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PERSPECTIVE-BASED DEVELOPMENT OF MODULAR PRODUCT ARCHITECTURES

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ABSTRACT

Defining modular product structures requires taking into account various requirements from different perspectives. One problem, however, is that different perspectives on modularization may lead to different optimal product structures, depending on the special requirements the perspectives may have. For this reason, modular product architectures often need to strike a compromise. The approach we present in this paper is based on a differentiated consideration of the *product strategy, purchase, assembly* and *after-sales* perspective. While the method shows up the conflicts which are liable to arise between given perspective, certain general concepts are derived from it.

Keywords: Modularization, Methodical Product Development, Product Architecture, Product Planning, Purchase, Assembly, After-sales

1 INTRODUCTION

Steadily rising customer demand is prompting producers to offer a high variety of individualized products. At the same time, there is increasing demand for improved maintainability, recyclability and upgradeable design. Added to this, products are now required to possess optimized assembly properties due to the need to save production costs, on the one hand, and to shorten delivery times, on the other. Increasingly, production and development aspects need to be outsourced to suppliers. A widely used strategy that can help tackle these requirements is modular product structuring.
However, modular product structures are frequently incapable of resolving the conflicts between the requirements of different business perspectives. Where particular requirements cannot be implemented simultaneously, the design of the product structure usually needs to be compromised in a way that allows for the best possible realization of the development aims. This paper introduces a modularization method that takes into account different perspectives on modularization and enables various development aims to be balanced in a structured manner.

2 METHODS OF DEFINING MODULAR PRODUCTS

The work of Pimmler/Eppinger [1] and Erixon [2] has been groundbreaking in the methodical development of modular product structures. Pimmler and Eppinger subdivide their approach into three steps:

1. Functional decomposition of the product into components. These components physically or functionally represent the product functions.
2. Documentation of the interaction between the components: Identification and evaluation of connections.
3. Matrix-based clustering of the components into chunks using permutation algorithms.

Their method is based on the Design Structure Matrix (DSM) shown in Figure 1, which illustrates the various relationships between components and interactions. The module definition is achieved by clustering the components into chunks using permutation algorithms. For this purpose, all components are listed horizontally and vertically. The types of connection between the components, and their evaluation scores, are contained in the fields of the matrix. Four different interaction types are considered: spatial, energy, information and materials. For the purposes of evaluating the interactions, they have applied a scale subdivided into the values 2 (required), 1 (desirable), 0 (insignificant), -1 (undesirable) and -2 (detrimental). Each field of the matrix therefore contains a numeric value for each of the four connection types. The clustering is performed independently for each of the four connection types. The permutation algorithm used moves positive values closer to the diagonal of the matrix, thus creating a block structure in the matrix with the help of which modules can be identified. The final product architecture can be chosen after comparing the four separate structures illustrated by the interaction-specific chunk creation. The modules identified can also be used for forming teams or organizational structures.

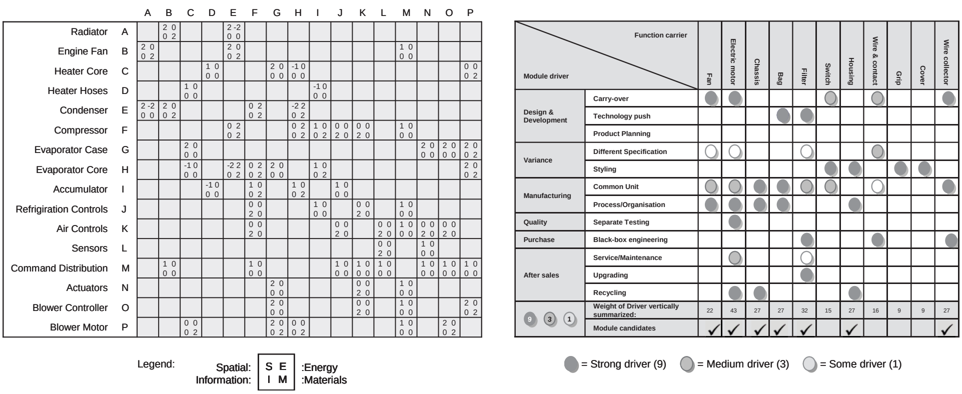

Figure 1. Design Structure Matrix (DSM) according to [1] and Module Indication Matrix (MIM) according to [2]

