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Developing Agile Platform Assets – Exploring Ways to Reach Beyond Modularization at Five Product Development Companies

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Abstract. The use of a product platform has been acknowledged as a strategic enabler for product family development and mass customization. However, many companies struggle with adopting the common platform approach building upon pre-defined modules and components as it constrains the fulfilment of unique customer requirements and a rapid introduction of new technologies. These are the conditions under which manufacturing companies acting as suppliers operates, where unique solutions are delivered to different business customers, market segments or brands. This work reports the results from case studies of platform development conducted in collaboration with five product developing and manufacturing companies. The focus of this paper is on their initial states; including how they work with their product concept before a development project is started, the character of requirements and the adoption of product platforms. The main contribution of this work is a presentation of criteria on, and identification of, new platform elements termed *Design Assets*. These are introduced as a means to enable diverse types of resources to be reused in a company and a pragmatic way to bridge the gap between the physical products and the knowledge, tools and methods needed to realise these.

Keywords. Modularization, platform, customization, supplier, engineer-to-order, design asset, agile, platform element, product development, industrial collaboration, case study,

Introduction

The advancement and implementation of flexible resources within the Industry 4.0 framework (Heng, 2014) enables a higher level of customization combined with efficient utilization of resources and flexibility in the location of the manufacturing. It is important to acknowledge that many industries are systems suppliers acting on a business-to-business market. Here, other capabilities are more important than a flexible production: short lead time in development, the ability to provide unique solutions and to master changes in requirements are of vital importance (André et al., 2016). A competitive edge is also gained by continuous development and application of new technologies, material and manufacturing methods. This may provide innovative solutions that bring competitiveness to their customers and is of vital importance for the long-term success of the company itself.

The use of product platforms, where external and internal efficiency is well balanced, has been acknowledged as a strategic enabler for customization. Platforms are generally described to be of one of either two kinds: (1) the module based platform that is characterised by sets of discrete components clustered into interchangeable modules that form the product, or, (2) the scalable platform that becomes adaptable due to letting some of the design variables be adjustable (Simpson, 2004). Several Original Equipment Manufacturers (OEM) have made successful implementations of platform strategies based on a modular product architecture. However, the adoption of such a strategy has shown to be difficult for suppliers working in an Engineer-To-Order oriented business environment (André et al., 2016).

An Engineer-To-Order (ETO) business process is required when the customers need high functionality and performance. They are not willing to make the trade-offs that a selection among the existing combinations of solutions would require. In an ETO business process, a product or system is designed, engineered and manufactured to meet the unique specifications defined by a specific customer or market brand. This implies that unique solutions may be developed for each specific case (Högman et al., 2009). As a result, the business environment may include joint development activities starting with a flexible requirement specification having a limited number of key requirements. During the development process, as the knowledge about the technical solution evolves, requirements change and new ones are introduced. This is analogous to the way requirements are developed in Set-based Concurrent

Engineering (Raudberget, 2010). A similar need may appear in OEM- companies (Raudberget, 2018) where new technologies are constantly required by the product management that are acting as internal customers for the organisation. This implies that the current design solutions may quickly be obsolete and that unique solutions must be developed.

This paper presents the results of an exploratory study of platforms and modularisation at five product developing and manufacturing companies. In the study, the view of platforms is grounded in the platform definition by Robertson and Ulrich (1998) where a product platform is constituted by different types of assets that reside in the company. What needs to be added to this generic definition is a coherent description or model that makes use of these assets in an efficient way, and a definition of the assets themselves. The paper clarifies the *Design Asset* concept. By identifying and systematically use different tangible and intangible essential resources that facilitate development, industry may gain the benefits of platforms also in the development phase.

1. Frame of reference within Platform-based development and modularisation

This chapter introduces and discusses approaches that support the platform needs of Engineer-To-Order companies and Original Equipment Manufacturers that are faced with rapid technology development. However, the definition of the platform concept is ambiguous and several types platforms can be identified (Zhang, 2015).

1.1. Product platforms

Customization is a way to increase the variety of products. Hansen (2003) suggests four different business models for customization: (1) Engineer-To-Order, (2) Modify-to-order, (3) Configure-to-order and (4) Select variant. For the latter two, the use of product platforms has been an essential enabler.

The definitions of product platform range from a platform consisting of components and modules (Meyer and Lehnerd, 1997), a group of related products (Simpson et al., 2006), or a technology applied to several products (McGrath, 1995). Product platforms are generally described to be of one of either two kinds: (1) the module based (discrete) characterised by sets of components being clustered into interchangeable modules that together form the product, or, (2) the scalable platform that becomes adaptable due to letting some of the design variables be adjustable (Simpson, 2004).

