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Modularisation in two Global Product Developing Companies – Current State and Future Outlook

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Abstract

Modularisation and platform strategies enable efficient utilization of resources through economies of scale and are therefore increasingly important for manufacturing companies. On the product side, modules are often considered the basis of product platforms by enabling a variety of product variants by combining interchangeable modules into different products. On the process side, modularisation enables faster and cheaper development of new product variants by reusing physical components, interfaces, and production equipment.

The benefits of product platforms and modularisation have led two global product developing and manufacturing companies to initiate research projects within this field. The companies have previously made unsuccessful attempts to implement modularisation founded on a component-based approach and the firms are now searching for other methods to get the benefits of modularisation.

This paper describes the initial state of practice in modularisation and product platforms in the two companies in their attempts to move from a purely physical approach to modularisation into the universal view that is presented in the Design Platform approach. Here, a platform is viewed as an evolutionary entity involving several company assets such as processes, knowledge, methods, and relationships which are essential to gain the benefits of platforms also in the development phase. The Design Platform contains various concrete resources such as the geometry of physical components, but also inhomogeneous resources such as design rules, processes, methods and design automation.

The results point to specific barriers that the companies experience when trying to adopt a modularisation strategy. Several barriers are experienced by both companies while some are specific for one of the companies. Through several workshops, the concepts of the Design Platform and a flexible view on modularisation are introduced, and their possibilities are elaborated and appreciated by the workshop participants.

Keywords: Modularisation, module types, barriers, product platform, product development

1 Introduction

Modularisation and platform strategies have been increasingly important for manufacturing companies in the last decades since these approaches enable efficient utilization of resources through economies of scale (Meyer & Lehnerd, 1997). Modules are often considered the basis of product platforms and some of the positive economic effects come from combining interchangeable modules where distinctive properties and functionality are achieved by changing one module for another (Gonzalez-Zugasti & Otto, 2000). Other advantages come from the faster creation of new product variants by reusing components, interfaces and production equipment (Halman, Hofer, & Van Vuuren, 2003). Companies can therefore significantly reduce the time and resources needed to develop products and their corresponding manufacturing system (Jose & Tollenaere, 2005).

The benefits above have led two global product developing and manufacturing companies to initiate research projects within modularisation and product platforms. This task is challenging, and the companies have made several attempts to implement a traditional modular product platform founded on the component-based approach described in the literature above. This approach has not been successful and the firms, therefore, need other ways to reap the benefits of modularisation apart from merely reducing the number of components.

One different approach is the Design Platform (André, Elgh, Johansson, & Stolt, 2017) where a platform is seen as an evolutionary entity based on various design assets, such as components, processes, and knowledge. These are essential to gain the benefits of platforms also in the development phase (Zhang, 2015). The Design Platform contains various concrete resources such as physical components, the geometry of physical components (CAD), but also traditionally unstructured resources such as design rules, processes, automated scripts and other methods. This holistic approach with its potential to form modules based on different assets attracted the companies and particularly the idea to give their resources a ´module status emphasizing their importance and formalizing them in the development system.

In the presented paper, flexibility refers to (i) the approach of considering both physical and non-physical objects as modules and (ii) the idea of creating the module division in a way to specifically create a low amount of coupling for specific modules. Non-physical objects are strategic knowledge, practices and tools etc. that could form modules in the design platform. These non-physical objects were part of the early definitions of platform thinking (Sawhney, 1998) but still lack methodological support in the literature and have not been thoroughly researched and applied in industry. Increased flexibility can be achieved by identifying strategic portions of a product platform where an increased amount of design flexibility is desirable to accommodate new requirements without affecting the whole system as reported in (Raudberget et al., 2017).

The first step towards flexible modularisation is to find the current State of practice in industry and this paper presents a descriptive study regarding modularisation in two companies. The purpose is to find barriers to its implementation and to investigate what new types of modules that could be included in a Design Platform.

