371

Platform Models for Agile Customization – What's Beyond Modularization?

Fredrik ELGH[a,1], Joel JOHANSSON[a], Roland STOLT[a], Martin LENNARTSSON[b],
Tim HEIKKINEN[a] and Dag RAUDBERGET[a]

[a]*Department of Product Development and*
[b]*Department of Construction Engineering and Lighting Science,*
Jönköping University, Sweden

Abstract. Many manufacturing companies are suppliers that deliver unique solutions to different business customers. Intense quotation work, with a high demand on accuracy and quick response, and development projects executed in close collaboration with customers and other actors characterize these companies. The projects can run for years or a few weeks depending on the business. Changes of requirements are frequent and technology development required for improved functionality, sustainability and competitiveness. The use of a product platform has been acknowledged as a strategic enabler for product family development and mass customization. However, companies struggle with adopting the common platform approach building upon pre-defined modules and components as it constraints the fulfilment of unique customer requirements and the introduction of new technology at high pace. This work reports the results from case studies conducted in collaboration with four companies. They are in many ways different but face the same challenges when it comes to customization, fluctuating requirements and need of high pace in technology advancement. The focus of this paper is on their initial states; including how they work with their product concept before the customer entry point, the work that is initiated when an order is accepted, the character of requirements and the adoption of product platforms. Criteria on, and identification of, new platforms models, termed Design Assets, are presented followed by a mapping to the Design Platform concept pointing out areas upcoming work, both scientifically and at the companies.

Keywords. Modularization, customization, supplier, engineer-to-order, design asset

Introduction

The development of flexible resources as part of Industry 4.0 [1] enables a higher level of customization combined with efficient utilization of resources and flexibility in the location of the actual manufacturing. It is important to acknowledge that many industries are systems suppliers acting on a business-to-business (B2B) market where short lead time in development of unique solutions and an ability to master changes in requirements are of vital importance. They are also expected to actively develop and supply innovative technologies for the competitiveness of their customers as well as 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

---
[1] Corresponding Author, Mail: fredrik.elgh@ju.se.

enabler for customization. Many examples of successful implementation of a platform strategy based on a modular product architecture by an original equipment manufacturer (OEM) exists. However, the adoption of such a strategy has shown to be difficult for suppliers working in an ETO-oriented business environment where unique solutions are developed for each customer or the final product [2]. One reason is that the customers are not willing to make the required trade-offs in functionality that a selection among the existing combinations of solutions would entail. As a result, the business environment includes joint development activities starting with a requirement specification with a limited number of key requirements and as the solution evolves, requirements change and new are introduced. A similar situation appears in companies where a rapid technology evolution is going on. New products are developed and launched at a high pace based on the needs and requirements defined by product management that act as internal customers to the product development organisation. If modular platform models are not sufficient in these cases – is there an alternative? This is the question address in an ongoing 3-year project that where initiated 2017-01-01.

1. Related work

Modularization, platform based development supporting customization and the character of product development in supplier businesses are in this chapter introduced. Together they outline the fundamentals that this work is based upon.

   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 [3]:

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

   One reason for introducing modules is to support standardisation – same solution is always used for economy of scale, reduce the lead-time in development and/or ensure even quality. Another reason is to support the formation of a product family where a set of product variants can be provided targeting different markets or customers while efficiency in purchasing, production, after sale etc can be kept at a competitive level. [4] introduces a set of motives, module drivers, to aid the work of identifying modules. These are: Carry-over, Technology push, Product planning, Technical specification, Styling, Common unit, Process/Organisation, Separate testing, Black-box engineering, Service/maintenance, Upgrading and Recycling. Beside the generic drivers, there could also be company specific. As can be concluded, there could be many reasons for the formation of a specific module. Another implication is that modules can be combined with unique parts for a specific product, i.e. the product is not completely modularized according to the definition by [3] above. Today, modularization is commonly regarded as the foundation of product platforms and configuration to support mass-customization [5] where Scania is a good example of a successful implementation [6]. However, increased adaptability of modules for integration in large systems is a topic for further research and development [7].