Whereas Pimmler and Eppinger use a functional technical perspective, Erixon considers product-strategic aspects in his “Modular Function Deployment (MFD)” method. This method is based on a Module Indication Matrix (MIM) which links the components of a product with so-called module drivers. Module drivers are aspects from different phases of the product lifecycle and represent reasons for defining modules. Erixon defines 12 general module drivers from the fields of design and development (carry-over, technology push, product planning), variance (different specification, styling), manufacturing (common unit, process/organization), quality (separate testing), purchase (black-box engineering) and after-sales (service/maintenance, upgrading, recycling). In the MIM, the components are evaluated with respect to the module drivers and are given a score of 0, 1, 3 or 9. The components with a high overall score are candidates for modularization, meaning they can either be a module themselves or be the base for a module. Additionally, components with similar module driver profiles can be identified and considered for integration into one module.

Various other methods can be applied on the basis of the approaches of Pimmler and Eppinger and Erixon. These methods either envisage additions to the existing methods ([3]) or combine several existing methods in order to cumulate the benefits of the functional technical view of Pimmler and Eppiner with those of the product-strategic perspective adopted by Erixon ([4], [5], [6], [7], [8]). Further stand-alone approaches ([9], [10], [11], [12]) will not be discussed at this point.

3 DEVELOPMENT OF A METHOD FOR PRODUCT MODULARIZATION

3.1 Motives for developing an enhanced method

Defining modular product structures requires taking into account various requirements from different perspectives. One problem, however, is that different perspectives on modularization may lead to different optimal product structures, depending on the special requirements the perspectives may have. For this reason, modular product architectures often need to strike a compromise between different approaches. For the purposes of the development of a new modularization method, we will employ and further develop the module driver concept proposed by Erixon. As a first step, we will give an explanation based on the work of Stake [3] regarding the classification of module drivers according to different perspectives. Stake has already undertaken an examination of the similarities and interdependencies between the module drivers identified by Erixon. He suggests grouping the drivers into *product family planning* related drivers and drivers related to *functional purity*. In addition, he associates the drivers of the first group with the *degree of communality* and *time* characteristics, and the drivers of the second group with the *location of effort* and *product life cycle* characteristics. The resulting representation is illustrated in Figure 2. Most relevant perspectives on modularization derive from this basis.

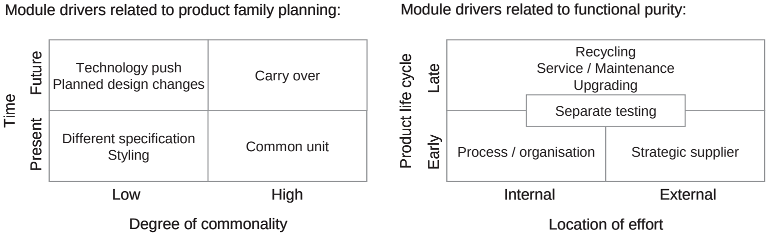

Figure 2. Grouping of module drivers according to [3]

All the module drivers which Stake has assigned to the product family planning group have very strong interdependencies, and as a result, they cannot be considered separately. For this reason, the *technology push*, *planned design changes*, *different specification*, *styling*, *carry over* and *common unit* drivers necessarily remain together in the *product strategy* perspective. The interdependencies of the drivers in the second group are less strong. These drivers can therefore be associated with three different perspectives. The first perspective is the *purchase* perspective, which consists solely of the *strategic supplier* driver. The second one is the *assembly* perspective. As testing is one of the major tasks of assembly, the *separate testing* driver has been added beneath the *process/organization* driver. The remaining drivers, *recycling, service/maintenance* and *upgrading*, are included in the *after-sales* perspective.