2 Platforms and modularisation

In the last decades, a multitude of frameworks, methods, and mathematical tools have been described and proposed to make use of modularization and platform-based approaches. The definitions of product platform range from a platform consisting of components and modules (Meyer & Lehnerd, 1997), a group of related products (Simpson, Siddique, & Jiao, 2006), a technology applied to several products (McGrath, 1995), to a platform consisting of assets shared by a set of products (Robertson & Ulrich, 1998).

Regarding modularization, two common keywords in the literature are standardization of interfaces and interchangeability, where interchangeable stresses that modules are independent units designed as parts of larger systems. Modularization is often described as a way to increase the number of end product variants variety while maintaining or reducing the number of unique parts. However, several researchers have suggested methods to find a good modular division such as (Ulrich, 1995) that fulfil other goals. As an example the methodology Modular Function Deployment is used to create module division (Börjesson, 2014) and the paper gives an example of how dedicated modules are identified based on the need for recycling of a battery. Another way to create the modular division is to use mathematical methods represented by design structure matrices (Hölttä-Otto, Chiriac, Lysy, & Suh, 2014). A module can be defined as "a functional building block with specified interfaces, driven by company-specific reasons" (Erixon, 1998). Traditionally, the exchangeability of one module for another is achieved by fixing key interfaces and geometry. Hence, from this point of view, there is no such thing as flexible modularisation. However, flexible modularisation is about identifying strategic portions of a product platform where an increased amount of design flexibility is desirable. This concept has three different things: Identifying future needs to find *what* is going to change, analysing the modular division to find *where* the change is placed, and reconfiguring the modular division so that specific modules are pinpointed. Increased flexibility can be achieved by identifying strategic portions of a product platform where an increased amount of design flexibility is desirable to accommodate new requirements without affecting the whole system as reported in reported in (Raudberget et al., 2017).

The Design Platform (DP) concept was developed from the needs of engineering-to-order companies (André et al., 2017) which, traditionally, have not been able to use modularisation as a passable way to harvest the benefits of platform thinking. Besides physical components and modules, a DP also includes re-use of assets that often are ill-structured and acknowledges their respective contributions to a firm's success. This is in line with Robertson and Ulrich (1998) who state that *"A platform is a collection of assets that are shared by a set of products. These assets can be divided into components, processes, knowledge, and people & resources. Only if taken together, do these four elements constitute a platform"*. Processes and knowledge are also critical elements of the DP, and a DP at a company is composed of different objects related to process, synthesis resources, product constructs, assessments resources, solutions and projects and a conceptual image is shown in Figure 1. The product consists of its generic structure, derived variants, cardinality, and attributes. The generic items of the structure (assemblies and parts) and its variants, in turn, points to the different resources used for their realization, existing solutions, and associated process step. The solutions are linked to the projects where they were developed. A process resource can be in the form of tasks and execution orders of activities required or intended to support some part of the design process.

Another approach is given by (Lundin, Lejon, Dagman, Näsström, & Jeppsson, 2017) who uses the concept of a design module in order to capture and reuse design knowledge. This knowledge is automated, containing all information to build design variants from defined product platforms.

This section has briefly summarized some research that has been conducted on modularization. It has also focused on two recent advancements, the DP, and flexible modules, which together aims at utilizing platform thinking when the rigidity of modularization is questioned. The DP has earlier been applied and evaluated for engineer to order supplier companies but has also been identified to show promise for OEM companies. The research opportunity brought forward in this paper concerns the reasons for why traditional modularity is hard to implement for certain OEM companies and how the concepts of DP and flexible modules can be adapted to fit their context.

