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TRANSFER OF METHODS FOR DEVELOPING MODULAR PRODUCT FAMILIES INTO PRACTICE – AN INTERVIEW STUDY

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Keywords: product families, method transfer, design practice

1. Introduction

Companies need to handle the increasing variety of products demanded by their customers and are using modular product families (mPF) to avoid a corresponding increase in complexity in the company [Otto et al. 2013]. The development of modular product families (DmPF) needs to consider and link numerous factors and can be supported by methods like product architecture definition [Jiao et al. 2007], modularization [Erixon 1998], complexity management [Lindemann et al. 2009] or the integrated PKT-approach for the development of mPF [Krause et al. 2013a] developed by the Institute PKT. Industrial case studies demonstrate that the integrated PKT-approach is able to support engineering designers in developing mPF [Eilmus et al. 2012]; however, new methods are seldom recognised or used in practice. Nobody in practice or academia is responsible for transferring new methods into companies and knowledge transfer is the missing link [Wallace 2011]. Thus, ways to transferring methods for DmPF into autonomous use in companies need to be studied (Figure 1).

The objective of this paper is to improve understanding of companies' challenges while developing modular product families, their views on the new methods and the transference of these methods into their development practice. For this purpose, the questions shown in Figure 1 will be discussed.
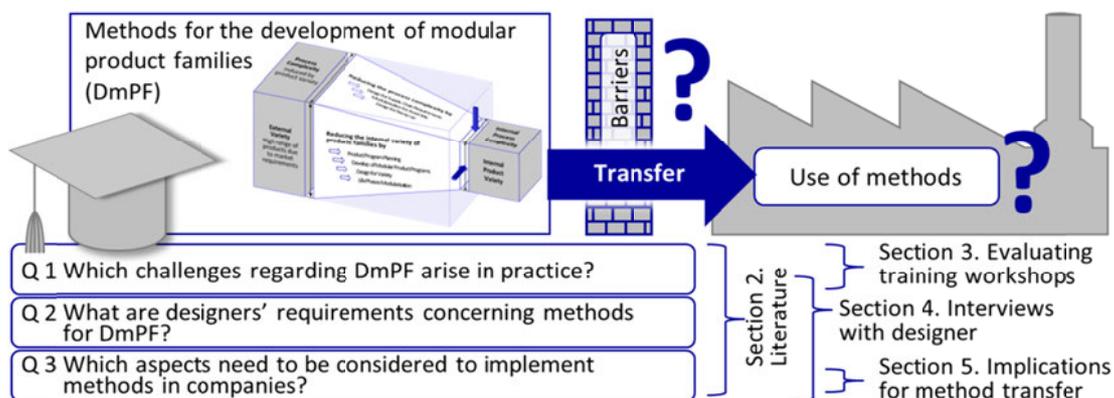

Figure 1. Scope and questions of the paper

Literature on requirements of methods and their transfer into practice are reviewed (Sec. 2). Feedback from a series of workshops to teach modularization methods is studied to give insights into the needs of practice (Sec 3). An interview study with trained designers is used to widen understanding of their requirements on methods and transfer of methods (Sec. 4) and to derive implications for transferring methods for DmPF into practice (Sec. 5).

2. Background

Design methods describe predefined ways to handle design tasks [Wallace 2011] and aim to overcome cognitive barriers, deconstruct complex problems, support communication and document decisions [Lindemann 2009]. Approaches for the development of modular product families (DmPF) are summarised by [Jiao et al. 2007] and [Krause and Ripperda 2013]. DmPF supports the search for design solutions and structures of product families that handle high external product variety with low internal product and process variety. Technical-functional (e.g. couplings of components) as well as product-strategic aspects (e.g. company structures) and the involvement of experts from different disciplines need to be considered [Krause and Ripperda 2013]. The integrated PKT-approach [Krause et al. 2013a] for DmPF offers a workshop-based procedure, supplies specialised visualisation tools, fosters communication between stakeholders and supports variety-focused redesign of components.