Knowledge Based Engineering (KBE) is an approach to support the design of unique products. This can be seen as a sophisticated realization of a scalable platform model. KBE can support and generate large continuous ranges of variant designs compared to the discrete solution space provided by configuration of pre-defined modules. One example is presented by (Johansson, 2015), where engineering tasks are formalised and defined in different software applications. These are tied together and can exchange parameters for the purpose to generate different valid variants. KBE has been extensively researched, but few successful long-lasting operational implementations have been reported and further research is required for a wide industrial implementation (Verhagen et al., 2012).

1.2. Platforms supporting Engineer-To-Order products

For Engineer-To-Order and Modify-to-order business models, pure modular approaches are not feasible (André et al., 2016). Due to the high level of customisation, they need platform types that also can support the development phase which may be referred to as “development platforms” (Levandowski, 2014). This includes embracing abstract assets such as knowledge and relationships as proposed by (Robertson and Ulrich, 1998). Development platforms include tangible and intangible resources essential for supporting a holistic platform development across all stages of a lifecycle.

One model that support the early phases of development is the Configurable Components (CC) framework. It holds information about the system solution, system variants as well as its underlying requirements and motivations. It is based on the Enhanced Function-Means tree creating a formalized specification of a technical system in a hierarchical model which is decomposed in subordinate sub-systems by a systematic design approach (Johannesson et al., 2017). This approach makes it possible to model not only a resulting design solution, but also “why things are” and “why things are the way they are”. One feature of the CC framework is that it can support Set-based Concurrent Engineering to model and analyse platforms at early stages of development. One example of this is given by Raudberget et al. (2015) where different platform alternatives are compared without the need for geometrical embodiment in CAD etc.

The Design Platform (DP) is developed from the needs of Engineering-to-Order companies (André et al., 2017). It aims to cover all stages of the development lifecycle for companies that traditionally have not been able to use modularisation as a foundation for platforms.

A DP includes re-use of assets that often are ill-structured and acknowledges their respective contributions to a firm’s success. Alongside assets such as physical components and modules, processes and knowledge are also critical elements for a company. A prerequisite, however, is that the DP only comprises elements that are qualified and validated.

Eight domains of the DP have been identified (André et al., 2017): *Process*, *Product*, *Synthesis Resources*, *Analysis Resources*, *Geometry Resources*, *Constraints*, *Solutions* and *Projects*. These could potentially be populated with different resources and support. The DP is collection of assets forming a “toolbox” for the development team and allows each discipline to manage their own set of assets as is illustrated in Figure 1.

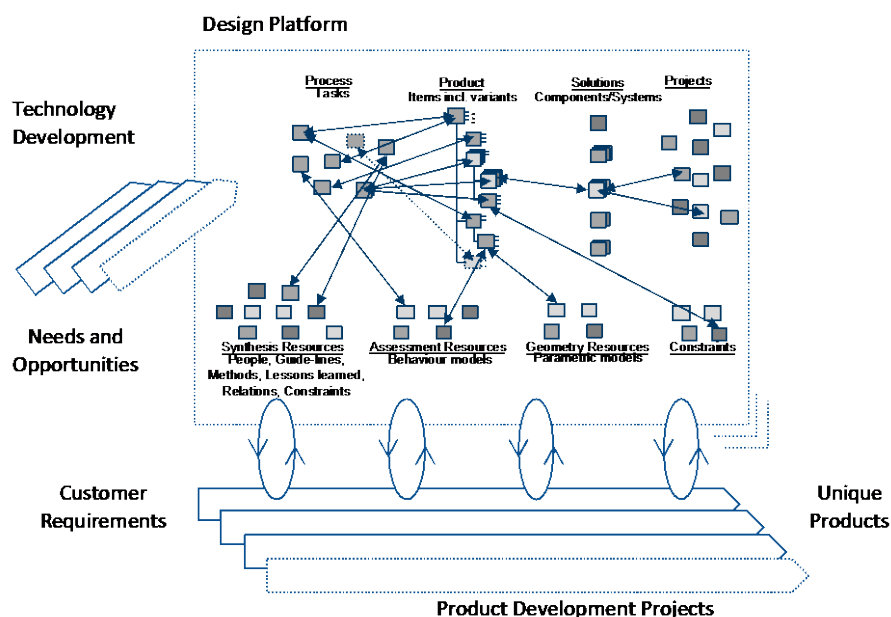


Figure 1. The Design Platform approach and its Design Assets. Redrawn after (André et al., 2017).

The definition of assets in the DP has not yet matured. Assets are of different types: Besides traditional platform elements such as pre-defined modules and components, also information, models, methods, and knowledge at different levels of abstraction can be included as validated design resources. To exemplify, a process resource can be in the form of tasks and execution orders of activities required or intended to support a specific part of the design process. Multidisciplinary synthesis and analysis work, including diverse types of design task, where requirements are allowed to vary in a Set-based manner, should be supported. Various kinds of product structures, process models and activities as well as results from previous projects, e.g. components, products, lessons learned etc, are to be included.

