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DESIGN PLATFORM - SETTING THE SCOPE AND INTRODUCING THE CONCEPT

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1. Introduction

Customisation refers to the ability and the strategy that aim towards the design and manufacture of tailored products for individual customers. Depending on where the actual customization starts, four different business models can be identified: Engineer-to-order (ETO), Modify-to-order, Configure-to-order and Select variant [Hansen 2003]. For the latter two, product platforms have gained a lot of success as enablers for efficient customisation. Several definitions of the product platform concept can be found in literature and depending on which definition is used, a product platform can be many different things. The existing definitions ranges from a platform consisting of components and modules [Meyer and Lehnerd 1997], a group of related products [Simpson et al. 2006], a technology applied to several products [McGrath 1995], to a platform consisting of assets such as knowledge and relationships [Robertson and Urlich 1998]. This is also reflected among suppliers, as shown in [André et al. 2014], where platform descriptions are categorised on four levels of abstraction and compared to the customisation strategy. Platforms are generally described to be of one of either two kinds: (1) Module based (discrete) is characterised by sets of components being clustered into interchangeable modules that together form the product. The module-based platform can either be integral, where functions are shared by several modules, or modular, where each function is delivered by a separate module. (2) The second platform approach is the scalable platform. This platform supports adaptation by the stretching or shrinking of the product instances following variations in design variables [Simpson 2004].

A platform approach has been shown to be an enabler for efficient customisation, reuse and production standardization. Johannesson [2014] questions if companies have a choice regarding implementing a platform or not since platforms can exist on several levels making them useful to all kinds of companies. 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 [Högman et al. 2009]. The question is - what kind of platform can ETO-oriented suppliers work with? This paper will address this question.

The overall research approach used in this work is based on the one suggested by Blessing and Chakrabarti [2009]. The work is part of a three-year long research project in close collaboration with four companies where joint activities are combined with focused case studies. This work reports the findings and the development of a concept up till the work package Formulation of tentative framework (Figure 1). The information about the presented cases has been gathered from meetings, demonstration of applications, reviews of documents and in-depth interviews.

