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Defining Modules, Modularity and Modularization

Evolution of the Concept in a Historical Perspective

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Abstract

Modularization is currently in focus as a means for increasing competitiveness of industrial companies. This is achieved by bridging the advantages of standardization and rationalization with customization and flexibility. But the phenomenon behind modularization itself is not very well described and understood in literature. In this paper, the evolution of the concept behind modularization is described in a historical perspective as a starting point for descriptions of the nature of modular systems. This leads to definitions of the terms: module, modularity, and modularization.

Over time the meaning of the term module has changed from being defined by the physical presence into being defined by structure and functionality. It is argued that modularity today is a combination of systems attributes and functionality of the module itself. Furthermore, modularization has evolved in an industrial context and there seem to be three basic drivers behind the desire for modularity: creation of variety, utilization of similarities and reduction of complexities.

This paper is mainly based on a literature survey complemented by the author’s own industrial experience. The paper will serve as a foundation for the author’s future research into more specific areas of modularization and product family development.

1. INTRODUCTION

Today, companies experience a number of challenges that change the business conditions. Firstly, the focus on customer needs leads to customized products, which means companies have to manage a greater variety of products. Secondly, competition enforces companies to strive for efficiency in the business chain: to reduce costs, increase quality and reduce response time. Finally, technology is evolving fast, engineering tasks are huge and complex, implying that companies have to cope with greater complexities and constantly changing environments.

Modularization is often mentioned as a means for handling these seemingly conflicting demands - and frequently in connection with the manufacturing concept of *mass customization*. The idea is that a broad variety of products can be produced by combining a limited number of modules. In this way modularity balances standardization and rationalization with customization and flexibility. Furthermore, better structuring and handling of tasks and knowledge are often mentioned as advantages.

However, there seems to be some confusion about what the term module really covers. In some part of literature, modules are defined as physical (mechanical) building blocks; while others refer to them as non-physical objects like software. Some focus on structure and others on functionality. Many deal with the advantages modularity may provide, but very few have been concerned with describing and defining the core phenomenon itself.

However, it seems reasonable to assume that in order to obtain all the highly praised advantages of modularity, it is necessary to understand and describe the phenomenon. This allows the creation of guidelines for good modular design. Such a basic understanding is not found today, which may be the reason why relatively few companies have used the concept over the years, despite the fact that the idea has been known for a long time. The purpose of this paper is to understand, describe, and define the phenomenon using the historical evolution as a starting point.

2. HISTORICAL BACKGROUND AND EVOLUTION

Modularity has recently got a lot of attention, but the concept is not new at all. Back in time the module was well known, even though the term was used in another meaning. In the beginning of the 20th century industrial building blocks were introduced in architecture, which has influenced the understanding of the concept. Today it seems as if the concept is changing again. In the following some of the most important trends are described.

2.1. Ancient Time

Originally, the term module comes from ancient time, where the Latin word *modulus* were a measure of length. It was described already by Marcus Vitruvius Pollio (Vitruve), who worked under the Roman emperor Augustus. He wrote in his 'Ten books on Architecture' (De architectura libri decem) about laws on proportions and symmetry in temples and columns. The module was a standard measure ensuring the right proportions. [Routio, '98]

2.2. Bauhaus

During the Bauhaus era (1919-1933) the German architect Walter Gropius for the first time combined the idea of standardization with functional thinking and industrial production in building construction. The module was linked to a building block concept (Baukasten), where the building blocks were functional units in buildings, e.g. kitchen, living room, sleeping room, etc. Under Bauhaus, the module kept the original meaning as a standard measurement, allowing combinations of many building blocks, inspired by children's toys. The purpose of the Bauhaus building blocks was to create buildings in a more rational way by standardization and prefabricated materials and to be able to make a more thorough and efficient planning. [Droste, '90]

The *functionality* of the building block was not directly connected to the module at that time, as the module was only related to the geometry of the interface. The module as a standard measure of length is today still used in architecture and construction.

Modularity in relation to Bauhaus buildings is often connected to monotonous container architecture and soulless giant constructions. It is true in some cases and is caused by a too radical and uncritical use of standardization and rationalization in areas, where the costs are huge measured as human uneasiness and alienation.

The following statement shows an example, on how the rational line of thought was pushed too far: " By the end of the year 1925 it was decided to introduce writing in sheer small letters [in the journal 'bauhaus"] and only use printed matters following the existing DIN-standards. On every sheet of paper it was now printed: "we write everything in small letters, because we hereby save time. furthermore: why two alphabets, when you obtain the same with only one? why write in capital letters, when you can't speak in capitals?" [Droste, '90]

Figure 1: The Toerten houses in Germany (1926-28) is one of the first examples of industrialized building block buildings. Gropius talked about "living machines". [Droste '90]

2.3. Technical Building Block Systems (Baukasten)

The concept of building blocks has been further elaborated in German, mechanical literature (in German: Baukasten). In the 1960's [Borowski, '61] described the nature of different types of building blocks and attributes including guidelines for designing a technical building block system. The building blocks were physical, typically machine elements, and interfaces typically described by geometry. The basic attribute of a building block system was described as the ability to create variety by combining and exchanging different building blocks.