Potential Design Assets has been described in (Elgh et al., 2017) where a method of automated FEM analysis of variant designs is described. The method reduces the work effort and lead time and eliminates unnecessary loops between design and analysis. In addition, a method that evaluates the weldability and a method that evaluates the inspectability are introduced. The methods have been implemented in a company's development environment for concept design where hundreds of variants are generated and evaluated automatically based on performance, product features and manufacturability. Finally, different resources, by example components, CAD models and calculation methods, for quotation and order design are described. These are managed in a virtual toolbox that designers can use to develop a unique solution and supports the re-work when changes in requirements arise during the project

1.3. Perspectives on modularisation

Modularization is a way to define a product's constituting element for a purpose that goes beyond the design phase of a single product. For a completely modularized product architecture, Ulrich and Tung (1991) state the following:

1. there is a one-to-one correspondence between functional elements and physical structures, AND
2. unintended interactions between modules are minimized.

However, in integrated, high performance products, a one-to-one correspondence between functional elements and physical features may be impossible to achieve.

One reason for introducing modules is to support standardisation – the same solution is always used for economy of scale. Reusing a module will give benefits such as a reduction of the development lead-time and/or potentially ensure even quality. Another reason is to support the formation of a product family where a set of product variants can be generated that target different markets or customers while efficiency in purchasing, production, after sales etc can be kept at a competitive level. For modularisation to work in practice, a standardisation of the interfaces between modules is critical.

Most products are not broken down into completely modularized architectures. Therefore, an allocation of a group of functions into a specific physical module must be done. Creating this functional division, i.e. allocating functional elements to specific modules, is tightly linked to the system architecture that must be defined early in the design process. However, it is difficult to generically define the functionality to the level necessary in early phases of development (Lehtonen, 2007). The mutual dependency between modularization and system architecture is challenging and several researcher present ways to address it.

One approach is heuristic and based on rules of thumb, engineering knowledge and the analysis of existing mechanical structures/relations (Meyer and Lehnerd, 1997). There are

also several approaches based on analysis of Design Structure Matrixes (Steward, 1981). Design Structure Matrixes may be used to cluster modules in a preferable way (Hölttä-Otto et al., 2014), or to select what functions to group into modules based on functional complexity and to evaluate different architectures as suggested by Raudberget et al. (2015). Another viewpoint is to create tools to evaluate potential and existing product families with the aim to improve modularisation such as presented by Simpson (2017).

Erixon (1998) presents the methodology Modular Function Deployment. Partly based on Quality Function Deployment, it starts not with an existing parts or modular structure but with the needs of the customer. It introduces a set of motives, module drivers, to support the work of identifying modules with the notion that every module is created by a specific reason. Some examples of module drivers are: Carry-over, Technology push, Styling, Common unit, Separate testing, Service/maintenance, Upgrading and Recycling. Beside the generic drivers, there could also be company specific. One advantage is that the methodology manages perspectives from different stakeholders when creating the modular division.

1.4. Matching supplier businesses and platform-based development

Several suppliers act in the business-to-business market and are involved in the actual development of the final product in collaboration with their customers. These suppliers have a product concept; however, this concept is more or less implicit, i.e. it is not fully described and managed in a structured coherent way, and it includes other resources than pre-defined parts and modules. They frequently respond to different customers' requests for quotation by submitting specific offers and it is vital to respond quickly and with a sufficiently accurate price (Elgh, 2012). Development projects are often executed in close collaboration with their customers and can run for several years where changes in the requirement specification are frequently faced (Andr  et al., 2014). The dynamic nature of requirements often results in changes or that new requirements are added, or others are dropped (Almefelt et al., 2006).

As can be concluded, several publications on platform have been authored, where the platform elements have different characteristics, ranging from physical modules to abstract functional elements or working methods. Today, modularization is commonly regarded as the foundation of product platforms and configuration to support mass-customization (Hvam et al., 2008) where the truck manufacturer Scania is a good example of a successful implementation (Scania, 2017). However, increased adaptability of modules for integration in large systems is a topic for further research and development (Stjepandi  et al., 2015) and copying the ways of a successful company into a new context may be counterproductive. There could be many company specific reasons for the formation of a specific module (Erixon, 1998). Modules can also be combined with unique parts for a specific product, i.e. the product is not completely modularized according to the definition by (Ulrich and Tung, 1991) above.

For cases when requirements are diverse, such as in an ETO- business environment or when core technology is evolving rapidly, a platform based on physical modules may be hard to achieve. In these cases, a development-oriented platform that includes other elements besides the physical parts can be a way to reuse asset in the development phase.

2. Beyond modularization – developing Design Assets

A modular platform approach enables efficient customisation, reuse and production standardization. However, the common platform definition that builds upon pre-defined modules and components has been shown to be insufficient for companies working with an ETO business approach (H gman et al., 2009), as well as for some OEMs (Raudberget,

2018). To address this challenges, the Design Platform (DP) approach has been presented by André et al. (2017). Besides physical elements, the DP is composed of different platform elements related to the domains of process, synthesis resources, product constructs, assessments resources, solutions and projects. These platform elements are coined *Design Assets* and are the backbone of the DP. They have, however, not been clarified nor elaborated, which is the purpose of this research.

