CAPTURE OF ACTUAL DEVELOPMENT PROCESSES OF HYBRID INTELLIGENT DESIGN ELEMENTS IN ORDER TO DEFINE A TARGET DEVELOPMENT PROCESS

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Abstract

Product development is characterised by an improvement of functional integration and a lack of new adapted design elements. For those reasons, within research unit 981 a new class of design elements called Hybrid Intelligent Design Elements (HIKE) has been developed. In order to enable companies to develop these design elements, developers have to understand the features of HIKE as well as the development processes resulting from them. This paper focuses on development processes of such HIKE. The paper presents the overall approach of how such a development process for HIKE shall be defined, as well as the results of the first important step: the capture of the actual development processes. For this, existing procedures from the field of process management are analysed, adapted and used to capture actual development processes through interviews. Furthermore, the paper briefly describes the performed interviews and captured processes of a HIKE lever. Finally, the paper ends with a critical discussion of the results and gives an outlook for subsequent research activities in order to define a target process for the development of HIKE.

Keywords: Design process, Hybrid Intelligent Design Elements, Process management, Capturing of processes

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1 INTRODUCTION

Nowadays, design elements are used in a wide range of applications. These include, for example, mechanical and civil engineering as well as aerospace technology. In general, the advancement of such design elements focuses on the improvement of their performance, such as their ability to carry loads. Therefore, for example, new materials and new simulation and calculation tools were used or new fields of application were identified. A conceptual further development of design elements regarding the principle integration of new functions in consideration of hybridity and intelligence was not focused on. Due to the necessity of implementing functions resulting – among others – in mechatronic systems, research unit 981 (Hybrid Intelligent Design Elements, HIKE), which is funded by the German Research Foundation (DFG), has set itself the task of developing a new kind of design elements in which new functions are implemented.

According to (Keller, 2011b), the aims which shall be reached using HIKE are a reduction of mass and costs. Additionally, the energy efficiency of superior systems in which the HIKE are implemented shall be improved. Based on the higher number of sensor signals which are provided by the HIKE, new functions shall be enabled and extended and new fields of application shall be identified. Existing design elements shall thereby not only be extended by using well-known technology, for example by gluing sensors to a rope. This is rather a question of a completely new development of design elements focusing on the implementation of the functions of sensors, actuators or controllers in a design element. In order to consider these integrations sufficiently, a new development process or an adapted one is necessary. (Keller, 2011b)

Regarding the literature, there are several authors who deal with the importance and necessity of processes in general as well as with particular processes. (Deming, 1993) appreciated that 94 % of all problems and possibilities for improvement (in companies) pertain to systems. In doing so, he defines a system as "a network of interdependent components that work together to try to accomplish the aim of the system" (Deming, 1993). According to (Deming, 1993), the system comprises – among others – the acting people as well as the processes they perform. He also said the following: "If you can't describe what you are doing as a process, you don't know what you're doing" (Deming, 1993). In the literature, there are several different aims listed which shall be fulfilled by defined development processes. (Ehrlenspiel, 2013) gives an overall view about achieved aims for the design methodology, including the aspect of describing development processes, of which only some aspects are mentioned here. By using design methodology (and thus process descriptions), a rationalisation of the design activity as well as of the necessary time shall be achieved. The teamwork of all involved developers from different departments shall be supported and simplified. Due to the use of design methodology, the design/product, as well as the process, shall become comprehensible and thus become more objective. Similar statements regarding the aims of design methodology or similar aspects are mentioned by (Vajna, 2014) in terms of Integrated Design Engineering (IDE), VDI guideline 2221 (Verein Deutscher Ingenieure, 1993) as well as (Pahl et al., 2007). Within the field of quality management, the DIN EN ISO 9000 (Deutsches Institut für Normung (DIN), 2005) points out the necessity for companies to "identify and manage numerous interrelated and interacting processes" because the output of one process is used by another process. Here, the identification and management of these processes as well as their dependencies is termed a "process approach" (Deutsches Institut für Normung (DIN), 2005). The aims of this process approach are the increase of the product quality based on a continuous improvement process (Wagner and Käfer, 2010), lowering the costs, lead time and a targeted and prioritised improvement. This shows the importance of processes for companies.