Special challenges while transferring these methods into practice arise, because they need to be usable by different stakeholders, on different hierarchical levels (designers and management) and in different use scenarios. Changing the development practice to DmPF exceeds the implementation of new support tools (like a creativity method). The firms' organisation, its development strategy and system, needs to be reworked and various departments are affected in order to gain broad positive effects of mPF. For instance the sales concept can be changed and new production processes may become suitable. Therefore, all affected stakeholders need to gain knowledge about new methods and need to be considered in the process of transferring methods.

2.1 Requirements and shortcomings of design methods

Designers implicitly apply systematic approaches in practice, but seldom pick up new methods [Wallace 2011]. [Blessing and Chakrabarti 2009] define three criteria to judge methods: usefulness, applicability and usability. The paper focuses on applicability and usability aspects, because usefulness of methods for DmPF has been shown in studies [Eilmus et al. 2012]. Methods need to be flexible, robust, built on a strong scientific foundation, be simple and intuitive to use, and show rapid benefits [Wallace 2011]. Designers especially seek methods that improve interaction with others (e.g. communication), support project planning and management, are efficient, and focus on the main task. They demand better integration into existing processes and continuous improvement according to their feedback [Geis et al. 2008]. Figure 2 gives an overview of requirements and shortcomings.
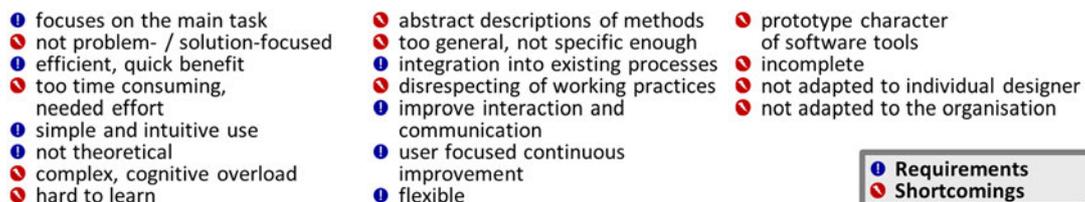

Figure 2. Requirements and shortcomings of methods, based on literature

Methods are not adapted to individual user's needs, organisations or processes of the company [Geis et al. 2008], too complex, theoretical and hard to teach [Badke-Schaub et al. 2011]. The effort to perform them is too high [Lindemann 2009], methods tend to be incomplete, not relevant to the daily work of designers and new software tools are only prototypes [Wallace 2011]. [Badke-Schaub et al. 2011] identified three major categories of shortcomings: limited performance, weak presentation and formulation as well as process-related problems while applying the methods. These requirements and shortcomings need to be addressed to be able to transfer methods into companies.

2.2 Transfer of methods into practice

"Researching, developing and transferring methods take time" [Wallace 2011]; however, timeframes until an impact is occurring differ (Figure 3). Continuous cooperation between researchers and companies is long-term knowledge transfer [Wallace 2011]. A general change in mind-set can only be achieved with education [Hubka and Eder 1996]. Students take key positions in companies and change practices [Wallace 2011]. Consolidation of the fragmented and modestly recognised design research is

necessary [Hubka and Eder 1996], e.g. by building a base for exchanging design knowledge by design ontologies [Štorga et al. 2010]. Methods for DmPF have evolved without interconnection or a clear structure [Otto et al. 2013]. Otto et al. propose a set of general steps of DmPF and corresponding methods to consolidate the research field. Design research must be more rigorous and built on stronger foundations of empirical data and implementation issues [Blessing and Chakrabarti 2009].

