MODULARIZATION MANAGEMENT AND NETWORK CONFIGURATION

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Abstract

A given product structure will have a crucial effect on the performance of the operations network. The product structure will impact the potential configuration of the product according to the customer needs, and, furthermore, impact the cost, quality and speed of delivery. It is generally recognized that a modular product structure will have an improved effect on all of these performance parameters, but empirical studies prove that many companies are challenged in realizing the full benefits of modular product structures. This paradox indicates that the cause-effect relationships between modularization and realized benefits are complex and comprehensive. Though a large number of research works have contributed to the study of efficient and effective modularization management it is far from being clear. Based on case based empirical studies the paper will present two frameworks to support the heuristic and iterative process of planning and realizing modularization benefits. This is to be seen as the critical elements in efficient network configurations

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1 INTRODUCTION

The concept of modularization has a strong strategic impact. However, despite the many reported success stories there still seems to be confusion about managing modularization in order to realize the potential benefits. A recent study revealed that companies in general were not able to realize the expected benefits three years after the launch of a modular product family (Hansen & Sun, 2010). The study also demonstrated that companies had to realize most of the benefits in the process of configuring operations network. The complex problem of configuring operations networks is illustrated in the 4D Modularization Model (see figure 1).

The model illustrates that the product structure can be seen as the basis for configuring the operations networks. However, the product structure will only support in realizing the potential benefits when it is utilized in the three additional dimensions. This is configuration to customer needs (Market Dimension), configuration to process capabilities and thereby cost and quality (Process Dimension), and, configuration to supply chain architecture and thereby speed and predictability in delivery (Supply Chain Dimension). A number of research contributions have demonstrated that these alignments between the four dimensions can be improved significantly by applying modular product structures (Sanchez, 2000), (Fine, 1998), and (Pasche et al., 2011). However, a number of research contributions do also demonstrate that most companies face serious challenges in realizing these potential improvements (Hansen & Sun, 2010) and (Pasche & Sköld, 2012).

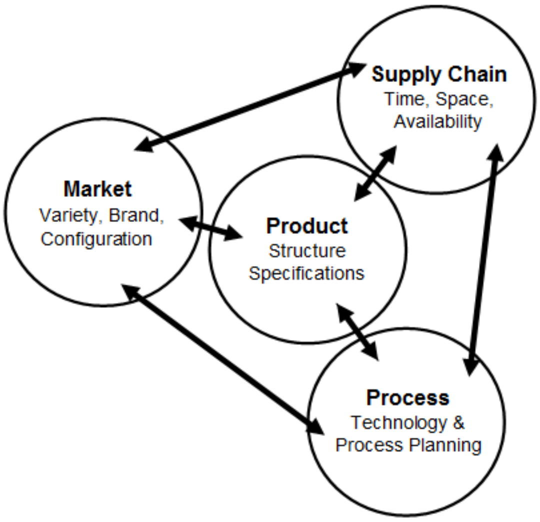

Figure 1. The 4D Modularization Model (Hansen & Sun, 2011)

The challenges in realizing modularization benefits can be explained by the complexity and the cross-disciplinary nature of the processes that involve product development, sales, service, supply chain, and the similar organizational functions at external suppliers.

The successful companies in realizing the modularization benefits also regard the effort as being highly confidential due to the importance to their competitiveness (Fine, 1998).

In the absence of best-practice models the companies can make use of more generic frameworks that can support their individual efforts. Our empirical research effort has developed two such generic frameworks that can support companies in configuring their individual processes. These generic frameworks will be presented in the paper.

2 RESEARCH SETUP

This study is based on open-ended interviews with managers representing 43 industrial modularization cases. Some companies have provided more than one case and the total number of participating companies is 23. The study is still ongoing and more cases are continuously included. The purpose of the study is to generate qualitative insight regarding how companies have organized their modularization efforts and to analyze to what extend they have been able to realized benefits from these efforts. Furthermore, the qualitative studies have aimed at investigating how the discovered phenomena could be researched further in a future large-scale quantitative study (Eisenhardt, 1989). The case-studies have largely followed six steps:

1. Initially the companies and prime contact persons were identified.
2. The first visit aimed at identifying relevant products and the modularization approach chosen by the companies.
3. A number of interviews were conducted at each company and supplementing materials were gathered and analyzed.
4. The next step focused on how the needed cross-organizational collaborations were established and how this impacted the realization of modularization benefits.
5. After the analysis phase the companies were involved in establishing a retrospective comprehensive model of their modularization effort so far. This step supported the refinement of the methods described in this paper.
6. In many cases the studies have continued as long term studies with frequent visits. The longest lasting research collaboration has been going on for more than 10 years and is still ongoing.