As a result, we obtain the four perspectives on modularization *product strategy, purchase, assembly* and *after-sales*, which are, to a very large degree, independent from each other. Figure 3 shows the new assignment of the module drivers to the four perspectives.

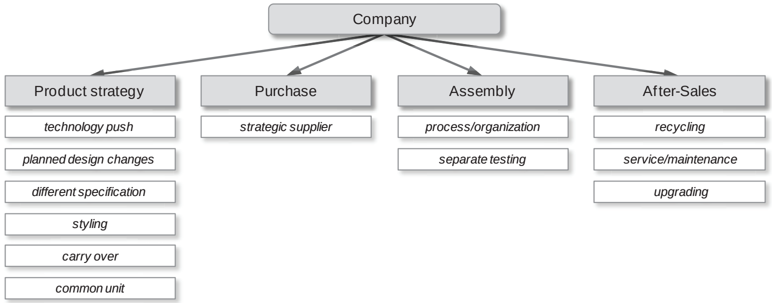

Figure 3. Assignment of module drivers to business perspectives

In the following section, we will describe the process which underlies the developed modularization method. We will base our approach on a differentiated consideration of the *product strategy*, *purchase*, *assembly* and *after-sales* perspectives. Furthermore, we will demonstrate that our method is designed in a way that facilitates reproduction and documentation.

3.2 A perspective-based modularization method

The process envisaged by our method and the corresponding tools are illustrated in Figure 4. The first step is an enquiry into the development objectives. This requires a definition of the product-strategic aims which need to be achieved by the modular product structure. In a subsequent step, the defined aims need to be transformed into specifications, which may then be used for the purposes of concept development.

The analysis of the development objectives should coincide with an analysis of the functional technical structure of the product, which forms a basis on which modular product structures may be

developed. The components of the product, their interdependencies and package requirements, as well as possible additional variants of the product are also analyzed at this stage. An overview of the functional technical product structure is then visualized with the help of the Module Interface Graph (MIG) ([13], [14]).
In a following step, the specific modularizations for the product planning, purchase, assembly and after-sales perspectives are developed and visualized in the MIG. Due to the differentiated approach, specific requirements can attain optimal implementation in this step without compromising other requirements.
Once these specific modularizations have been obtained, alternative concepts may be derived in view of a final modularization. This requires an investigation into whether the specific modularizations can be merged into a final concept without making changes, or whether the comparison of modularizations shows up conflicts. If there are conflicts, further investigation is required into whether the problems can be solved by carrying out design changes to the components. If this does not resolve the conflict, one of the specific modularizations needs to be prioritized. The aim of the integration process is, in so far as this is possible, to obtain several alternatives for a final modularization.
Lastly, one of the integrated concepts is chosen for further detailed design. This selection process should be carried out with the help of a key metrics system, which will allow a detailed assessment of the concepts.
In the following, a detailed explanation of the modularization process is given.