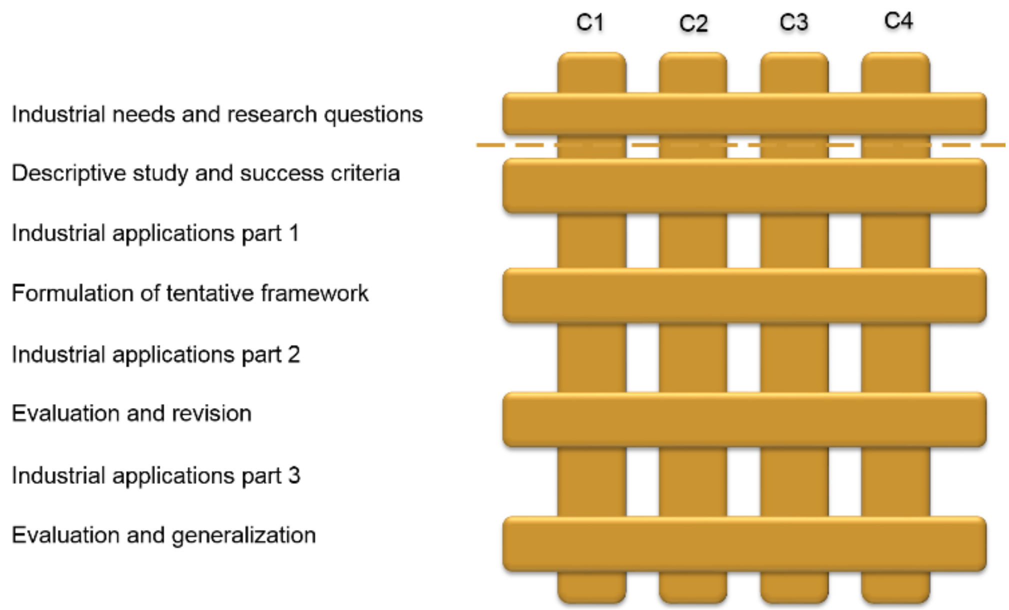

Figure 1. Research model

2. Platforms at ETO-oriented suppliers – practice and needs

The use of a product platform, where external and internal efficiency is well balanced, has been acknowledge as a strategic enabler for mass customization. There are many examples of successful implementation of a platform strategy based on a modular product architecture by OEMs. However, the adoption of such a strategy seems not to be very common among suppliers working in an ETO-oriented business environment where unique solutions are developed for each customer. The solution can be based on a shared concept, however, this concept is more or less implicit and includes more than pre-defined modules, if any. The development projects are executed in close collaboration with the customers and can run for years where changes in the requirement specification are frequently faced. When the final design is set, the production quantity is determined by the need of the customer. To get a deeper understanding about product development and use of platforms as well as the need of improved support in ETO-oriented suppliers, four companies have been involved in this research, Table 1.

Table 1. Characteristics of the four case companies

Company	Business area	Nr employees in the studied organisation	Nr employees total in the company
C1	Automotive	300	3 000
C2	Product and production system	70	150
C3	Automotive	600	10 000
C4	Aerospace	2 000	44 000

2.1 Product development and the use of platforms

The overall models for product development (PD) at each company and the support by any kind of platform are summarized as followed.

C1. Four different project types exist to support PD at C1. The company have one full featured five gate development process consisting of the phases: market research, concept phase, design phase, production engineering and production. The other project types are derivatives from the full featured one. C1 develops their product platforms as general as possible. It is very important for C1 to make sure the platforms are scalable, ensuring the inclusion of products targeting different customer segments. The reusable assets at C1 are realized through modules and shared components and they try to keep the number of variants as low as possible. C1 has policies for capturing the experiences in several documents, but still some information is lost. Therefore it is emphasized by the company that new engineers work with and learn from more experienced ones. A project documentation is used called “lessons learned” aiming to store the main issues that have been noted during the project such as problems, obstacles, tricks, and some issues that should be avoided.

C2. The PD processes for C2 is similar to C1 with a few differences. Market research is not part of the process. The concept phase is divided into idea generation and concept development. No formal gates exists except for acceptance between concept development and PD. C2 sees themselves as a service company that can offer PD as well as customized machines. In this way they can offer theire customers production systems customized to the products they have developed. The reusable assets is made out of the knowhow and the modules and components used for the manufacturing the customized machines. The PD development deliverable is a requirement specification for the machine developer and manufacture, all within the same company. Experience is passed on through different documents (e.g. CAD-files). When problems or questions arise, the customer can get in contact directly with the engineers. This supplies the engineers with first-hand information from the customer.

C3. The product development process at C3 is initiated by an inquiry from the customer. The Knowledge Owner (KO) determines if the technology exists, analyses the requirements and search for available technologies to solve the problem. One or several proposals are then given to the customer in different price ranges. At C3 the PD process aims at front-loading the projects. The development model is a gate model containing four phases much similar to C1. Market research and concept development are however part of the first phase. The PD process includes a reflective phase where Knowledge Briefs (K-briefs), carrying lessons learned, problems and inventions, are developed. This document can also contain descriptions ranging from a broad scope, e.g. a product concept to details, e.g. component. The K-briefs are stored in a tree-like structure in which the KOs can browse for solutions. In order to streamline the handling of a product concept, there is a set of basic components that are to be adapted to the case at hand. Efficiency is achieved by dedicating one person per product concept, the KO, which answers questions from market concerning the concept´s ability to adapt to customer specifications. To be able to answer such questions, trade-off curves originating from the K-briefs can be used. The trade-off curves shows the relations between important design parameters and aids the KO in determining the validity of the product concept. A finished product concept design is controlled by the top assembly with underlying articles in the PDM environment.