In sum, the motivation for the definition of a development process for the Hybrid Intelligent Design Elements (HIKE) results from the necessity to define a teachable and transparent development process to enable companies and their developers to develop HIKE in an efficient way on their own.

2 PROBLEM STATEMENT AND GOALS

Based on the described motivation for the development of new kinds of design elements and the necessity of dealing with processes, this section contains the problem statement and the research goals. The section is divided into two parts. The first part contains the overall problem statements directly derived from the introduction. In the second part, derived from the overall problem statement, the concrete problem statement for this paper is presented.

Keeping the final aim of the research in mind, to enable companies to develop and produce HIKE on their own, it is obvious that developers have to understand the nature of HIKE as well as peculiarities regarding the development and manufacturing caused by these. The peculiarities of the development of a HIKE have to be analysed and suitable development processes that can be communicated, planned and trained, have to be defined.

The definition of reference processes is one important key factor here. These processes are generally accepted generic processes which have to be adapted for the individual case and thus, they describe the process how it should be (e. g. V-Model of the VDI Guideline 2206 (Verein Deutscher Ingenieure, 2006)). Before such reference processes can be defined, existing processes have to be recognised and rated concerning their importance. For this last purpose, the question of whether a definition of a reference process is necessary or not must first be answered (Wagner, 2007). In the case of a development process which is a very important business process, the importance of standardising a reference process is obvious (Pahl et al., 2007).

For the planning of research activities, (Blessing et al., 2009) defined within the Design Research Methodology (DRM) a procedure including four main steps: "Research Clarification", "Descriptive Study I", "Prescriptive Study" and "Descriptive Study II". In the Research Clarification, the existing problems are analysed and described in order to clarify the research approach. Literature and the results of empirical research are analysed in the second stage so that the understanding of the phenomena can be increased (Descriptive Study I). Afterwards, in the Prescriptive Study, suitable supports are developed for improving the current situation. In the last stage (Descriptive Study II), the developed support is assessed and implications for improvement are developed. (Blessing, 2009)

Keeping the main steps of the DRM in mind, it is necessary to analyse the actual state and the necessity of a new development process regarding the development of HIKE. For realising this, there are two approaches. On the one hand, developers of HIKE can be asked to develop a HIKE using a standardised process model (e.g. VDI Guideline 2221 (Verein Deutscher Ingenieure, 1993) or VDI Guideline 2206 (Verein Deutscher Ingenieure, 2006)). Afterwards, the different processes will be analysed and rated regarding their suitability under consideration of the quality of the developed HIKE. This approach necessitates the development of the same HIKE by the same developers using different development processes. Because developers gain experience, the conditions change from one development to the next. An additional influencing factor like an unknown process would increase the risk of an unsuccessful development, especially in the case of the development of a new kind of product. On the other hand, the developers could develop HIKE using their own and known processes. Then, these are used as a starting point for defining a reference process based on products which are actually under development. In this research project, the second approach was chosen.

In the research field of process management, there are slightly different approaches defined for how to define/develop a reference process. Therefore, the authors define four or five steps depending on their focus. These steps are the delimitation and capture of the actual process, its modelling and analysis, the definition of a reference process/of improvements of the process and the introduction and monitoring of the process (based on (Wagner, 2010), (Koch, 2011), (Qasim, 2013)).

Based on these approaches from process management and from (Blessing et al., 2009), Figure 1 presents the general steps to develop a development process for a HIKE in the upper area. At first, the development processes of different HIKE have to be captured. Based on the documented and corrected processes, a superior more generalised process, which is derived from these captured processes, will be defined in the second step. In the following, this process is called generalised process. It describes a generalised development process based only on all captured development processes. In contrast to the reference process, the generalised process describes the state of the art, which still has to be optimised. In a third step, this reference process will be compared with known development processes in order to identify the process steps which are supported insufficiently by existing process models. Resulting from this analysis, the necessary support can be determined and subsequently developed. Based on this overall problem statement, the focus of this paper can be derived. The focus of this paper is the capture the existing development processes of already developed HIKE. The main research question for this paper can therefore be stated as follows: "How do developers develop HIKE at the moment?"

The research question can be operationalised by using the following subordinated research questions. How can the actual development processes be captured? Which process steps are used for the development of HIKE? In which order are the process steps performed? Which input is necessary for each process step and which output does each process step generate?