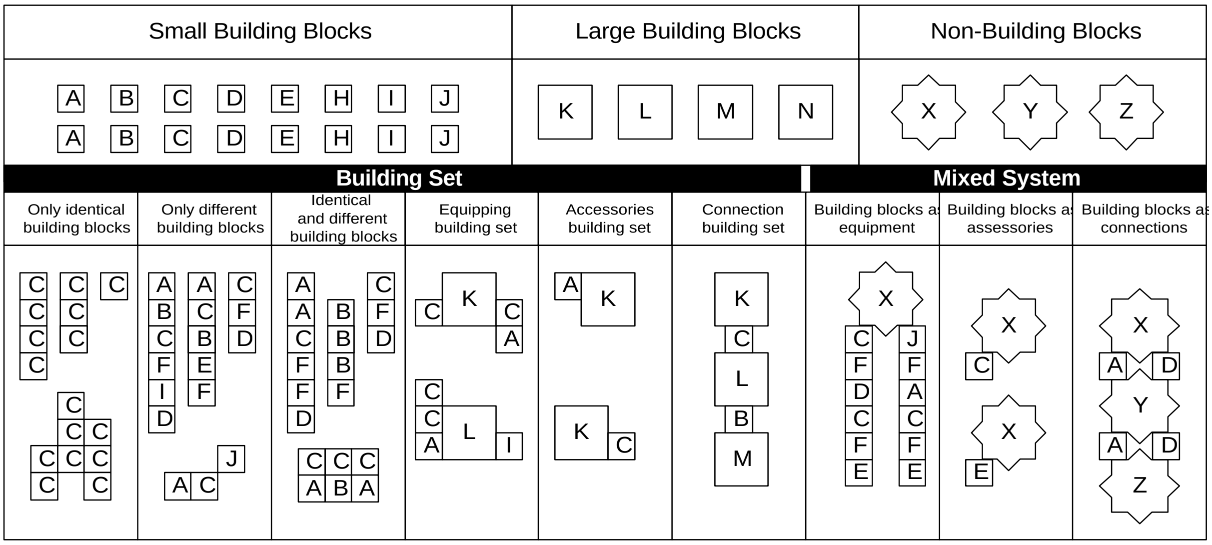


Figure 2: Different types of building block systems.
The building blocks are mainly characterized by size. From [Borowski, '61]

2.4. Difference between Building Blocks and Modules

The original building block idea (Baukasten) from Bauhaus has evolved in the later years with companies striving for combining the advantages of standardization and customization - mass customization. Today the original senses of the words module and building block have merged, so that a module is used for a building block containing specifications of *both* interface *and* functionality which can be combined with other modules. On the other hand, the contemporary meaning of a building block has lost some of its previous contents compared to the Bauhaus time.

A new difference has occurred between the module and the building block. A module has to posses a certain considerable amount of functionality compared to the final product. It can for example be a power supply module in a mechatronic product like a printer. In an industrial context, it is important that this functionality has to be sufficient for independent testing. The meaning of building block is on the other hand reduced to a more limited functionality compared to the final product.

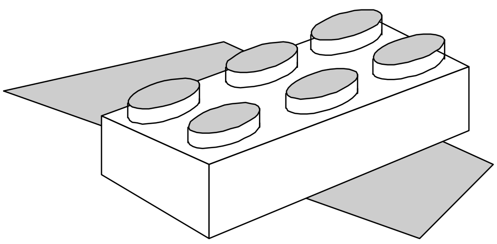


Figure 3: Lego-blocks are usually not modules as they do not posses a considerable amount of functionality compared to the construction of which they are a part. But they do have a standardized interface allowing constructions by combinations.

Following this line of thought, Lego-blocks and traditional bricks are building blocks, but usually not modules, as they do not posses any substantial amount of functionality compared to the construction of which they are a part. - The brick is neither kitchen nor living room and therefore not a module, though still a building block.

2.5. Modules Linked to Functionality

[Pahl & Beitz, '96] directly link the definition of modules to functionality and define different types of modules based upon a range of functions (basic, auxiliary, special, adaptive). A module is in this way the physical realization of a function. If an element does not relate to any of these functions, it is defined as a non-module. In this way Pahl & Beitz avoid that everything becomes modules. Furthermore, they categorize modules according to the following criteria: type of function, importance, complexity, combination, resolution, concretization and application. But the fundamental understanding of the concept behind modularity is not well founded, as for example, the whole interface problem is not approached.

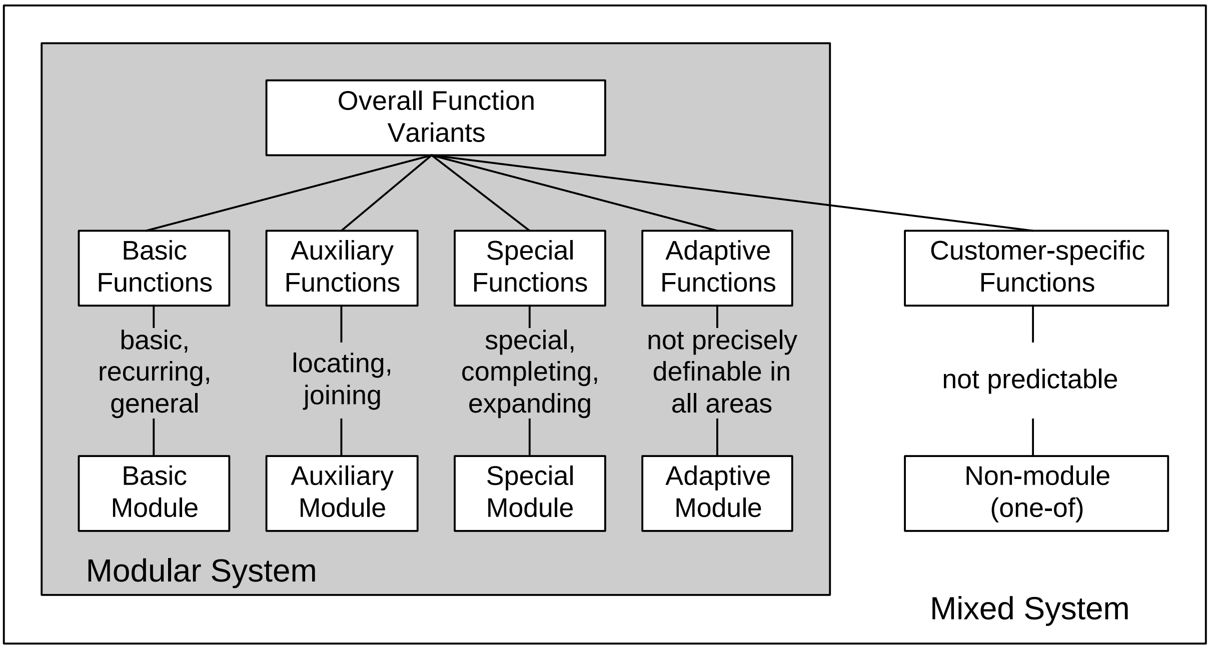


Figure 4: Function types and module types in modular and mixed product systems. [After Pahl & Beitz, '96]

2.6. Modules - From Mechanics to Mechatronics

[Ulrich & Tung, '91] link modularity to functionality, but differ from [Pahl & Beitz] by focusing on different types of *modular structures* instead of defining individual types of modules. In their paper, it is argued that modularity for products require similarity between the physical and the functional structure as well as and management of interactions between modules. It is described that the interface problem is not trivial in product modularity. It is not sufficient to consider geometry alone, since information, energy and material also create important relations between product modules.