   Four different business models for customization are: (1) Engineer-to-order, (2) Modify-to-order, (3) Configure-to-order and (4) Select variant [8]. 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 [9], a group of related products [10], a technology applied to several products [11], to a platform consisting of assets such as knowledge and relationships [12]. This diversity is also seen in industry [13]. 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 vary [14]. Another approach to support the design of unique products is Knowledge Based Engineering (KBE). KBE can be seen as a sophisticated realization of a scalable platform model that can support large continuous ranges of variant designs compared to the discrete solution space provided by configuration of pre-defined modules. KBE has been extensively researched, but few successful long-lasting operational implementations have been reported and further research is required for large scaled industrial applications [15]. A third approach is based on a process support where engineering tasks defined in different applications are connected for the purpose to generate different variants [16].

Many 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 assets and resources than pre-defined 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 [17]. They join development projects executed in close collaboration with their customers. The projects can run for years where changes in the requirement specification are frequently faced [13]. The dynamic nature of requirements often results in changes or that new requirements are added, or others are dropped [18].

2. Industrial practise and target for new platform models

The need for a platform-based approach beyond pre-defined modules and components has been raised by industry with the motivation that pre-defined modules and components constraint the possibility to fulfil unique customer requirements and the introduction of new technologies at high pace. A collaboration project was formed based on a jointly defined problem statement addressing this. Four companies participate in the project, (Table 1).

Company 1 (C1) is a global actor in the area of development, production, service and maintenance of systems for aircraft, rocket and gas turbine engines.

Company 2 (C2) is a global manufacturer of a wide assortment of products for transporting equipment by car, including roof racks, bike carriers and roof boxes.

Company 3 (C3) is a manufacturer of schools, sheltered housing, student housing and offices for both the public and private sector based on industrialized construction of wood buildings. The buildings are design and manufactured in modules where ventilation, heating and pluming are pre-installed as well as the interior.

Company 4 (C4) 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.

In depth interviews were conducted to understand the specific situation, practices and challenges at each company, as well as similarities and to support the outline of further research. 21 interviews of experts and managers (Table 2) at the companies were conducted by two persons for about one hour using a semi-structured questionnaire with open-ended questions in the main categories: before order, at order, requirements, and platform view. Summaries of the results are presented in Table 3.

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

Company	Business area	No employees at site	No employees total
C1	Aerospace	2 000	44 000
C2	Automotive	300	3 000
C3	Industrial house-building	150	200
C4	Outdoor power products	2000	13 000

Table 2. Respondents at the companies.

Comp.	No.	Functions
C1	4	Head of design, simulation engineer, sales engineer, and group-chief
C2	4	Project leader, tool-designer, head of design, and head of technology
C3	5	Heads of electrical, construction, climate/plumbing, and technology manager
C4	8	Designers, group-chiefs, head of mechanical development, and product managers

The companies vary to which extent customer adaptation is provided, where C1 offer the highest level, followed by C3, C2 and C4. Point of order is not an obvious or clear concept. Technology and product development differs with respect to how well-defined the processes are, how mature the solutions derived from technology development are, and is conducted at separate departments at all companies except C3. Processes, tools, models, and sources of information are used to a large extent, but it can be difficult to get an overview, see how they relate to each other, and how validated or up-to-date they are. Much of the knowledge is in the minds of the employees. Management of requirements is important at all companies and variations often occur on specifications of loads and geometrical interfaces. A platform-concept is in some parts used at C4 and C3, it has been discussed at C1 but is not extensively used, and is not formally used at C2.

In a workshop including representatives from all companies, the target on new platform models were set in two sessions guided by the following questions:

- **Session 1 (S1)** - <u>What criteria</u> on new platforms models are essential for an increased ability to efficiently adapt to changes in requirements and/or technology?
- **Session 2 (S2)** - <u>What new platform models, including methods and tools</u>, can support an increased ability to efficiently adapt to variations in requirements and/or technology

The participants were divided in three groups, G1, G2 and G3. The procedure was the same for both sessions – first, individually write statements; then, in the groups, share, discuss, clarify and add additional statements; finally, the groups cluster the statements and agree upon a characteristic label for each cluster identified (Table 4).

Table 3. Summary of interviews.

