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INTERRELATIONS BETWEEN PROCESSES, METHODS, AND TOOLS IN COLLABORATIVE DESIGN - A FRAMEWORK

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Abstract

Handling the increasing complexity of modern products like mechatronic systems requires knowledge from different disciplines. Engineers are called to collaborate across companies and disciplines in order to acquire the knowledge needed. However, collaborative design is an established way of product development in practice, there is an increasing need to describe and understand the challenges between processes, methods, and tools as well as the persons involved. We propose an overall framework containing an explanation model and a concept to support the application of methods and communication. The explanation model comprises three views namely process, personal, and technical-methodical view to describe the elements within collaborative design in detail and give insights for the interrelations between the views. The purpose of the model is to analyze collaborations to plan and implement new methods and tools as well as changes in corresponding processes. Based on a detailed description of the single views and prior research on interrelations between personal, process and technical-methodical view, an overall framework and a detailing explanation model are introduced.

Keywords: Collaborative design, Design methods, Process modelling, Communication technologies

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1 INTRODUCTION

Since products are becoming more and more complex, there rarely is a single individual, team, or organization possessing all the knowledge necessary to perform all tasks within the design process. For this reason, there is an increasing relevance of collaboration across all industry sectors and between different disciplines. In this paper, we focus on three different views upon collaborative design. We define collaborative design as a design situation in which multiple persons, at least two parties, are involved to fulfil a common design task. Thus, the different stakeholders have to work together, have to communicate and coordinate their individual tasks to achieve the common goal effectively. This demand leads to an increasing need for support, which can be provided regarding the process, methods, tools used and the competencies and qualifications of the designers involved. The following two sections will highlight the importance of collaborative design and set the focus of our research.

1.1 Importance of collaborative design

Due to the increasing complexity of technical systems, the involvement of various disciplines (e.g., mechanics, electronics, and software development) in design projects becomes a present fact across nearly all sectors of industry. On the one hand, the knowledge of different experts is needed to work out solutions for subsystems of different disciplines to complete the tasks. On the other hand, persons who are able to overview the whole system are required to point out interrelations, for instance, in case of changes, and to arrange the single components within the total system. Hence, the work becomes more specialized, requiring the participation of various persons or companies from different fields of knowledge (Vietor et al., 2015). This knowledge-based collaboration is one of the potentials of collaborative design, since resources can be used flexibly, with a positive effect on development and production costs. Further drivers for collaborative design, as stated by Gaul (2001), are amongst others the proximity to customers or the systematic use of different mind-sets across the cultures within intercultural collaborations. Another present driver for collaborative design is the increasing digitalization of the working environment. Digital techniques, for instance, for knowledge transfer and communication, enable a more effective distant working; contrariwise, the growing demand for collaborations pushes the development of new technologies, and thus, the digitalization. Schleidt and Eigner (2010) already found that the time spent on coordination and communication in relation to professional work was growing during the years 2000 to 2006 up to a percentage of nearly 25 %. It can be assumed that this tendency continues due to the increasing digitalization of the working environment. This development and the increasing use of digital technologies result in changed and new competencies and qualifications of the designers involved in collaborative design.

1.2 Research approach and structure of the paper

Because of the increasing importance of collaborative design across all industry sectors and the resulting effort for communication and coordination, our research focusses on the understanding of interrelations between processes, methods, and tools used within the design process as well as the competencies and qualifications of the persons involved in the collaborative design tasks. The research work is driven by the following assumptions:

- Modern technologies for communication, knowledge sharing, visualization, and data handling have major effects on the organization of collaborative design as well as on the required competencies and qualifications of persons involved.
- In order to support engineers and gain benefits in terms of saving time or reduced stress, it is essential for designers to understand the interrelations between processes, methods, and tools used.

Following these hypotheses, our research aims at answering four questions:

1. Which elements can form a framework to describe and support collaborative design?
2. What are relevant elements (e.g., stakeholders, activities) to describe processes in collaborations?
3. How can a model look like to describe and structure the interrelations?
4. How can the application of methods be supported, focusing on their effect on processes?