Figure 3. Aspects of knowledge transfer

For short-term transfer, the training of designers can create a limited mind-set change in shorter time, e.g. through training workshops, such as those run by the Institute PKT [Krause et al. 2013b], (Sec. 3). In design research, different models of method transfer are providing sets of measures (Figure 4) that need to be carried out iteratively and cooperatively by companies and researchers. [Geis et al. 2008] propose the steps simplification, adaption, promotion and training of methods. The framework of [Stetter and Lindemann 2005] allocates measures to the layers: Initiation of the implementation process, analysis of the product development system, choice and adaptation of methods, implementation of methods, and evaluation of the impact, that need to be used in an iterative manner within a transfer project.
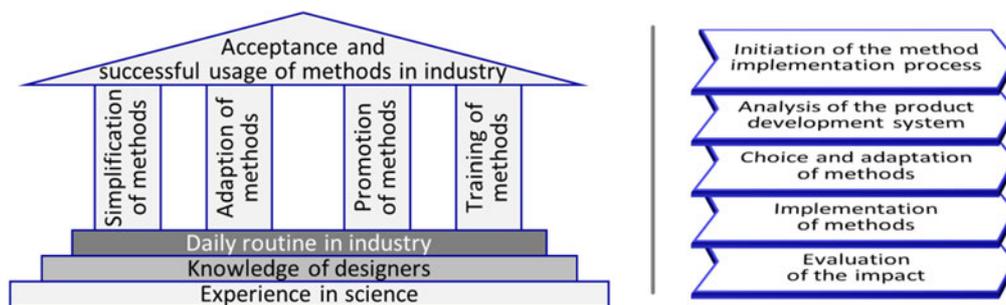

Figure 4. Method transfer frameworks, l. [Geis et al. 2008], r. [Stetter and Lindemann 2005]

The frameworks (Figure 4) are based on success factors and barriers of method transfer which are summarised in Figure 5. People, their attitude towards methods, and the process of convincing them of their usefulness are crucial. Implementation needs to be planned based on an analysis of current development processes. Implementation projects should involve affected designers, use pilot projects [Stetter and Lindemann 2005] and can be supported by "method champions" (experts) [Wallace 2011], [Geis et al. 2008]. Methods must be selected to suite specific situations and should be kept simple [Sheldon and Foxlex 2003]. They have to be anchored in the organisation and must be continuously improved [Stetter and Lindemann 2005].

Figure 5. Success factors and barriers of method transfer, based on literature

Transfer and implementation is hindered by barriers (Figure 5), like a lack of recognition of a method's advantages and the big effort required to apply them [Geis et al. 2008], [Jänsch 2007]. Implementation takes time while companies are under pressure; the benefit is delayed and capacity as well as management support is insufficient [Stetter and Lindemann 2005], [Wallace 2011], [Badke-

Schaub et al. 2011], [Geis et al. 2008]. Presentation and documentation of methods are too complex while training is insufficient [Jänsch 2007], [Wallace 2011]. Using new methods requires far-reaching changes in development processes and organisation that discourage companies [Jänsch 2007].

3. Evaluation of training workshops

To study challenges and requirements from practice in developing mPF, feedback from training workshops on modularization methods [Krause et al. 2013] with over 45 participants was evaluated. The two-day workshops have been hosted four times since 2012 by the Institute PKT.

3.1 Concept and content of the workshops

The workshop provides designers from industry with basic principles, benefits and methods of modularization. Training is carried out by presentations and application to an example product family of vacuum cleaning robots in interactive exercises (Figure 6). The first day covers the use of module drivers of Modular Function Deployment [Erixon 1998], defining product architecture by network diagrams [Göpfert 1998], and analysis of couplings by a Design Structure Matrix (DSM) [Pimmler and Eppinger 1994]. On the second day, the method units "Design for Variety" and "Life Phases Modularization" [Blees et al. 2010] of the integrated PKT-approach are presented. Participants develop variety-optimised components, create modularizations for different product life phases and align these modularizations in a role-play exercise. Participants are designers and managers from development departments. Companies from sectors that offer products and solutions in aviation and transportation, materials handling, shipbuilding and machinery, personal safety, bearings, plant engineering, test plants, and production systems participated, as well as consultants.