The mechanical point of reference for Borowski's building blocks has thus been widened by Ulrich & Tung to further include mechatronics and electronic products.

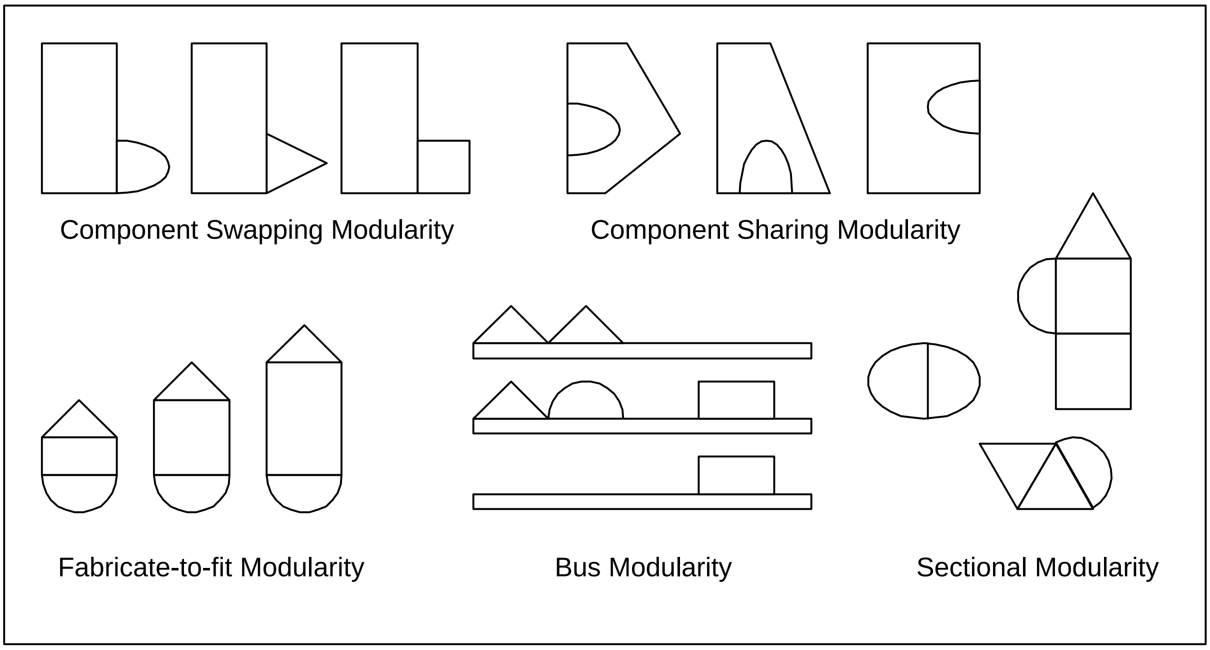


Figure 5: Five approaches to modularity in order to obtain standardization of components and a variety of products. [Ulrich & Tung, '91]

Modularity is described as a relative property of a product structure as opposed to an integral structure. In a modular structure, a module implements only one or a few main functions in its' entirety, whereas in an integral structure, the functionality is spread all over the product. Even though the understanding of modularity has become more abstract and more related to functionality than geometry, a module is still fundamentally defined as a physical unit. [Ulrich & Tung, ´91]

2.7. Non-Physical Modules

Throughout the first three quarters of the 20th century, physical products have been the core of industrial evolution. It has, as described above, had great impact on the understanding of the concept of modularity. However, in recent years, new non-physical types of products have gained increasing industrial importance.

The software domain has thus also benefited from utilizing the concept of modularity for handling complex systems and rationalization of design tasks. Modularization has proved very beneficial and the concept is widely used within programming. Opposed to earlier times, software modules are not physical and their interfaces cannot be described by geometry. This pushes the understanding of modularity towards being defined as structural, self-contained functional units rather than geometric blocks.

2.8. Modules as Carriers of Knowledge

The tendency towards a more abstract understanding of modularity is further strengthened by the fact that modularization in an industrial context can be seen as reuse of engineering resources. Companies are increasingly aware of knowledge as a strategic resource that can be managed and utilized. An important part of the knowledge of the company is embedded in the products. By reusing modules well-known knowledge is utilized meaning savings in time and money. However, it is not necessarily the finished, physical modules that are reused in order to gain the benefits. Also so-called *intellectual reuse* of earlier stages, like reuse of engineering specifications, may lead to the desired effects. This kind of reuse blurs the boundary between 'knowledge management' and traditional modularization. [Sanchez et. al., '96]

When modules are no longer defined by the physical presence, the concept approaches the 'design patterns' suggested by [Alexander, '64]. They are solutions that in accordance with a Darwinistic line of thought have proved to be good solutions to a certain problem over time. The description of a design pattern encapsulates and carries knowledge about problem, context, and solution. They contain preliminary stages of the final solution and help the designer to structure and cope with the task. [Gamma et. al., '95]

From the reasoning above it follows that modularity can relate to knowledge reuse in two ways. Firstly, a knowledge module can be seen as the preliminary stage to the physical module, like engineering specifications or CAD-drawings leading to the final assembly module. These abstractions of the physical module will be reused if the module is reused, as they are preparations for the final solution. Secondly, the design domain with all its knowledge can be seen as a system in itself. Within this system, specifications can be regarded as products that can be created by combinations of self-contained functional units. This is the case for many engineering consulting companies. However, a design pattern can be seen as a knowledge module in the design domain only if it contains an essential and self-contained functionality in relation to the final product in the knowledge system so the solution is a result of combinations of modules.