	Before order	At order	Requirements	Platform view
C1	Pre-contract development is often part of a research project with a strong focus on the manufacturing processes. R&T are involved with developing new products and technologies and at a certain point, (TRL 4-6) it is handed over to the chief engineers' office. They will market and sell it to the customers. There are extensive in-house developed aids for technology development. TRL is used. Tools are tested by running standard cases with known solutions. Feedback of experiences are done using DP's (Design Practises). There is nothing configurable prepared beforehand, except simple machine element like bolts.	Customer specific products are made, but the same product can be used in several different aircrafts. Several variants can be offered. They are in most cases made from existing parametric CAD models through scaling. Strength and aerodynamics must be recalculated. Exactly the same component is only used in one type of engine. There is no sharing of components between different engine-manufactures. In house developed models and methods are extensively used. Information about materials is stored in shared databases. There are DP's to all (top level) processes, so it is easy to get an overview. However, since the DP does not cover everything, it can be time consuming to understand all details. A thorough follow-up that all requirements are fulfilled is carried out. There ought to be a standardized structure of catalogues in all projects. When a validation has been carried out, the validated version of the software must be used throughout the entire project. In some cases, models of components are re-used.	The requirements specification is central and the process around its management is carefully controlled. It is described in documents adapted to different views. The requirement specification, extensive documents, is obtained from the customer. From this, an internal specification is created including for example processing requirements. The requirements that vary the most are the loads and the geometrical interfaces while requirements from authorities are constant. The set of requirements is elaborated and refined during project execution. It is desirable to freeze the set of requirements prior to the conceptual design. Sometimes the loads are changed after physical tests.	The concept "platform" is not extensively used. However, it was much discussed some years ago. The meaning of platform has become a way of structuring information so that it is prepared for reuse. It mostly concerns knowledge, methods and solutions. Platform in the sense of supporting reusing components is not applied. Still, forming of variants can be done by the scaling of existing components. There are manufacturing platforms used for example in fabrication, welding and AM. It is not possible to determine which strengths and weaknesses the current platform has since it is not clearly defined.
C2	Points of order/request was seen as either the point of which market requests something as a result of the market-investigation as well as each time a new car-model is released. Technology development work with new solutions. Technology development is done at a separate department. TRL is not used. There are several product-families. Support-aids vary from software applications, process descriptions linked to hundreds of documents with instructions for design and assessment as well as automation-solutions. Feedback is captured by documenting each phases in development and at meetings discussing lessons-learned from customers.	Customer unique products are made with respect to each car-model, but also in the form of packaging for different resellers (package, logotype, assembly instructions). Support includes CAD-templates for tooling design and checklist. Drawbacks with the information sources are that they are too many, spread, uncertain and uncoupled. Technical information such as drawing, test reports, and meeting-notes are kept track of by adding datum-stamps, versions, and prohibiting write-access. Network-drives are more difficult. There are parametric CAD-models to generate new kits and tooling-models in CAD to adapt each tool for new kits.	The requirements specification is done using templates for both technical and economic goals. Standard-specifications such as ISP and DIN are always included. A system is used to analyse the requirements from different perspectives. The requirements vary between car-manufacturers (such as maximum allowed load) and can sometimes change as a result of the tests during the development process.	Platform is not a well-established concept but the roof-rack was discussed as one type of platform where several components are reused to meet different applications. The challenges are to spread knowledge about platforms, how they can be used, and get it widely known. But also to make sure it can match a majority of the car models, especially considering safety requirements which needs to be fulfilled. The perceived strengths pointed out with a platform approach is its flexibility and the support to quickly and easily see which car models there are solutions for.
