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Procedia CIRP 70 (2018) 398–403

www.elsevier.com/locate/procedia

28th CIRP Design Conference, May 2018, Nantes, France

A Training Framework for the Synthesis of a Consistent System of Objectives in Modular Design

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Abstract

Modular design (MD) enables a set of methods to reduce development costs. There are extensive scientific findings on MD, but in practice, many companies still find it difficult to harvest the full potential of introducing and sustaining MD. One challenge are the highly interactive objectives of MD and the associated products. These different objectives have to be managed in such a way that a consistent System of Objectives is created. To this end, the various stakeholders can develop a common understanding in their MD processes. Consequently, a framework to support a consistent System of Objectives in MD can support this. In this paper a demand and target group oriented training concept to bridge this gap between theoretical findings and in practice-exploited potential as well as to improve the introduction and sustaining of MD is introduced. An important cross-functional insight is thereby how training concepts for Systems of Objectives in modular development can be designed. With expert interviews different requirements, such as “corporate structure”, “dealing with conflicting objectives”, “temporal robustness of products against changes”, “product configuration”, “change management”, “product architecture” and “process integration of suppliers” were identified. Based on these findings a three-stage framework was developed to identify the relevant fields of knowledge for each training concept individually. The training is based on a multi-media approach with participative learning and gamification elements. The concept is modular and round-based, so that the difficulty level can be increased in each round, in order to maximize training effects. It focuses on intra-corporate stakeholder management and communication between different disciplines, such as management and engineering.

Peer-review under responsibility of the scientific committee of the 28th CIRP Design Conference 2018.

Keywords: Design Methods; Knowledge Transfer; Modular Design; Change Management; Conflicting Systems of Objectives

1. Introduction and Motivation

The development of new technologies and approaches often entails the generation of implicit knowledge. To more effectively capitalize on the potential of this implicit knowledge it should be made utilisable in practice. This can mean building up new competences based on new knowledge, enabling situation-appropriate a correct application of the knowledge [1]. A delta between implicit and in practice utilisable knowledge can be observed in different domains. Examples are the development of new methods such as modular design (MD), new manufacturing processes such as fibre-reinforced composites or new products such as self-driving vehicles. This paper focuses on the knowledge about differing objectives in construction kit (CK) development and MD.

MD enables, among other things, to vary the function of products by exchanging, adding and omitting modules and to use identical modules in different products [2]. However, modules must therefore function in combination with a significantly higher amount of other modules. This results in strong interrelationships between different modules and products. Due to these interrelationships and the resulting far-reaching impact of decisions, the various stakeholders (development engineers, validation engineers, production engineers, etc.) have to cooperate even more closely than usual.

Peer-review under responsibility of the scientific committee of the 28th CIRP Design Conference 2018.
10.1016/j.procir.2018.02.035

Some stakeholders initially optimize their objectives only based on their own field of work and interests. This leads to increased complexity in the product engineering process (PEP), especially the development of new modules [2]. However, in order to holistically improve the CK and to ensure interchangeability and reusability of modules, the stakeholders involved need a common understanding of the objectives of the MD system. In addition, it is possible that the Stakeholders have a differing understanding of already formally defined objectives. Consequently, a framework is needed to support the consistent creation of Systems of Objectives (SO) in MD. In order to meet this requirement, various research projects have been conducted [2][3], though, a training concept on the use of consistent SOs in MD in the engineering application is still lacking.

In order to build up competence through a training course, knowledge elements (procedural knowledge and declarative knowledge) as well as motivation of the participants is required. [1] This paper focuses on how the declarative and procedural knowledge can be combined to utilize the existing implicit knowledge. In order to make the exchange of knowledge between stakeholders as effective as possible, a common state of knowledge with a common basic understanding and a common language is required [4].

Therefore, in the following, the current state of the art on MD and knowledge management is discussed and a training concept for MD is presented.

2. State of the Art

For the development of a training framework, first the current state of the art on its context (MD), on training courses in general and knowledge management is presented.

2.1. Modular Design

In line with the megatrend of individualization, companies try to offer their customers products that are as individual as possible. For that purpose, companies are increasingly relying on MD to allow for higher external systems variety, but to simultaneously reduce the internal systems variety [5].