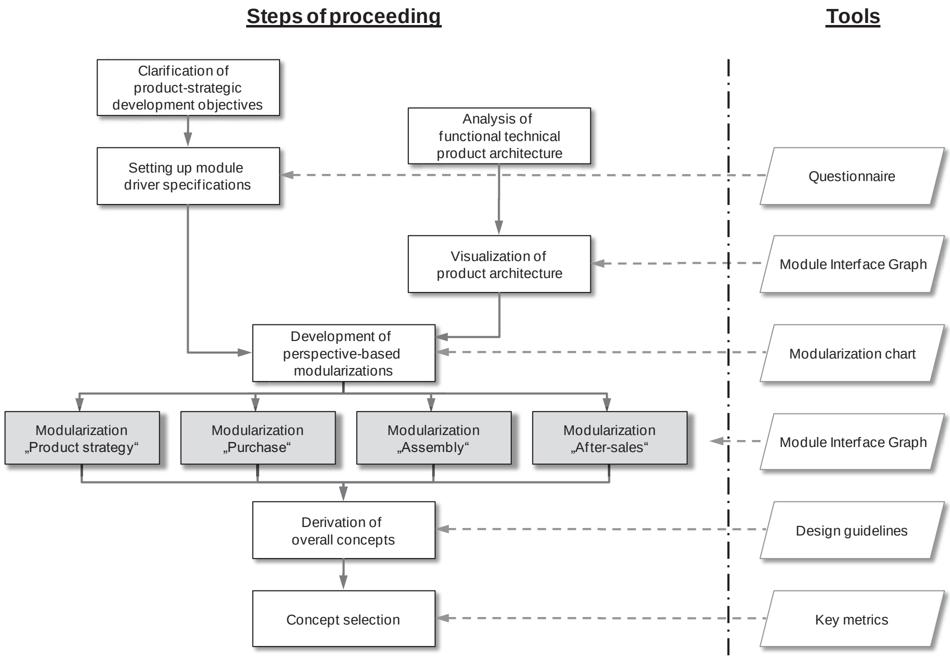

Figure 4. Steps of proceeding and corresponding tools

3.2.1 Definition of the development objectives
In the first step, the development objectives are clarified and transformed into modularization requirements. For the representation of the modularization requirements, we use Erixons's module driver approach. Furthermore, we have extended the module driver list using further sources ([1], [5], [6], [15], [16]). We have also grouped the module drivers in accordance with the four previously defined perspectives: product strategy (*variant, version, design changes, technical changes, different styling, different technical specification*), purchase (*modular sourcing*), assembly (*separate testing, final-assembly module, assembly process, handling*) and after-sales (*recycling, upgrades, maintenance*).

In order to ensure sufficient precision and repeatability of module definitions, and for the purposes of incorporating special product properties, the module drivers need to undergo further specification in line with the requirements of the individual product before the components are evaluated. This allows the user to bring his product knowledge directly into the modularization process. When narrowing down these module driver specifications, the user can refer to a questionnaire which lists possible specifications for each module driver. Figure 5 shows an excerpt from the questionnaire for the "separate testing" module driver. Questions such as "Are there different types of test?" may result in specifications such as "electrical test" or "hydraulic test".

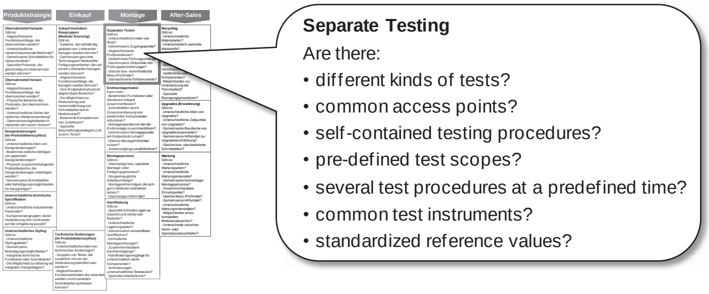

Figure 5. Excerpt from the questionnaire for the "separate testing" module driver

3.2.2 Analysis of the functional technical product structure

The function carriers – that is the components – form the basis for the application of the method. The product can either be an existing product, or it can be a description of a new product. In most cases, even the product structure of a new development will be based on an existing benchmark product. The visualization of the product structure is obtained via the Module Interface Graph (MIG). The MIG prepares a layout of the estimated package dimensions of the components and their relative position within the product. The MIG visualization is supplemented by the structural connections as well as power information and media flows (Figure 6). As concerns the degree of detail in which the original product structure is described, the assumption according to [17] is that the number of function carriers used should not be significantly in excess of 30.

Optionally, a base component can be defined. This is a component which fulfils mainly structural functions and is used as a base for mounting further components. Since a base component cannot be classified as an explicit module, it only will be considered in the final steps of modularization.