These questions define the focus of this contribution, which is laid on the interrelations between processes, methods, and tools. Therefore, this work pursues and complements our approach for competency-oriented application of methods proposed earlier (Bavendiek et al., 2016). Combining both approaches, an overall framework for analyzing and supporting collaborative design will be proposed.

In order to answer the research questions, we will introduce different views on collaborative design in section 2. The views will be described in detail whilst the focus is laid on the processes, methods, and tools. Additionally, previous work in the field of collaborative design is presented to subsequently show the needs of an interrelation between processes and methods. Section 3 proposes the overall framework and a more detailed so-called PMC model to describe and structure the interrelations within collaborations. The model helps to analyze collaborative design from different views and indicates the correlation of changes within these views. The explanatory character of the model proposed is highlighted giving two examples of collaborative design in section 4. The results will be discussed. The paper ends with a conclusion and a proposition for future work to be done.

2 BACKGROUND AND LITERATURE REVIEW

The development of the overall framework presented in section 3 is based on previous work described in the following sections. Starting with three views on collaborative design, each view is explained in detail. Research done in the corresponding fields is presented and reflected. A concept for collaborative design is described as a result of prior work.

2.1 Views upon collaborative design

The different views on collaborative design were established to distinguish the fields of research in the wide field of collaborations. The views-model described by Bavendiek et al. (2016) is based on earlier models, e.g., (Bender, 2001; Schleidt, 2009). It defines three views, namely, (1) the involvement of the designers and their competencies as one of the views (personal view), (2) the methods and tools used to support single design tasks (technical-methodical view), and (3) the process to organize the collaboration (process view). Figure 1 shows the three views and their corresponding interrelations.

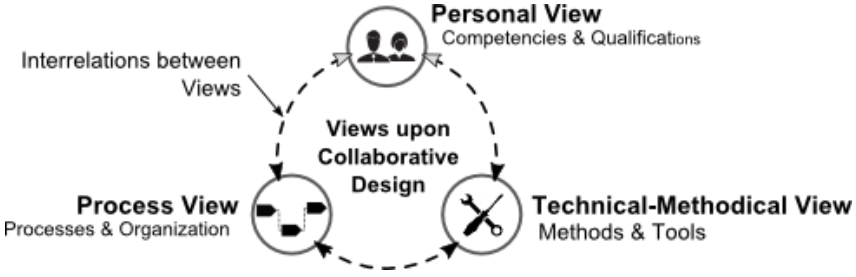

Figure 1. Three views upon collaborative design

2.1.1 Processes and organization

The process view contains procedural and organizational aspects within the collaborative design (Bavendiek et al, 2016). A process in this context is a sequence of interdependent and linked smaller procedures that serve the purpose to convert an input into an output to achieve a certain goal (based on Luthra (2016a)). An example for a process in practice is the decision-making process for a design review or the whole design process. Various aspects like physical interdependencies between components, organizational conditions, and resource restrictions influence the process. Thus, it is important to know the factors that have an impact. The more complex the process, the more influences may appear. Another aspect to consider are the stakeholders of and in a process. This is particularly relevant in a collaboration, as the assignment of tasks has to be clear in order to work in parallel.

To support the process view in collaborative design, various approaches were presented. Pol et al. (2008) developed a method to define (design) processes in collaborations by tracking single so-called events between the designers. The aim is to implement these processes into PLM systems for a better coordination of the processes. Girard and Merlo (2003) work with the GRAI model for engineering design in which they distinguish between a decision system, a technological system, and an information system on the hierarchical levels: strategic, tactical, and operational. The focus of this approach, thus, is laid on the coordination of processes in between stakeholders, designers, and coordinators. Yesilbas et al. (2006) presented results on the investigation on the exchange of information and knowledge within collaborations. Zhang et al. (2013) proposed a formal approach to model the flow of knowledge within collaborative design processes. Therefore, Petri Nets are used to represent knowledge sources and sinks, for instance, stakeholders/team members, or knowledge portals as nodes and edges representing the

knowledge flow itself. However, Zhang et al. state that the uncertain nature of design processes makes them difficult to plan and represent (Eckert and Clarkson, 2010). With regard to collaborative design, another challenge is to understand and represent different parallel tasks and their interdependencies carried out during the design process. Current empirical studies to analyze the information flows and processes in industry projects were conducted by Škec et al. (2016) who used a special mobile application to record the information flows within design teams. They utilized predefined classifications like information seeking and information processing to analyze the processes.