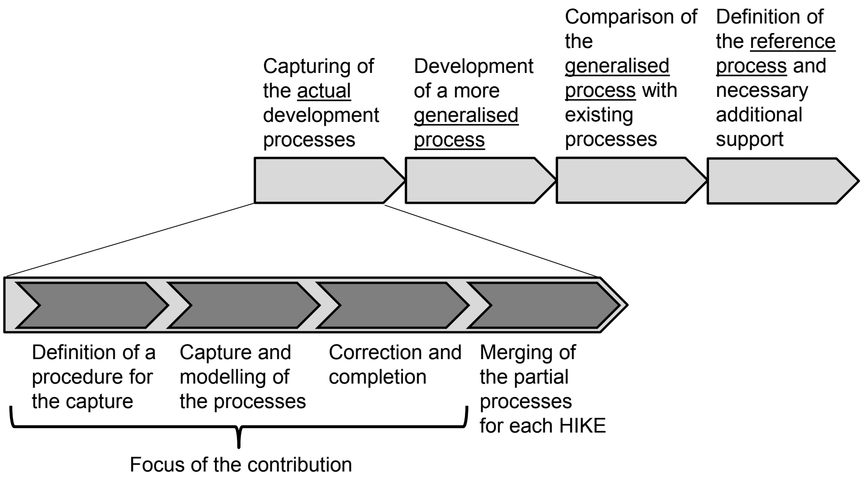

Figure 1. Research approach and focus of the paper based on (Wagner, 2010), (Qasim, 2013), (Koch, 2011) and (Blessing et al., 2009)

In order to answer these questions and thus the main research question, the following procedure was used (see Figure 1, lower part). In order to define a procedure for the capture of development processes, literature research was conducted and a procedure to capture the development processes was defined. The different development processes have been captured based on this procedure. After the modelling of the development processes, these were corrected and completed by the developers of the respective HIKE. Since there are two developers for each HIKE, one for the mechanical development and one for the development of the controller structure, there are two separate partial processes for each HIKE. Resulting from this, both partial processes have to be merged together in a final step for the definition of a single continuous process for each HIKE. This paper focuses on the first three steps and thus presents the procedure of how to capture development processes, the capture itself as well as one example of the captured and corrected development process.

3 STATE OF THE ART

A brief overview about the definitions of design elements and machine elements, the Hybrid Intelligent Design Elements (HIKE) and regarding the capture of processes is presented in this section. Searching in the literature regarding the definition of design elements (German: Konstruktions-element) leads to different definitions. According to (Koller, 1998), design elements contain all material and immaterial resources (components or parts) which can be used by the designer in order to develop technical products. Design elements thereby include all elements which are used to define solutions of function and principle structures and finally the real product (Koller, 1998). In contrast to this, for example, (Bröckel, 2012) does not distinguish between machine elements (German: Maschinenelement) and design elements. Both design and machine elements are, according to (Bröckel, 2012), design elements as described by (Koller, 1998), but are of different complexity. For the following definition of HIKE, aspects of Koller's definition are used.

3.1 Hybrid Intelligent Design Elements (HIKE)

According to (Keller, 2011a) the hybridity (H) of HIKE comprises the integration of hybrid materials (e.g. fibre-reinforced composites) or the use of hybrid manufacturing technologies (e.g. thixoforming as a hybrid of a forging and a moulding process). Furthermore, each HIKE integrates at least two functions of a common mechatronic system (functions of the sensors, actuators, mechanical structure and/or of the controller). In the first phase of the research unit, the focus was on the integration of sensory functions into HIKE. Within the second phase, the additional integration of the functions of actuators is covered in detail.