2.1. Researching current Industrial practises to identify targets for a new platform approach

A first step towards a structured implementation of new design assets is to identify important resources that are used today but not recognised as a part of a platform. Previous studies (André et al., 2017) suggests that various kinds of product structures, process models and activities as well as results from previous projects, e.g. components, products, lessons learned etc, are included as assets in the DP.

One observation is that the term ‘asset’ implies that a resource is a valuable element of a company’s platform. Hence, it must be properly used, developed and maintained. The Design Asset concept entitles an ‘asset status’ also to resources that are not physical parts.

The research is a collaboration project between five product developing and manufacturing companies and the School of Engineering at Jönköping University, Sweden. Three companies represent the Engineer-To-Order businesses, whereas two companies represent Original Equipment Manufacturers. However, the technical development speed in the Original Equipment Manufacturers makes it hard for them to use a traditional platform approach. This creates several challenges in platform development similar to the ones experienced by the Engineer-To-Order businesses. The unit of study is a product development department and basic information regarding the five companies are given in Table 1.

Table 1. Main characteristics of the five companies (approx. figures).

Company	Business area	Business type	No employees at site	No employees total
Aero Company	Aerospace	ETO	2 000	44 000
Equipment Company	Automotive	ETO	300	3 000
Building Company	Industrial house-building	ETO	150	200
Garden Company	Outdoor power products	OEM	1900	13 000
Lighting Company	Professional lighting products	OEM	700	5000

The companies are described briefly below:

Aero Company is a global actor in the area of development, production, service and maintenance of systems for aircraft, rocket and gas turbine engines.

Equipment Company is a global manufacturer of a wide assortment of products for transporting equipment by car, including roof racks, bike carriers and roof boxes. Most products have a modular design.

Building Company is an industrialized manufacturer of wood buildings that deliver schools, sheltered housing, student housing and offices. The buildings are design and manufactured in modules where ventilation, heating and plumbing are pre-installed as well as the interior.

Garden Company is a global, multi-brand company that develops, manufactures and sells forest, park and garden products such as chainsaws, robotic lawn mowers, hedge trimmers and ride-on mowers.

Lighting Company is a leading Original Equipment Manufacturer which designs and manufactures professional indoor and outdoor lighting products for the European market.

To unveil the state -of-practice and current challenges at each company, data was collected through interviews and workshops. The principles for the data collection and the interview results are summarized in the following sections.

2.2. Data acquisition

The data acquisition was done in two phases. The first phase aimed at capturing the state of practice at each company through interviews with different types of engineers. The second phase was the workshops to identify new platform elements.

The series of in-depth interviews aimed at clarifying the specific situation, practices and challenges at each company, as well as similarities between them. The interviews were conducted by two persons except for Lighting Company, where the interviews were conducted by one person. They lasted about one hour using a semi-structured questionnaire with open-ended questions. All data was reviewed by two researchers and the results support the outline of further research.

In total, 28 respondents were interviewed, each possessing appropriate knowledge and experience of the current working practices. To get a broad perspective of the state of practice, the interviews covered different roles in each company, from experts with deep domain knowledge to managers having a more holistic view on design assets (Table 2).

Table 2. Respondents at the companies.

Comp.	No.	Functions
Aero Company	4	Head of design, simulation engineer, sales engineer, and group-manager
Equipment Company	4	Project leader, tool-designer, head of design, and head of technology
Building Company	5	Heads of electrical, construction, climate/plumbing, and technology manager
Garden Company	8	Designers, design team managers, head of mechanical development and product managers
Lighting Company	7	Designers, design team managers, production engineer, head of mechanical development and product managers

2.3. Interview results

Below are the findings from the interviews, describing the current state-of-practice at the companies. They are sorted in the categories: before order, at order, requirements, and platform view.

2.3.1. Before order

The extent to which customer adaptation can be prepared before an order is made vary between the companies. The Aero Company offer the highest level of customer adaption where each part is specifically tailored to the customers specification. This is followed by Building Company that reuse common components between buildings and Equipment Company that bridges the unique interface between a car and roof rack. Lighting Company

has a department that redesigns existing products for specific customers, typically smaller adjustments and adaptations. Finally, Garden Company mass produces products for internal stakeholders and specific customers such as retail stores.

2.3.2. At order

The Point of order is an important milestone for ETOs that marks the beginning of customer adaptation. For the ETOs, this may include some portion of technology development.

The Point of order is, however, not a clear concept for the OEMs Lighting Company and Garden Company. At these, the point of order is considered the moment a development project is started with the aim to deliver products to the market i.e. not pure technology development activities.

Technology and product development practices differ between the companies with respect to how well-defined the processes are, and the maturity of the solutions derived from technology development. Except for Building Company, technology development is conducted at separate departments or by specialised individuals at all companies. This may prove problematic from a knowledge transfer viewpoint. At Garden Company, the technology development department delivers a prototype and a report, which is not adequate for a successful knowledge transfer into subsequent product development projects, especially regarding platform compliance.