2.1.2 Methods and tools

The technical-methodical view focusses on methods and tools supporting the work within a collaboration. This can occur on different levels, like communication, coordination, or collaboration, based on a differentiation of Teufel et al. (1995). In this contribution, method shall be understood with a general definition: A method provides an operatively applicable thinking and behavioral pattern to achieve a goal. A tool can support the method application, and can also represent a communication technology, like video conferencing or a representation of a product model. There are several influences on this view like the given IT structure of the enterprises involved in the collaboration, or the methodical background and knowhow of the persons involved (Bavendiek et al., 2016). The challenge is to identify the best suitable method in combination with a tool or technology to exchange the information needed to collaborate. Therefore, the interrelation with the other views is of essential importance. The interrelation between the technical-methodical and the process view is described in section 2.3.
To support this view, within the field of computer supported collaborative work (CSCW), a lot of work has been done before. CSCW mainly focuses on communication features (messaging) and coordination (approval forms, work flows) (Robin et al., 2007). So, there already is a link to the process view considered. Typical tools for communication are e-mails or video conference systems, whereas workflow-management-systems assist the coordination within a collaboration. To support the adequate selection of a communication tool in regard to the information exchange, Gaul (2001) proposed the so-called House of Communications. Further research has been done on the importance of informal communication in collaborative design teams, e.g., (Törlind and Larsson, 2002).

2.1.3 Competencies and qualifications

Competencies and qualifications of the persons involved in design have been an important research field since the 1980ies (see e.g., Frankenberger et al., 1998). In this context, competencies are understood as the individual disposition of a person to show a specific behavior in a specific situation (Schleidt, 2009) whereas a qualification in general is defined as "capacity, knowledge, or skill that matches or suits an occasion, or makes someone eligible for a duty, office, position, privilege, or status" (Luthra, 2016b). The terms are differentiated because a qualification does not essentially imply a competence. Besides professional competencies and qualifications, increasing digitalization requires additional skills like, first, handling these new technologies and, second, dealing with the stress caused by misunderstandings between stakeholders. The possible involvement of different countries and cultures as well as time zones demands extra qualifications like language skills and supplemental competencies like intercultural awareness. Concerning collaborative teams, a dependency between the degree of virtuality of a team and the competencies required is stated by various authors, e.g., (Schleidt and Eigner, 2010; Shin, 2004). Hence, the support and development of competencies is an important field of research. Some work was done to train corresponding competencies, e.g., (Auffermann et al., 2007; Rose et al., 2009).

2.2 A concept to support collaborative design

As mentioned before, prior research has been done to support collaborative design with focus on the technical-methodical and personal view (Bavendiek et al., 2016). The proposed concept is based on the House of Communications by Gaul (2001) and the House of Engineering Competencies by Schleidt (2009) and uses the structure of the method Quality Function Deployment (QFD). Figure 2 shows an overview of the concept, which consists of three matrices and two correlations represented as a "roof" of the house. The following aspects are considered within the concept:

- collaboration characteristics describing the type of collaboration, such as the local distribution or the number of parties/persons involved
- competencies of the persons involved, like social and professional competencies

- available communication technologies such as, videoconferencing, e-mail, or telephone
- methods and tools, e.g., Gallery Method, checklists, or tools supporting the method application

Note that in this context, a tool only assists a method application and does not fulfil the function of a communication technology. The elements addressed in the concept demonstrate the focus of the technical-methodical and the personal view. The processes were not considered in detail. It was proposed to use the task of a design process as the starting point (Bavendiek et al, 2016).