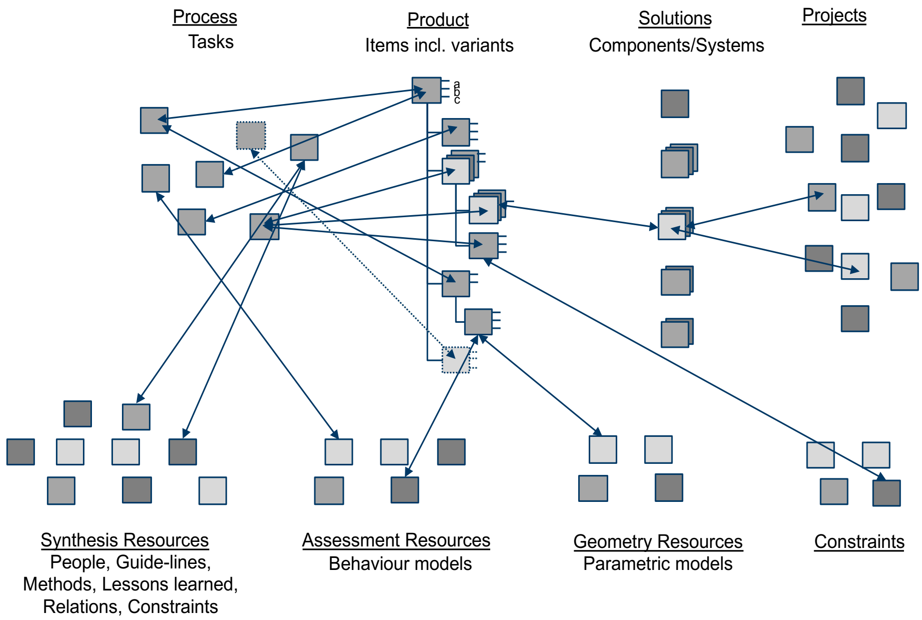

Figure 1. The Design Platform with its resources. After (André et al., 2017).

3 Research approach

The research is a descriptive study of the participating companies corresponding to the Research Clarification and Descriptive study in the Design Research Methodology framework (Blessing & Chakrabarti, 2009). The companies were chosen because of their efforts to implement modularisation, rather than the selection of an ideal sample of companies. This corresponds to the opinions of Eckert, Clarkson, and Stacey (2003) p.3, declaring that researchers must balance openings for empirical studies that fit a company's ambitions, against the need for well-grounded research results. The research is a part of a larger study aiming at improving the efficiency of the companies through new ways of modularisation and platform methods. The unit of study is a product development department.

The study is a two-year joint-venture between the two companies and the School of Engineering in Jönköping. The companies were selected since they both have a suitable product portfolio and have a clearly stated interest in better modularisation methods. They have different sizes and represent different types of businesses, as seen in table 1. One common characteristic is that their products have a high variety and are highly influenced by industrial design.

Information was collected from semi-structured interviews with managers and design engineers from a set of pre-defined questions. However, the order in which the questions were asked was flexible to adapt the interviews to the respondents and their specific role in the company. The respondents all had long experience of product development and were selected by the managers at the companies. Other data sources were workshops at the companies where project members and researchers participated, and through studies of documents.

In total fifteen face to face interviews were held, seven at Company F and eight at Company H. Also, one inter-firm workshop with representatives from both companies as well as two company-specific workshops at Company H and four at Company F.

Company F is a is a leading Original Equipment Manufacturer for the professional lighting market producing indoor and outdoor lighting products that are sold and distributed in 40 markets worldwide. The products are driven by industrial design around a core technology with a majority of the design work is done in-house. The products are manufactured in both small and large volumes. One challenge is the high number of variants where the firm has 20 000 variants in its range of products, composed of large numbers of unique parts. Another challenge is the major shift in technology by the introduction of LED lighting and the rapid development within this field has reduced the market life of a product from seven to two years with corresponding higher demands on the product realization system.

Company H is a global Original Equipment Manufacturer of outdoor products for forest, park and garden care. The company experiences an intense pressure from its competitors for both shorter product development lead times and lower prices. At the same time, the consumers are rapidly increasing their demands for quality, styling and a desire for innovative features.
A major challenge is the on-going transformation of core technologies from petrol to batteries, which has led to a shift in essential competencies in several engineering areas.
To maintain the position as a market leader, the company must improve its efficiency, by example, increasing the interchangeability of technical solutions between brands and markets.