In all companies, a variety of processes, tools, models, and sources of information are used in the development process. The number of different sources makes it difficult to get an overview of how different documents relate to each other, and how validated or up-to-date these are. Another common trait between the companies is that a significant part of the knowledge needed to design the products resides in the minds of the employees. The companies therefore try to use formal ways to capture this in form of guidelines, standards etc.

2.3.3. Requirements

Management of requirements is important at all companies but the precision in the formulation of these varies largely between them. Aero Company, as a part of the aerospace industry, has by far the highest maturity in the requirement specification in the study. Aero Company has a rigorous system to ensure safety and the traceability in several aspects such as specifications of thermal loads and geometrical interfaces.

2.3.4. Platform view

Regarding the view of platform, the term is used to some extent at Garden Company and Building Company. At Garden Company it often refers to interfaces and key geometry of the moving parts in a two-stroke engine and at Building Company it refers to a breakdown of type houses and the available choices. The term platform is not formally applied at Equipment Company or at Lighting Company. It has previously been discussed at Aero Company but is not extensively applied. Here, a platform mostly consists of knowledge, methods and solutions and has become a concept for structuring information so that it is prepared for reuse.

3. Workshops to identify new Design Assets

Two workshops were held to target new platform approaches and the identification of Design Assets. One workshop involved the three ETOs and the other one involving the two OEMs. The reason for this division was a practical decision based on the location of the companies.

The workshops mixed representatives from the companies and were set in two sessions guided by the following questions:

- **Session 1** - What criteria on new platform models are essential for an increased ability to efficiently adapt to changes in requirements and/or technology?
- **Session 2** - What new platform elements /Design Assets, including methods and tools, can support an increased ability to efficiently adapt to variations in requirements and/or technology?

The procedure was identical for both sessions – first, individually write statements; then, in groups, share, discuss, clarify and add additional statements; finally, the groups cluster the statements and agree upon characteristic labels for the identified clusters. The results for criteria on new platform elements and suggestions for new platform elements/ Design Assets is given in table 3.

Table 3. Clusters for criteria on new platform models (Session 1), and types of new platform elements/Design Assets (Session 2). The two OEMs are represented in group 4.

	Group 1	Group 2	Group 3	Group 4
Session 1: Criteria on new platform assets	Definition Follow-up Knowledge building Requirement management Interfaces	Common information model Design re-use Experience feed-back Product development process Enable set-based design	Scope Formalization Maintenance User Friendliness	Single information source Consistent module definition Low overhead on new methods
Session 2: Types of new Design Assets	Process Simulation Knowledge Requirement management Roles	Data handling and process model Product models Knowledge transfer Information integration	Methods Product models Preparation / operation of the platform	Economic calculation methods Flexible Modularisation Knowledge reuse

3.1. Criteria on new platform models

To support Design Assets, the following criterion on new platform models were established:

- *Definition, Common information model, Scope, Formalization, Single information source* and *Consistent module definition* points out a need of **an explicit, shared and clearly defined overall model**. This prevents confusion about the contents of the DP at a specific company, what elements are included, and which are not part of the DP.
- *Follow-up, Knowledge building, Design reuse, Experience feed-back* and *Maintenance* highlights the importance of **supporting a platform that can evolve**. This means that new platform elements and types can be added over time.
- *Requirement Management, Interfaces, Product development process* and *Enable set-based design* can be interpreted as providing **a support for collaborative multi-disciplinary work to manage changes in requirements**.

- Finally, the cluster *User friendliness* and *Low overhead on new methods* is highlighted for successful implementation and use in operation.

3.2. Characteristics of new types of platform elements/Design Assets

When it comes to new types of Design Assets, the following characteristics were established:

- *Process, Simulation, Data handling and process model, Methods and Economic calculation methods* gives an emphasis on **a process approach including activities with supporting methods.**
- *Product models and Flexible Modularisation* point out that **item-oriented models, with different kind of structures, should be included.**
- *Knowledge, Knowledge transfer and Knowledge reuse* highlights that **descriptions and design rationale should be supported.**
- *Requirement management, Information integration and Preparation/operation of the platform concerns* **methods that allows for adaptive behaviour**, e.g. untightening requirements, generate alternative solutions, suggest trade-offs.
- The cluster *Roles* emphasises the need of **methods to manage the content** on various levels and for different stakeholders.

To conclude, a new platform approach should be an explicit, shared and clearly defined overall model that support collaboration in a multidisciplinary work setting. The concept of *Design Asset* is introduced as a means to enable diverse types of resources to be reused in a company. Design Assets can be traditional item-oriented models, with different kind of structures or have a process approach including supporting methods and tools.