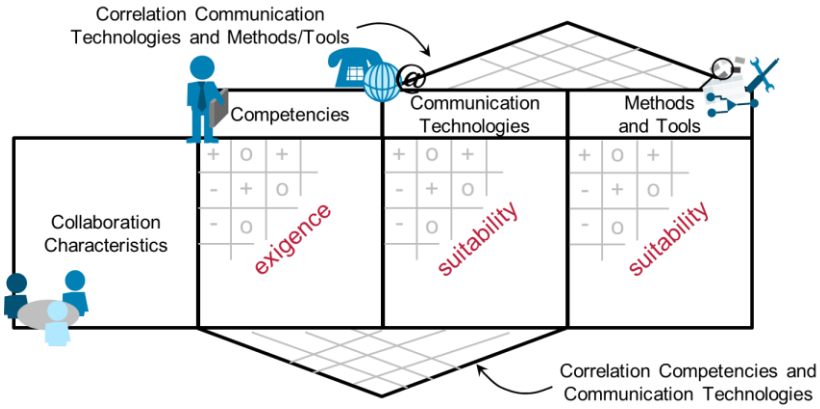

Figure 2. Concept for a collaborative design (Bavendiek et al., 2016)

First applications in a student project and an industry project led to preliminary results concerning the applicability and support. One of the major problems for the user was to derive corresponding characteristics of the above-mentioned aspects of the concept from the given task. Hence, the overall concept helped the users to prepare and to support the team for and during the collaboration by providing suitable methods and tools. More detailed results of a first application will be presented in section 4.

3 A FRAMEWORK TO COLLABORATIVE DESIGN

Based on the first results of the application of the above-mentioned concept and the main fields of action to support collaborative design, the interrelation between processes, methods, and tools was considered relevant for further research. In a survey among several companies with international distributed locations, Grieb and Lindemann (2005) found a good relation between the design process and the communication media (here seen as tools): According to 44 % of the participants, the improvement of communication media can enhance the design process. However, concerning the form of media, they state that there is no dependency to specific situations in the process (Grieb and Lindemann, 2005). Nevertheless, various classification models exist assigning certain forms of media to situations or communication purposes, e.g., Ellis et al. (1991) or Teufel et al. (1995). It becomes clear, that there are several approaches mainly focusing only on specific views. Thus, it is essential to understand interrelations between the threes views when planning and implementing measures to support collaborative design, e.g., when planning to implement new digital technologies for communication or knowledge sharing within a company. An overall framework bringing together the different views and single elements to analyze or support collaborative design are considered helpful.

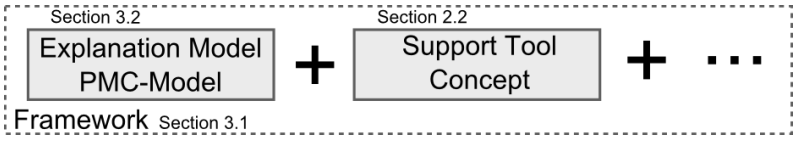

Figure 3. Elements of a framework to collaborative design

3.1 The framework

The framework to collaborative design is based on the idea of Grieb (2008) who proposes a guideline to establish a collaboration. He considers the aspects human, methods, tools, processes, and situations. To select suitable tools or media, a so-called Media Model is presented that relates media to situations in the design process (Grieb, 2008). Our framework pursues this idea and serves to systematically analyze the collaboration and derive specific support for stakeholders in the collaboration, e.g., within

design activities with a great organizational complexity. To do so, the existing concept to support collaborative design as a support tool and the in the following described model as an explanation model were combined. Future work will contribute to a detailed overall framework comprising different concepts to support collaborative design (see Figure 3).