The studies are still ongoing and new cases and new companies are frequently added.

3 THE PHENOMENON OF MODULARITY AND MODULARIZATION

Modularity is a general systems concept describing the degree to which a system's components may be separated and recombined (Schilling, 2000). The term, modularity, has been developed in parallel in many different academic and practical areas. This parallel development history has lead the term to be rather comprehensive and meant that there is no unified practical definition since each application includes many different aspects of the overall term modularity.

When the task of developing and managing a system is exceeding the human capabilities one way of managing a complex system is to break down the system into manageable modular parts. In this sense the concept of modularization can be interpreted as an encapsulation of complexity. By encapsulating parts of a system (by means of modules) a significant part of the complexity can be reduced to handling and specifying the interfaces between modules (Baldwin & Clark, 2000). In this case only a limited number of specialized people need to be involved in the handling of the complexity within the module boundary. The majority of involved people can operate with the modules based on their knowledge of the module functionality and the module interfaces (Fine, 1998). This understanding applies broadly to products, services, production setup, markets, knowledge, and supply chains.

As modularity is expressing the degree to which a system's components may be separated and recombined it is by nature a relative phenomenon. Principally, any system can be separated and recombined in endless ways. This spans a continuum between a mainly integral structure and a mainly modular structure of a given system. Furthermore, the modularity perspective is recursive applying both to a given system, the various subsystems, and the sub-subsystems that compose the overall system. In the context the challenge of deciding on the degree of modularity is inherently complex. Complex, as defined by Herbert Simon (1996), "Roughly, by a complex system I mean one made up of a large number of parts that interacts in a non-simple way. In such systems the whole is more than the sum of the parts, not in an ultimate, metaphysical sense but in the important pragmatic sense that, given the properties of the parts and the laws of their interaction, it is not a trivial mater to infer the properties of the whole".

Modularization is defined as the process of breaking down a system into modular subsystems. This is a crucial management task, since the decisions will have a significant impact on the company's potential performance level.

3.1 Challenges in Modularization Management

Modularization management does not differ from management in general. As modularity is a means, the management challenge will be to apply this means so it may serve the short and long term goals of the company best possible. The goals that are impacted by decisions on modularity are characterized by being many and cross-organizational. Some generally impacted goals are related to: expected product changes, expected product lifetime, product variety, product family commonality, sourcing possibilities, various lead-times, product performance, manufacturability, product cost policy, competition policy, purchase policy, logistic setup, investment policy, and technology change policy.

The wide-spread natures of these goals do impact many different management systems at various organizational and strategy levels. The empirical studies have revealed two types of challenges that can repeatedly be found in the case companies. These challenges relates to the operational process of product development and to the strategic problem of implementing strategies involving modularity as a means.

In the operational product development process the phenomenon of disposition describes a mandatory relationship between the cost that at any given time is incurred and the cost that at the same time is committed (Cooper & Kaplan, 1999). The disposition phenomenon depicts that by nature the cost committed early in the process before the detailed design is finished often account for more than 80% of the total cost committed in the whole lifetime of the product. At the same time only a fraction of the total cost is incurred (se illustration in figure 2).

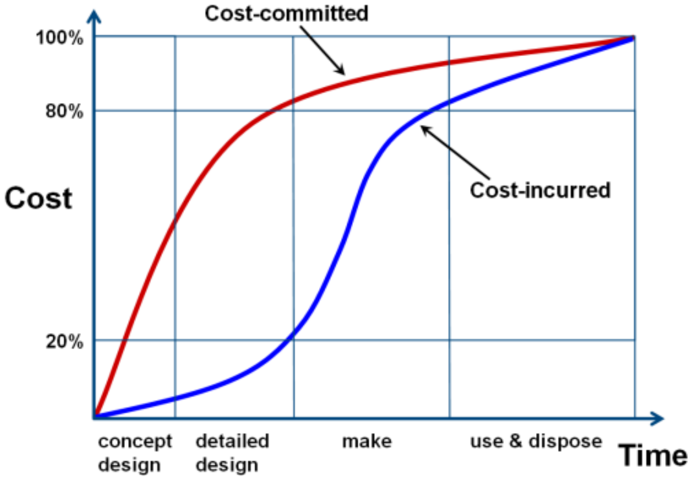

Figure 2. Time difference between cost-committed and cost-incurred, adapted from (Cooper & Kaplan, 1999)