MD is a corporate strategy and product strategy approach in which customers are offered a wide variety of products, which are manufactured using a small number of differing modules. The external systems variety (the number of offered product variants) is generated by the reuse of modules and platforms in various products and product variants [6]. Thereby the internal systems variety (number of different components used) can be kept low. Costs can thus be reduced through scale and learning curve effects in the production division [7].

According to ALBERS [2] various standardization methods can be used in order to achieve this: module, platform, hat section, type series and the construction kit (CK). The **construction kit** contains all subsystems from which various systems can be built through configuration. The CK also contains a set of rules that regulates the architecture of the subsystems, in particular their interfaces, and thus ensures the compatibility of the subsystems. [2]. Within **construction kit development**, the subsystems of the construction kit are developed and products are built through combining them. CK development also includes the development of the CK rules and the monitoring of compliance with it [2].

By reducing the internal systems variety, development capacities can be concentrated on fewer components. At the same time, however, new challenges arise in product development [8]. The reuse of modules across various products results in a greater number of more distinctive interrelationships between the individual products and modules. Therefore, the definition and modification of module properties has an effect on far more products, product generations [9] and other product components. As a result, products cannot be changed by simply changing component properties as usual. This means that the actions of an individual stakeholders participating in the PEP also have an impact on a larger proportion of the component portfolio and thus also on a larger proportion of other stakeholders. As a result, the complexity increases significantly when developing new modules of a construction kit [2].

Overall, the introduction of the MD results in an increased need for communication and coordination between the relevant stakeholders [10].

Due to the differing reactions to the change and the wider scope of actions of individual stakeholders in MD, this also increases the potential for conflicting objectives. For the handling of the interrelated Systems of Objectives, the stakeholders require the knowledge how to handle these conflicts. One important factor is the effective exchange of knowledge about the respective systems of objectives.

The Systems of Objective represents the objectives that are required to develop the right products, as well as the interrelationships and rationale of these objectives [4].

The different sub-processes (e. g. development of different product generations or validation systems) that are required to develop the right product and the process participants of a company can have different objectives. These can then be represented in a singular, consistent Systems of Objective [11].

The employees of a company define these objectives according to their state of knowledge. A larger state of knowledge enables the definition of more specific goals. The state of the Systems of Objective is therefore directly dependent on the state of knowledge. [4].

2.2. Training-Courses

One possibility to expand the state of knowledge is the use of training courses. It cannot be assumed that a teaching/learning approach can be applied to every topic. Due to the large number of different learning styles, there is no optimal teaching and learning method in general [12]. Nevertheless, there are some recommendations in the adult education literature on how to conduct learning events successfully. The following are some examples important to this paper:

- A coherent structure helps participants to follow the content [13].
- Active working on the learning content by the participants and targeted feedback with subsequent anchoring of the

content, through reflection, repetition, etc. help participants to internalize the contents [12][13].
- Practical relevance or linking the contents to the participants' experience and future tasks helps the participants to anchor the contents [14].
- Participants learn better with partners or in small groups compared to learning alone [13].
- A positive learning atmosphere and a motivating climate support the learning process [13].

According to motivation psychology, the intrinsic motivation is primarily based on three needs that can be addressed: need for power, need for achievement and need for affiliation [15]. The need for power is associated with the pursuit of prestige and reputation, as well as the excelling of others. The need of achievement is about achieving or exceeding a self-established quality standard for performed activities. The need for affiliation is characterised by the desire to enter into positive relationships with others and to maintain them [15].

Training courses can be structured as workshops.

According to LIPP AND WILL [16] a Workshop is a working meeting in which a group of people take on a chosen topic in closed atmosphere outside of their routine work.

The training can be structured according to the Workshop - standard procedure LIPP AND WILL [16].

Prior to the beginning of the Workshop, organizational questions are clarified and objectives and contents are defined. At the beginning of the Workshop, participants are introduced to the topic. Subsequently, a common level of knowledge is established and the participants are convinced of the objectives with arguments. Afterwards, solutions for the task are generated. The ideas are evaluated by the group and a catalogue of measures is prepared. In the end, the importance of the results and how to proceed with them are emphasised [16].

