INTERDISCIPLINARY SYSTEM ARCHITECTURES IN AGILE MODULAR DEVELOPMENT IN THE PRODUCT GENERATION DEVELOPMENT MODEL USING THE EXAMPLE OF A MACHINE TOOL MANUFACTURER

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ABSTRACT

This paper considers the orientation of product development structures towards interdisciplinary system architectures using the example of a tool machine manufacturer. Due to the change from simple mechanical products to extensively designed systems, whose successful development requires the integration of all disciplines involved, it is analyzed which requirements there are for these interdisciplinary system architectures in today's development environment. In addition, it is validated on the basis of the investigation environment that interdisciplinary system structures are necessary for the development on the different levels of the system view. In doing so, the investigation environment addresses the concept of extracting customer-relevant features (systems) from a physical-tailored modular system (supersystem) in order to develop and test them autonomously, as well as to transfer them to the entire product range in a standardized manner. The elaboration identifies basic requirements for the development of a knowledge base in interdisciplinary system structures and places them into the context of an agile modular kit development.

Keywords: Systems Engineering (SE), Multi- / Cross- / Trans-disciplinary processes, Integrated product development, agile modular development, interdisciplinary modularization

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1 INTRODUCTION

In order to meet the increasing intensity of customer requirements in providing and developing new products, the scope and processes of development must be adapted accordingly. One way of meeting this demand for a wide range of variants and individualization while keeping internal complexity to a minimum is the modularization of products and mechatronic systems. The increasing relevance and volatility of customer-relevant requirements on the system requires a further consideration of previous approaches to modular product design. Since a customer-relevant property in mechatronic systems is not only implemented by a single discipline, such as software development or mechanical engineering, the necessity follows to include interdisciplinary collaboration as an important further influencing factor in the development of modular mechatronic systems. The assumption is supported by the fact that expanded competencies are required for the further implementation of engineering in the area of digitization and Industrial Revolution 4.0, and explicitly also for the development of cyber-physical mechatronic systems (Abramovici and Herzog, 2016). In addition to the previous mechanical components of a product as a central sales factor, the software components of a product are growing in significance, as these can decisively influence the functionality of the product in external terms. These extended competencies can only be fully developed through an interdisciplinary exchange. (WiGeP, 2017). In this paper, interdisciplinary collaboration in the development of modular products is examined using the example of the development environment of a German machine tool manufacturer, which implements its product portfolio through a modular strategy. Thereby, it is considered which requirements arise during the implementation of customer-relevant features in interdisciplinary structures and how these can be put into the considered focus.

2 RESEARCH BACKGROUND

Derived from the motivation of this research, two main topics of investigation were focused on the research subject:

- **interdisciplinary & cross-disciplinary product development**
  Within the context of this work, interdisciplinary and cross-disciplinary structures are considered domain-specific. A discipline is mapped as a development domain, such as software development or mechanical design.
- **modular kit development & modular product design**
  Modular kit development and modular product design addresses, in the scope of this research, the targeted decomposition of the product variety offered in order to generate internal synergy effects and reuse. The development of modular product families is dealt with in this context.

As a basis for this publication, a literature review was conducted in various databases, such as Scopus and Web of Science, on the defined main topics. The result of this review revealed that only a few publications could be found on the combination of the above-mentioned aspects, e.g., (Marshall and Leaney, 1999; Albers et al., 2015b; Bursac et al., 2016; Scherer et al., 2017; Drave et al., 2020). In a further co-occurrence analysis of the results, it could be deduced that these publications show rather weak links (less than 2) between the given keywords. Therefore, it can be concluded that these aspects should be further investigated in the context of this research.