C4. C4 uses a gated process for PD with two main parts: Plan product (develop new technology or explore product concept) and Develop product (for specific customer). The phases are much like the ones of C1 and is well described in the company organizational system. The company has three different platforms: a technology platform, a product platform and a manufacturing platform, which are all extensively defined. C4 views a platform as an explanation model that contains a set of rules and standardized methods used in the development process. The platform is most useful for the company when something done earlier is reused and is then used as a start point in the next project. The platform differs from the one identified in automotive companies (C1 and C3), having no versions, are not made out by physical components and is continuously evolving. The company uses a wiki that is editable by anyone in the company. This enables easy capture and access of knowledge and experiences across the company.

To be observed is that only one company (C4) uses the term platform internally. For the others, the platform constructs and their relations were identified by the research team. The main conclusion is that there exists parts that could be integrated, improved and when combined with additional constructs form a coherent platform description to be used in product development.

2.2 Success criteria, abilities and support

The overall objective of the research project is “A novel method to develop and describe adaptive technology solutions supporting an increased ability to manage changing and conflicting requirements in the development of customized products.” To get a firmer grip on what effects the companies want to achieve and to ensure that the project works in that direction, success criteria with associated indicators were defined and ranked. Further, the companies were asked about their view on improved abilities and support to manage changing and conflicting requirements. In Table 2, the success criteria with measurable indicators identified by practitioners at the companies are presented. A ranking of the success criteria was done at each company and aggregated for the whole project. They ranked Reuse knowledge (T1), as the most important followed by, Time to respond to quotation (L2) and Time spent in project (L3). Short start-up time (L1), Time invested in building a system support (L5), Assure that the requirements are fulfilled, (Q1) and Number of loops (Q3) are in a third ranked category. The difference in prioritization increases successively, although, they all pointed out that none of the success criteria was unimportant.

Table 2. Success criteria and indicators

	Category	Success Criterion	Indicator	Rank
T1	Transparency	Reuse knowledge	Time to access and understand relevant information	1
L2	Lead time	Time spent to respond to quotation	Time	2
L3	Lead time	Time spent in project	Number of design hours per project	
L1	Lead time	Short start up time	Time spent to introduce a new user	3
L5	Lead time	Time invested to build the system	Investment/use	
Q1	Quality	Assure that requirements are fulfilled	Number of changes after verifying tests	
Q3	Quality	Number of loops	Number of formal design loops required to achieve series production	
P2	Productivity	Support the designer	Assessment by designers	4
P3	Productivity	Re-use components	Number of carry-over parts	
T2	Transparency	Keep up to date	Time spent on documentation	5
T3	Transparency	Exchange of information	Time spent to hand over information between different persons	
L4	Lead time	Time to implement design changes	Time	6
Q2	Quality	Lower number of errors	Number of changes in series production	
Q4	Quality	Keep the project time	Number of projects ready on time	
Q5	Quality	Precision in quotation	Compare quote with revenue per deal	
P1	Productivity	Resource utilization	Number of designs created/design hour	

In workshops with all companies, abilities and support that would improve their work when facing fluctuating requirements where addressed by two questions. The first question was:

1. What would increase your ability to continuously manage changing and conflicting requirements when developing customised products?

C1 statements. Parallel solutions and concepts. Cost calculations. Efficient ways to estimate costs. Involve the right competence. Increased the number of variants. Access to and visualisation of trade-offs.

C2 statements. Clarity around concepts, terms and requirements. What is the customer or internal staff really asking for? What has been done before? Is there any similarities with what we have done in the past? Communicate with the part setting the requirements. Inform about what effects changes can have on cost and time. Specify what requirements that have a high possibility to change. Make clear in what phases the requirements are allowed to change. Increase the general understanding of what changed requirements implies.

C3 statements. Better access and knowledge about product data internally to get measurements, estimate cost and find what have been done before. Access cost estimates for each article. Access to trade-offs.