The participants to whom the training should be directed are the PEP stakeholders who are part of the company. According to LINDEMANN the relevant stakeholders are the employees of the following divisions: sales, product marketing, project management, development, testing, quality assurance, ergonomics, purchasing, production, assembly, maintenance and repair, authorisation, industrial design, packaging and logistics [7]. The management of the company is also included.

2.3. Knowledge Management

According to Probst [17] the activity of knowledge management can be described by the building blocks of knowledge management. The six core processes and their connections to each are the central to the concept: knowledge identification, knowledge acquisition, knowledge development, knowledge distribution, knowledge use and knowledge preservation. Particularly relevant for this paper is the analysis and description of an organization's knowledge environment through knowledge identification, the subsequent knowledge distribution of existing knowledge in order to make it usable across organizations, and the development of new competences based on distributed knowledge within the framework of knowledge development. The objective for knowledge management is to thereby enable the productive use of organizational knowledge for the benefit of the company [17]. The activities are conducted according to defined objectives, referred to as plan knowledge [17].

The knowledge stair of NORTH [1] represents levels that can be influenced for a effective knowledge management. "Information" can be interconnected and thereby "knowledge" is created. The practical use of knowledge is "action". Competence "is the ability to act appropriately according to the situation. Companies that develop unique competencies can thus improve their "competitiveness" [1].

Knowledge can be classified into procedural and declarative knowledge [18]. Declarative knowledge is knowledge about facts about the world. It is comparatively easy to formalise. Procedural knowledge is knowledge how to do something. It is difficult or even impossible to formalise. The distinction is analogous to the distinction between program and data in computer sciences. [18].

3. Aim of Research and Methodology

As described previously, modular design can lead to frictional losses due to conflicting objectives of individual stakeholders. In order to improve the consistency of the System of Objective (SO), its creation by the operation system can be influenced. The company-wide SO is composed of the SOs of the individual stakeholders. These SOs in turn are based on their individual state of knowledge. Based on a common fundamental understanding and a common language, an improved alignment of the individual states of knowledge can be achieved. Thus improving the consistency of the company-wide SO. In addition, the declarative knowledge about MD should be supplemented by the required procedural knowledge that enables the stakeholders to deal with the conflicting objectives appropriately. This is because if it is known how the declarative knowledge can be applied, it can be applied.

Therefore, an approach has been developed to improve knowledge transfer between stakeholders in MD. To this end, the following research questions were addressed:

1. **Which fields of knowledge are relevant for the content of a training course on MD?**
2. **How can a MD training framework be designed to provide the procedural knowledge required for MD to different type of stakeholders?**
3. **How can this framework be used to promote the exchange of knowledge about the individual System of Objectives of the stakeholders of the CK PEP?**

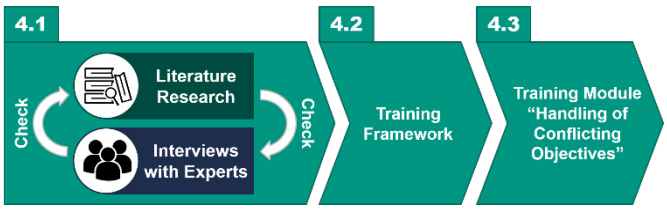

Figure 1: Development process of the training framework and module

In order to answer the questions, the topics relevant for MD were identified in preliminary literature research. The topics were supplemented, weighted and specified on the basis of expert interviews with MD specialists (a department head and a technical expert from a leading German machine tool

manufacturer and a post-doctorate researcher who specializes in MD). On this basis, a framework was developed to transfer the knowledge required for modular development. Finally, a training module on one of the identified topics was developed. (Figure 1).

4. Framework for a training course to transfer knowledge in MD

In the following, the identified fields of knowledge for MD are presented. Subsequently the training framework is established and the training module "Handling of Conflicting Objectives" is presented.