3.2 Observations and results

The participants were asked about their background and expectations at the beginning of the training workshop. Their answers fell into the following categories:
- Get to know new methods from research and pick up usable methods for specific projects
- Insights into background, theory and basic principles
- Learn about advantages of DmPF in different possible use scenarios
- Overview of strategies; new perspective on DmPF
- Sharing experience across companies

Designers in practice are interested in new methods for DmPF, are missing knowledge about strategies to overcome challenges, and are looking for methods directly applicable to daily work.

While introducing their companies, the participants reported challenges that give some answers to the first question (Q1, Figure 1): which challenges arise in practice regarding the DmPF?
- Handling and reducing high external variety caused by special requests from their customers.
- Reusing existing solutions or components to avoid high variety by standardisation.
- Incorporating different stakeholders and cooperation in the company for the purpose of DmPF (often mentioned by the participants). Modularization needs to be included in the entire process chain and tools that create a basis for communication were requested.
- The participants have to evaluate and quantify the numerous effects of new modular concepts in terms of costs caused by complexity to mediate benefits of DmPF to senior management.
- Useable tools for daily work and software support are envisaged.
- Implementing methods is a major challenge and participants need to present the concept of mPF in order to convince others of its usefulness.
- Maintaining a modular product structure over a long time after its definition.

The participants provided feedback on the training, on methods, and on future development needs. Mixing theoretical background and practical examples, applying methods to a real product in interactive exercises, and the possibility to network with others was valued. Participants liked the systematic procedure and the good documentation supported by methods. Using visual tools to create an overview e.g. of variety and product structures and incorporating different stakeholders in the life phases modularization of integrated PKT-approach was complimented. However, not all participants

were convinced that the methods also work for larger and more complex products. They requested software support and pointed out the need for an estimation of cost reduction when using DmPF.
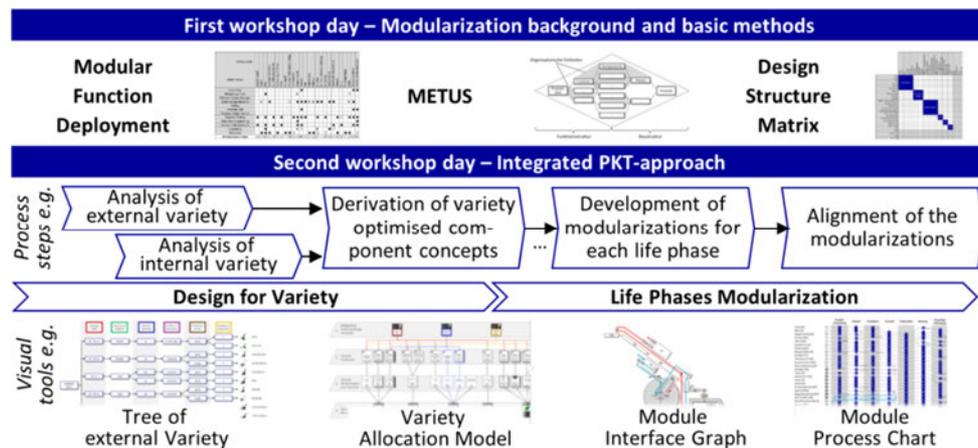

Figure 6. Content of the evaluated training workshops on modularization methods

Initial insights were gained by evaluating the workshops, although they were not focused on collecting feedback from practice. High external variety is a major challenge, inclusion of different stakeholders is highly relevant and the need for support to transfer methods was confirmed by the participants.

4. Interview study with designers working in practice

The workshop participants' view of new methods is of highly value to gain practical insights, as they are aware of challenges and have gained a theoretical background. An explorative interview study of requirements of methods and the success factors of method transfer was conducted to qualitatively substantiate the above findings from literature and the workshop feedback.