The challenges seen in relation to the disposition phenomenon are concerning the organizations ability to know and agree upon the future conditions and features of the product even before this product is realized. In many cases the product is not a single product but a product family or a derived product of a product family. The problems reported are related to communication, patterns of collaboration, and decision making based on expected future benefits:

1. How does an organization efficient conceptualize and communicate the many fuzzy and contradictory needs and wants in relation to the product?
2. Which forms of collaboration and coordination do support the inclusion of many cross-organizational input and involvement in the process?
3. How can decision-making be based on solid predictions of the future benefits of particular solutions?

The other type of challenge relates to implementation of strategies. A pragmatic way for organizations to develop and implement strategies is to distinguish between different levels of strategies. Thereby strategies can be made for different groups of people or different types of activities within an organization. The most common distinction between levels of organizations is between corporate, business, and functional levels (De Wit & Meyer, 2010). Figure 3 illustrates a simplified hierarchy of strategies including the implementation level.

Figure 3 do indirectly illustrates the complexity of the strategy process. The overall strategy for the different Business Units is normally mainly financial oriented specifying expected turnover and earnings. At the Business Level these expectations are broken further down and budgets are allocated for the different organizational units. At the Business Level the more specific content emerge: Which specific markets are we operating within? Which specific technologies do we develop or apply? Which specific partners do we engage? What are our primary distribution channels? Etc. Finally, at the Functional Level and at Implementation Level the strategies become very specific and merge with normal daily activities.

Complexity arises when the different strategic activities are to be coordinated. The different organizational units are specialized, focused, and dedicated to their particular area. When conditions changes in one area there is a delay before awareness emerge in neighbouring areas, and thereby, the whole hierarchy of strategies can be compared to an unstable system. Most cases of failure can be explained by instability within the hierarchy of strategies. However the logical explanation only emerge in retrospect, hence the complexity (Snowden & Boone, 2007).

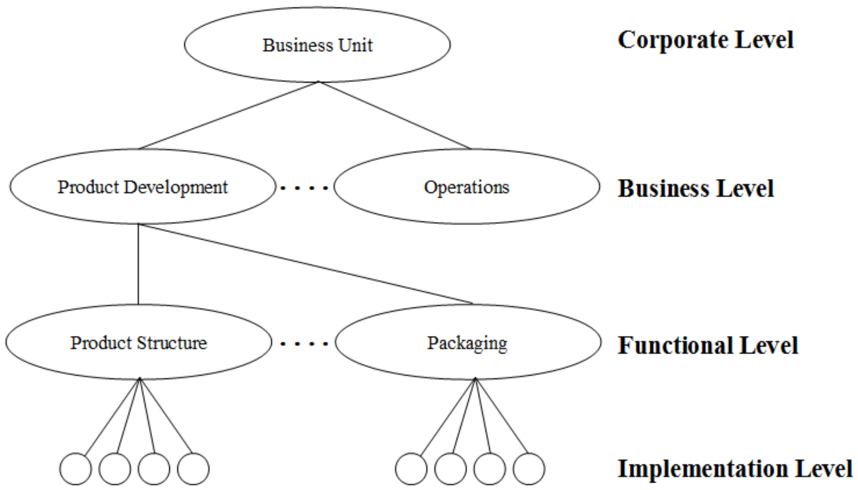

Figure 3. Strategic Levels and Strategy Hierarchy

The nature of the strategic work is different at the different levels. At the Corporate and Business Level the approach tends to be top-down driven by analyses and specific goals. At the Functional Level, and, in particular at the Implementation Level the approach tends to follow a more emergent nature (Mintzberg et al., 2009). The emergent nature is supported by various inputs from outside and by the fact that solutions themselves gives input to new ways of interpreting the problem or improve communication by means of conceptualizations or emergence of prototypes. These differences in nature tend to amplify the instability tendencies of the hierarchies of strategies.