4.1. Knowledge to be Transferred

For the initial identification of relevant knowledge fields, potentials, risks, requirements and common module drivers were identified within the scope of a literature search. The results were subsequently augmented by expert interviews. The identified knowledge fields were then analysed and sorted into the following clusters according to similarity and overlapping topics. Thereby the relevant subjects for the individual training modules were identified:

- **Handling of Conflicting Objectives:** Differing Objectives [10][19][20], Corporate Structure [10], Change Effects [10]
- **Documentation and Communication:** Visualization and Documentation [7][10][19], Modelling [19][20]
- **Organizational Assignment/Corporate Structure:** Clear assignment of organizational units [10][19], Corporate Structure [10][19], Parallel Development [7][10][21][22]
- **Temporal Robustness of Products against Changes:** Adaptation or Extension of the Functional Scope [10], Change Effects [10][22], Product Generation Development [19][20]
- **Product Configuration:** Configuration of Product Variants [7][10][21], Reuse of Modules [7][10][21][22], Adaptation or Extension of Functions [7][10][21][22]
- **Change Effects and Change Management:** Product Strategic Relationships [10], Change Effects and Change Management [10]
- **Product Architecture:** Handling of Complexity [10][19][21][20][22], Technical-functional Relationships [10][19], Temporal Robustness [10][20], Design of Construction Kits [7][19][21][22]
- **Process Integration of Suppliers:** Acquisition of pre-assembled and pre-tested modules [7][10], Outsourcing of Development Activities [7][10]
- **Tests and Validation:** Evaluation of Concepts [10][20], Quality and Function Testing on Module and Product Level [7][10][20][21][22]
- **Maintenance and Repair:** Replacement of Defective Module [7][21][22], Scale and Learning Curve Effects [7][10][21][22], Retrospective modification of product functionality [7][10][21][22]
- **Disposal and Recycling:** Assignment of Modules to Recycling Groups [7][10]
- **PEP-evaluation:** Quantification MD value (interview)

4.2. Training Framework for MD

Knowledge requirement of organisation varies depending on the state of knowledge of the organisation and the progress of the CK introduction. In order to meet the different requirements, a customisable training concept is proposed. The training courses take place over a limited period of time and serve the initial distribution of knowledge to the stakeholders of the individual CK development process.

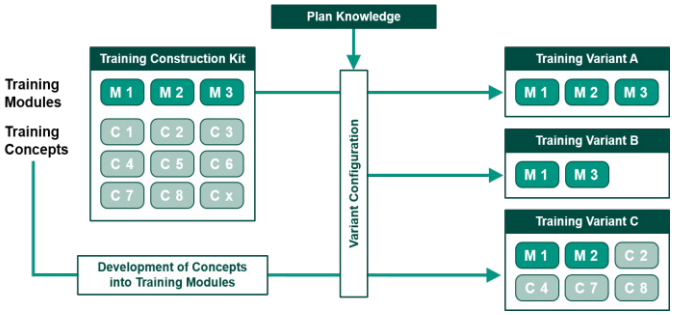

Figure 2: Training construction kit and training variant generation

The training concept is based on a CK for flexible generation of training courses (Figure 2). This CK contains several training modules on different topics (Section 4.1) and concepts for additional training modules. Individual training variants can be generated by combining the training modules. The training modules are selected based on the organisations plan knowledge. These are jointly defined by the training provider and the organisation based on the knowledge gaps within the organisation. The identification of the plan knowledge and the generation the individual course form the preparation phase of the training (Figure 3). A 3-stage framework for generating courses has been developed. If required, additional training modules can be added to the training CK. These can be generated by adapting existing concepts into concrete training modules (Figure 2). The content/knowledge of the training is identified from existing scientific findings. The primary focus is to impart this knowledge to build procedural knowledge through practical application. The main objective of the training is to thereby enable the participants to act appropriately to the situation and to develop competence.

The procedure of the training (Figure 3) is based on the Workshop procedure of LIPP AND WILL [16] and follow the following pattern: In the beginning, the participants are introduced to the topic at the macro level. Through the subsequent imparting of the objectives of the training course, commitment to its contents, i.e. motivation for the application of the content built [1].