3.2 The PMC model

In order to identify and point out the various interrelations, in the following, one part of the framework, a model called Process-Methods-Competencies model (PMC model), is introduced, see Figure 4. In this model, the three views described in section 2.1 are represented as layers. These layers display the elements like stakeholders, design activities, or competencies the different views are focusing on. Therefore, the layers serve as a refinement of the views introduced before. The order of the layers can be changed since there are interrelations between all the layers. However, the order proposed in Figure 4 is the most familiar one because processes are often in focus when speaking about organization of collaborative design. Each scenario in collaborative design can be described by a specification of these elements and interrelations on the three layers. A design scenario in this context describes an exemplary process and is the consequence of a specific design task like the evaluation of a design solution or the definition of a goal for a design project. Therefore, the process includes the design task and defines, for instance, the stakeholders with regard to professional expertise or locations as well as the flow of information in between. The design task itself defines the purpose and goal of a design action, including organizational or technical boundary conditions like costs and time targets. The PMC model serves as a description model of collaborations and is not intended to be used as a support tool. It helps to structure analysis of existing collaborative designs and identify hot spots to support the collaboration. Since it is not a formal model aiming to represent all elements on the different layers and their relations, it should be understood as an explanation model for observation and training purpose mainly in industry. The following sections provide an overview of the elements and interrelations.

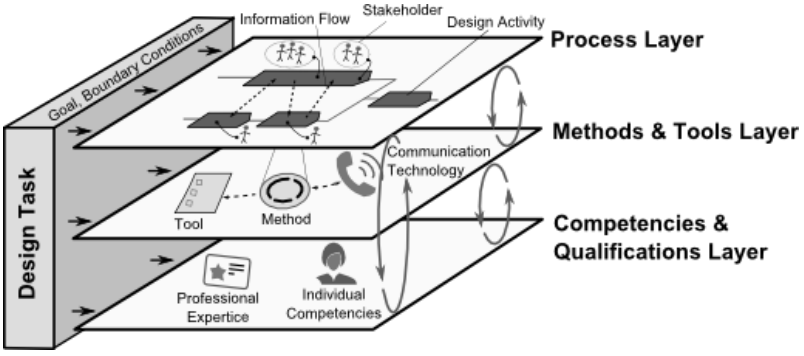

Figure 4. PMC model to describe collaborative design on different layers

3.2.1 Process layer

The process layer represents a flow-oriented view upon the collaborative design. The aim of this layer is to represent the structure, the purpose, and the flow of information as well as the activities, and involved stakeholders or systems providing specific knowledge. According to different types of collaboration, like collaboration between departments within one company or collaboration of different companies, the process layer represents the radii of the information flow as a first evidence of the effort of information allocation. Furthermore, the radii of information flow indicate which kind of communication and methods can be used, see section 3.2.2. Main elements to be represented on the process layer are, c.f., (Wohed et al., 2006):

- **Stakeholders** involved in the collaborative design process, for instance team members, departments or whole companies.
- **Information flows** in terms of connections between different stakeholders with specification of direction of the flow.
- **Design activities** as several procedures executed within the overall design process. An exemplary design activity is the integration of sub models within a simulation model for collision control.
  Furthermore, preconditions to execute design activities (sequence of activities) as well as parallelism of different activities are represented.

In addition, on this layer, aggregations of stakeholders and design activities can be represented. The introduced elements of the process layer can be used to describe current processes in collaborations in order to identify hot spots, e.g., in terms of missing or redundant information. Based on this analysis, specific measures to structure the process more effectively by means of methods or tools can be derived.

3.2.2 Technical-methodical layer

The focus of the technical-methodical layer are technologies and methods to support the different design activities defined on the process layer. Like stated in section 2.1.2, design methods for the generation or evaluation of solutions within teams as well as specific communication technologies to provide and share information across different locations are considered. The communication technologies available in a design scenario are specified by the given design task and the boundary conditions of the involved companies. These technologies are means to realize the information flows defined on the process layer and support both the formal (like represented in the process) and the informal communication (Törlind and Larsson, 2002) between the involved persons. The different methods support the execution of the design activities of single persons as well as distributed design teams. Since the starting point and purpose of the different design activities is defined on the process layer, suitable methods can be selected by process related criteria like described in Franke et al. (2003). Furthermore, the purpose of the design activity and the character of the method define the professional experience needed. For instance, in case of an evaluation task of a first machine design, experts for each sub system as well as production engineers and personnel from service have to be included in an interdisciplinary and possibly virtual team. By the application of methods, the communication within the team can be structured (Bavendiek et al., 2015). However, it becomes obvious that there is always a linkage between methods and the way communication is supported by technologies. Furthermore, the application of methods involves the use of different tools, e.g., for documentation or gathering information like checklists. The interrelations between the process layer and the technical-methodical layer are given by the following criteria:

- The application of methods is defined by the purpose of design activities to be carried out. The method itself gives advices on which stakeholders to involve and what information to share.
- The tools and technologies to use in a design scenario are restricted by the technical boundary conditions, the local distribution of the stakeholders (process layer), and the methods used (technical-methodical layer).