4.1 Setup of the interview study

For the interview study 18 workshop participants were contacted who have recently attended one of two workshops held in 2013 and gained background knowledge about methods for DmPF. The remaining of the over 45 participants were not contacted, because they participated in a workshop after the study, their workshop was too long ago, they are not involved in DmPF in their daily work or they are working in the same company as interviewees. 12 of the 18 contacted workshop participants replied and were interviewed. 9 interviewees from 7 companies work in development departments, as designers or often in leading positions, and are from the industrial sectors aviation, materials handling, ship machinery, bearings, plant engineering, test plants, and production systems. Three interviewees are consultants reporting experience from four client companies working in aviation and production systems. The company size varies from few hundred up to more than 10,000 employees.

The twelve participants have a sound and comparable foundation in methods for DmPF due to their workshop participation. They are representative for the target group, which are designers and managers, because strategic decisions on the product structure need to be made along with concrete embodiment of designs. They are confronted with increasing variety of products sold globally. In addition, broad background information about the participants is present through the workshop that can be used to judge their answers and balance the number of interviewees.

For the 45-minute, semi-structured telephone interviews, the interviewees received a questionnaire containing nine questions structured into three blocks: current situation of the company regarding DmPF, needed adaption of methods, and implementation of new methods. The second and third block address questions Q2 and Q3 of this paper (Figure 1). The first block mainly addresses the use of visualisations for DmPF, which is the subject of a separate paper [Gebhardt et al. 2014]. Two researchers undertook the interviewing, accompanied by a Masters student. One researcher guided the interviewee through the questions with additional optional trigger and detail questions while the other two took notes. The interviews were not recorded to avoid reservations of the interviewees. The

questionnaire included a graphical overview of methods covered in the training workshop (similar to Figure 6), to trigger the interviewees recollection of the methods. The questions are formulated to collect qualitative insights and are not aiming at quantitative data.

After the interviews, the notes of the team were compared, conflicting notes discussed, and a consolidated protocol created. To interpret the data, similar answers to each question were grouped manually into categories, which were critically discussed and sharpened in the team. In addition, the numbers of entities matching a category is counted, but due to the small sample size the evaluation is focusing on the qualitative findings and only the most mentioned entities are marked. The created categories relating to questions Q2 and Q3 are presented in the following, after a summary of the current development situation of the interviewees.

4.2 Current development practice of the participants

Asked for strategies of their companies in terms of DmPF, more than half of the participants noted that no concrete strategies are given. Two companies envisage a platform or a modular system and one company fosters reusing of components across different organisational units. The firms often concentrate on fulfilling individual requests by customers and have inherited it in their philosophy. The topic DmPF is rising in priority, and pilot projects are carried out by development departments.

When asked for methods, tools, processes, and organisational roles in their companies for the purpose of product structuring, the interviewees stated that specialised methods are often not used. However, designers are doing modularization and variety considerations in an intuitive way and develop simple supports, like tables showing product variety. These tools are only used individually and in isolation by individuals or single departments. In some companies, the product structure is regulated by guidelines and catalogues of preferred solutions. Standard tools like ERP systems are used, along with product configurators, and classification and search systems. Reusing solutions often depends on individuals, but some companies have established a matrix organisation or pre-development groups in charge of defining and maintaining shared solutions, components or modules across product segments and organisational units. Overall, companies rely more on individuals or their organisational structure than on strategies or methods for product structuring and handling of variety.

4.3 Requirements of the interviewees regarding methods for developing mPF

The requirements from practice (Question Q2, Figure 1) are extracted from answers to the interview question "What characterises a user-friendly method in your opinion?" and manually grouped (Figure 7). The interviewees were prompted by showing them impressions (similar to Figure 6) of methods presented in the workshop and asked for the reasons why some of them are more suitable than others. This and mentioned shortcomings in their daily work were transformed into requirements.

According to the interviews, methods should be simple and focused on essential ideas, intuitive to understand and trainable. The effort required needs to be limited, method application should save time in daily work, and results must be achieved fast, while the benefit should be transparent. Software support is often asked for and should allow automatic processing of existing data and integration into existing systems to automatically incorporate changes made to the product family. Handling of methods should be consistent throughout the company and oriented towards existing working habits, conventions, language and terminology of the users.