This is followed by the primary transfer of knowledge through the implementation of individual training modules. In each training module the participants go through a simulated PEP based on game cards (Figure 4). The basic cards are divided into function (1) and shape (2) cards. By combining them, the participants create product components (1+2). This is intended to illustrate the usual binding of functions to interchangeable modules in MD. Product components can be interconnected by means of interface cards (3). This underlines the importance of interfaces in MD.

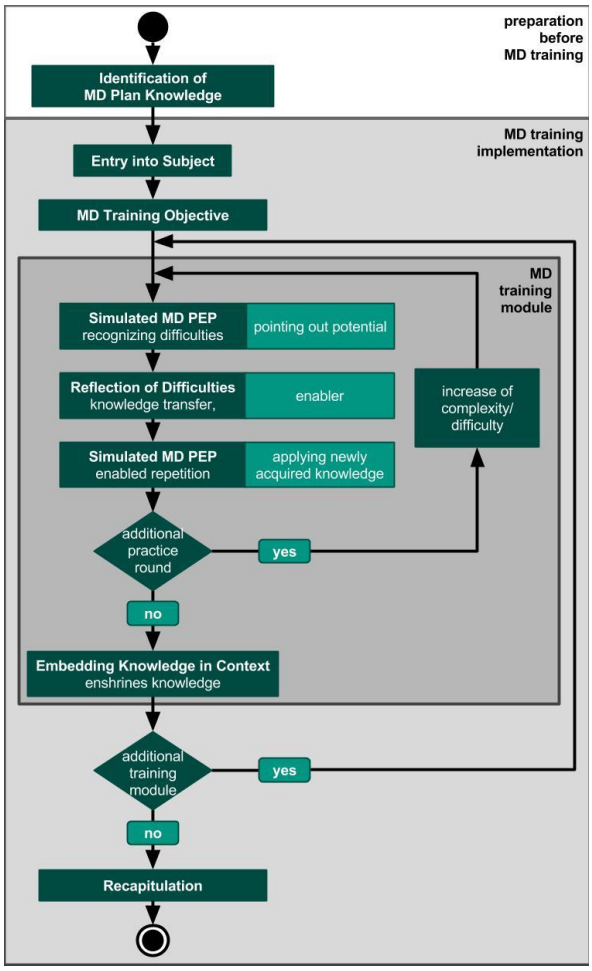

Figure 3: Training Procedure

The resulting structures can be combined into modules. For this purpose, the overall function of the structure is described in a module card (4). By inserting the modules into a predefined platform plan (5), product variants are generated. Variations on the platform illustrate the reusability of modules and the variation of the function by exchanging modules (Figure 4).