Table 1. Company characteristics.

	Company H	*Company F*
Business	Outdoor garden and forest products	Lighting products
Number of Employees	13000	3 000
Business Type	Orig. Equipm. manuf	Orig. Equipm. manuf.
Customer adaption	Yes, cosmetic adaption for specific retailers	Yes, minor adaption of existing products
Manufacturing volume	Medium to High	Low to High
No. products	1 000	20 000
Modular design	No	No
End-user adaption	No	No

4 Results: State of Practice

The companies have several similarities: they both design and manufacture mechanical components, software, and electronic hardware. They have in-house competence for these three areas within the company and sell products that are driven by industrial design and state-of-the-art performance.

4.1 Development processes

The companies have well defined and mature product development processes. These are traditional processes based on phases and milestones. In the early phases of development, the product management of the companies define the market requirements and also the planned product variants, even if some variation is not planned at the beginning and occurs at later stages of development.

In both companies, the formal requirements are formulated differently depending on which individual that has formulated the requirements, even if there are templates on what is expected. Several respondents at both companies acknowledged that the specification process should be improved to clarify the development task. As an example, some of the requirements are not well defined and it can be hard to design a product based on these, for example, “easy to start”, “A low number of guarantee claims” etc. It is also hard to control the fulfilment of these requirements.

None of the companies has a formal process or method for how to create the planned product variants in the early phases of development. Some product managers at Company F has created a template where the key performance of the planned variants is described and visualized, but it is not included in the formal process.
Both companies have different personnel for concept development and product development. After the concept development phase, important knowledge may be lost in the hand-over of the project between stakeholders. This is especially true for Company H that has a separate organization for the concept development phase.

4.2 Barriers to the implementation of Modularisation

Even though both companies have made prior serious attempts to introduce modularization, the companies have no formal definition of a module. Furthermore, in their processes, the firms have no formal methodology for defining modules, product families and platforms, even though Company H has taken a management decision to focus on modules. This lack of methodology is evident in the different practices used for creating product families that are based on individual practices. The barriers to the implementation of Modularisation found in the study are presented in table 2:

Table 2. Summary of identified Barriers to the implementation of Modularisation.

Company H	*Company F*
Brand identity and brand distinction	Customer adaption is done as a late variant design by an aftermarket department
Introducing variants late in development	Economic calculation methods
Lack of managerial commitment	
Industrial design	Industrial design
Mind-set	Mind-set
Lack of Module definition	Lack of Module definition
Lack of Interface control	Lack of Interface control
Lack of product architecture methods	Lack of product architecture methods

Brand identity and distinction: The need to differentiate brands from each other drives a need for different features, physical appearance, and performance. A challenge is to have high brand distinction while maintaining the commonality. Company H uses different software to control the performance and designs different visual parts for brand identity.

Customer adaption: Company F serves the aftermarket and architects to adapt existing lighting sources to specific buildings. This customer adaption is done after the regular development at a special department and only considers smaller adaptions. One challenge is that most of these changes are not known or planned at the design stage and therefore generates an unnecessary number of variants.

Introducing variants late in development: Company H can introduce a new variant late in the development project based on the requests form brand managers. This uses more resources than to plan it in from the beginning.

Economic calculation methods: Development projects at Company F has no economic incentive to take modularization related expenses such as increased tooling cost on behalf of future projects. This hinders the investment in modules that can be reused in other projects.

Lack of managerial commitment: the modularisation development at Company H was postponed for 6 months in order to transfer resources to an ongoing product development project. This indicates that there is no true commitment from management to support the development of a modularization system.

4.2.1 Common barriers

Both firms are experiencing the following common barriers:

Industrial design: An important driver in product development at the companies is industrial design. It sets the frame for packaging since the designers often pursue the thinnest possible or lightest possible products. This, in turn, puts high demands on the internal components, thereby affecting product cost and /or performance.