C3	Product development includes the entire structure, predominantly catalogue houses but all the way down to details and mostly connected to the market. Technical development is about all parts included by the "technical platform" and to be updated with changes in demands, norms and rules of the construction sector. Connected to the production process and divided in different technical departments such as electrics/HVAC. TRL is not used. The process should be managed according to a way of working dependent whether if problems arise and their severity. However, the departments can initiate work separately. Validation of new technology is done in real projects. Product families exist (schools, offices, living, sheds). Planning for these are mostly based on the market conditions. Experience feedback is conducted with improvement board and disturbance log.	The company offers customer specific solutions, either it is an input demand from the client or departs from existing house models. Assessment is made if the building system has capacity to manage the project. Design work is commonly required for structural, electrics and HVAC and subsequent production preparation and specification for assembly and work on site. Possibly new catalogue houses can be developed if similar solutions have been used in multiple projects. Mainly cad-software is used as support in contact with the client. Sketching is also used. Configurator is missing. There is too much customization and variants.	Demands divided in 10-15 technical departments. Internal and from client. Building protocols, technical descriptions, changes and add-ons. No specific tools are used except checklists. Demands are changing all the time since the problem scope is not always defined from the start. Societal demands are changed, e.g. national norms and standards Energy demands are the toughest to comply with. Information sources used beside company software, are webpages, construction databases. Low cost solution but it becomes fragmented as a holistic view is missing. There is also a lack of connections between the separate sources which increases the risk of continuing until failures occur and results can be dependent on the individuals.	Technical Platform with a huge range of variants. Breakdown of type houses and all the available choices. Challenges lies in the continuous change of norms (e.g. energy efficiency). The platform is not completely documented or defined – No overview, the complete picture is missing. The strengths are a consensus at the company and the formation of a knowledge database. Give a competitive advantage. To achieve better structure on the general development, that should run parallel with the projects, is something that needs to be improved. Although, it is difficult to find time for systematic development as the same resources are used in projects with clients.
C4	The company is an OEM, although, the order point is considered as an order from the Product Management. The specific product area is high-tech in strong expansion with rapid technology change and high competition. A clear development process with two separate organizations for product and technology development. Technology development takes place within the organization Concept which is a separate department that follows its own, less constrained, process compared to product development. Two separate organizations are problematic as "market believe that the product is ready, but it is just a prototype with an accompanying report". TRL is not used but this is starting to be introduced. Knowledge is lost in the handover from pre-development to project. However, the product area has established a "System Group" to overcome this.	There are several product families and a common factor is the size of the series / the components included. Families of products / brands are considered, but not always at the beginning of a project. The product family can grow organically. Modularization is used in design, some modules are identical over a large portion of the range, e.g. cutting systems. It becomes overspread for many models, but reduces product family complexity. A skeleton model is used with well-defined interfaces and rules as a basis for the design variant. It is unclear if the degree of customization of its products, but this is likely to increase, for example, by "late customization" to adapt generic products close to the dealers. Knowledge reuse is usually verbal, such as Cross-Functional Design Review. However, the use of design guidelines has increased. Validation is done by testing according to company's test codes. A lot of knowledge is available in connection with product tests.	Requirements from product department formulated in a standardized document Market and User Requirements. Content varies depending on who writes the document. The idea is that engineers should respond to this with a detailed specification. Difficult to measure certain requirements, varying levels of abstraction; for example, processed square meters, price, warranty. Support for requirements management exists and actions are taken for increased support.	By example, the term platform refers to the interface and key geometry of the moving parts in a two-stroke engine that can be reused. Otherwise, the platform comprised of physical components: components and packing / architecture. Challenges to the current platform include differentiation between brands. A physical platform may become outdated when new requirements come, such as safety standards or technology change. Platform based on components has too low flexibility when technology / legal requirements change rapidly. The term Time -To-Market is common: This means that there must be more ready-made designs to meet the demand, or to make deliveries less extensive. Interviewees were receptive to the idea to include non-physical platform elements such as flexible CAD models, trade-off curves, guidelines.