Aside from the process-oriented view upon the technical-methodical layer, in case of the selection of a method, there is an increasing influence of technologies to the process. Furthermore, there is a strong interrelation to the personal view focusing on the competencies and qualifications of the persons involved in the design scenario.

3.2.3 Competencies and qualification layer

On this layer, competencies and qualifications of the stakeholders involved are in focus. Since the different stakeholders are sources of information as well as members of a (virtual) team and users of methods, both their professional expertise and their soft skills are of interest. This drives the interrelation to the process layer as well as to the technical-methodical layer. With regard to the process layer mainly the responsibility, for instance, for a sub system and the required knowledge is considered. This allows allocating the stakeholders to specific design tasks like simulations or a team meeting she/he is involved in as an expert to explain the function of a single sub system. In the interrelation to methods and technologies used, soft skills like communicational behavior, stress resistance, or qualifications for specific communication techniques are of interest at this layer. In order to evaluate and represent these different competencies, there are different approaches like (Kauffeld, 2006). Furthermore, there are approaches and tools to select suitable methods and communication tools considering the competencies of single persons or a design team (Bavendiek et al., 2016). Moreover, there is research focusing on the new competencies needed to handle the increased digitalization, e.g., (Getha-Taylor, 2008).

The introduced layers of the PMC model help understanding, which elements and relations have to be considered within collaborative design. However, the layers cannot be treated independently from each other since there are strong interrelations between them. For instance, in every layer, the stakeholders are included with regard to different aspects: professional expertise on the process layer, participants of a method on technical-methodical layer, and an individual with specific competencies on competencies and qualification layer. For this reason, the PMC model should be understood as an explanatory model without claiming an exact and formal representation of all elements on the single layers and

interrelations between the layers. However, it is suitable to describe and understand existing processes. In combination with the prior proposed concept, it is possible to derive measures to improve the collaboration by applying methods and tools or by the qualification of the persons involved.

4 EXEMPLARY DESIGN SCENARIOS DESCRIBED BY THE FRAMEWORK

The usage of the framework, model and concept presented in sections 2.2 and 3 will be demonstrated in this section. Therefore, two examples are described with the above-mentioned framework.

4.1 Explanatory example: goal definition in interdisciplinary teams

The first example explains the explanatory character of the framework and PMC model: The definition of consistent and comprehensive goals is essential to every design task. In case of automotive engineering, this task is subject of an interdisciplinary team process. With regard to the introduced process layer, there are stakeholders from different departments of a company representing experts, e.g., with regard to design aspects or driving performance of a car as well as stakeholders from strategy. All these stakeholders are gathering information about cars of competitors or define strategic goals regarding the market position to be achieved in parallel activities. Therefore, different methods like benchmarking or survey tools are used (technical-methodical layer) and information is exchanged, e.g., about criteria to measure and hierarchical order of properties. In a common activity, the gathered information is represented in a radar chart (tool on technical-methodical layer) and the profile of the required properties is defined in a communication intensive design activity. The defined properties profile is provided to different departments of the company in order to be detailed as a starting point for the development of solutions. This detailing itself can also be seen as a design activity on the process layer involving a new set of stakeholders. This design task is supported by lists of aggregated properties (technical-methodical layer) and required technologies for communication and information flows.
In order to support this complex design task, there are different approaches focusing mainly on the technical-methodical layer, aiming for instance to build up integral models for planning and goal definition based on object-oriented modeling languages. These models can be seen as new tools. However, their implementation and structure have to be lean on the existing processes since the different stakeholders have to put in or remove specific information.