Focusing on the handling of complicated and interdisciplinary projects, the literature increasingly refers to systems engineering. According to *INCOSE* Systems Engineering is defined as an interdisciplinary approach with the goal of successfully realizing systems. In this context, systems engineering focuses on the definition and documentation of system requirements in the early phase of development, the elaboration of the system design, and the validation of the set requirements for the system, taking into account the overall problem. It is also interesting for this investigation that systems engineering integrates all disciplines and provides a structure over the entire product life cycle. (Walden *et al.*, 2015)

Continuing on from systems engineering, model-based systems engineering enables a consistent description and analysis of technical systems on the basis of their modeling. Modeling the system can thus contribute to a common understanding of the technical product (Dumitrescu *et al.*, 2014; Bursac *et al.*, 2016). Winzer (2016) takes a more comprehensive look at various systems engineering approaches and attempts to derive a *Generic Systems Engineering*. In doing so, she divides systems engineering into a thinking model and a procedural concept, whereby these components must fulfill certain minimum requirements in order to enable effective and targeted problem solving.

There are many different approaches (Erixon, 1998; Pimmler and Eppinger, 1994; Gausemeier *et al.*, 2001) to supported product creation and the development of modular products. For the study conducted here, both the *Integrated Product engineering Model* according to Albers (2016b) and the *Integrated PKT Approach* according to Krause (2014) were chosen. The *Integrated Product Engineering Model* was chosen because it has a generic character and contains elements that are necessary to derive models adapted to individual problems (Meboldt, 2008; Albers and Braun, 2011). The *Integrated PKT Approach* to the development of modular product families considers both the technical-functional view and the product-strategic view, which is the reason why this approach is suitable for the consideration of modularization in this study (Blees *et al.*, 2010; Ripperda and Krause, 2017).

The integrated product development model offers a method construction kit, which provides the developed teams with different methods to develop and validate solution alternatives adapted to their problem. The approach goes beyond product development and includes other domains along the product lifecycle, as well as continuous activities throughout the project lifecycle, such as project planning and validation (Albers *et al.*, 2016b). As a component of the *iPeM* metamodel, the *System Triple of Product Engineering* offers the possibility to transfer the synthesis of requirements via the action system into an object system and via the action system back into the target system (Albers *et al.*, 2011). Munker (2016) places this analysis and synthesis of requirements and feedback into a technical product in an interdisciplinary context, allowing the shared knowledge base to be considered an essential part of interdisciplinary system modeling. In addition to the interdisciplinary nature of Munker's *System Triple of Product Engineering*, the *model of PGE - Product Generation Development*, as part of the *iPeM* metamodel, supports the interdisciplinary development of technical systems. By considering reference systems and their influence through principle, design and adoption variation into the product to be developed, various preceding knowledge syntheses of the reference systems are drawn upon (Albers *et al.*, 2016b).

Another approach, which serves to build a common understanding, is *the Integrated PKT Approach* to the development of modular product families. This approach is also a toolbox of methods that provides the developing teams with various methods for analyzing systems, generating understanding and structuring them (Krause *et al.*, 2014). Through various visualization methods, such as the *Module Interface Graph* (MIG) and the *Product Family Function Structure* (PFFS), models are created that sharpen the understanding of the system. These visualization methods make it easier for stakeholders to understand how the system is structured and how it works. In addition, the *Integrated PKT Approach* to developing modular product families offers various procedural methods, such as *Life Phase Modularization according* to Blees (2011). *Life Phase Modularization* integrates cross-departments into the modularization of products right from the beginning, so that the product can have a uniform understanding of modules across all life phases. Components of this method are the structuring of the technical system in its own life phase, as well as the workshop-based synthesizing of all discipline-specific understandings into a common overarching understanding (Blees, 2011). From the presented state of the art, different approaches for the consideration of a knowledge base of interdisciplinary collaboration can be derived and specified to the considered research goal.

3 RESEARCH QUESTIONS AND METHODOLOGY

Based on the research background, three research questions were established to further address the research focus of this paper:

1. What are the requirements for supporting interdisciplinary structures in modular product development based on the selected approaches and practical development of modular products?
2. How can requirements for the knowledge base of interdisciplinary modularization be worked up so that they can contribute to the further development of the approaches examined?
3. Do the identified requirement clusters for a knowledge base of interdisciplinary system structures reflect a relevance in the practice of developing modular product families?