Mind-set: Both companies are highly successful. In the past, there has not been a pressure on designers to re-use physical parts and the companies can afford the large variation. The engineers can create their own solutions as long as they fulfil the requirements. At company H there is an ongoing cost reduction initiative where the reduction of parts through modularization is an important part.

Lack of Module definition: At the companies, there is no formal consensus about what a module is. This is not entirely surprising since literature and research has not yet come up with a coherent, clear and unambiguous definition of the concept "module". However, striving for modularization requires a clear goal and a common understanding of what constitutes a module internally in the company.

Lack of Interface control: To achieve a modular architecture, de-coupled interfaces between the components are required (Ulrich, 1995). Since none of the firms has formal methods to work with interfaces, modularity is hard to achieve.

Lack of Product Architecture methods: None of the firms has methods to work with the product architecture, which is the scheme by which the function of a product is distributed to physical components (Ulrich, 1995). Product architecture is a prerequisite for modularization and methods are therefore needed to specify interfaces and the connection between functional elements and physical components.

4.3 Exploring the possibilities for Flexible Modularisation

In this paper, Flexible Modularisation refers to the (i) approach of considering both physical and non-physical objects as modules and (ii) the idea of creating the module division in a way to specifically create a low amount of coupling for specific modules.
Succeeding the individual interviews, workshops were held to investigate the conditions for flexible modularisation. In the workshops, the engineers were presented both a model of flexible modules (figure 2) and of the Design Platform (figure 1). Initially, a majority of the respondents stated that the goal of modularization is a reduction of the number of parts, even though some also mention other goals, such as flexibility, reduced development cost, risk, and lead-time. During the workshops, the respondents were positive to the idea of promoting more resources apart from physical parts.
In figure 2, the question was what systems or functions that should be less integrated into a product to accommodate changes and if it is a feasible idea to create the module division in a way that generates a low amount of coupling for specific modules that will be replaced in the future etc.

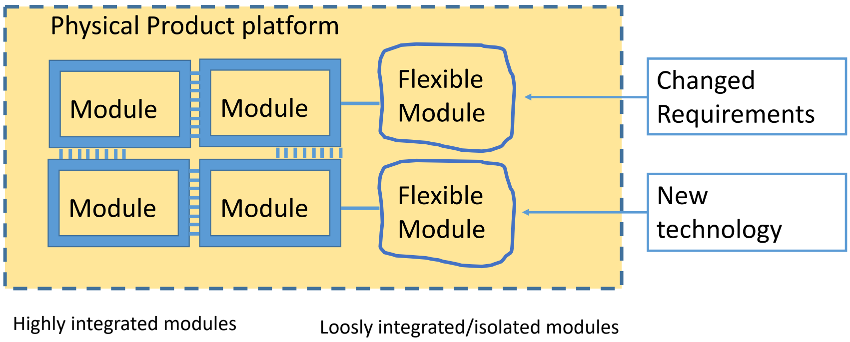

Figure 2. A model of a flexible module division shown to the respondents to communicate the concept.

After this, the respondents were given a brief introduction to the Design Platform (André et al., 2017) framework, see figure 1 in Section 2.
The respondents were asked to come up with examples from their daily work that could be considered a resource in the design platform. The discussion continued discussing both physical and non-physical objects and how objects in this platform could be other things than physical parts, such as processes and tools. The respondents were also asked how they could place themselves in this context and what resources that they would contribute to and what resources they needed to do the job.

The following potential Flexible Modules were identified in the workshops:

Modules concerning testing: Current test standards are rigid and extensive, aiming at verifying the final design. Instead, tests would be modularly divided into smaller chunks that are more adapted to different phases of development when a full investigation is not possible or desirable.

Modules that contain methods and tools for specific tasks. It was found that the companies have several important methods scattered over the organization in an unstructured and undocumented way. By identifying and structuring these methods, the companies can control the quality of the methods and be less vulnerable when people change employer. As an example, thermal calculations are needed in all lighting projects but calculated by one engineer in a self-designed Excel sheet without any documentation or possibilities to trace the computations.