The problems revealed in the empirical studies are similar to the problems experienced with the disposition phenomenon and related to communication, patterns of collaboration, and decision making based on expected future benefits:

1. How does a given modular solution within one functional area relate to another modular solution within another functional area?
2. How can this be efficient communicated before and during implementation?
3. Which forms of collaboration and coordination do support alignment between synchronous implementation in two or more functional areas?
4. How can decision making be based on solid predictions of the future benefits of the combined solutions?

Both the challenges related to disposition phenomenon and the challenges of implementing strategies will amplify when it involves more than one company in an operations network.

3.2 Realizing Modularization Benefits

The two types of challenges in modularization management as described above represent both operational and strategic challenges. The operational challenges is related to the specific decisions that must be taken in the forward moving product development process, and the strategic challenges is related to the creation of a flexible foundation that can incorporate future changes in general business conditions. In the few best cases the two challenges can be worked out and are synchronized. Even within one company this is a significant challenge. When more companies are involved in operations network the challenges will amplify. The consequences are lack of synchronization of both decisions and the following implementations. This lack of synchronization leads to sub optimization that seen isolated makes sense but when connected in a whole supply chain will neutralize the summarized effort.

The empirical cases have revealed a high variety in the approaches that various companies apply, and this even applies to different departments within the individual company.
The companies that perform best are able to initiate a continuous process that approaches the challenges in a stepwise process. In this process they can be supported by theoretical frameworks that enlighten the various complex cross-organizational relationships (Hansen & Sun, 2010). In the following we present and discuss two theoretical frameworks that have been distilled from the work with the empirical cases.

3.2.1 Platform Template Framework

Modularity, product architecture, and product platform are terms that often co-exist both in practical industrial settings and in research. In research the terms are normally well defined within individual research communities. However, the terms are ambiguously defined when comparing the global research community.
In industry the terms are often used without precise definition and often synonymous. Different organizational units within the same company use different definitions. The definitions are mostly based on specific industrial reference cases, e.g. Volkswagen or LEGO. In both cases companies are referring to these companies as being able to create a variety of products based on a relatively large degree of re-use.
During the empirical case studies we have consequently included experiences from both Volkswagen and LEGO in our discussions with the companies. The LEGO case clarifies that the modularity is associated with the physical building blocks and that well-defined interfaces are crucial in the design of modular products. The participants in the companies find it relatively easy to transfer this to their own products.
When presenting the so-called A-platform from Volkswagen we challenge the companies to identify the platform. Clearly the visual representation of the A-platform illustrates the re-use of approximately 60% of all components across the different car brands: VW, Skoda, Audi, and Seat. However, the discussions generally end with concluding that the Volkswagen A-platform should not be defined as a platform. It is rather a simple visual representation of a number of structural subsystems. Furthermore, there is missing some of the most important issues: the associated supply chain systems and their interfaces to the product subsystems. These subsystems and their interfaces are an important part of the explanation for the specific physical form, and most important, are the reason why Volkswagen can realize benefits in both product development (high variety, fast lead-times) and in supply chains (cost reduction and both direct cost and capital binding).
The platform hence becomes an overall slightly abstract phenomenon that incorporates different types of sub-systems. We have chosen to use the term architecture for such sub-systems. These architectures can be more or less modular.
The benefits are realized in a complex interaction between a numbers of multidisciplinary architectures. To develop and configure these architectures and their interaction is, in short, the management challenge of working with platforms.
Due to differences in market dynamics and technologies platforms will be different from company to company. Consequently, there is a need to provide a rich and comprehensive view of platform options to support the company specific work with platforms. We have chosen to name this a platform template framework in order to emphasize that the realization of a platform challenge is to be considered as a company individual task (Hsuan & Hansen, 2007). Based on the literature review and our on-going empirical research, the following factors have been identified as essential elements to define a Platform Template Framework:

1. The platform is based on one or more architectures that in co-operation define a relevant area of interest.
2. The architectures can be product architectures as well as other relevant architectures
3. The architectures specifies internal interfaces within an architecture and external interfaces between architectures
4. The architectures can be partly modular
5. The architectures can include knowledge relevant to the given domain.
6. The platform can be integrated with long-term strategic plans.
7. The platform stipulates and integrates short-term and medium-term continuous improvement efforts.

8. Managing the platform includes being specific about how to realize benefits

These elements of the platform template framework have been widely accepted and recognized by the case companies. Also, the elements have supported in defining the challenges in the cases that have developed into long-term case studies and research collaboration.