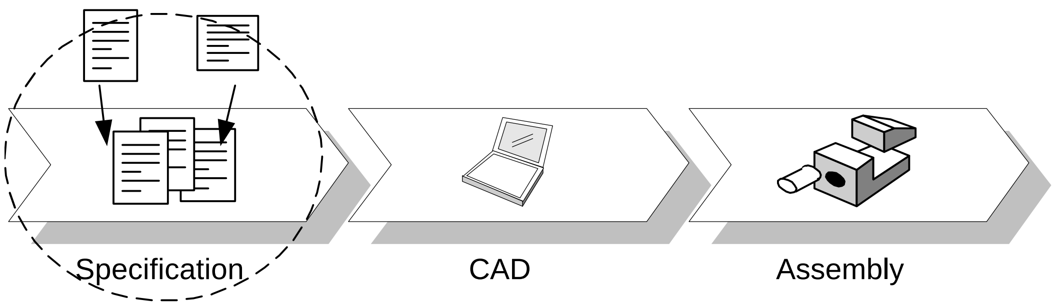


Figure 6: Modularity can relate to knowledge management in two ways.

The tendency towards seeing modules as structural, functional units carrying knowledge is seen by e.g. [Anderson & Pine, '97]. They use the term *virtual* modules in connection with product development and mass customization. [Victor & Boynton, '96] describes modularized knowledge as a pre-requisite for mass customization as a business capability coming from mass production and incremental improvements.

2.9. Evolution of the Concept over Time

As described above the understanding of the concept of modularity has evolved over time. The original geometrical definition is no longer valid. The original measurement module has been connected to the idea of industrial building blocks carrying functionality and also, in the later years, to immaterial things like software and knowledge. Therefore it does not seem reasonable to limit the definition of modularity to physical entities, as it is seen in large parts of the mechanical technical literature, e.g. [Ulrich & Tung, '91]. Furthermore the different authors have *either* focused on the different types of modules and their functionality *or* the types of modular structures. No one has seemingly found the underlying core of modularity which ties together the two viewpoints. But what is it then? How should we define modularity? Before giving a definition, we will look at the basic drivers behind modularization.

3. WHY MODULARIZE?

In order to get a deeper understanding of the core phenomenon of modularity, it is useful to consider the context and desired effects behind the desire for modularization.

Modularity, as we use the concept today, has emerged in an industrial context and is inextricably bound up with the wish for utilizing resources in the most efficient way when a number of related tasks are to be solved, or a range of related products are to be produced. In times when customization is a necessity, companies strive for modularization as a means for balancing a broad product variety with a rational production. At the same time modularity is a structuring principle which enhances clarity, reduces complexity, provides flexibility and has some organizational advantages allowing work in parallel and tasks solved independently.

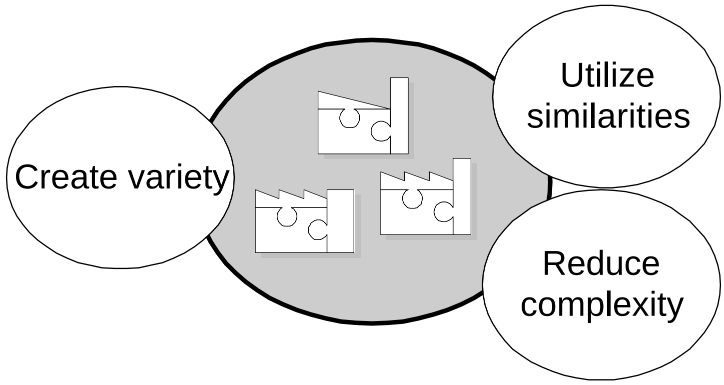
The more specific effects and advantages of modularity are well-described in literature. Many effects are described in relation to the stakeholders in the product life-phase systems - both internally in the company and externally by the users/customers, e.g. in relation to engineering designers, production system, service system and users. See [Pahl & Beitz, '96], [Ulrich & Tung, '91], [Jespersen & Miller, '95] and [Erixon, '98].

The authors believe that there are always three basic drivers behind the wish for modularity: creation of variety, utilization of similarities and reduction of complexities. See also [Andreasen & Riitahuhta, '97], [Karlsson, '95]

3.1. Balancing Standardization and Customization

[Lampel & Mintzberg, '96] describe how modularity can be seen as a means for balancing two opposite forces: standardization and customization. This is despite the fact that for many years it was a common thought that companies had to choose a strategy as either mass producing (standardization) at the expense of customization or tailored production at the expense of efficiency. [Lampel & Mintzberg, '96] state that there are three different areas in industrial production that can be standardized and/or customized: The *product* can range from being commodity to be tailored. The *working processes* from development to assembly can be either craft or mass production. Finally, *transactions* connected to sales/services can be either generic or personalized.

Basic Drivers Behind Modularization



Create variety (customize)	**Utilize similarities** (reuse resources and standardize)	**Reduce complexity**
…in order to provide the customer a well-fitted product!	*… to gain rationalization benefits!*	*… to increase overview and better handling!*
• Provide useful external variety - the customer wanted variety created by combination of modules *The following types of variety are not wanted:* [Anderson & Pine, '97] • Useless external variety - choices the customer is not interested in • Internal variety - variation in processes, materials and solutions, which generate costs, but adds no value to the customer	• 'Avoid work' - not inventing the wheel over again • Working faster and better by learning effects and supporting tools • Reduce risks by using well-known solutions • Reducing internal variety, because it generates costs, but adds no value to the customer	• Break down in independent units • Work in parallel • Distribute tasks • Better planning • Separate testing • Better and easier perceived by humans • By encapsulation and creation of structures, humans can more easily grasp, understand and manipulate

Figure 7: Modularity balances three important basic drivers: Creation of variety, utilization of similarities / reuse of resources and reduction of complexity.