4. Identifying Design Assets at the five companies

In the following section, the focus is to clarify the Design Asset concept by giving examples of the status and areas in focus when introducing and populating the Design Platforms at the five companies. Based on the characteristics of Design Assets as presented in section 3, the researchers revisited the material gathered during the interviews and workshops to identify tools and practices that the companies use today. Several practices that could qualify as Design Assets in a formalised Design Platform were found. However, it is not possible to make a consistent classification of a given tool into the suggested domains *Process, Product, Synthesis Resources* etc. The reason for this is that a given resource, such as a design guideline, often is used in different ways. In one company this could be used to support the synthesis of new designs, whereas in other cases it may be used to analyse if a new design meets the design objectives. The domains are still relevant since they, among other things, can target weak or missing areas of the formalised Design Platform.

4.1. Company 1: Aerospace industry

Aero Company provides products that are completely custom engineered for an international market with high competition. The products are integrated in complex systems working in extreme environments for long time periods with both customer and legal demands for complete documentation and traceability. The ongoing trend in the aircraft industry is a shift from production in low volumes to larger quantities, shorter lead-time in development and a continuous strive for decreased weight for reduced fuel consumption. This drives the development of new materials as well as new approaches and models to support

quick introduction of emerging high-fidelity discipline methods for design and analysis. Moreover, there is a need to adapt to changes in requirements and to make assessments of implications and balance trade-offs.

Aero Company develops Design Assets for *Process*, *Synthesis Resources*, *Analysis Resources* and *Geometry Resources*. As for process resources, the company needs increased support to quickly introduce new technologies, both in manufacturing and design. Software and working methods are developed and sometimes superseded over time, so a process with version control is implemented. As an example, no calculation tools are allowed to be scattered on personal hard-drives.

Since more than a decade, *Synthesis Resources*, *Analysis Resources* and *Geometry Resources* are used for automation of design and production preparation through Knowledge-Based Engineering. In this platform environment, Aero Company routinely explore new design concepts prior to approaching prospective customers. This is to clarify what effect a variation of design parameters can have on the performance of the design. Performance is meant in a broad sense, including several different disciplines such as aerodynamics, strength and manufacturability. Full automation of the variant generation, the analysis and the compilation of the results is a necessity considering the vast amount (hundreds) of variants that are evaluated. Having insight in the effect on the performance allows Aero Company to identify promising areas of the design space for further elaboration.

To realize these explorative studies, several different types of design assets are used. One of the more common assets are python scripts for controlling the process, setting up the analyses and reviving the results. There are also scripts written in Knowledge Fusion for controlling the generation of CAD model variants. In addition, there are Visual Basic for Applications scripts and macros for initiation and execution of actions inside CAD, FEM and CFD software. Other examples of assets are information sources such as excel files.

4.2. Company 2: Automotive accessory supplier

Equipment Company must be able to quickly launch a roof rack for every new car model. The trend in the car industry is an increased pace in the introduction of new models on the market and Equipment Company needs to provide an individual adapted attachment to each new car. Each new attachment is validated through crash simulation and tools must be designed and manufactured. To target the challenges imposed by the increasing number of variants, five areas of Design Assets are developed.

The roof rack is based on standardized *Solutions* in a modular design consisting of a footpad and bracket. A clear *Process* is in place to adapt the roof racks to new car models: The roof is scanned, and the data is used to search a database for existing foot pads and brackets that may be combined to secure the rack on the new car model. If there are no suitable components, new ones must be developed.

The process is supported by several tools in the form of *Synthesis Resources*, *Analysis Resources* and *Geometry Resources*. One tool is a spread sheet that can configure and manage the design in a semi-automated process that controls what process steps must be taken and who is responsible. When tasks are completed, emails are autogenerated from the spread sheet to initiate downstream activities. The synthesis of design proposals is supported by Case Based Reasoning, which is integrated in the CAD-system to interactively indicate search criteria and to visualize results in context of the CAD-assembly.

The roof rack product is a safety component and it is hence necessary to assess each new product variant through testing. Physical testing cost is substantial, which calls for virtual testing. A full functioning prototype software is used to automate the creation of crash simulation models in such a way so that design engineers could use pre-defined geometry

resources to execute the assessment routine while computation expert could maintain and develop the routines.

Currently, computer routines are developed for automatic tooling development of two components for new roof rack variants. The software updates the spread sheet documentation and drawings as well as adapts CAD-models by generating certain geometrical features.

4.3. Company 3: Modular buildings

Construction Company designs and manufactures turnkey timber buildings using an industrialized modular system where ventilation, heating and plumbing are prefabricated as well as interior furnishing. The buildings are unique for each project and come in many types such as schools, student housing, offices etc. Industrialised timber housing is a complex field and currently, as the prevailing culture of the construction trade prescribes, customizations are allowed. During the order design phase, design solutions must often be adapted to the client's specific requirements as a part of the negotiations between clients and the sales department at the company. This has led to a constantly increasing number of variants and documents in the database, currently exceeding 1.5 Million documents.