C4 statements. Being able to incorporate adaptability in new technologies. How can the technology adaptability be secured when it is to be used in another product (with e.g. changed dimensions) than what the technology has been validated for and then even manage the fluctuating requirements during PD. Adaptive technology solutions that can handle scalability and load cases. Know the limits, band widths and flexibility. Evaluate producibility since it often comes in as a problem late in PD. To separate

the terms conflicting and fluctuating. Visualising the effects of changed requirements, ability to question and evaluate different requirements in order to discuss conflicting ones with the customer. Methods to visualise the effects of fluctuating requirements.
C1-C3 give answers that emphases increased reuse of assets and the use of trade-off curves. Ways to calculate and estimate cost is also sought. C4 points out adaptability as an important means. They wants to be able to describe the adaptability of a technology and to make use of this description when the technology is to be used in a new application.
This was followed by a second question:

2. What descriptions can support the work of customising adaptive technology solutions?

C1 statements. Simulations validated through test results. CAD-files, BOM, generic product structure. Prototypes. Product cost calculations and analyses in order to track costs.
C2 statements. Design rational.
C3 statements. Graphical presentations. Descriptions of standards. Problem and solution descriptions that are coupled to the product and not the project. Visualisation of the product or component (picture). Access to descriptions of performance, FEM calculations coupled to the product and not the project.
C4 statements. Enrich the product model. Today they can describe some adaptability on geometry level such as distribution of dimensions. But what does adaptability mean for material etc.? The result of TD is a technology description consisting of reports etc. An adaptivity section would be useful in the report that is handed over from TD to PD to describe the possibility for adaptation of the technology. Can adaptability be represented? Can a map be made where each category's adaptability is described?
C1-C3 gives similar answers emphasizing cost descriptions and decision support which should be quick and easy to understand. Many of the proposed descriptions are created today but not always saved in a useful format or structured to enable access in the future. Design rational is pointed out as an interesting field. C4 propose descriptions which is of a new kind and is not used in the companies today. The proposition is to enhance the product model with information that can embody adaptability.

2.3 The outlook of a coherent ETO platform

From the first question that was asked to the case companies it can be concluded that there are many ways to increase the ability to manage fluctuating requirements. The answers to the second question shows that the descriptions that are used and could be used for this purpose are many and diverse. In order to work platform-based, these ways of working and describing solutions need to be supported. However, the methodologies and models for working with platforms have for a long time focused on physical component-based product platforms. It is however assumed that the positive effects from using a platform can also be gained by other constructs on different levels of abstraction. An issue with product platforms is that they are rarely allowed to evolve. For suppliers of customized systems, however, the evolution of knowledge and the uncertainty regarding future customer requirements requires a platform description that is allowed to evolve over time.

3. A generic Design Platform for ETO companies

For companies working in an ETO business model there is a need of a coherent platform model that support customization and easy adaptation to fluctuating requirements during the course of a development project, Figure 2. This ability is gained by:

- Acknowledge change
- Apply a set-based approach in scoping, quotation and order processes
- Foster reuse
- Provide adaptable solutions defining design spaces
- Develop an ability to efficiently redesign and assess the implication of changes

What is missing is a platform description to support the development in order to gain the benefits from platform thinking to a higher degree. However, it is not uncommon that suppliers devlop single instances in every TD and PD project rather than systematically develop a shared platform from which instances can be derived. This is especially true for companies developing and manufacturing ETO products. The challenge of using a module- or component based product platform can have several reasons such as unknown and ever-changing interfaces to the system the product is to be integrated into, different markets, different product useage, individual preferences and a relatively low number of developed and manufactured products. The platform should also support continuous evolution and the reuse of items used in previous projects. Reuse goes hand in hand with platform thinking as a way to keep the design effort efficient and at a manageable level. The platform introduced in this work is not only composed by the physical elements that is the product, rather it consists of different integrated models that supports the designing of the product. Therefore the name "design platform" is more suitable than "product platform" since it refers to both the activity as well as the thing.