There are several different definitions of intelligence (I) in literature. (Legg and Hutter, 2007) collected these definitions and tried to summarise them. Based on these definitions, the aspects of intelligence fulfilled by HIKE were identified and completed within the research unit. In accordance with these definitions, HIKE have the ability to store and combine information. Consequently, they are able to adapt themselves to new situations and conditions to a limited extent. They have sensory

capacity as well as the ability to act purposefully. Because of the ability for self-adjustment, the HIKE are able to act appropriately in an uncertain environment. However, this is also only possible to a limit extent. HIKE can be controlled on their own (intrinsically), which means the function of a controller is also integrated, or they can be controlled from outside (extrinsically). In both cases, the controllability of the superior system in which HIKE are used is supported. Resulting from this, the HIKE themselves – or the superior system – can be adapted to changing conditions. Furthermore, according to the (Verein Deutscher Ingenieure, 2006), HIKE are intelligent because of their functional integration.
In general, design elements are not changed, or if so, then only during their integration into superior systems. If a screw connection is used in development, the screw itself will not be adapted, or perhaps only its length will be adjusted, for instance. Since HIKE are also design elements (KE), HIKE shall likewise not be changed, or only slightly. Additionally, they have a different complexity, similar to classic (i.e. mechanical) design elements. Due to their functions, HIKE take an explicit role in control systems, which means they transmit sensor signals, are part of the plant or act as a controlled actuator.
Figure 2 shows an exemplary HIKE. In this case, the HIKE is a textile actuator in which additional sensory yarns are woven. These sensors measure the pneumatic pressure in the "pillow". The necessary supply (pneumatic, electricity etc.) is not part of the HIKE. In the centre of Figure 2, the pneumatic textile actuator is shown applied with different pressures. Due to the rising pressure within the actuator, the length of the actuator will be reduced (see Figure 2, right-hand side). Because the actuator is clamped on both sides of an aluminium plate, a bending moment is generated and the aluminium plate under the actuator is deflected (see Figure 2, right-hand side). Actually, this HIKE is extrinsically controlled and the controller is not shown in Figure 2. However, generic software modules are under development in order to realise an intrinsic controllability.

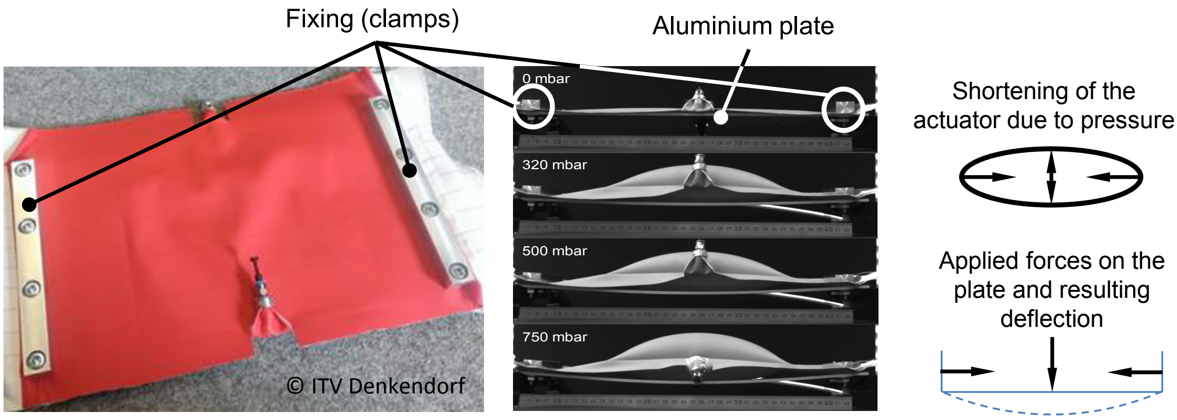

Figure 2. Pneumatic textile actuator with additional sensory capacity (left-hand side), under different loads (centre) according to the Institute of Textile Technology and Process Engineering Denkendorf (ITV Denkendorf)

3.2 Process management focusing on the capture of processes

Within the literature, there are several descriptions regarding process management (cf. (Wagner, 2010), (Koch, 2011), (Qasim, 2013), (Schwegmann and Laske, 2012). In these, the authors focus on the different points of process management. Because of the focus on the capture of processes, the following discussion is based primarily on (Wagner, 2010) and (Koch, 2011). (Wagner, 2010) defines an approach comprising four steps for the definition of new standardised processes. These steps are the identification and delimitation of the process, the capture and analysis of the process, the definition of an ideal process (reference process) and the realisation of potentials for improvement. In the first step (Step 1), the process which has to be defined must be identified and delimited from other processes. Therefore, the purpose, the customer of the process, their requirements, the output of the process and the necessary input for the process has to be identified. Output and input comprise all kinds of possible outputs/inputs. These include, in particular, information (e.g. material characteristics), knowledge, documents (e.g. CAD models, simulation models), products or services. To support this step, he defines a guideline including the main aspects which have to be determined. (Wagner, 2010)
The process will be captured and analysed based on this rough description (Step 2). A detailed capture of the process in cooperation with the users of the process is therefore necessary. (Schwegmann and Laske, 2013) point out that often documentation is insufficient as a sole basis for the capture because