This elaboration was structured and conducted using four phases of the *Design Research Methodology* (Blessing and Chakrabarti, 2009).

The *Literature Research* in various databases has shown that there are various methods for collaboration in interdisciplinary system structures that deal with these circumstances by means of systems engineering approaches. However, the analysis shows that there is a deficit in the requirements for interdisciplinary collaboration in relation to modular product design and modular kit development.

This reveals the need to analyze what requirements should be imposed on approaches to the development of modular product families in order to be able to develop them through interdisciplinary structures. This analysis, in the context of *Descriptive Study I*, is addressed in Section 4. Requirements at the interdisciplinary development of modular product families are identified both from the literature, whereby also limited reference is made to the system engineering and from the investigated environment at a German tool machine manufacturer.

Section 5 represents the *Prescriptive Study*, in which the analyzed findings of the identified requirements were processed and clustered. The collected requirements were assigned content-related keywords and subsequently combined into clusters; whereby similar keyword tags were aggregated. The procedure is not described further in detail, as this is beyond the limits of the paper. The clusters are visualized and refer to a selection of standards relating to systems engineering in order to show that some of the identified requirements are already supported.

In order to put the analyzed requirements into the context of the practical development of modular product families, they are validated in *Descriptive Study II*. The evaluation is shown in section 6. Experts in the study environment were asked about the requirements and their clusters, which differed from the experts in *Descriptive Study I*. The results are shown in Figure 3 and Figure 4.

4 ANALYSIS AND IDENTIFICATION OF DIFFERENT REQUIREMENTS FROM LITERATURE AND PRACTICE

4.1 Analysis of requirements from literature

The approaches already emerged from the current state of research, will be analyzed below with regard to requirements for interdisciplinary system architectures in the development of modular product families. The focus was expanded to include *Generic Systems Engineering* (Winzer, 2016), through which systems engineering is brought into consideration to some extent. In addition, expert interviews, as well as a six-month observation in agile modular development at a German machine tool manufacturer were conducted for further analysis. The identified requirements are presented in Table 3 in Section 4.2.

For the analysis of the method building blocks, these were broken down into their components in order to be able to look more closely at which requirements for the study aspect can be derived from them. The objects of consideration were on the level of individual activities, respectively accompanying, as well as recurring tasks. An example of this is the analysis of basic activities of product development from the integrated product development model. All activities were extracted from this and examined for their relevance to the topics considered here. For the activity "*Validate and Verify*", it was derived that interdisciplinary system architectures not only have to validate customer requirements, but due to the cross-discipline composition, discipline-specific requirements also flow into the overall project, which must be documented, structured and validated. From the point Verify derives the requirement that the correctness of the modeling of the system understanding must be verified, which serves as the basis for the common understanding. Another example from the *Integrated PKT Approach* to the development of modular product families is the detailed analysis of *Life Phase Modularization* according to Blees (2011). Here, it is analyzed that the approach of workshop-based finding a common compromise across all involved life phases to form a common understanding again highlights the requirement for common system modelling.

The results of the overall analysis and the identified requirements for interdisciplinary system architectures, are summarized in Table 3. The analysis of *Generic Systems Engineering* that builds on this is guided by the 17 *basic principles of systematic thinking and action* identified by Winzer (2016). According to Winzer (2016), these represent an elementary component of the thought model and the procedure model of systems engineering. As an example, the "*basic principle of recurrent reflection*" (e.g., Dörner, 2011) is intended to support the mastering of more complex tasks by not losing sight of the holistic system through constant reflection. From this basic principle, the requirement of continuous validation can be derived, which has already been derived from a basic activity of product development. In addition, this also allows the definition of a system model to be derived, which can describe a system under consideration in a holistic and interdisciplinary manner. Supplementing the identified requirements from the literature, expert interviews were conducted. From these, it was derived which requirements exist from the point of view of participating developers and other experts with regard to an interdisciplinary system architecture. The results are shown in Table 1 and have been included in the consolidated Table 3. The sample of experts covered all disciplines involved in the agile modular development of the machine tool manufacturer under investigation (e.g., fluidics, mechanics, simulation, software development), as well as upstream and downstream functional areas (e.g., production, service, product management), and additionally covered a range of development experience between 2-13 years. In order to keep within the number of pages, the results have been visualized in Table 1 in a pre-grouped representation. The raw data was retained for further processing.