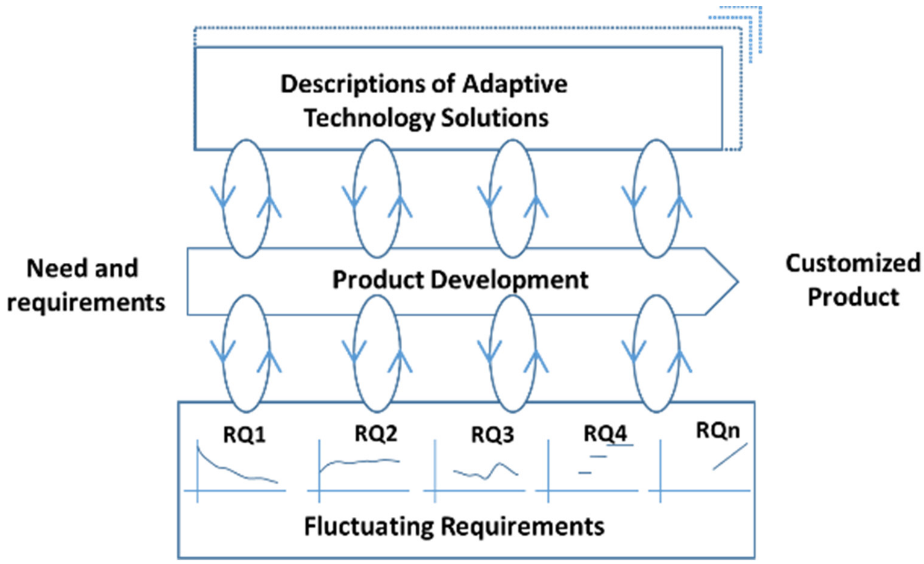

Figure 2. Matching of fluctuating requirements with descriptions of adaptive solutions

3.1 The Design Platform concept

A Design Platform is composed of different objects related to Process, Synthesis Resources, Product Constructs, Assessments Resources, Solutions and Projects, Figure 3.

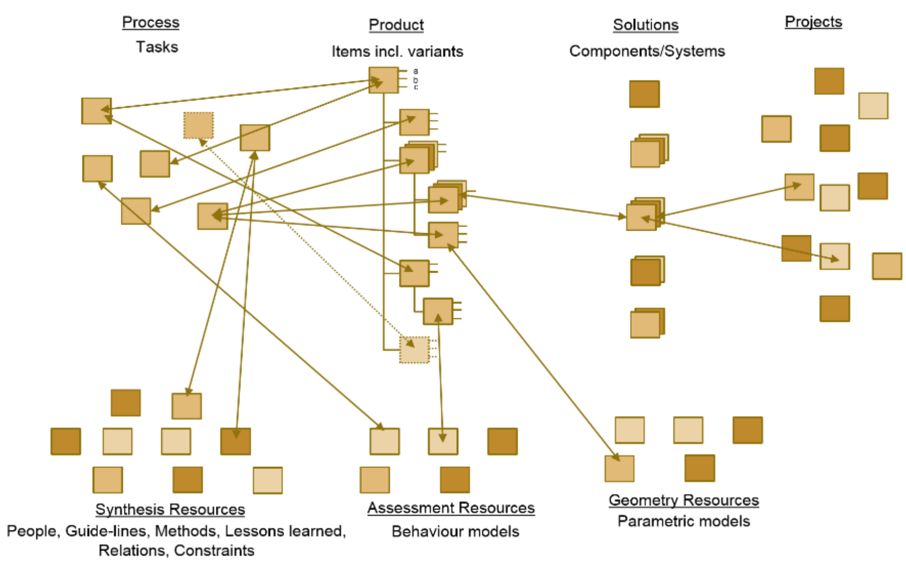

Figure 3. A model of the generic Design Platform

The Design Platform structure consists of Items (parts and sub-assemblies) at different levels of realization. Standard Items (Geometry) are components that are purchased or made to stock. These cannot be changed. Automated adaptable, flexible or tailor made Items (Geometry + Logics + Constraints) are components that are mathematically defined in CAD-models so that they can easily be changed and still have a sound geometry and be manufactured. Tasks to complete the embodiment for these parts are partly or fully defined. These component are normally developed and produced by the company (in future parts-manufacturers may provide such adaptable components with their entire design space embedded into the geometrical model). Non-automated adaptable, flexible or tailor made Items (Geometry + [Logics] + [Constraints], [ ] indicates optional parts) are components that are mathematically defined in CAD-models so that they can be changed and still have a sound geometry [and be manufactured]. These components are developed and produced by the company. The logical model might not be complete. The constraints definitions on these models are normally scars. The focus is often on the adaptable geometrical model. Specialized or engineered Items (Logics [+ Constraints]) are components that are developed from time to time at the company but where the geometrical differences are that big that no general geometrical model can be developed. The focus is on developing the logical model, including tasks, and to some extent the constraints. When demanded the logics and tasks are configured into a process that is executed (manually, semi-automatically or automatically) to render the components.
The introduction of continuous evolving Design Platforms that encapsulates different descriptions and carriers of information and knowledge requires the following actions:

- Define solutions as design spaces (continuous or discrete)
- Generalize product structures
- Mapp existing solutions (components/assemblies) and projects
- Develop parametric geometry models
- Assess trade-offs
- Retrace, improve and publish engineering processes
- Define tasks with supporting methods, guidelines etc.
- Build knowledge, skills and abilities (competence teams)
- Improve by experience from product development
- Organize management of the platforms

In addition, support is required to efficiently feed the Design Platform from TD. This include collect, fine tune, prepare and transfer models, methods, guidelines etc. It is essential to build knowledge about solution spaces and not just single instances

3.2 Application of the Design Platform concept

In order to develop or improve current support for a platform description for efficient product development, the scope and objectives for joint activities where set at each company. The following four cases where defined so that they each would contribute to the shared Design Platform model.
C1. Has an add-in to a CAD-software that works as a geometrical search engine and is used to search for previous designs that could be candidate solutions for new customer enquries. The computer system contains models for a number of types of components and is one example of how technical know-how can be formalized and automated using computer programming. The formalization and the automation was a big effort and was done when a product concept already existed. When a product concept is develop, the underlying technology has to be described and formalized in a way that makes it easy to subsequently automate. The research case aims to identify what models and descriptions are needed to do so, and also to some extent try to develop them during the technology development. There is also a vision to be able to capture the underlying documentation for decisions during the technology development process.
C2. The company provides automation services, robotic solutions and special products to the manufacturing industry. It is an "all inclusive" service where the products as well as related production equipment is developed. In order to support decision making during the development process, the related information should be easily searchable and accessible, and the information should be presented in a

proper way. It is believed that a visual protocol, presenting the information in graphical format instead of textual format, is more efficient, especially when there is a need to compare modified versions of a design. Graphical presentation on a shared workspace enables retrieval of information by all involved practitioners without need for training in specific software. C2 aims to investigate the technical difficulties in finding information (e.g. level of access, privacy, file formats and indexing) of existing solutions, components and assemblies by one software and how to use another software for efficient visualization in order to support decision making, and thereby shorten the development time.

C3. When the company receives a customer inquiry, the subsequent quotation process is completely manual. At the moment, there are issues regarding lead time and precision in the quotation process. The company wants to reuse existing components as far as possible in order reduce the cost of development and tooling. Reuse of components is hard since there is a lack of support in the PLM system. Each designer has his/her own way of saving information and knowledge. There is a principle to structure technology and product knowledge called K-briefs. The process of creating, saving, structuring and managing them is lacking which makes it hard for engineers to use them. The company faces changes in requirements and geometrical interfaces which makes it unlikely for a former developed product instance to be reused completely. The objective is to introduce a support including a better way of describing and structuring what has been done previously and display it for the engineers. This will help in finding what is actually exists. To enable redesign or support in designing new solutions, an ability to manage other kinds of knowledge than highly concretized items is also essential. This in order to aid the designer when a component does not exist, but similar ones have been designed before, or in the development of a new component by means of methods and guideline governing the design.

C4. The company has a development process where new technology is introduced pre-sales, without having a customer. They try to predict requirements of the next aero-system and new technology concepts are created which are evaluated in automated multi-disciplinary numerical simulations in a tailored software packed. The main objective is to study the effect of parameters' changes on the performance of the areo-system. This will provide an understanding of the design options for the concept. The study will result in settings for parameters which are most favourable. A number of candidate designs are identified and further evaluated and finally presented to prospect customers. Currently, it is not evaluated how the manufacturability is effected as the values of the parameters changes. One aspect that is effected is the reachability with the welding equipment. For some values of the parameters, a change of welding method and / or technique is necessary which will also affect the cost. The decision between candidate concepts could include manufacturing cost. There is also an objective to improve the models in the tailored software and use them in the actual product development.