To handle the situation, Construction Company has introduced the Design Platform approach by identifying and formalizing Design Assets. Currently, the company has a representation of the product in a five-level hierarchical model called a technical platform, arching from *building* down to *parts* (Lennartsson and Elgh, 2018). Undisputedly, there are assets present in Construction Company that has not been fully documented and much of the contents are residing in the heads of the design department. Therefore, the focus for the Design Asset development at Construction Company has been to scrutinize the document database to address what solutions and ways of working that could be elevated into Design Assets.

When researching *Process* Design Assets, it was found that the use of design templates and standard operations follow the protocol for the generic approach for a construction project rather than a structure from a platform perspective. To develop a logical and well-defined product architecture as well as methods for modelling of product and engineering tasks, the strategy has been to organize the current set of documents with the hierarchy of the technical platform rather than the content and order of a construction project, that would facilitate the transfer to a PDM/PLM system.

The *Process* Design Assets is further emphasised through the introduction of a platform strategy on two levels; products including their variants; and a general technology platform that includes standardised design solutions.

The strategy is to organise the *Analysis Resources*, *Geometry Resources* and *Solutions* that are found in templates and standard operations and are used both in design and manufacturing. A large share of these documents was developed in the 1990s and they do not contain metadata or other attributes that facilitate efficient search and retrieval, and a challenge is to organize and visualise these assets and remove superfluous documents.

In conclusion, to utilise the design platform, customer demands must be managed more disciplined to not compromise the product architecture and the production, the know-how in the company should be extracted and better managed rather than being attached to specific individuals.

4.4. Company 4: Outdoor forest and garden products

Garden Company continuously work with introduction of new products, while reducing cost and time to market. Garden Company is challenged by the rapid evolution in battery technology and Internet of Things which calls for new means to describe technology for easy

introduction and adaptation. In this context it is not feasible to work on large platform development projects due to the amount of work and time-to-market that this will require. A comprehensive approach is therefore required, including a platform strategy that supports the development and management of different assets to support swift introduction of new technologies and increasing diversity among customers. Garden Company is currently developing Design Assets within the fields of *Process*, *Geometry Resources* and *Solutions*.

Within the *Process* domain, development includes the formation of a better platform and modularisation approach that can support both modular and integrated designs. This approach must allow the combination of both integrated and shared solutions. Optimized and integral product architecture has the potential to fulfil opposed targets. They may simultaneously provide the product performance with a low product weight, thereby achieving low energy consumption as well as facilitating easy operation by customers. On the other hand, shared solutions can improve the business performance by lowering the development and manufacturing costs. Therefore, the company needs a platform approach allowing some systems to be modularized whilst others are integral and optimized.

Other focus areas are related to the support of design knowledge. Some methods to improve existing design guidelines by a better structure and a content more adapted to the tasks at hand were previously developed (Raudberget and Bjursell, 2014) and will now be incorporated in the Design Platform.

Within the *Geometry Resources* domain, improved CAD methods and prepared CAD models are developed. The goal is to make the design process smoother by enabling a logically structured “single source” for commonly used tasks and its connected information providing it in a familiar format. Also, improvement in the tools is developed, such as adding support geometry and standardised interfaces in CAD models.

In the *Solutions* domain, a new modular system is being developed that can provide a higher level of functionality and be used in more product variants. This will be the first qualified solution in the Design Platform that is clearly designed and prepared for reuse in future projects.

4.5. Company 5: Professional lightning products

Lighting Company designs products around a core technology that is packaged within the boundaries of an industrial design. This generates a high number of different product variants and the company can deliver 20 000 unique products, composed of large numbers of unique parts. However, the major shift in technology caused by the introduction of LED lighting and the rapid development within this field has reduced the market life of a product from 7 to 2 years with corresponding higher demands on the development and manufacturing organisation. Platform approaches can be found on a smaller scale in the form of modularization of product families. A platform strategy is therefore needed that supports the development and management of different assets to support the introduction of new technologies as well as managing the diversity among product families.

Lighting Company is developing Design Assets within the *Process* domain. This includes developing a better economic model that can manage the scope of modularisation. Currently, there are no economic incentives for modularisation on a project level and there is no method to value modularization related expenses such as increased development and tooling cost on behalf of future projects. This creates sub-optimal product families by hindering investment in modules that can be reused in other projects.

Geometry Resources are being developed, such as better prepared CAD- templates that increase design quality. This is accomplished when important aspects of the design are formalised into datums and support geometry in the models rather than only residing in the

minds of experienced engineers. The new CAD-templates are also meant to be structured in a way in the PDM system so that they are easy to use and hence a natural part of the daily work.

Moreover, *Synthesis Resources* are developed in the form of design knowledge formalised as a structured approach for selecting materials for new designs. To meet the specifications, most luminaires use a combination of several materials to get the correct optical properties. Since numerous new or improved optical materials are available every year, a structured approach to selecting and maintaining materials is developed.