4.2 Exemplary case study: complaint management in international collaboration

The second example is based on a case study within an international collaboration industry project using mainly the concept of the framework as a support tool. The companies considered are part of the same holding company, which acts in different fields like logistics or automation. The collaboration consists of persons from central Europe and Eastern Europe (process layer). The development of new products takes place in Central Europe; the colleagues from Eastern Europe assume the production as well as the support of the systems (professional expertise of the stakeholders). The process considered was the complaint management. Complaints detected during the production or the support with the customer are reported to the development team in Central Europe. Now, small and easy to fix complaints shall be eliminated in Eastern Europe. To address this, a new process had to be established.
The objective of the application of the concept for collaborative design was the deduction of measures making the collaboration work. Thus, the task as well as the collaboration characteristics were given. As suitable communication technologies (tools), the personal meeting for the production and recording the complaint, e-mails as communication tool to Central Europe and documentation via a digital protocol were rated as best combination (technical-methodical layer). In addition, an online tool supports the complaint management in which the complaints are documented. In the past, complaints were not detected systematically. To identify possible errors or deficits before delivering the system to the customer, the failure mode and effect analysis (FMEA) was chosen from the proposed methods to support the process (technical-methodical layer). By aid of the correlation matrix to the competencies, a responsible person who suited best the required competencies was named (interrelations between methods and competencies). In addition, a language course was identified as measure to improve the collaboration (measure on competencies and qualification layer). The process of the complaint management was firstly observed over a period of three weeks, later a second time over a period of two months. In between, a checklist describing the process of avoiding errors was introduced as another tool to support the engineers involved. The amount of e-mails sent to Central Europe concerning complaints,

the amount of complaints in total as well as interviews with responsible persons (kind and amount of information flows) served the purpose to analyze the process. The results indicate that during the first period, only a few complaints were supported and then reported but the amount of complaints solved internally was almost the half of all complaints in the first period. However, several complaints were not worth a complaint because they were prioritized wrong. To avoid this, the above-mentioned checklist describing a process pattern how to handle a complaint was introduced in the second period. The results of this period display a positive development, although the language problems were still present.
Overall, the application of the concept for collaborative design in this case can be seen as helpful. Further tasks in the collaboration considered were accompanied by the concept, which showed similar results.

5 DISCUSSION AND CONCLUSION

Based on the introduced views, process, technical-methodical and personal view upon collaborative design, a framework as well as the PMC model have been introduced as an overall framework and an explanation model to understand and describe interrelations between the different views. Subsequently, two examples demonstrated the use of the model to describe different collaborations and the prior presented concept to support collaborative design. The PMC model serves as a description model of collaborations and is not intended to be used as a support tool like the concept. Thus, the combination of the PMC model and the concept can contribute to identify and then support collaborative design.
On the one hand, the exemplary application indicates the general usability of the PMC model as it mirrors necessary adaptions within processes in the collaboration. On the other hand, it does not offer a formalized approach to describe or represent processes and their elements yet. Moreover, the interrelations between processes, methods, and tools are neither formalized. This allows the user to understand and describe the interrelations between the views on an abstract level only. The resulting model can then be used to identify first hints concerning the application of methods and tools and their effects of processes or vice versa. Effects on costs or time cannot be demonstrated yet, although the time and costs are deeply interwoven with processes and, hence, with the interrelation to methods and tools.
The example presented in section 4.2 reflects the suitability of the concept presented earlier to support collaborative design. The preliminary results confirm the general applicability and demonstrate single positive changes within the processes of the collaborative design. However, the concept - as it is - is not easy to apply due to the complexity of the structure using correlation matrices.
Further research has to be done to formalize process descriptions within the PMC model. In addition, the descriptions of the interrelations have to be refined and described in a model-based manner. With the help of a corresponding modeling technique, processes within collaborations can be represented as an analysis of the current state. This representation and analysis will include not only stakeholders but also data systems within various information flows. By modeling and analyzing the different processes, patterns can be derived and defined in relation to methods and tools. The model of the interrelations can then be used to formulate measures with the help of the prior concept. Moreover, it can be analyzed whether design activities of different stakeholders can be parallelized. In this way, the communication and coordination is defined by the model to enable an appropriate exchange of information.

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