these documents often do not represent the real actual state. Starting from the process description in a top-down approach, the process will be detailed in an increasingly iterative way. Necessary resources will be identified, and thus in the case of analysing the process, well-known methods and tools like the 7M method can be used to analyse the process and to identify improvement potentials (Wagner, 2010). In this instance, it is possible to divide the process which is to be captured so that partial processes can be captured in parallel. However, there is the risk of modelling redundant steps caused by insufficient coordination (Schwegmann and Laske, 2013).

Based on the detailed processes and the results from the process analysis, a reference process can be defined including the development of process descriptions, checklists and work instructions (Step 3). Furthermore, criteria to measure the efficiency of the process are determined and monitored. Based on these results, the reference process will be released and introduced in the fourth step. (Wagner, 2010)

This paper focuses on the first two steps of the approach described by (Wagner, 2010). Because of the previously presented guideline for the first step, step two (capture and analysing of the process) will be presented next in more detail.

For the preparation of the capture, the existing documentation about the process, work instructions etc. is used for three aspects. Firstly to improve the understanding of the process by the people who capture the process and secondly to determine the techniques by which the process shall be captured. Additionally, the level of detail for the captured process has to be defined. (Wagner, 2010)

Depending on the complexity of the process which shall be captured, it might be necessary to detail the process in several iterative steps. In the beginning, the process, its weaknesses and the boundary for the process are hard to define. Therefore, a rough process will first be captured which has to be detailed in subsequent iterations. This procedure is described as 'top-down' because of the increasing level of detail. However, the necessary level of detail for the captured process has to be defined because the capture necessitates a great deal of effort. The level of detail should be set under consideration of the aim which shall be reached by the capture of the process, the expected quality of the process, its complexity and its resistance to disturbances. Here, the level of detail has to be defined so that conclusions regarding the interfaces between different processes can be drawn and thus the transparency of the process is ensured (Koch, 2011).

According to (Koch, 2011), there are different techniques for capturing processes. These include in particular interviews and workshops, observation, the analysis of existing documentation and questionnaires. Each of the techniques has its own advantages and disadvantages. (Koch, 2011), for example, describes the main goal for each technique and the advantages and disadvantages of single interviews and workshops with groups of developers. Regardless of the technique used, the following aspects of the process and its single process steps always have to be determined in accordance with (Koch, 2011):

- What is the trigger for the process?
- Which process steps are part of the process?
- Which documents are relevant for the process steps?
- Who are the people responsible for the process steps? Who supports the process steps?
- What are the outputs of the process steps?
- How is the procedure defined in the case of disturbances or changes to the process?
- How can the process and its process steps be improved and monitored?

After the capture of the process is completed and before the analysis of the process starts, the process should be corrected and completed by the questioned developers. In case of captured partial processes, these processes have to be merged together into a single process. (Koch, 2011)

In literature, there are several numbers of languages and tools mentioned for the modelling of processes. Among others, these are, according to (Koch, 2011), flow charts, event-driven process chains, process tables, object-orientated methods like the Unified Modelling Language (UML) or the Knowledge Modelling and Description Language (KMDL) according to (Gronau, 2006).

(Becker, 1995) defined a set of generally accepted modelling principles (GOM) to ensure the quality of modelled processes and to raise the efficiency of capture. The GOM comprises six different principles. The first principle is the principle of correctness, which corresponds to the requirement that the captured processes should be corrected and completed by the questioned developers. The second one is the principle of relevance, which means that the model should not be completed in the narrow sense, but all relevant aspects should be captured. The principle of efficiency demands an optimal level of detail. The capture and modelling should not be as detailed as possible, but only as detailed as necessary. The principle of clarity demands the readability and comprehensibility of the models. Models should be as simple as possible and – for example – the starting event should be on the left or at the top. The principle of comparability requires that models which are created by different methods should be comparable. Following the principle of systematic design, all different views which are modelled should be consistent with each other. (Becker, 1995)

4 FIRST RESULTS OF CAPTURED DEVELOPMENT PROCESSES

In this section, the first results concerning the capture of the actual process as well as the captured process of a HIKE lever will be described. The process presented here is the already corrected model. Keeping the research approach in mind (see Figure 1), the procedure for the capture will be described at first, followed by the captured process itself.