It is worth mentioning that there is a difference between standardization and modularization. Whereas it makes sense to talk about standardization of both products, processes and transactions, it is still an open question whether the two last-mentioned can be modularized. In this paper it is only the product, both physical and immaterial that is regarded the object of modularization.

3.2. A Structuring Principle for Handling of Complexity

Another important aspect of modular structures is their clarity - they are easy to grasp. [Alexander, ‘64] described how design, both of products, architecture, etc., requires that the designer can handle, asses and select a great variety of solutions based upon a broad range of information - often exceeding the cognitive capability of the human mind. However, hierarchically structuring, decomposition and classification help reducing the complexity of a task by allowing tasks to be encapsulated and solved separately, and problems/solutions to be regarded at a superior level, which later can be broken down to smaller pieces. Modularity is a concept that supports the designer as pre-scribed by Alexander.

This is why modularity is applied for very complex products like software programs. Here modularity allows e.g. for working in parallel and separate testing of modules.

Within construction engineering and shipbuilding the artifacts are also broken down to smaller units. This helps the handling of the huge and heavy building blocks, but also to structure the engineering task. Whether or not it is modularization or just decomposition into smaller units depends on the functionality of the units. If the module is just used in the ‘old geometrical way’ as a standard measurement, it is not really modularization as we understand it today.

4. ATTRIBUTES OF MODULAR SYSTEMS

Based on the previous reasoning, the authors see two attributes that crystallize as carriers of modularity, independent of the application - whether it is mechanical, mechatronic or immaterial products:

- Modular systems are recognized by the ability to *create variety by combination and interchange of different modules*. Interchangeability and combinations requires that the modules have standardized interfaces and interactions. (See section 4.4)

- Modules contain *essential and self-contained functionality* compared to the product of which they are a part. Self-contained means that the function is realized within the module and limited to this, or in other words, the module is independent.

Both of these attributes are needed for modularity. The first describes the modular system, while the other describes the module itself. This deserves further explanation.

4.1. Modularity is a Structuring Principle for Systems

The demand for creation of variety by combination and interchangeability goes beyond the individual module. Variety and interchangeability have no meaning unless there are more than one module. Only by seeing the module as part of a system this make sense. From this it follows that *modularity* is an attribute which relates to the structure of the system - *A structuring principle for technical systems.*

But the demand for interchangeability is not sufficient in itself. Alone, this demand would qualify many components in a product to be modules, as for example electronic resistors and transistors in a radio. However, it serves no purpose to call such components in a radio for modules. They do not each possess sufficient functionality to contribute essentially to the creation of variety. This is why also the demand for essential and self-contained functionality relative to the product is needed. Like the demand for interchangeability, also the demand for essential and self-contained functionality goes beyond the limits of the individual module, because *essential* must be seen relative to the product of which the module is part.

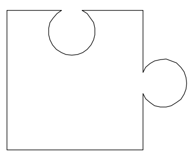
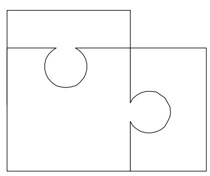
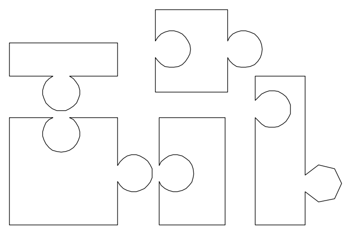
From *one module* point of view *(*)*	**From *one product* point of view**	**From a *system* point of view**
		
• Self-contained functional unit (testable) (*) It doesn't make sense to talk about one module isolated according to the previous reasoning. Modularity is a system attribute. A unit is a more correct word. But it does not illustrate the purpose of this comparison as well.	• Self-contained functional unit (testable) • *Well-defined* interface and interaction	• Self-contained functional unit (testable) • *Standardized* interface and interaction • *Combination* as a principle for creation of variety

Figure 8: Modularity must be a system attribute.

From the reasoning above it is clear that we cannot define a module from the module itself. We can not find the modularity, if we do not know the system to which the module belongs. But at the same time the module itself has to possess essential and self-contained functionality.

This leads to another paradox. If we imagine one (!) radio consisting of one receiver, one amplifier and one power supply, it would not consist of modules, as no units could be interchanged with any others. However, the moment another radio variant was to be introduced using another power supply, and reusing the other units, the existing power supply would suddenly become a module, as it was interchangeable and possessed essential and self-contained functionality relative to the radio. The change from non-module to module would happen without any changes of the module itself. However, what has happened is that the system has been redefined and now consists of two radios.

This leads again to another question: Will the amplifier and the receiver become modules, when the extra power supply module is introduced? - They are now a part of a modular structure and go together with different power supplies and possess essential and self-contained functionality. The answer must be that they are only modules if each of them possesses essential and self-contained functionality. In this case they would be modules.

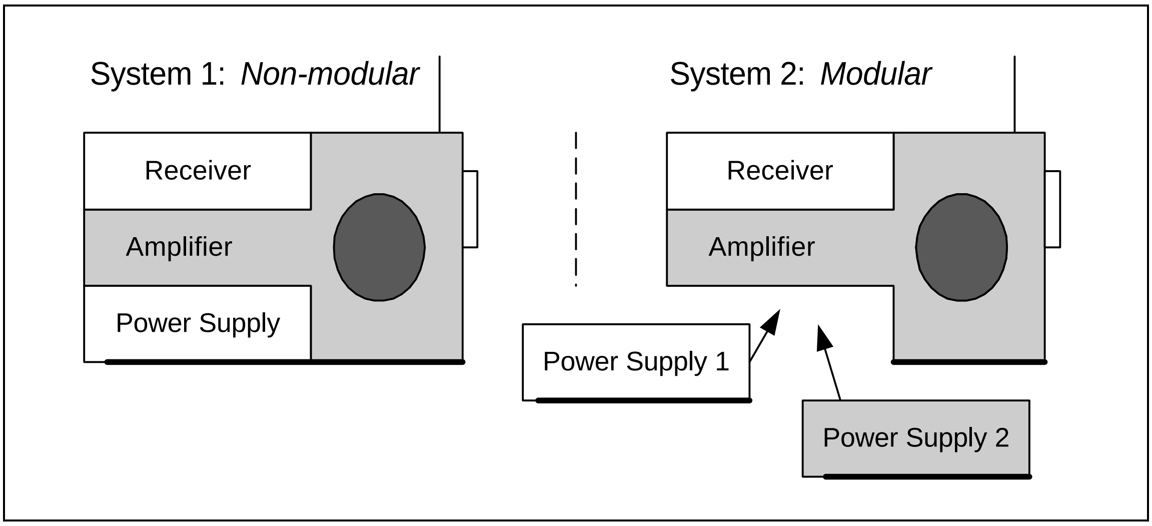


Figure 9: The radio example illustrates that modularity depends on the system view.