These requirements correlate with literature (Sec. 2.1.), but the interviews often highlight special need for interaction and incorporation of different stakeholders, typical to DmPF. Methods need to be suitable for different users incorporated in the cross functional development, and results need to be comprehensible by all different affected departments. For this task, visual, product-related approaches and discussion in workshops are preferred. DmPF works on different hierarchical levels and scalability of methods is important to give a quick overview to managers or only partly involved departments, but provide detailed information for designers working in the core development team.

Due to the need to adapt methods, as discussed in literature, interviewees were asked about their views on needed adaptations, focusing on method examples shown (Figure 6). Clustered results are presented in the lower half of Figure 7. Interviewees see a need to primarily adapt methods and then, later on, companies' organisation and processes responsible for developing and handling mPF.

Methods need to be adapted to organisations and positions, processes, work practices, characteristics of products, typical time constraints, and capacities. The level of detail and focus needs to be adaptable and the methods have to be simplified and focussed on essentials. Methods need software support that is linked to existing systems in order to reduce variety of tools and standardise user interfaces. For transfer and adaptation of new methods, they should be modular in structure and form a "modular methods toolkit" as suggested by an interviewee.
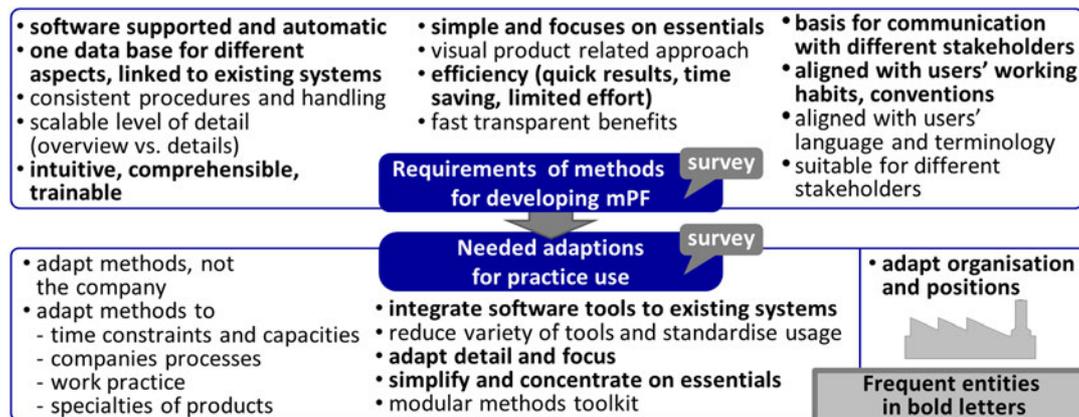

Figure 7. Categories of requirements and needed adaptations mentioned in the interviews

Findings correlate with literature; however it became obvious that most interviewees agree that using DmPF specially means to introduce far-reaching changes in the company, like fully revised development processes, changes in the organisational structure and new positions.

4.4 Success factors for transferring methods for development of mPF

The interview questions "Which aspects and steps are necessary to implement methods in your company?" and "Which barriers do you expect?" are used to gain answers to Question Q3 (Figure 1). Method transfer success factors and barriers in the DmPF are extracted and grouped in Figure 8 and most frequent entities marked in bold letters.

Transfers of methods need to be built on applicable and practical relevant methods. Implementation should start with sound planning, ensuring all impacts are known and addressed. Needs and aims of the improvement should be fixed, the progress monitored and feedback of affected persons included. Organisation, positions and processes need to be adapted, but participants suggest adapting methods first to minimise changes in the company.

