticipated.

Phase 4. Implementation

Implement modular product architecture

Our method can be concluded by implementing the selected modularization alternative. The result is a clearly structured product with a defined range of modules. The product can be described in terms of the configurations of the specific module variants. This can be a static definition or one that is created dynamically at the point of sale.

Similarly, the product forecasts and actual demands need to be translated into a supply plan for the modules. As a product is launched onto the market in stages, the development of module variants needs to be closely coordinated to match the schedule. PLM software has the ability to define products from a selection of components within a master bill of materials. The selections are based upon the desired properties of the product. There is a logical approach that allows the combination of components to derive the best product solution.





Conclusion

Since Henry Ford's first initiatives, the automotive industry has remained at the forefront of modern production processes and is now the most comprehensive user of modular product architectures. Volkswagen's MQB⁹ platform is an example of how an abundance of configuration options can be realized with a limited set of standardized parts and modules.

However, introducing modular product architectures is a complex task, and many industries do not have the resources and capabilities to modularize their product portfolio. Instead, they continue to struggle with the increasing individuality of customer demands.

Originating from the manufacturing industry, modularization concepts can be applied wherever complex systems have to be managed and have already been successfully transferred to branches such as logistics and IT. The methodology presented in this article provides a clear step-by-step process to successfully developing modular product structures and has been effectively applied in the plant engineering industry. ■

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