For the definition of a generalised and subsequent reference process, it is possible to capture the development of six different HIKE within the research unit. These HIKE are a lever, a pneumatic textile actuator (see Section 3.1), a rope, a fibre-reinforced composite tension bar, a sandwich panel and a spring. With the exception of the sandwich panel, all of these HIKE will have the additional integrated functionalities of sensors and actuators at the end of the second phase of the research unit. Due to their heterogeneity, each of the development processes focuses on different aspects. For example, the development of the lever focuses on the thixoforming and thus on the question of how to integrate sensors during the thixoforming process. In contrast to this, during the development of the rope, the question of how a rope can become an actuator, especially along the length of the rope and not at the connectors on its end, is of central importance. In general, two persons are responsible for the development of each HIKE within the research unit. One person is responsible for the development of the mechanical structure, the integration of selected sensors and actuators. The other developer is responsible for the development of the control systems of all HIKE. In the case of the research unit, both developers are academic assistants. In contrast to the first developer, who is responsible for the mechanical components, the other developer has only worked in the second phase of the research unit.

The capture (Step 2) was performed in two phases. First, the existing documentation regarding the development of the HIKE were analysed. Since the development is part of research unit 981, these documents are reports in the form of presentations, the original applications of the research project and some interim reports from the end of the first research period. Based on these, an initial process in the form of a flow chart could be generated, which then was corrected by the developer. Due to the focus of the first phase of the research unit (integration of the sensory functionalities), there was no explicit control system for each HIKE. Therefore, the definition of a reference process based solely on the processes of the first phase of the research is not possible. However, the demonstrator of the research unit, including all HIKE as well as several actuators, also includes a control system. In order to capture the development of a control system in the context of HIKE, the development of the demonstrator was also captured and examined.

As a result of the analysis of the first captured processes, it became obvious that the level of detail of these processes was insufficient to merge together the partial processes depicting the development of the mechanical structure and the control systems. One main reason for this is the focus of the documents, which do not focus on the documentation of the development processes but on the presentation of results of their research. However, these initial processes gave an overview of the activities of the developers, which have to be captured and examined in more detail. Based on these initial processes, the process to be captured as well as the necessary level of detail could be determined more precisely.

In the second phase of Step 2, additional individual interviews with the developers of the HIKE were performed to detail the development process of each HIKE. In these interviews, the results of the analysis and the derived aims for the interviews were presented first. For the interviews, the initial processes, documentation of the first research phase as well as a checklist based on (Wagner, 2010) and (Koch, 2011) were used. Furthermore, a whiteboard and blank sheets for sketches were available.

The following questions were used as central questions for the interviews. What are the functions/aims of the process steps? Why are they important? Who is affected by the process step? What is the input and output of the process step (information, knowledge, documents etc.)? Which activities are performed in this process step? How can the process step be delimited from previous or following process steps? What are the interfaces of the process step? Which tools or methods were used for the process step? Here, the answer of one question might help answering another question and thus the questions are not always independent of each other. For example, in order to optimise a HIKE, several different simulations can be performed. Resulting from these simulations, additional knowledge is created as well as a computer file. During the discussion of another process step, the necessary input has to be defined. Remembering the already created simulation models, the input of the later process step can be identified more easily. It was not only the development of the HIKE of the first phase of the research unit that was captured during the interview, but also the lessons learned and the changes and adaption of the development process for the new/extended HIKE of the second phase of the research unit. After the interviews, the processes were modelled and corrected again. Because the detailed process comprises more than 50 steps, in Figure 3, the corrected development process of the mechanical aspects of the HIKE lever is presented only in a very abstracted version on the left-hand side. It includes the examination of concepts of sensors, actuators and reinforcement components.