Main tasks are convincing, incorporating and educating people. Employees fear rationalisation or additional liabilities and the benefits of new methods have to be mediated and quantified. A critical barrier to method implementation is the benefit of DmPF, which is hard to quantify and appears delayed like the cost effects achievable by reduced complexity and a likely initial regression in performance that needs to be communicated. In addition, companies lack key performance indicators (KPIs) suitable for allocating higher costs to product structures when considering a single variant, but saving money if the overall mPF is considered. "Convincing businessmen" without engineering backgrounds, who do not understand issues of mPF, is challenging. However, top management support is highly important and change is a general management task, including controlling peoples' adjustment to the new practice. An efficient way to convince and teach people is to use examples of their products. For this, pilot projects can be undertaken to create good examples so that people can experience the benefits of the method. Some interviewees recommend an interdisciplinary change team which e.g. carries out a pilot project supported by external method experts. This team, now method experts, can be used to spread methods across the company. Overcoming old work practices and substantial relearning is tough and training must be provided to familiarise designers, managers, and other stakeholders with the new methods. Transfer takes time and endurance, quick realisation is needed and introduction may be undertaken in small steps. Too rapid, far-reaching or frequent changes and missing time for using methods, tight timescales, and big effort all hinder the transfer.
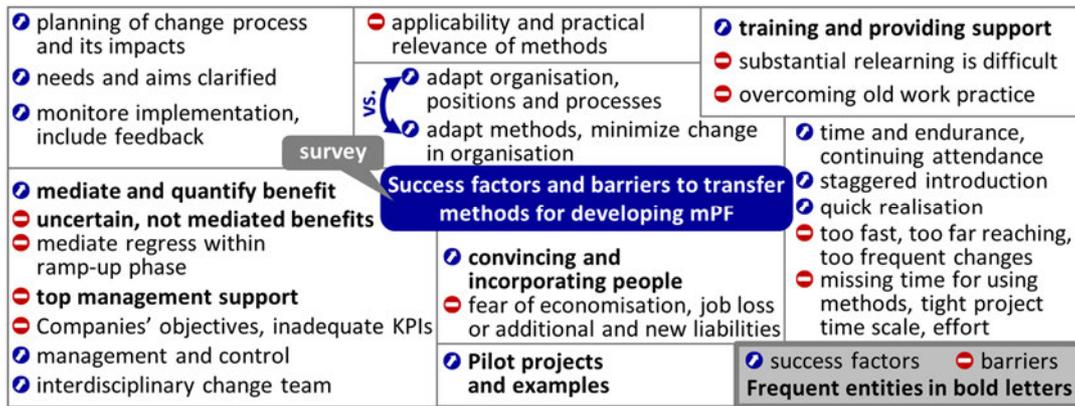
Figure 8. Categories of success factors and barriers mentioned in interviews

The findings correlate with earlier studies (Sec 2.2), but special challenges in DmPF arise from implementation in different departments and convincing management of investing in DmPF while only being able to roughly quantify the positive effects of reducing complexity.

5. Implications for the transfer of methods for DmPF

The literature and the studies have shown the need for measures in the research domain and in companies to transfer new methods. The findings are used to define a framework for transferring methods for the DmPF (Figure 9).

Academia is responsible for providing methods aligned with general requirements of practice which have been collected in the study (Figure 7). However, methods need to be developed universally and cannot meet every company need. Thus, the developed framework includes the step "Description and structuring of methods", utilising the idea of a modular methods tool kit as mentioned in the interviews. Complex approaches for developing mPF should be structured into method units that can be easily selected, adapted and combined. For this purpose, a process visualisation of methods was developed [Beckmann and Krause 2013] to analyse methods, focusing on visualising integration of different stakeholders in each activity as well as the required methodical and product family-related knowledge. As a structuring criterion, the essentials of a method must be allocated to a method unit to keep the selected method focused and to dispense with unneeded parts, as demanded by the interviewees. The description and structuring of methods is a preliminary activity undertaken by academia independent of a specific company. The initial step of an implementation project is the "Analysis of requirements", including observation of the development process and organisational structure of the company, the individual needs, and the problem to be solved. By comparing the needs of the company and new methods, generally suitable method units can be selected, but a compatibility gap can occur, e.g. a divergence between procedure proposed by the method and current development practice. It is handled by an "Adaption of methods" to create a method set that fits the company and can be implemented by "Transfer of methods". Success factors derived in the interviews can be helpful to choose adequate implementation measures. E.g. a pilot project by designers, managers and experts from academia can be used to show improvements when using the method and build a group of method experts within the company. Afterwards, the new methods need to be integrated in the development process and the people need to be trained to create a "revised development process and practice". Feedback from the pilot project and later stable use can be used to improve the application of the methods and provide input into academia for future improvements.