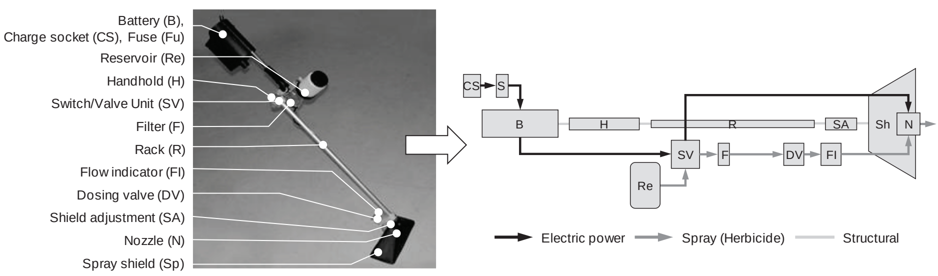

Figure 6. Module Interface Graph (MIG) using the example of a spraying device

3.2.3 Development of modularizations in line with specific perspectives

The specified module drivers as well as the components are brought together in the evaluation chart in Figure 7. In this chart, the interdependencies of components and specified module drivers are given the score 0 (no influence), 1 (weak influence) or 2 (strong influence). For a better overview, zero scores are not explicitly included in the chart.

Following the evaluation of the components, the next step is to carry out the independent perspective-specific modularizations, which are developed by grouping together components in the evaluation area of the above chart. Given that module grouping is unlikely to be possible without causing conflicts, the evaluation score needs to be considered as soon as a conflict arises. If this does not solve the conflict, further investigation is required into whether a component design change may bring about an improvement. On the basis of this procedure, four different and independent modularizations can be developed in accordance with the different perspectives. It is not necessary that each and every modularization developed should involve all of the components of the product.

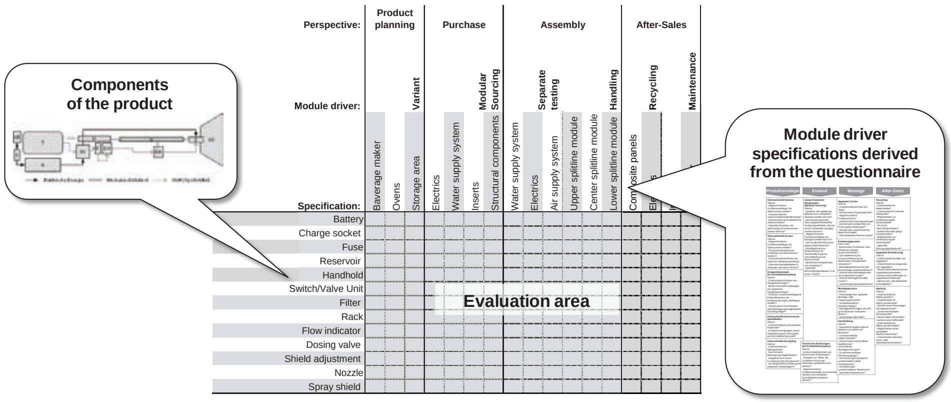

Figure 7. Module development chart

Once the four specific modularizations have been defined, each one is implemented and visualized in a Module Interface Graph (MIG). The defined component groups are encircled with a dotted line, thus enabling the visualization of modules. Again, it is at this stage that the user can apply his product knowledge and implement possible design changes. To provide support to the user in this process, a catalogue of design guidelines has been developed (see the example in Figure 8) using the sources [18], [19] and [20].

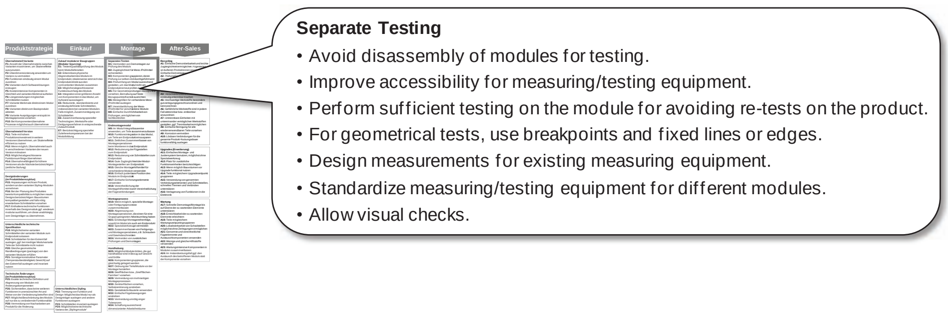

Figure 8. Excerpt of the design guidelines for the “separate testing“ module driver