4.6. Cross-case analysis and discussion

The assets presented in the previous section are all consistent with the criteria suggested in the workshops. The Design Platform serves as an *explicit, shared and clearly defined overall model* to organise the Design Assets. Assets can be added step-wise, thereby supporting a *platform that can evolve*. This aspect is important since it means that the threshold for deploying the Design Platform concept is low and it can evolve on demand by adding new assets or refine existing assets whenever they are needed. Product development in complex environments involves several organisational disciplines and by allowing different disciplines to add assets and link them to related disciplines, changes in requirements can be traced which *support multi-disciplinary work to manage changes in requirements*.

Reflecting on the types of assets that already exists in the companies and those that are under development, it is clear that several common challenges can be found for the five companies:

One is the need to improve management processes and working practices in order to apply Design Assets into the daily work process, e.g. applying *a process-oriented model including activities with supporting methods*. This need is related to the organisation of the development work, where all companies state that documentation of tools and methods needs to be raised to a level that allows them to be valid assets in the design platform.

There are also challenges in the way these assets are deployed in the organisation. A new methodology for a specific task may be successfully developed in a pilot study, but a company-wide implementation is a totally different thing and could be hard to realise. Therefore, all companies are working on means to encourage the use of Design Assets as well as ways to creating a coherent documentation of methods and tools.

It is also clear that the companies have different maturity regarding design processes and working practices. Looking at the computer support, Aero Company is the most advanced company and uses a well-developed way of designing and automatically evaluating its aerospace components through simulations, as well as simulating manufacturing and inspection sequences. Equipment Company can design key components automatically and are working on ways to also simulate the crash tests and tool design for these components. The other companies are developing new or improved computer support in an effort to better being able to integrate the planned Design Assets into a structured platform.

A summary of the existing, potential assets that could be refined and included into the Design Platform as well as the assets under development is presented in Table 4.

Table 4. A summary of potential Design Assets at the companies, e.g. the types of models and means currently used (solid dot, ●) and means under development (circle, ○).

Focus area for the development of Design Assets	Aero Company	Equipment Company	Construction Company	Garden Company	Lighting Company
New/improved computer tools	○ ●	○	○	○	○
Support the introduction of new materials	○ ●				○

Methods to balance trade-offs	◦ ●			◦	
Handle specification changes	◦		◦		
Support the introduction of new technology in products	◦ ●			◦	◦
Support the introduction of new manufacturing methods	◦				
Speed up manufacturing tooling through automation	●	◦			
Speed up product development through automation	●	●			
Frequent use of formalised Design Assets	◦	◦	◦	◦	◦
Coherent documentation of methods and tools	◦	◦	◦	◦	◦
Improved product architecture			◦	◦	◦
Structured modularisation methods		●	◦	◦	◦
Support for design rationale				◦	◦
Standardised CAD methods	●	●		◦	◦
Economic calculation models for modularisation					◦

5. Conclusion

This research presents a study at five companies that corroborate the findings of André et al. (2017) stating that platform models beyond modularisation are needed for Engineer-to-Order companies. This is also the case for the two OEMs in this research, where a high level of customization and rapid technology development makes existing technical solutions obsolete and a more agile platform approach is therefore required.

The concept of Design Asset is introduced as a complement to traditional modularisation within a platform context. It offers a new way for efficient customisation, reuse and standardization by introducing and structuring platform elements that are traditionally not used in a platform setting. Thereby the efficiency of a platform approach may also be reached in the design phase by systematically extending a traditional parts-based platform with intangible element, such as prepared CAD models, working methods, function representation and different types of knowledge representations. In the five cases, we have seen several examples of employees that have developed individual methods for managing important tasks. However, as long as these methods and tools are not structured as assets, they are not available for others in the organisation to use, hence the need for the Design Platform.

The objective is that systematic modelling, upgrading, development and structuring of heterogenous design assets will improve the agility regarding the development of solutions for different customers' demands, the mastering of fluctuating requirements appearing during the development, and the continuous integration of new technology. By entitling an 'asset status' also to resources that are not physical parts, it implies that these resources are qualified to be included into the Design Platform and receive the proper use and maintenance.

The main contribution of this work is a presentation of criteria on, and identification of, new platform elements termed *Design Assets*. These are introduced as a means to enable diverse types of resources to be reused in a company and a pragmatic way to bridge the gap between the physical entities that build up the products and the knowledge, methods and other

assets needed to realise these. The concept is clarified by giving real life examples of Design Assets from five companies.

Regarding the validity of the findings, the companies represent different sizes, businesses, indicating that the suggested Design Assets should be applicable also for other companies with the same characteristics. There are, however several difficulties to manage when implementing changes in organisations. A fundamental precondition for successful application of the Design Asset concept is its acceptance from a majority of the users.

The research is a work in progress and the industry partners have confirmed that it is a promising approach for reaching beyond modularisation. Further development, realization and evaluation of the Design Asset concept will be part of upcoming case studies.

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