Overall the methods must be selected, combined, and adapted to increase their usability in companies while development practice steadily shifts towards the theoretically ideal process by incorporating essential ideas of methods into the daily work of designers and managers (Figure 9).
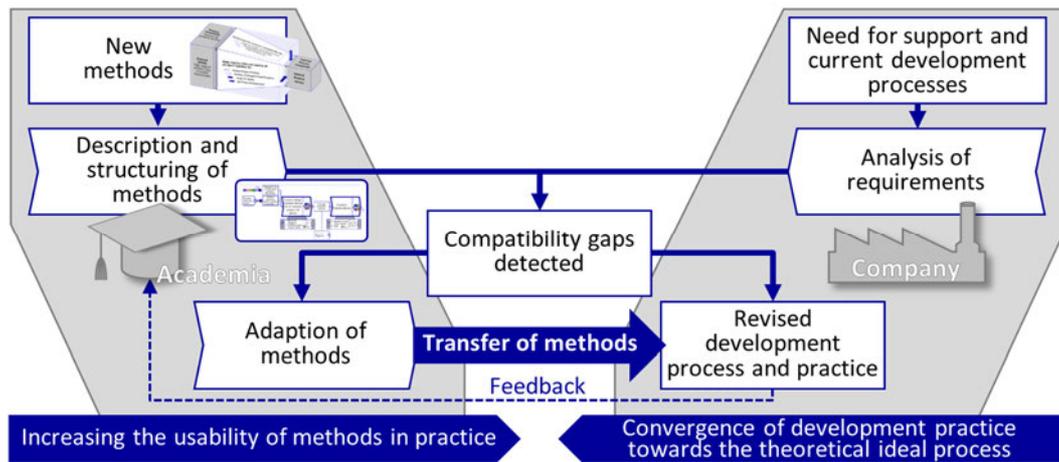
Figure 9. Framework for transferring methods for the development of mPF

Some steps of the framework correlate with existing frameworks (Sec. 2.2.). E.g. adaption of methods can also be found in both presented frameworks from literature (Figure 4). However, new and specific ideas are included in the framework, like the description and structuring of methods. A specialised way of describing methods focusing on the interaction between stakeholders allows detailed considerations how methods can be included into the existing organisation structure. This is vital as communication is one of the most important steps of DmPF. Besides, the study showed general and specific needs for adapting the DmPF methods that need to be considered for refining the steps of the framework.

6. Conclusion

To reap promised improvements in developing modular product families by using new methods, active transfer and implementation in companies need to occur. The studies done in practice are supporting the literature in showing the need to adapt existing approaches to the studied requirements of companies. Methods must fit existing work practices, be simple, task-oriented, and teachable, and should be included in existing software systems. Methods for developing modular product families have to support communication between different stakeholders and thus need adaption to their different requirements and use habits. While the appearance of methods needs to be adapted, essential ideas, like creating transparency of variety, need to be included and development practice has to change. This process is a management and education task, including mediating benefits, convincing people of new methods, and providing skills to methodically develop modular product families.

In future research, the framework needs to be detailed. An evaluation is needed, how sufficiently modular product family development methods can be woven into company structures and if they are able to fulfil major tasks like incorporating and mediating between different stakeholders. In a long term perspective, methods fully integrated in companies should be studied to derive more detailed and concrete requirements for method development, compared to findings of limited case studies.

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