One important element in working with platforms is however not covered by the template. That is the organizational processes including the management efforts. Companies find these managerial issues to be the most difficult cope with. As articulated by Robertson & Ulrich, "Good platform decisions require making complex trade-offs in different business areas. Top management should play a strong role in the platform process for three reasons: (1) platform decisions are among the most important a company makes, (2) platform decisions may cut across several product lines or divisional boundaries, and (3) platform decisions frequently require the resolution of cross-functional conflict." (Robertson & Ulrich, 1998).

As explained by Meyer & Dalal, platform management is "the integration of the building blocks (the core technologies and processes) with common architectures (the shared subsystems and interfaces), with user requirements aggregated into target market segments towards the end of producing value rich products and systems (Meyer & Dalal, 2002).

3.2.2 Platform Benefits

There are several reasons why companies pursue a product modularization strategy. Some of the benefits of product modularization include reduction of fixed costs of developing individual product variants, greater degree of components and subsystems reuse, increased responsiveness, offer higher product variety to customers, reduction of development lead time, and improved customer service.

The empirical case studies have given specific input to a variety of areas where expected and unexpected benefits have been realized. Among the empirical observations are:

- Product modularity reduces costs in the product life cycle due to the possibilities of economy of scale in production
- Product modularity reduces delivery time due to the possibilities of postponement in supply chain
- Product modularity enhances speed in the product development process due to the possibilities for distribution of activities
- Product modularity enhances speed in the product development process due to well-known structures in the product development project management
- Product modularity enhances speed in the introduction of new product variants due to the reuse of components and structures
- Product modularity enhances the variety due to the flexibility in configuration of the final product
- Product modularity enhances organizational flexibility due to the ease in communication of the product structure
- Product modularity enhances organizational learning due to the inherent structure for accumulation of knowledge

The most frequent type of benefit is the cost reduction. However, the case companies report difficulties in estimating this type of benefit. This is partly due to the diversified nature of this type of benefit and partly due to the fact that the benefits are to be realized in other parts of the organization. Product development can only provide the modular structured product solution. The benefits can emerge in different ways, e.g.: Sales can sell more configurable products by reuse of modules; Supply Chain can source more efficiently due to the modular product structure; Production can produce more efficiently due to economy of scale of modules and due to quality improvements stemming from reuse of production setup; Service can operate more efficiently due to the modular structure.

However, these cross-organizational benefits require a highly synchronized effort between the organizational units. The case companies report difficulties in identifying the variety of cost reduction potentials.

Some of these cost reduction potentials can be measured by strict financial methods but most of them incorporate types of benefits that either stretch over a period of time or are rather difficult to transfer to financial terms. How can increased speed in product launches be measured in financial terms? Intuitively there is a financial benefit but this benefit will occur in future financial years and it is at the

point of decision a highly potential benefit. On the other hand the investments in modular products are normally significantly higher than investments in more integrated products.
Based on the empirical findings we have categorized the benefits in six major benefit driver categories and 3 major benefit categories. The six benefit drivers can overall be categorized into Research & Development and Manufacturing & Logistics. The benefit drivers and the benefits can be combined in a matrix structure (see table 1).

Table 1. Modularization Benefit Matrix

	Cost, quality, complexity	Capital binding	Lead-time reductions
Research & Development - Carry over - Technical update - Customization and styling			
Manufacturing & Logistics - Processes and organization - Supplier availability - Gradual completion			

Research & Development benefit drivers:
- Carry over. The benefits derived from carry over or re-use of components across more products.
- Technical update. The benefits derived from the ability to upgrade the product technically without changing the product architecture.
- Customization and styling. The benefits derived from the ability to customize or style the product without changing the product architecture.

Manufacturing & Logistics benefit drivers:
- Processes and organization. The benefits derived from having an existing manufacturing process set-up and an organization that can produce the product.
- Supplier availability. The benefits derived from having known suppliers available that can produce needed components at a specific quality level.
- Gradual completion. The benefits derived from being able to produce the product in steps and only specifying the specific product features at a late stage in the production.

Benefit categories:
- Cost, quality, complexity. These benefits will be measured in direct cost.
- Capital binding. These capital binding will occur as intermediate stocks, finished stocks, machines, tools, moulds, etc.
- Lead time reductions. Lead-time reduction will occur as reductions on product development lead times, production lead times, logistic lead times, ect.