Table 4. Clusters for criteria on (S1), and types of (S2), new platform models.

	G1	G2	G3
S1	Definition Requirement management Interfaces Follow-up Knowledge building	Design re-use Common information model Product development process Enable set-based design Experience feed-back	Scope Maintenance Formalization User Friendliness
S2	Process Requirement management Roles Knowledge Simulation	Information integration Data handling and process model Product model Knowledge transfer	Methods Product models Preparation / operation of the platform

Regarding the <u>criteria</u>, the clusters Definition, Common information model, Scope, and Formalization points out a need of **an explicit, shared and clearly defined overall model**. Follow-up, Knowledge building, Design reuse, Experience feed-back and Maintenance highlights the importance of **supporting a platform that can evolve**. 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 is highlighted for successful implementation and use in operation.

When it comes to <u>new types</u> of platform models the clusters Process, Simulation Data handling and process model, and Methods gives an emphasis on **a process approach including activities with supporting methods**. Product model(s) point out that **item oriented models, with any kind of structure, should be included**. Knowledge and Knowledge transfer 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 need of **methods to manage the content** on various levels and for different stakeholders is emphasised by the cluster Roles.

3. Beyond modularization – Design Assets

A platform approach has been shown to be an enabler for 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 [2]. For ETO industry, a platform description, combining modular and task-based approaches have been previously introduced [19,20]. The following criteria on new platform approach supporting this are:

- an explicit, shared and clearly defined overall model
- supporting a platform that can evolve
- support multi-disciplinary work to manage changes in requirements

The types of models and means to be introduced includes:

- a process-oriented model including activities with supporting methods
- item-oriented models, with any kind of structure, should be included
- descriptions and design rationale should be supported
- methods that allows for adaptive behaviour
- methods to manage the content

The development of product includes many different tasks, and these can be classified, in ascending order of creativity, in six categories based on [21]:

- Selection – Choice of individual component among predefined set to satisfy specified constraints and objectives.
- Configuration – Choice of individual components (from predefined set) to be assembled into a system with specified properties ("catalogue design"). Choice governed by specified rules/constraints and objectives.
- Parametric Design – Dimension driven geometry that adapts a predefined base design (including topology variations) according to input specifications, formulas, methods, constraints or relations (template design).
- Configuration of parametric components – Combination of above.
- Redesign – Includes work to adapt, modify, improve and optimise an existing design solution to new requirements.
- Original design – The design task is defined by requirement specifications and given constraints but the principles as well as the details are left to the designer. Future variations of an original design concept belong to previous categories.

Usually, the design of a customized product includes a combination of these. Another characteristic is the alternation between synthesis and analysis [22]. System suppliers and ETO oriented companies have product concepts, however, these are more or less implicit, i.e. they are not fully described and managed in a structured coherent way, and include other assets and resources than pre-defined module. According to [12], a platform is the collection of assets divided into four categories. Two of these are:

- Components – the part designs of a product, the fixtures and tools needed to make them, the circuit designs, and the programs burned into programmable chips or stored on disks.
- Knowledge – design know-how, technology applications and limitations, production techniques, mathematical models, and testing methods.

3.1. Design Asset

Based on the above, new platform models that can evolve with experience and technology advancement are needed. Information, models, methods, and knowledge, beside pre-defined modules and components, of different levels of abstraction should be included. Multidisciplinary synthesis and analysis work, including diverse types of design task, where requirements are allowed to vary, 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.

The concept of **Design Asset** is introduced as a means to enable this. The concept is also based on the fact, that in many companies there exist diverse types of design resources, however, they are not shared, generalised, mapped, maintained, managed and developed. This is in contrasts with the prevailing practice in manufacturing, where a more systematic approach is applied for the manufacturing assets. Initially, eight domains of Design Asset have been identified: Process, Product, Synthesis Resources, Analysis Resources, Geometry Resources, Constraints, Solutions, and Projects. The modelling and mapping of these will provide an explicit and shared overview to support maintenance and systematic development. The collection of assets is a "toolbox" for the development team and each discipline can manage their own set of assets. When an asset is used, it is instantiated with a mapping to its origin to enable traceability. The Design Asset concept is part of the Design Platform approach [19,20] illustrated in Figure 1.
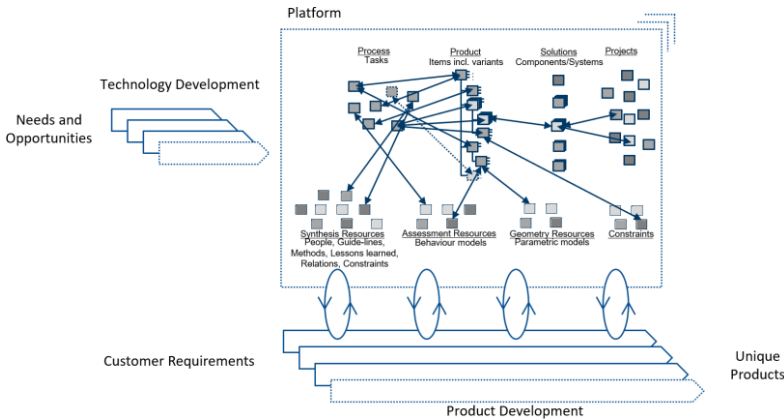

Figure 1. Design Assets as part of the Design Platform approach.