Table 1. Requirements from expert surveys

#	Requirement from expert survey
1	Versionability and traceability of changes
2	Common repository and central system for management
3	Predefined definitions and processes for development
4	Possibility of intuitive collaboration of each developer
5	Uniform understanding of the development environment
6	Visible cascade of assignment
7	Existing structures and no new systems
8	Use of native data
9	Involvement of all stakeholders

The third source of analysis of requirements for interdisciplinary system architectures is a six-month observation of the agile modular development of a machine tool manufacturer. Here, further requirements from the methodology of agile working could be derived from the observation. Here, continuous validation and early testing also serve as examples. These agile principles have their origins in software development, which already works in interdisciplinary structures and can therefore be used as a reference system for integration in mechanical engineering (Schwaber, 2012). Table 2 lists the requirements from observation in agile modular development. In order to keep within the number of pages, the results here were also visualized in Table 2 in a pre-grouped representation. The raw data was retained for further processing.

Table 2. Requirements from practical observations in agile modular development

#	Requirement from the practice of modular development
1	Iterative procedure to increase the quality of the output
2	Use of established and accepted structures and roles
3	Clear regulation of responsibility
4	Mapping and support of a common understanding
5	Establishment of all relevant views and their aspects
6	Possibilities for continuous validation

From the observations of the research environment, it can additionally be deduced that the use of established and accepted structures is a requirement for a common understanding. Many developers are critical of new tools. According to the observations, this critical attitude refers not only to systems used but also, to roles and responsibilities. Therefore, the clear assignment of responsibilities is another necessary requirement to enable an orderly process.

4.2 Identification of requirements from literature and practice

To complete the analysis and identification of requirements for interdisciplinary system architectures, 29 requirements were derived from literature and practice, which were incorporated into an overall summary in Table 3. The multiple identifications that occurred due to the sequential examination of the components were summarized during the process of analysis to reduce redundancy.

Table 3. Identified requirements for a knowledge basis of interdisciplinary system structures in modular product development