The Modularization Benefit Matrix has emerged during the empirical research period. As the matrix finally found the form as shown in table 1 it had a significant impact on the quality of the benefit discussions. In most cases we were able to depict both the initial expectations, intermediate realized benefits, the current state of benefits realized, and finally to discuss expected future benefits (Hansen & Sun, 2010).

4 DISCUSSION

The two frameworks presented above (Platform Template Framework (PT) and Modularization Benefit Matrix (MBM)) have proven beneficial in the process of configuring networks. The process of aligning platform views is crucial in order to synchronize efforts between partners.
LEGO Company is one of the case companies that have delivered more cases. One of the cases is the product Bionicle that was an active part of LEGO's product portfolio for 10 years between 2001 and 2011. Bionicle was an attempt from LEGO side to make its first Intellectual Property based on the experienced success with merchandise for the Star Wars movies. The product is essentially action figures that are supported by a story line (LEGO Bionicle Story, 2013). The story line is developed by on external design company.

The main actors in the network configuration are: various departments within LEGO, external design company, external plastic mold manufacturer, external packaging manufacturer, and external packing equipment manufacturer. LEGO knew all the external partners in advance but the product challenges were new and the business success was highly dependent on extensive re-use of existing modular product structures.

The core product architecture was the *Technic* architecture (LEGO Technic, 2013). LEGO has 14 different product architectures of which the best known and most frequently known is the *System* architecture (LEGO System, 2013). The critical interfaces within this architecture are the various connectors that are used to realize the functional needs and to assemble the product. As the Technic architecture was originally developed to support various vehicle products the interfaces was not sufficiently supporting the more organic expression that was needed to design action figures. The most crucial function was the ball joint that is connecting the limbs (e.g. legs to body) within a more organic LEGO model. Originally a ball joint had been developed for the Technic architecture and this was developed further in order to fulfill the needs of the Bionicle product.

An important part of any consumer product is the packaging. In the case of Bionicle the packaging architecture is partly developed and fully manufactured by external suppliers. LEGO wanted the Bionicle product to have a whole new appearance and decided that the packaging should have the form of plastic cans.

The existing package system was designed to handle cardboard boxes, and therefore, new package architectures had to be developed. This was developed and manufactured by external suppliers.

The network structures and associated challenges described in the Bionicle case above is heavily simplified but can serve to illustrate the process of configuring networks based on modular architectures.

There are several critical architectural alignments that determine the efficiency of the operations network. Here the focus will be on the relationship between *product – packaging – packing equipment* only. The critical initial decision relates to the choice of plastic cans (cf. figure 2). This decision triggered a parallel development of product, packaging and packing equipment (cf. figure 3).

The initial considerations regarding modularization benefits were to focus on product development lead-time reduction, manufacturing cost reduction, and to less extend on reduction of capital binding in operations (see table 2). These were all based on the intensive use of modular product structures.

Table 2. Modularization Benefit Matrix for LEGO Bionicle 2001

	Cost, quality, complexity	Capital binding	Lead-time reductions
Research & Development - Carry over - Technical update - Customization and styling			+++
Manufacturing & Logistics - Processes and organization - Supplier availability - Gradual completion	+++	+	

However, the situation developed different compared to the initial expectations. The product proved to have a much larger appeal and a much longer lifetime than initially planned. This meant that the initial expectations in regards to modularity benefits (see table 2) were not realized. In particular the goals regarding operations cost and the operations capital binding failed. These failures can all be explained by the missing alignment between the product architecture, the packaging architecture, and the packing equipment architecture. All of these were partly modular but the alignment between them ended up being insufficient due to sub optimizations (cf. figure 3). The missing awareness of the need to align between architectures of different nature were in retrospect acknowledge to be the main reason for the failure.

5 CONCLUSION

Companies use very different approaches in the modularization effort, and, furthermore, they use very different terminologies. This has led us to take a very empirical approach followed by a retrospective discussion and rationalization. So far this process has resulted in two frameworks that have proven valuable in the retrospective discussions**.** Though the participating companies have used very different terminology they have easily engaged in a discussion based on the elements specified in the two frameworks. The most common insight generated by the companies is the distinction between architecture and platform, as described in the Platform Template framework. When making this distinction – even in retrospective – the companies fully realize the complexity in realizing the estimated benefits. The second framework, Modularization Benefit Matrix, has demonstrated that it can support companies in both a qualitative and quantitative effort to specify the benefits. The future research process will add more retrospective cases and seek to adopt a more action research based approach in emerging modularization processes.

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