Often a system consisting of related products is called a product family accompanied by the terms architecture and platform. Architecture is often used to describe the structure of a modular system in relation to a product family. A platform is used in two ways. Either it describes functionality and interfaces of a modular structure which forms the basis for development of a product family. Or a platform describes a foundation, something stable, which is used as the basis for design of variants. This subject deserves further exploration. See for example [Robertson & Ulrich, '98], [Ulrich & Eppinger, '95] and [Elgård & Miller, '98].

4.2. Superimposed Structures

[Andreasen, '95] has described how products posses superimposed structures depending on the viewpoint and the purpose of the view. As modularity is a structuring principle, it follows that a product can be modular from one point of view, but not from another. Consider for example a radio designed with an ASIC. The ASIC contains essential and self-contained functionality and can be a module from a functional and an electronic point of view. From the assembly point of view, the ASIC will only be a component to be mounted like many other components.

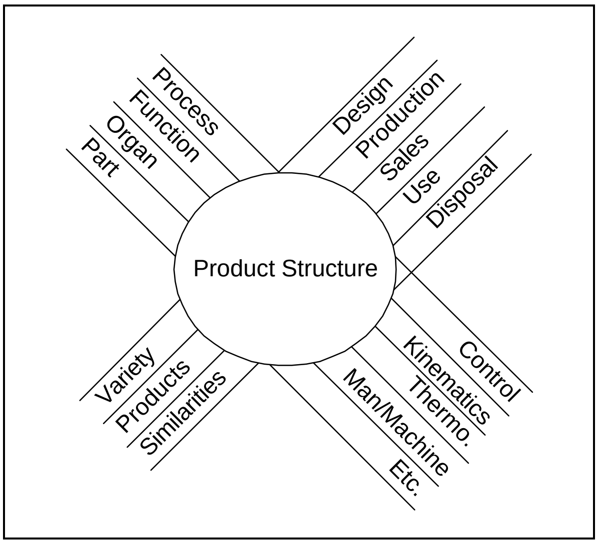


Figure 10: [Andreasen, '95] shows that a product can posses superimposed structures

4.3. The Perception of Modularity Depends on the View and Scale

The demand that a module has to possess essential and self-contained functionality in relation to the product of which it is part is a subjective demand. No objective scale can lay down what is essential functionality. It depends on the perception and definition of the system. In general, the perception of what is component, module and product depends on the viewpoint.

As an example, we may consider a flow-meter. The manufacturer (A) of the flow-meter sees the flow-meter as a *product*. Another manufacturer (B) produces energy-meters for hot water. (B) buys the flow-meter from (A) and uses it as a *module*, which is combined with a processor and a temperature gauge for creation of a series of energy-meters. Finally the flow-meter can be seen as a *component*, when it is used in large process plants.

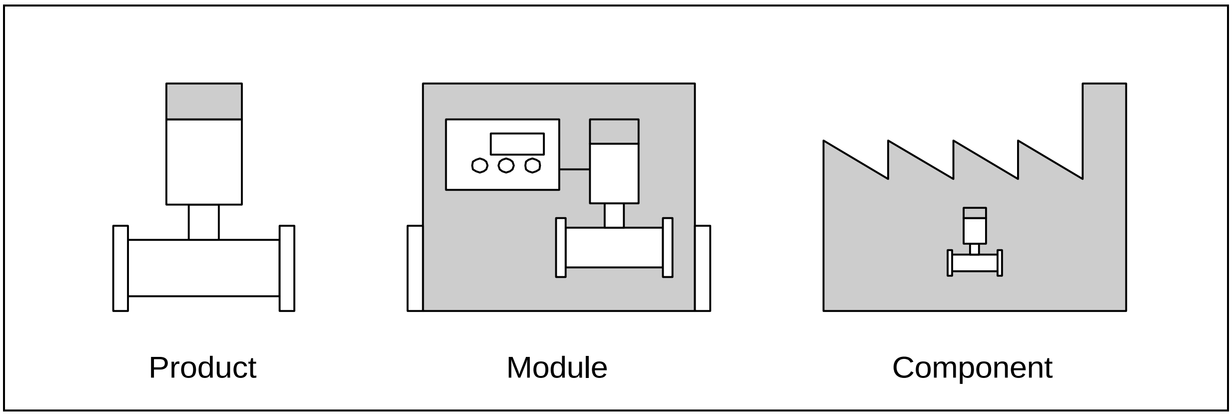


Figure 11: A flow-meter can be seen as product, module and component respectively. All three viewpoints can be equally correct depending on the purpose and viewpoint. This illustrates that the perception of modularity is closely related to the perception of the system.

4.4. Interface and Interaction

As it has been emphasized in the previous, the demands for interchangeability and creation of variety by combination imply a well defined allocation of functionality and standardization of interfaces and interactions in the modular system. Modules can only be interchanged if they have compatible interfaces and interactions. The compatibility is ensured by setting a common system standard for interfaces and interactions. The famous Lego blocks have a standardized interface - but no interaction. It is a very simple interface. Usually interfaces are more complex.

Interfaces are the boundaries of the modules facing each other. Some relevant types of interfaces are: 1) Functional interfaces which follow the allocation of functionality. 2) Mechanical interfaces, like connectors, plugs, surfaces, etc. 3) Electrical interfaces, like communication, signals, or power. This subject needs further exploration.