3.2.4 Integration of the specific modularizations for the development of final concepts

In order to develop alternative final concepts, the four specific modularizations need to be merged. This requires the user to identify the modules which are defined identically and those which show up contradictions with each other. Therefore, the specific modularization which contains most of the components is used as a basis and is complemented by the others. Where components in different specific modularizations are located in different modules, they need to be relocated into one distinctive module for the purposes of defining one of the final concept alternatives. In case of very marked conflict, components may need to be split, or it must be considered whether a design change or another mechanical solution may solve the conflict. In extreme cases, the whole modularization procedure may need to be performed repeatedly with new components.

If initially a basis component was defined, it now can be defined more precisely according to the developed product structure approach. If meaningful, the basis component could be assigned to a single module or otherwise divided and assigned to different modules.

3.2.5 Key metrics evaluation of the modularization alternatives

The last step of the process consists in selecting the best-suited final modularization alternative for further detailed designing. We envisage that in the future, a key metrics system will ensure an objective selection procedure and measure the degree to which development aims will be fulfilled. A possible graphic analysis, in the form of a spider diagram, is provided in figure 9. The development of a suitable key metrics system will be the focus of future research work.

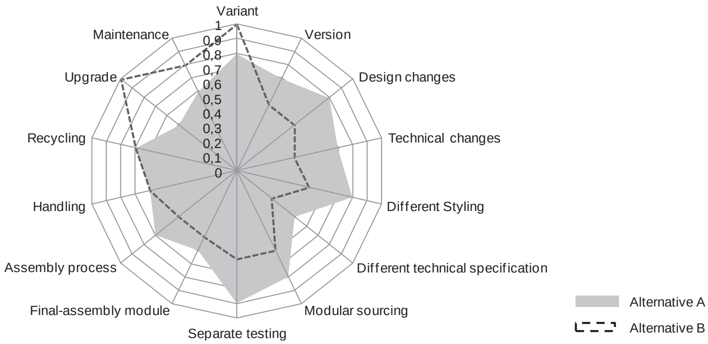

Figure 9. Example for the visualization of key metrics

4 APPLICATION OF THE METHOD TO THE EXAMPLE OF AN AIRCRAFT GALLEY

To demonstrate our method, we have applied it to the example of a center galley on a single-aisle passenger aircraft. Figure 10 shows the components of the galley.

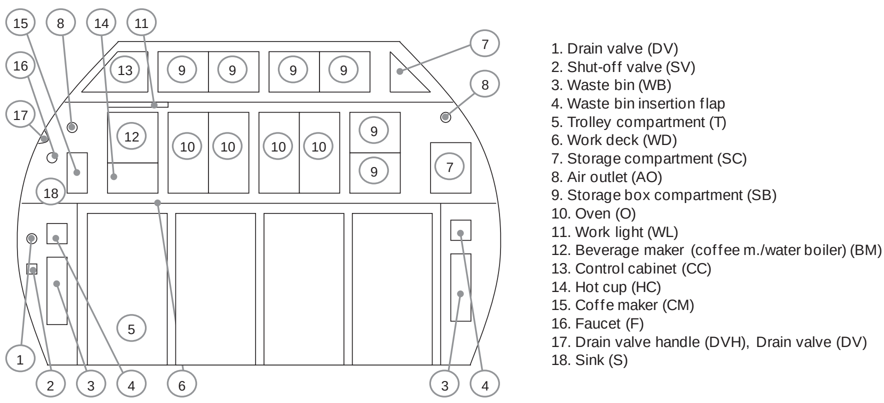

Figure 10. Components of a center galley

In accordance with the procedure outlined above, the first step is to derive the module driver specification. At the same time, the product structure of the existing product is visualized in the MIG. The resulting specifications are: variant area coffee makers/boiler/hot cup, variant area ovens/standard units/stowage compartments (*variant*), electrics, pipes, sandwich panels (*modular sourcing*), water supply system, electrics, air supply and extract (*separate testing*), splitline modules (*handling*), panels/composite materials, metal/pipes and electrics (*recycling*) and water filter (*maintenance*).
Figure 11 shows the completed modularization chart, containing components versus module driver specifications with scores.