Modules representing knowledge and information: There is a multitude of different forms of information and knowledge around the companies. Some response suggested that mission-critical information and knowledge could be organized to form a module. The advantage would be that a ´module status´ would require that the information has the right quality and is properly maintained

Modules concerning CAD: Current reuse of CAD models are often based on using previous models as a baseline when creating a new product. A CAD module could consist of smaller segments and geometrical features with the goal to reuse these for partly standardized design work.

Modules that accommodate the variation created by industrial design. This module would accommodate some of the variation created on the system by styling and industrial design by being less integrated into the product. This may be achieved by creating a module division in a way that it generates a low amount of coupling for specific modules containing industrial design.

Modules that are scheduled to be replaced: this was a need that emerged from the challenge of technology that is being obsolete. A potential solution is to use the same suggestion as for modules affected by industrial design, i.e. a low amount of coupling and this concept is interesting and worth developing further.

From the list of identified potential flexible modules, three are consistent with the module drivers in Modular Function Deployment (Börjesson, 2014; Erixon, 1998). These are modules concerning testing, modules that accommodate the variation created by industrial design and modules that are scheduled to be replaced.

5 Discussion and conclusions

This research project was initiated by the need for improved modularisation methods at the two companies. In this paper, current barriers to modularisation and new types of suitable modules are presented. The companies have different characteristics and represent different types of businesses which makes the results useful for other companies having a portfolio of mechatronic products.

Given the results above it is not surprising that previous modularisation attempts were unsuccessful since there are several barriers present at both companies. Most of these barriers are related to working methods and practices rather than technical limitations of the company and should be possible to overcome, thereby creating a better condition for coming modularisation attempts. As an example, a clear definition of the term module should be useful.
Dividing a product platform into modules can also give negative effects. One evident drawback is that a modular design is not optimized across the platform since it is a compromise between commonality and customization. Another drawback is the lack of flexibility both in the aspects

of having rigid interfaces constraining the design possibilities and the optimization of integrated products.

One barrier at company H is not found in the study but in literature. The products are highly optimized and the physical parts often realize several functions, an example of an integral product architecture. Ulrich (1995) p.427 states that *"products with integral architectures require changes to several components in order to implement changes to the product's function"*. For a product where the steering handle serves as interface to the user and a part of the fuel tank, the architecture is simply not suitable for decomposition into a handle module and a fuel module. In this case the concept of Flexible Modularisation could be attractive. Adding to the difficulty is that modules usually must span several products or lifecycles to be a justifiable investment. This requirement becomes harder and harder to oversee doe to the rapid changes in the future unknown market place and customer demand.

Company H has a separated organisation for concept development and product development. Opinions differ about what is to be delivered between the organisations and the product platform strategy is often considered to the responsibility of the product development department. Coming back to that modularisation requires several product variants or lifecycles to be justifiable, requires that the planning for modularity starts already in the concept development.

Flexible Modularisation entitles a 'module status' also to resources that are not physical parts. This implies that a resource is qualified as an asset in the Design Platform and that it is properly used and maintained. Several employees at the companies have developed individual methods for solving important tasks and one way to control this would be to codify and reuse the methods as modules in the Design Platform. In this way these methods and tools are also visual in the organisation for others to use.

There are also opportunities to introduce systematic modularisation of CAD models with the purpose to increase the development speed and the quality of the designs through standardised design work. CAD modules would be quality assured and prepared in a way that downstream activities would be more efficient. As an example, CAD modules could have associated pre-made drawing views, being designed for manufacturing with correct taper angle, having pre-defined material properties and mesh for Finite Element Analysis etc. A CAD- module could also provide a standardised 'skeleton' controlling the architecture of one or several CAD models for easier manipulation and variant control.

As a concluding remark, the companies were given new insights and are committed to tear down some of the barriers identified. The DP approach has earlier been in detail applied to original equipment suppliers. A contribution from the presented paper is a first step to show the applicability of the DP approach to OEM companies. The next step is to identify potential physical and Flexible modules at each company and place these in an outline for their respective Design Platforms.

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