Interactions describe the input/output relations between modules. Also the input/output relations between modules need to be compatible. The relations can be of the following types: 1) energy, 2) information, 3) material and/or 4) spatial. This subject needs further exploration.

As described in section 2, Ulrich & Tung, among others, have showed that the type of interaction and interface is not trivial when we leave the pure mechanical and geometrical perception of modules. The structuring task when designing a modular system is huge and often very difficult. In practice, it is often difficult to allocate functionality to a module without getting variant specific - that is to create modules which are sufficiently universal to be used in a product family and not just in one product. Some of the advantages of the modular system are disappearing when variants of modules are introduced. It must be carefully considered, if it then would be better to have two dedicated products which were not modularized.

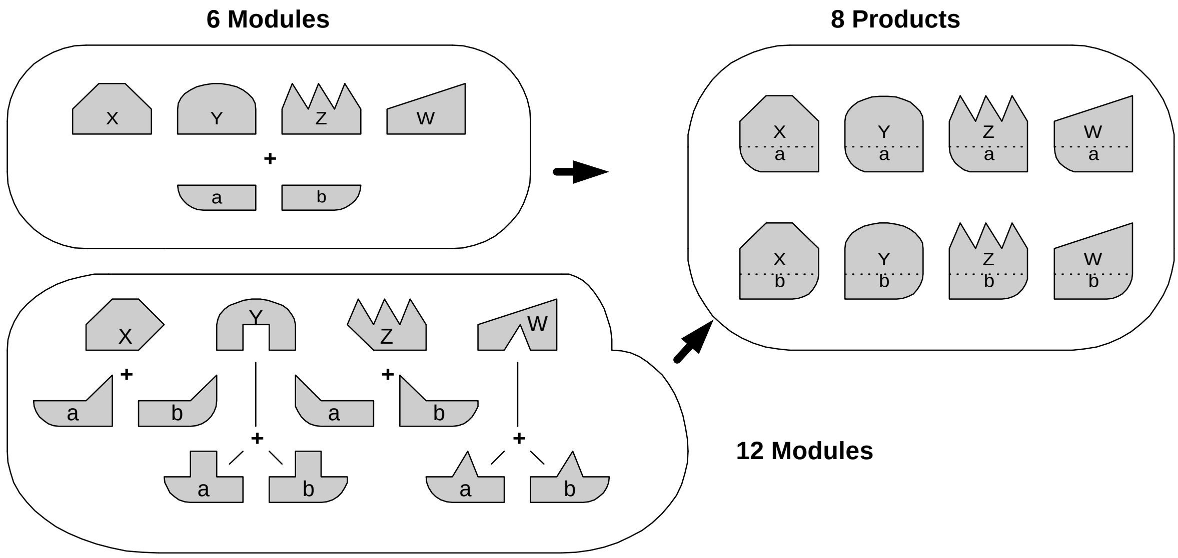


Figure 12: The design of interfaces and interactions and allocation of functionality have great impact on the generality of the modules.

Above an example illustrates how a product family consisting of 8 members can be realized of 6 or 12 modules respectively depending on the general applicability of the modules - that is the distribution of functionality and design of interfaces and interactions. It requires strong coordination and strict management of development projects to avoid this situation.

4.5. Dimensions of Variety

In order to support an efficient structuring of the entire product family, it is advantageous to divide the customer requirements into a set of independent dimensions of variety, which describe directions of variety useful to the customer. Within each 'dimension of variety' the functionality of each 'variant' is specified. The dimensions of variety do not describe all technical functionality, but will be limited to the functionality connected to the useful variety requested by the customer. We will use the following terminology adapted from [Jespersen & Miller] to describe this:

- A *dimension of variety* is an aspect of a product that can be varied. A dimension of variety is characterized by the set of values it can have.

- A *variant* describes a product having a set value within a dimension of variety. A variant is linked to a dimension of variety.

To exemplify this, consider a product family having two different supply voltages, 24V and 230V. In this case, the supply voltage will be the dimension of variety having the two variants 24V and 230V. Another example is given below.

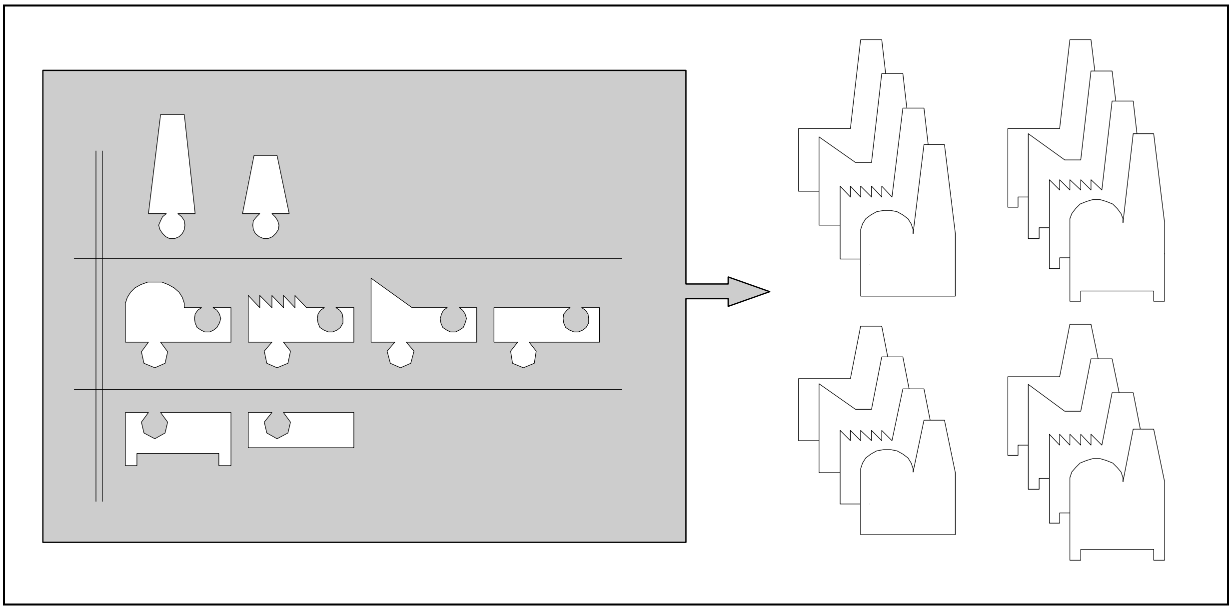


Figure 13: A system of product variants can be described by dimensions of variety. In this example 16 factory variants exist. They can be described by three dimensions of variety: type of chimney, type of main building, and type of base.