Perspective:	Product planning			Purchase				Assembly						After-Sales			
Module driver:			Variant				Modular Sourcing			Separate testing			Handling		Recycling		Maintenance
Specification:	Baverage maker	Ovens	Storage area	Electrics	Water supply system	Inserts	Structural components	Water supply system	Electrics	Air supply system	Upper splitline module	Center splitline module	Lower splitline module	Composite panels	Electrics	Inserts	Water filter
Trolley compartment 1..7							2						2	2			
Storage box compartment 1..4							2				2			2			
Storage box compartment 5..6			2				2					2		2			
Waste bin 1							1						2				
Waste bin 2							1						2				
Storage compartment 1							2				2			2			
Storage compartment 2			2				2					2		2			
Air outlet (left)							1			2	1	1					
Air outlet (right)							1			2	1	1					
Control cabinet				2					2						2		
Water shut-off					2			2									
Water filter					2			2			1	1					2
Oven 1..4		2		1	1	2		2	2	1		2			2	2	
Faucet					2							2					
Coffe maker (upper)	2			1	1	2		2	2	1		2			2	2	
Coffe maker (lower)	2			1	1	2		2	2	1		2			2	2	
Water boiler	2			1	1	2		2	2	1		2			2	2	
Hot cup	2			1		2			2	1		2			2	2	
Air relief valve					2			2									
Work light				2					2		1	1			2		
Work desk							2					1	1	2			
Drain valve					2			2									
Drain valve handle					2			2									
Sink					2			2				1	1				

Figure 11. Modularization chart of the galley

In this example, there are no overlaps between different modules, and module definition can therefore be achieved by simply grouping the components. In the modularization chart, potential modules which can be grouped have been circled. Figure 12 illustrates the resulting modularization concepts in MIG-visualization based on the four different perspectives.

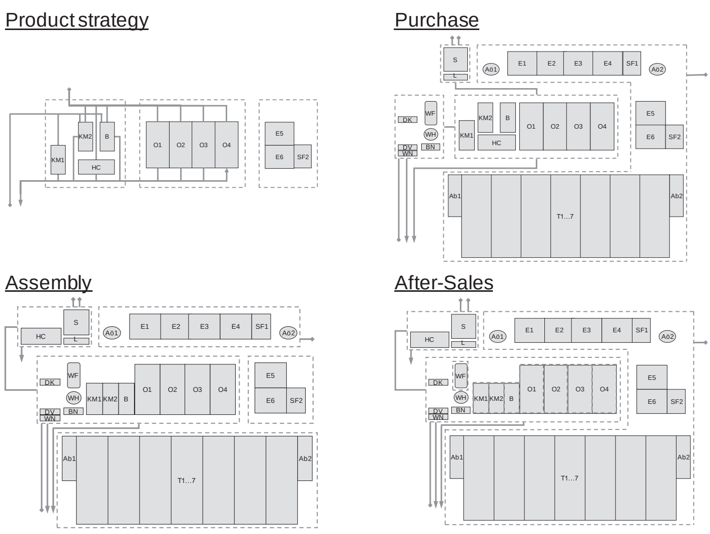

Figure 12. Modularization concepts based on different perspectives

Given that the developed concepts show a general coincidence between the module definitions, it appears likely that it will be possible to finalize one concept without creating several alternatives. Figure 13 illustrates the final concept for the galley modularization.