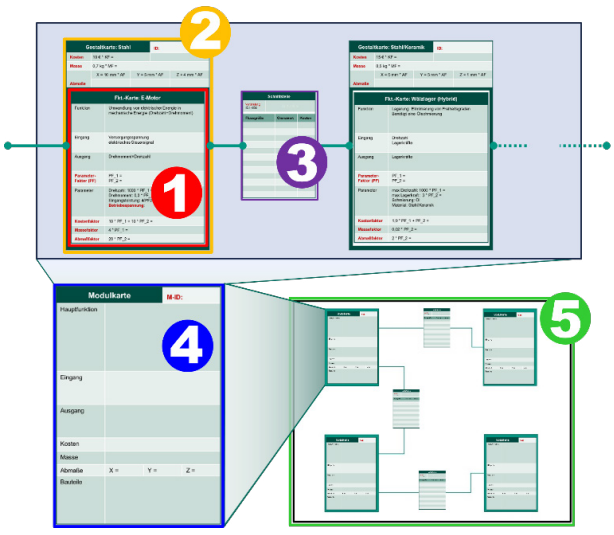

Figure 4: Card based simulated PEP

The fractal structure in three system levels (product component, module, platform/product variant) represents the fractal character of system theory and is intended to promote thinking in systems. The abstract and practical examination of modules, platforms and the use of modules as hat sections makes the standardization methods according to ALBERS [2] (Section 2.1) tangible and helps to anchor the understanding of these methods. After working on a specific development task in the simulated PEP, the results are measured according to the task. Thereby deficits and difficulties are illustrated. Subsequently the simulated PEP is reflected upon to identify specific deficits and develop new strategies. Thereby the prior identified knowledge is imparted. This knowledge enables the participants to better solve the task in a second round. Through the direct application of the imparted knowledge, participants can acquire procedural knowledge (cf. knowledge acquisition). In a subsequent in-depth lecture, the imparted knowledge is embedded and anchored in a larger context. If necessary, further training modules are conducted subsequently. At the end, the imparted knowledge from all training modules is recapitulated to anchor the knowledge and to generate further motivation for the application of the imparted knowledge by showing the learning success.

4.3. Training Module "Handling of Conflicting Objectives"

As a guiding example for the training framework, the concrete developed training module "Handling of conflicting Objectives in MD" is described below. The topic was selected based on unfortunately in practice occurring potentials for conflicting objectives and the far-reaching effects of conflicting objectives of CK development. In groups, participants are confronted with different customer requirements (e. g. price expectations, maximum dimensions, required performance). The success of the participants is assessed individually and each participant of a team is assigned a separate System of Objective (SO), which is in conflict with the SOs of other team members. Thereby every participant is provoked to work primarily according to its own SO, based on a real PEP. This restricts the Group's overall effectiveness. After the conduct of the simulate PEP, the group reflects together. Subsequent, the group, with the support of the trainer, discusses which problems arose and how the overall effectiveness can be increased while still taking the individual objectives of the team members into account. In order to deal with this problem, the participants receive a lecture on the following topics: Fundamentals of systems theory [23], holistic SO synthesis [4][24][25], intra-corporal stakeholder management (Change Management [24][25] and communication and decision-making in situations with divergent SO). The training module is intended to enable the participants to improve upon their exchange of SO knowledge in the context of MD. Through direct application, procedural knowledge is acquired. The acquired knowledge about the handling of SOs should enable the participants to exchange knowledge about SOs more efficiently and effectively in order to synthesise a more consistent company-wide SO.

5. Conclusion and Future Works

In this work, knowledge fields were identified that can be relevant for stakeholders in the modular design (MD) process. In addition, a holistic training framework was created. This training framework is designed as a modular system itself. The different modules can be used together with the developed set of rules to create individual training courses. The feasibility was demonstrated using the example of the specifically developed training module "Handling of Conflicting Objectives", as this topic is highly relevant in the context of MD. Due to the iterative, round-based concept, the participants can continuously adapt and concretize their common state of knowledge and thus enable them to form a common SO for the CK. Thus, the SO of the individual stakeholders in the PEP are based on the same information or state of knowledge. This can improve the consistency of the common SO. The Approach is based on the integrated Product engineering Model (iPeM) [11] and the Advanced System Triple Approach [4]. These methods are extended by the transmission of procedural knowledge about knowledge transfer (through practical application) which is than anchored by embedding it in practical context.
Further, it is to be investigated how the framework or training module for dealing with conflicting goals can be used to build up competence beyond the ability to act. To this end, it should be further investigated how the framework and training module can be utilised to improve the distribution of SO knowledge and how far a more consistent SO is achieved. For this purpose, a qualitative study with students has already been conducted in three iterations. Furthermore, a quantitative study to quantify the success of the knowledge distribution and the influence on MD in teams is planned. The study will evaluate the improvement of the participants' knowledge about SOs and weather the gained knowledge helped to improve their team's performance in the simulated PEP. Additionally the teams' SO consistency in the simulated PEP is going to be evaluated before and after the reflection/enabler (Figure 3) to measure the effectiveness of the framework to improve SO consistency.
In order to create the framework, several for MD relevant topics were identified (Section 4.1) and a concrete training module for one of them was developed as a guiding example. The training framework and the guiding example can be utilized as a basis for the development of further training modules. In addition, it is to be investigated how the developed training concept for the consistent development of SOs can be transferred from construction kits to other areas. One example is the area of fibre-reinforced polymers, since experts from different fields are involved here.

6. Acknowledgements

We thank the German Research Foundation (DFG) for funding this project in the scope of GRK 2078 "IRTG".

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