5. DEFINITIONS

Based on the previous text, definitions for the terms module, modularity and modularization is suggested, which is independent of application and technical domain. Based on [Miller, '97] and [Jespersen & Miller, '95]:

- A *module* is an essential and self-contained functional unit relative to the product of which it is part. The module has, relative to a system definition, standardized interfaces and interactions that allow composition of products by combination.

- *Modularity* is an attribute of a system related to structure and functionality.
  A *modular* structure is a structure consisting of self-contained, functional units (modules) with standardized interfaces and interactions in accordance with a system definition.
  Replacing one module with another creates a new variant of the product.

- *Modularization* is the activity in which the structuring in modules takes place.

[The word modularization is often used informally to describe the structuring principle in general. Thus, it is often heard that a company can benefit from modularization. Hereby is meant that the company can benefit from utilizing the concept of modularity.]

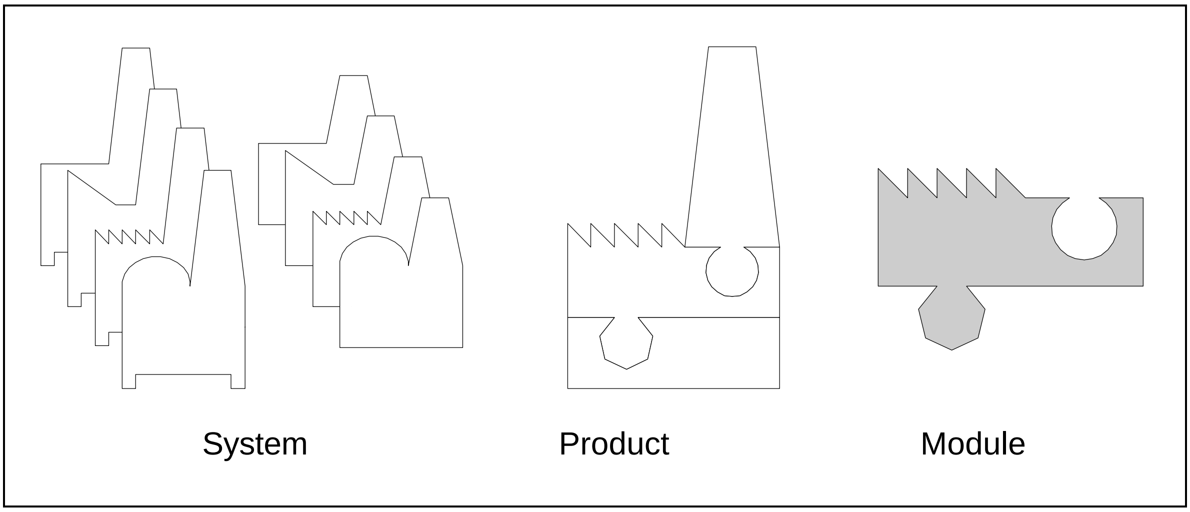


Figure 14: The module must be defined together with the product and the system to which the module belongs.

With these definitions modularity is linked to the functionality of the system. It is essential that the module cannot be recognized isolated, but must be defined together with the system to which it belongs. The definition allows that a module can be an immaterial unit, so it can be used for both physical modules and for immaterial modules.

With these definitions it is emphasized that a module is a self-contained functional unit relative to the purpose of the product of which it is part. By self-contained is understood that the function is realized within the module itself and limited to this. Furthermore, it is essential that modularity requires the ability to create products by combinations of modules. This implies a common standard for interfaces and interactions which is defined for the whole system - here called a system definition.

Modularity is a dualistic concept which depends on both the module itself, but especially on the structure of the system to which it belongs.

6. CONCLUSIONS

With this paper, we have sought to clarify the terms module, modularity and modularization. Our starting point has been the evolution of the concept in a historical perspective from which we have derived the core phenomenon. It is described how ‘the module’ has moved from being a geometric standard measure into being an industrial building block, and how this has further moved from being defined by its physical presence into being defined by functionality.

It is argued that the previous definitions of product modularity are no longer valid as products have become increasingly immaterial. Instead, modularity must be understood in relation to both the structure of the system to which the module belongs, and in relation to the amount of functionality of the module relative to the product of which it is part. The suggested definitions apply for both physical and immaterial products, as modularity is defined as a structuring principle for technical systems in general. The basic drivers behind modularization are described as: creation of variety, utilization of similarities and reduction of complexity.

Modularity, as we use the concept today, has emerged in industrial context and is inextricably bound up with rationalization efforts. That is, the wish for utilizing resources in the most efficient way when a number of related tasks are to be solved or a range of related products are to be produced. Or in other words: modularity may be used to strengthen the business performance when families of related products are designed and manufactured.

Design tasks in companies may change when modularity is introduced. The scope of design is widened from one to many. Traditional development approaches may prove insufficient when further integration between projects and products are needed. Methodologies from systems engineering may serve as inspiration for development for guidelines for modular design. Furthermore, research in relation to design reuse, platform design and system architectures may provide some inspiration. This field deserves further exploration. Also, modularity in relation to knowledge management and modules seen as knowledge carriers need further exploration.

This paper is to be seen as a contribution in relation to the authors Ph.D.-research in modular engineering and design of product families. It is the hope of the authors that the description of the concept of modularity and the suggested definitions may provide some clarification, when the overall business ideas of mass customization are to be transformed into guidelines to be used in engineering design departments.

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