#	Identified requirements	supporting sources of requirements
1	**Collaborative project planning**	(Albers *et al.*, 2016b;Daenzer and Haberfellner, 2002,2002;Sitte and Winzer, 2012)
2	**Integration of all stakeholders into validation process**	(Böhm *et al.*, 2002; Badke-Schaub and Frankenberger, 2004;Albers *et al.*, 2016b; Dörner, 2011;Wulf, 2002;Schwaber, 2012)
3	**Shared documentation storag**	(Albers *et al.*, 2005;Albers *et al.*, 2016a;Böhm *et al.*, 2002;Munker, 2016)
4	**Collaborative change process**	(Albers *et al.*, 2016b;Daenzer and Haberfellner, 2002; Munker, 2016)
5	**committed requirements to the system**	(Blees, 2011;Greve *et al.*, 2020; Krause *et al.*, 2014;Ott, 2009;Pahl *et al.*, 2003; Schwaber, 2012;Sitte and Winzer, 2012;Wulf, 2002)
6	**Collaborative design of the system model**	(Albers *et al.*, 2016b;Blees, 2011; Böhm *et al.*, 2002; Daenzer and Haberfellner, 2002; Dörner, 2011; Greve *et al.*, 2020;Krause *et al.*, 2014;Lindemann, 2005;Pahl *et al.*, 2003)
7	**Continuous and early testing of the system**	(Albers *et al.*, 2016b;Badke-Schaub and Frankenberger, 2004;Dörner, 2011; Maurer and Schulze, 2012; Schwaber, 2012;Wulf, 2002)
8	**Constant validation of different requirements**	(Badke-Schaub and Frankenberger, 2004;Blees, 2011;Böhm *et al.*, 2002;Dörner, 2011; Ott, 2009; Pahl *et al.*, 2003; Schwaber, 2012;Wulf, 2002)
9	**Integration into the system view across all life phases**	(Blees, 2011;Böhm *et al.*, 2002;Daenzer and Haberfellner, 2002;Greve *et al.*, 2020; Krause *et al.*, 2014)
10	**Collaborative abstraction and structuring of the system**	(Albers *et al.*, 2005;Albers *et al.*, 2016b;Böhm *et al.*, 2002;Daenzer and Haberfellner, 2002;Dörner, 2011;Sitte and Winzer, 2012)
11	**Risk reduction through integration of reference systems/kno w-how**	(Albers *et al.*, 2015;Albers *et al.*, 2017;Lindemann, 2005)
12	**Integration of different kn owledge and experience**	(Albers *et al.*, 2015;Albers *et al.*, 2017;Böhm *et al.*, 2002; Greve *et al.*, 2020; Krause *et al.*, 2014; Lindemann, 2005)
13	**Common understanding of the system**	(Albers *et al.*, 2016b;Böhm *et al.*, 2002;Daenzer and Haberfellner, 2002; Munker, 2016; Sitte and Winzer, 2012),observation "agile modul.developm."
14	**Common understanding of tasks**	(Albers *et al.*, 2016b;Blees, 2011; Schwaber, 2012)
15	**Use of existing structures**	(Lindemann, 2005), Expert surveys
16	**Create work split and common increment**	(Daenzer and Haberfellner, 2002;Dörner, 2011), observation "agile modular development"
17	**Integration of all relevant views and their aspects**	(Böhm *et al.*, 2002; Lindemann, 2005), observation "agile modular development"
18	**Continuous validation of team and system requirements**	(Ott, 2009; Pahl *et al.*, 2003;Wulf, 2002), observation "agile modular development"
19	**Traceability of changes**	Expert surveys
20	**Versionability of changes**	Expert surveys
21	**Shared repository and central system for management & planning**	Expert surveys
22	**Predefined definitions and procedures**	Expert surveys
23	**Possibility of intuitive collaboration**	Expert surveys
24	**common understanding of the development environment**	Expert surveys
25	**Use of native data**	Expert surveys
26	**Integration of all stakeholders**	Expert surveys
27	**Joint prioritization of the scope of work**	observation "agile moduhr development"
28	**Use of established and accepted structures and roles**	observation "agile moduhr development"
29	**Clear assignment of tasks**	observation "agile moduhr development"

5 PROCESSING AND CLUSTERING OF REQUIREMENTS FOR INTERDISCIPLINARY SYSTEM STRUCTURES

After different requirements from theory and practice have been identified in this research, the identified requirements were processed in clusters. The six requirement clusters are shown in Figure 1. In addition, a selection of already existing standards from the *Systems Engineering Book of Knowledge* (SEBoK) is incorporated in Figure 1. The representation is intended to give an impression of the clusters in which there is already overlap with established works, such as *ISO 15288* and the *SEBoK*, which have no claim to be complete. The clusters are not intended to differ from the already established literature, but to provide an assessment of the requirement for interdisciplinary structures in the development of modular product families.