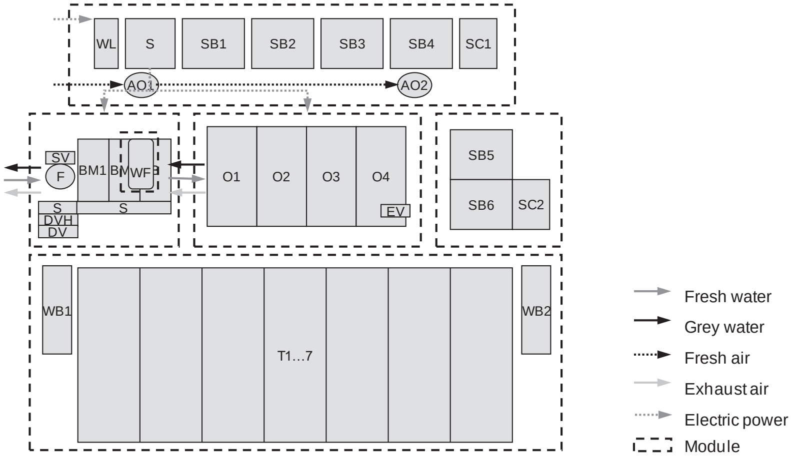

Figure 13. Final concept of the modular product architecture for a galley

As illustrated in Figure 14, the galley is divided into 3 variant and 2 invariant modules. From a product-strategy point of view, the developed product structure allows a platform design of the galley. Using the platform approach, the upper and lower part of the galley are the standardized product platform, and the middle modules represent the hat which can be customized by the client. Accordingly, coffee makers, a boiler and hot-cups can be located in the left-hand module, a variable number of ovens or standard units can be fitted in the middle module, and the right-hand module can accommodate a variable number of stowage compartments and/or standard units.

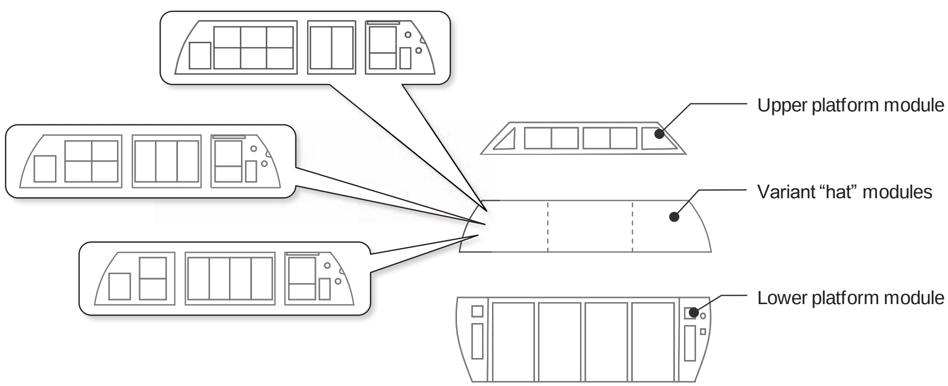

Figure 14. Platform concept of a galley

From a purchase-and-assembly point of view, the concept offers the possibility of sourcing pre-assembled modules, which then can be assembled in just one final assembly step. The grouping and reduction of media and power interfaces effectively makes this possible. This means that only few connections need to be mounted and tested in the final assembly step.

The modularization also facilitates maintenance of the galley, as the water filter, which plays an important role in maintenance, is designed as a sub-module with easy disassembling capabilities.

5 CONCLUSIONS

The method we have presented is based on a differentiated process aimed at achieving modularization in accordance with the respective product-planning, purchase, assembly and after-sales perspectives. While the method shows up the conflicts which are liable to arise between given perspectives, certain general concepts can be derived from it.

A major aspect in developing this method was to design the procedure in a way that facilitates reproduction and documentation. This particularly is supported by the Module Interface Graph (MIG), which visualizes the product structures easy usable.
In developing modular product architectures, the user is supported by a design questionnaire and design guidelines. The necessary knowledge for creating the module driver specifications is provided by the questionnaire. This allows the user to concentrate in bringing in his product knowledge directly into the development process. By the guidelines he is supported in considering design changes for improvements.
Currently the user is not supported in evaluating the developed concepts. Therefore the aim of future research work is the development of a suitable key metrics system, which allows objective concepts evaluation and selection.

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