3.2. Focus for the Design Asset concept development

Industry representatives have confirmed that modelling and management of assets in a coherent way to support the design of customized solutions is needed and the principles of Design Assets as promising for this. Examples of assets have been described in previous work [20, 23] together with applications in industry. The focus for the Design Asset concept development will be on means to: capture, describe, model, store, share, instantiate, execute, identify target condition, evaluate the status of different assets (e.g. TRL), identify areas of improvement, enable continuous development, maintain, apply different views, support version control, and enable traceability.

3.3. Focus for case-studies at the companies

(C1) provides products that are completely custom engineered in an internationally 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. Automation of design and production preparation by the use of knowledge-based engineering (KBE) has been used at the company for more than a decade to enable evaluation of different design solutions, however, new approaches and models are needed to support quick introduction of

emerging high-fidelity discipline methods for design and analysis. The ongoing trend in the aircraft industry is a shift from production in low volumes to larger quantities, shorter lead-time in development combined with the continuous strive for decreased weigh for reduced fuel consumption. The company has adopted different platform models but needs increased support to quickly introduce new technologies, adapt to changes in requirements, make assessments of implications and balance trade-offs. The focus will be on methods and tools, Design Assets, for new materials, product solution and increased complexity integrated in a heterogeneous platform environment.

(C2) has to be able to quickly launch a roof rack for every new car model. However, every model requires an individual adapted attachment consisting of a footpad and bracket. The trend in the car industry is a higher pace in the introduction of new models on the market. Product development needs new support to be able to provide a higher variety of products at a higher speed. It is not enough to only focus on the design activity; crash simulation and tooling design must also be included. In order to maintain the position as a market leader, the company has to increase its ability to manage changes using a platform strategy. A platform has to be able to include heterogeneous descriptions and support product design, crash simulation, tooling design and increase the ability to master changes in requirements during design work. A flexible product architecture including Design Assets combined with management support of the platform descriptions will be in focus.

C3 has started to work with a platform strategy on two levels; products including their variants; and a general technology platform that includes design solutions. When a bid is won, the final solution has to be designed to comply with the customer's specification and the changes in requirements that occurs during the order design phase. The company needs increased product adaptability and new methods to swiftly assess implication of changes. Industrialised wood construction is very complex. Integrated designs with smart solutions are required to cut cost but, at the same time, shared solutions are required to get the economy of scale. The company needs a coherent platform model supporting increased customization, shorter development lead times and an increased ability to master changes in requirements during product design. The focus will be on well-defined product architectures and methods for modelling of product and engineering tasks. Design Assets, combined with management support of the platform descriptions.

C4 continuously work with reduction of cost and time to market. Platform modelling have been introduced on a smaller scale, mainly modularization, in some projects but a comprehensive approach is needed, including development and management of different assets, in the platform strategy to support swift introduction of new technologies and increasing diversity among customers. It is not feasible to work on large platform development projects. The company has a wide assortment of product variants and brands for different market and customers. Optimization and integral product architecture are combined to keep the weight down for low energy consumption and easy operation for customers. The company needs a platform approach where some systems are modularized whilst others are integral and optimized, Design Assets. The rapid evolution in battery technology and IoT also calls for new means to describe technology, Design Assets, for easy introduction and adaptation.

4. Conclusion

A platform approach enables efficient customisation, reuse and production standardization. With a higher pace in design, increased level of customization and rapid technology development, platform models beyond modularisation are needed. The concept of Design Asset is introduced for that purpose. The objective is that systematic modelling, upgrading, development and structuring of heterogenous design assets will improve the agility when it comes to the development of solutions for different customers' demands, the mastering of fluctuating requirements appearing during the development, and the continuous integration of new technology. Industry partners have confirmed that it is a promising approach and further development, realization and evaluation of the Design Asset concept will be part of upcoming case studies.