Figure 1. Clusters of requirements for the knowledge base of interdisciplinary system structures in modular product development

- The first cluster combines the requirements for **interdisciplinary project planning and coordination**. This aims at the cross-disciplinary concretization of the project and the joint approach, as well as the responsibilities.
Requirements here are: *"collaborative project planning", "collaborative documentation filing", "collaborative filing and central system for management", collaborative prioritization of work scopes", "clear assignment of tasks", "splitting work packages & creating joint increment".*
- The second cluster refers to the **integration of cross-departmental domains**. This cluster combines all requirements for cross-development and cross-discipline synchronization.
Requirements here are: *"cross-life-cycle integration in the system view," "integration of all stakeholders," and "integration of all relevant views and aspects."*
- The third cluster contains requirements for **change management and generation development**. These are the requirements that must both serve as a reference for system development and map changes so that they are documented and traceable across different versions.
Requirements here are: *"common change process", "risk reduction by integration of reference systems & known", "integration of different knowledge and experience", "traceability and versioning of changes".*
- The fourth cluster is the **Iterative approach & validation**. The cluster is used for continuous validation of requirements on the developed system.
Requirements here are: *"integration of all stakeholders in the validation process", "continuous and early testing of the system", "continuous validation of the different requirements", "continuous validation of the requirements on the team and the system".*
- The fifth cluster represents the **Structural Requirements**, which enable an interdisciplinary system architecture to work together effectively.
Requirements here are: *"use of existing structures", "use of native data", "use of established and accepted structures and roles".*
- The sixth cluster combines the requirements for **Interdisciplinary System Modelling**. This includes joint system modelling and a resulting common understanding.
Requirements here are: *"Committee's requirements for the system", "Common design of the system picture", Common abstraction and structuring of the system", "Common understanding of the system", "Common understanding of tasks", Given definitions and processes", "Common understanding of the development environment".*

The established clusters are not clearly separable and have intersections. The intersections are considered as relevant interactions between the clusters. As a result, the benefit of the overall representation of the requirement clusters is greater than the sum of all the benefits of the individual clusters.

6 EVALUATION OF THE REQUIREMENT CLUSTERS IN RESEARCH ENVIRONMENT

The identified and clustered requirements were validated in the study environment, the agile modular development of a machine tool manufacturer. The identified clusters were validated by experts out of the investigative environment, which were not directly involved in analyzing requirements. The classification of the clusters was generated in workshop-based queries and in sum represents the uniform understanding of the experts. Figure 2 shows the agreement on the individual clusters.

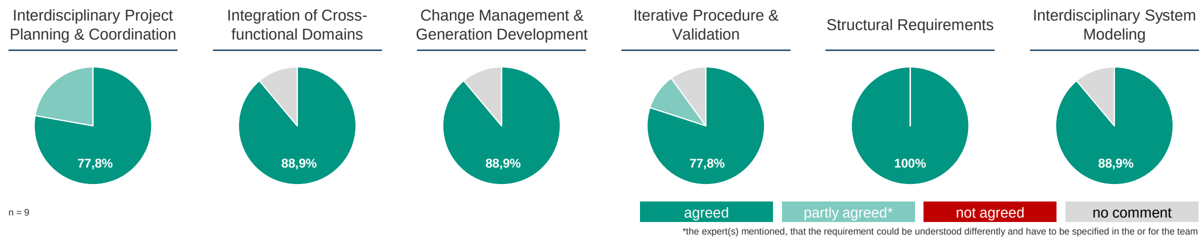

Figure 2. Experts' evaluation of the individual requirements clusters

#	realization	style	effekt
1	● (green)	Collaborative project database	▲ —
2	● (yellow)	Not all stakeholders integrated yet, a few are integrated into sprint reviews	▲ —
3	● (green)	Confluence database as area of collaborative documentation and know-how-exchange	▲
4	● (green)	Using Backlog Refinements from agile project management	▲ —
5	● (green)	Collaborative sprint planning	▲
6	● (green)	Collaborative system modeling via draw.io	▲
7	● (green)	Using sprint events for continious reviewing increments	▲
8	● (green)	Due to Sprint reviews	▲
9	● (yellow)	Not yet identified and integrated all necessary life phases	▲ ▼
10	● (green)	Due to agile events there is an constant exchange about the system	▲
11	● (yellow)	Already impact in system creation due to the usage of reference systems / earlier product generations	▲ —
12	● (yellow)	High impact on system mindset, but no possibility yet to store all the knowledge	▲ —
13	● (green)	Collaborative system modeling via draw.io	▲
14	● (green)	Sprint Retrospective and collaboratively commited Definition of Dones (DoD)	▲ —
15	● (green)	Sucessful usage of existing structures for collaborative teams	▲