A mapping of current and future practice to the generic Design Platform model is depicted in Figure 4.

C1 has a support for finding similar existing components and a general product structure. Parametric CAD-models exist if new designs need to be defined. Other resources exist to some extent. The future objective is to define tasks with associate resources and identify a process that can be executed semi-automatically in PD.

C2 has support for searching of candidate existing solutions. The objective is to further support PD by the development of synthesis, assessment and geometry resources together with descriptions of product constructs and tasks, however, the latter two are unstructured due to that the final products are very unique.

C3 has a mapping between projects and components. The objective is to develop synthesis, assessment and geometry resources together with descriptions of product constructs and tasks. The product constructs are to be structured and tasks organised in a process to be executed manually in PD.

C4 has synthesis, assessment and geometry resources together with descriptions of structured product constructs and tasks organised in an automatically executed process. However, the platform is only used pre-sales in scoping and learning activities. There is an objective to improve and transfer this platform so it can be used in PD. There is also a need to incorporate methods for producibility assessment and traceability to products in use.

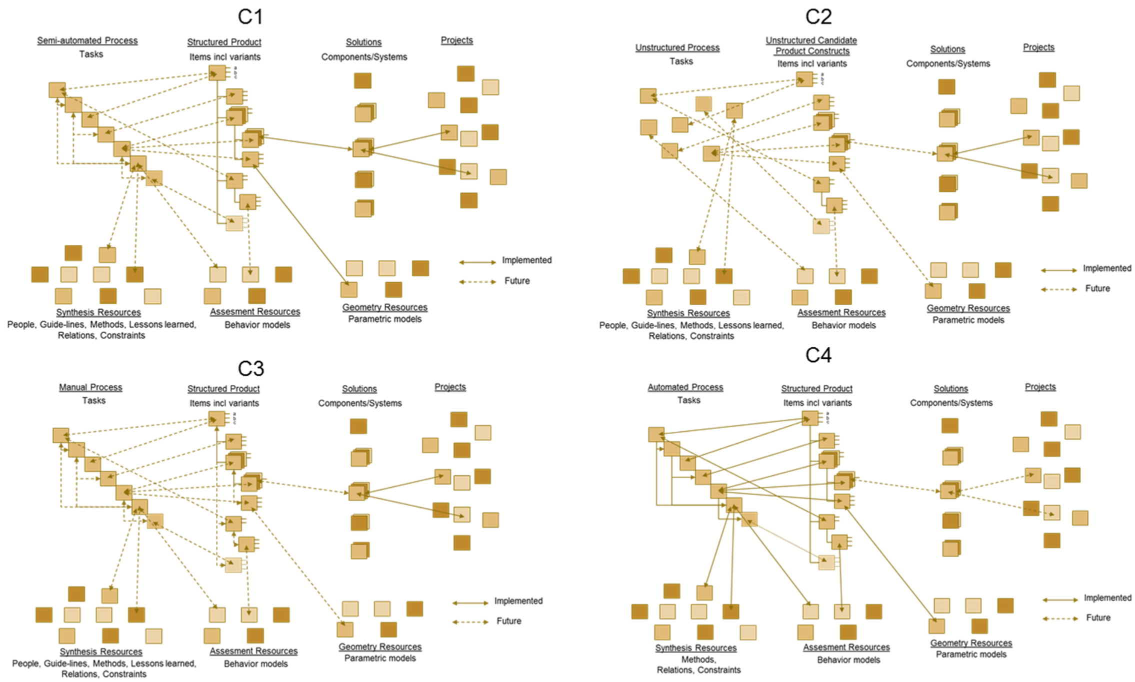

Figure 4. Implemented and future Design Platforms at the case companies

For suppliers it becomes more and more important to proactively develop new technologies to be competitive partners in joint development initiatives. In some case, the supplier takes full responsibility for creating a solution for a sub-system in accordance to the functional needs defined by the OEM. The OEM expects to be presented with new and better solutions than existing that will give them a competitive edge. The supplier, on the other hand, can by the development of new technology stay ahead of the competitors by marketing activities and gain economy by scale using the technology in different solutions for different customers. Technology development aims at developing knowledge, new technology (e.g. artefacts) or a technical capability (e.g. skills) in order to enable development of new products. Deliverables can also include demonstrated feasibility or a technological platform. Examples include changed material (e.g. composite, nano etc.), changed manufacturing technology (e.g. additive manufacturing) or changed technology (e.g. electric engine). According to Clausing [1996] TD and PD should be separated to:

- enable time for creativity (without holding a product program hostage)
- provide a creative environment
- develop flexible (robust) technologies that can be used in several products
- minimize risk and have control over cost and lead time

this is however not always practiced in industry. In ETO industries, some technology development initiatives are separated whilst others are combined with product development projects taking a more evolutionary approach to the development of new technologies. Independently of approach, the new technology should be adaptable and describe in a way that support efficient customization. This calls for actions in technology development and technology transfer. Technology transfer is acknowledge as a required action to bring the new technology from TD to PD and make it ready to be used. The following guidelines support the work of feeding the Design Platform with adaptable solutions.

Guidelines in TD initiatives to develop technology that can adapt to fluctuating requirement as an alternative to one single over-specified solution:

- Identify future range of application
- Identify critical requirements and constraints of the range
- Identify the relevant distribution of each critical requirements and constraints
- Define a guiding set consisting of combinations, instances, that sufficiently covers the space drawn by of requirements and constraints

- Develop (synthesize and analyse) the technology with the guiding set as input
- Assess continuously the technology bandwidth in relation to the guiding set and identify gaps, causes and possible countermeasures
- Ensure a sufficient level of documentation and management of models (test protocols, CAD, FEA etc.)

In technology transfer the scope is extended to include the definition of a technology design space with supporting documents, methods, models and tools. The design space, bandwidth, and trade-offs is drawn by the development of:

- activities that govern the work of generating an adapted solution
- methods to define properties
- parametric CAD-models (constitutional models)
- simulation ready behaviour models
- trade-off curves
- rules for controlling product constructs
- guide-lines for manual work
- structures for lessons learned and other supporting documents
- expert support

Finally, the Design Plaform should be managed as an important asset and it should be able to evolve as knowledge is gained of its application in PD. Its completeness and the maturity of the different constituting parts should be continosly reviewed to ensure and improve the platform's usefullness.

4. Conclusion and future work

This work addresses an area in platform based development where not much has been explored. The body of knowledge in the areas of component and module based product platforms as well as in knowledge reuse is extensive, but the combination of the two with a focus on suppliers in the ETO business is missing. Only one company in this work used the term platform explicitly, however, the other three have parts that could be integrated and improved. With additional constructs, this could form a coherent platform description to be used in product development. The overall objective of the research project is "A novel method to develop and describe adaptive technology solutions supporting an increased ability to manage changing and conflicting requirements in the development of customized products." Such a method is expected to increase the reuse of knowledge primarily and reduce the time to respond to quotation as well as the time spent in projects. Reuse of assets, the use of trade-off curves adaptability of solutions together with means to estimate cost are pointed out as important to increase the ability to continuously manage changing and conflicting requirements when developing customised products. Descriptions that would support the work of customising adaptive technology solutions include cost and decision support which should be quick and easy to understand. Many descriptions are created today but not always saved in a useful format or structured to enable access. A platform definition, called Design Platform, consisting of knowledge in combination with manufactured solutions is introduced. This platform provides a coherent environment, to be used as a means to systematically develop, manage and use corporate assets in ETO industries. The model is built upon the needs identified in cooperation with four companies. The model can describe both the companies' current state and future target condition. Future work will consist of further improvements and evaluations of the concept. A system is currently developed to support implementation in practice. How to manage a Design Platform in a PLM-environment, formal modelling and supporting theories of the constructs will also be subject for future research.

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