References

[1]   N.N., *Industry 4.0 Upgrading of Germany's industrial capabilities on the horizon*, Deutsche Bank AG, Frankfurt, 2014.
[2]   U. Högman, D. Bergsjö, M. Anemo, H. Persson, Exploring the potential of applying a platform formulation at supplier level - The case of Volvo Aero Corporation, *Proceedings ICED 09*, 2009, pp. 24-27.
[3]   K.T. Ulrich and K. Tung, Fundamentals of product modularity, *Proceedings of ASME Winter Annual Meeting Symposium on Design and Manufacturing*, 1991, pp. 73–79.
[4]   G. Erixon, *Modular function deployment – a method for product modularisation*, Ph.D Thesis, The Royal Institute of Technology, Stockholm, 1998.
[5]   L. Hvam, N.H. Mortensen and J. Riis, *Product Customization*, Springer-Verlag, Berlin, 2008.
[6]   N.N., *Scania Annual and Sustainability Report 2016*, Scania AB.
[7]   J. Stjepandić, E. Ostrosi A.J. Fougères and M. Kurth, Modularity and Supporting Tools and Methods, J. Stjepandić et al. (eds) *Concurrent Engineering in the 21st Century*, Springer, Cham, 2015, 389-420.
[8]   B.L. Hansen, *Development of industrial variant specification systems*, Tech. Univ. of Denmark, 2003.
[9]   M.H. Meyer and A.P. Lehnerd., *The power of product platforms - Building value and cost leadership*, The Free Press, New York, 1997.
[10]   T.W. Simpson and Z. Siddique and J. Jiao, *Product platform and product family design - Methods and application*, Springer science Business media, New York, 2006.
[11]   M.E. McGrath, *Product strategy for high-technology companies*, Irwin, New York, 1995.
[12]   D. Robertson, K. Ulrich, Planning for product platform, *Sloan Management Review*, 1998, pp. 19-31.
[13]   S. André, R. Stolt, F. Elgh, J. Johansson and M. Poorkiany, Managing fluctuating requirements by platforms defined in the interface between technology and product development, *Advances in Transdisciplinary Engineering, Vol. 1*, IOS Press, Amsterdam, 2014, pp. 424-433.
[14]   T.W. Simpson, Product platform design and customization: status and promise, *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, Vol. 18(1), 2004, pp. 3-20.
[15]   W.J. Verhagen, P. Bermell-Garcia, R.E. van Dijk, R. Curran, A critical review of Knowledge-Based Engineering: an identification of research challenges, *Adv. Eng. Informatics*, Vol. 26, 2012, pp. 5-15.
[16]   J. Johansson, Howtomation suite - a novel tool for flexible design automation, *Advances in Transdisciplinary Engineering, Vol. 2*, IOS Press, Amsterdam, 2015, pp. 327-336.
[17]   F. Elgh, Decision support in the quotation process of engineered-to-order products, *Advanced Engineering Informatics*, Vol. 26(1), 2012, pp. 66-79.
[18]   L. Almefelt, F. Berglund, P. Nilsson, J. Malmqvist, Requirements management in practice: findings from an empirical study in the automotive industry, *Res. in Engineering Design*, 17(3), 2006, 113-134.
[19]   F. Elgh, S. André, J. Johansson, R. Stolt, Design platform - setting the scope and introducing the concept, *Proceedings 14th International Design Conference*, 2016, pp. 1253-1264.
[20]   S. André, F. Elgh, J. Johansson and R. Stolt, The design platform – a coherent platform description of heterogeneous design assets for suppliers of highly customised systems, *Journal of Engineering Design*, Vol. 28(10-12), 2017, pp. 599-626.
[21]   D.G. Ullman, *The mechanical design process*, McGraw-Hill, New York, 1997.
[22]   N.P. Suh, *The principles of design*, Oxford University Press, New York, 1990.
[23]   F. Elgh, S. André, J. Johansson, R. Stolt, Design platform: a coherent model for management and use of mixed design assets, *Adv.Transdisciplinary Eng., Vol. 5*, IOS Press, Amsterdam, 2017, pp. 327-336.