● implemented/validated; ● implemented/not validated; - not executed

Style = Comments about the way of realization

▲ Added value, — equal / not yet foreseeable, ▼ negative impact

#	realization	style	effekt
16	● (green)	agile working environment	▲ —
17	● (yellow)	Not yet both included all relevant stakeholders and identified the way of integration (direct or indirect)	—
18	● (yellow)	Not yet identified how to validate the team mindset regarding the developing system	—
19	● (green)	Validated due to an Engineering Change Management System	▲
20	● (yellow)	References in Database incl. SAP®	▲ —
21	● (green)	Confluence Database	▲
22	● (green)	Collaborative system modeling and templates for knowledge exchange	▲
23	-	-	—
24	● (green)	Overall reviews for higher understanding of development strategy	▲ —
25	-	-	—
26	● (yellow)	Not yet identified how to validate the team mindset regarding a develop. system	▲ —
27	● (green)	Agile working environment incl. Sprint plannings	▲
28	● (green)	extending established with newer and additional systems for acceptance	▲ —
29	● (green)	Task assignment by Jira-Tool	▲

Figure 3. Validated requirements from Table 3 and the style of realization in the observed environment

In addition, knowledge bases of different teams from the agile modular development were built and evaluated based on the identified requirements. Figure 3 shows the validated status of the implementation of the requirements, how they were realized in the test environment and how they contribute to it. The numbers in Figure 3 correspond to the numbering in Table 3.

As can be seen in Figure 3, most of the requirements and their implementation have positive effects on interdisciplinary collaboration. For some requirements, the effect is still considered cautiously, because the implementation of the measures is still ongoing and therefore no meaningful effect can be proven yet. With regard to requirement #9, it should be noted that the integration of other life phases is a complicated undertaking, which shows both positive and cautiously considered negative effects. The point should be considered critically, since a coordinated integration in the study environment is assumed. Requirements #23 and #25 could not be validated due to missing resources.

7 CONCLUSION

This study is about the design of a knowledge base in interdisciplinary system structures in modular product development, which deal with interdisciplinary designed modules in the research environment. Various clusters of requirements, which are intended to support complexity reduction through the formation of a common knowledge base, can be identified. These requirements also emphasize that all stakeholders involved in a problem-solving process develop and formulate a common understanding. This understanding will be shaped in further collaboration into a common, but for the project individual, knowledge base. The elaborated requirement clusters are derived from the concept of interdisciplinarity developed modules, but are oriented towards general applicability and adaptability to individual development processes, so these requirements have to be compared with established methods, concepts and approaches, as e.g., the NASA Systems Engineering Handbook or the Systems Engineering Book of Knowledge. In addition to providing a framework for the creation of an interdisciplinary knowledge base, the six identified requirement clusters also provide focus topics for further investigation of interdisciplinary structures in the modularization of technical systems. This provides a basis for further consideration of research directions in the context of interdisciplinary product development of modular product families, as well as eventually smart engineering. Thus, research topics such as the modularization of customer-relevant and performance-enhancing properties, as well as functionalities can be supported in this context. Due to the transformation of development scopes from discipline-specific to cross-discipline project work and system considerations, cross-discipline collaboration in such development environments is becoming increasingly important. Further consideration of interdisciplinary collaboration in the context of modularization opens up extensive possibilities for investigating the extent to which the improved synchronization of disciplines and the increasing exchange of knowledge can change at the system level, or which methods can support this change. In addition to the points mentioned, interactions with the tangential life phases and also trends bring in additional possibilities for consideration.

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