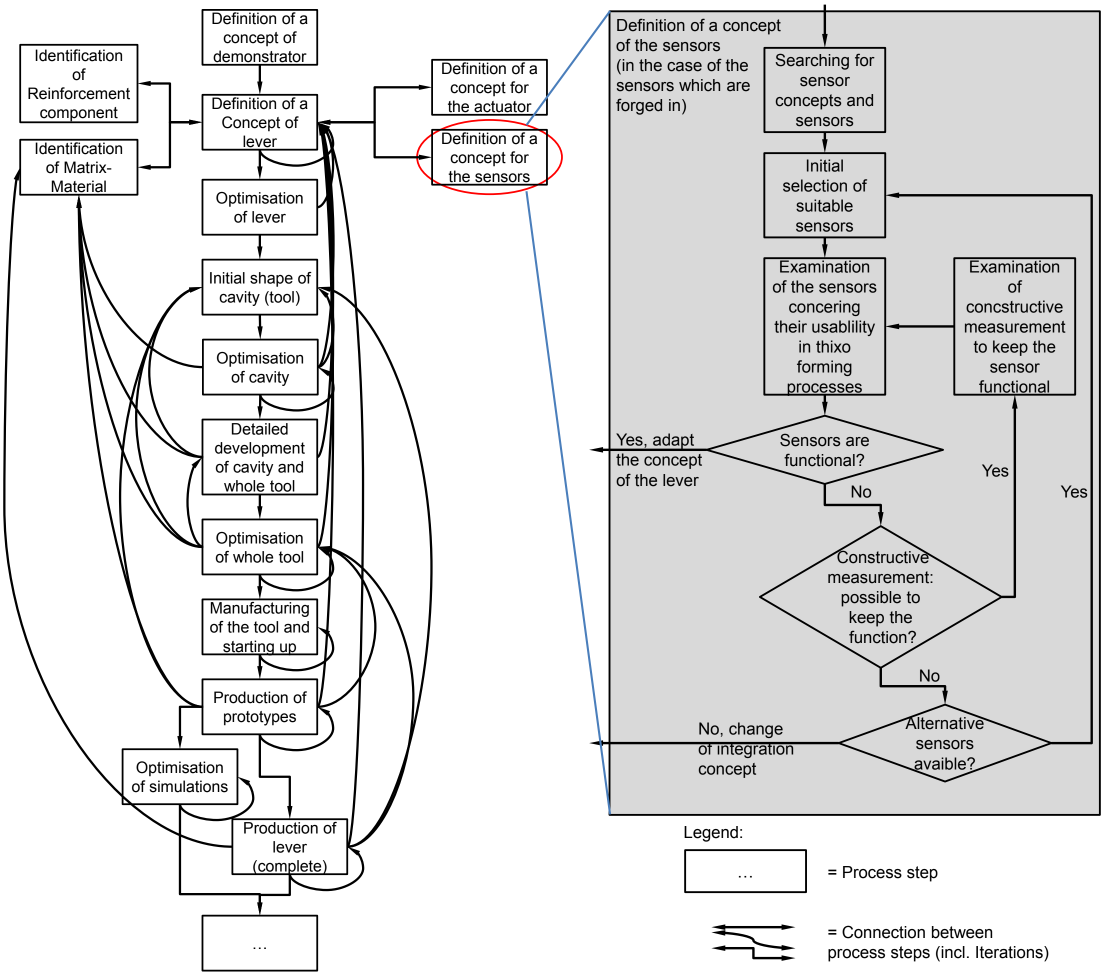

Figure 3. Abstracted development process of the mechanical aspects of the HIKE lever (left-hand side) and a small excerpt of the detailed process concerning the selection of the sensors (right-hand side)

Based on the concept of the demonstrator of the research unit, requirements for the lever were derived and a concept of the lever will be defined. This rough concept of the lever includes the rough shape under consideration of selected sensors, actuators and reinforcement components and will then be optimised iteratively. In the next step, the shape of the lever will be used to derive an initial shape of the cavity for the thixoforming process. Then, the cavity is optimised based on flow simulations of the forming process. Because of the direct influence of the cavity on the lever, it might become necessary to improve the concept of the lever. Hence, the optimisation of the cavity also leads indirectly to an optimisation of the lever. Based on this optimised rough cavity, a detailed development of the cavity and the manufacturing tool can be performed, which will also be analysed and optimised within further simulations. After the production, assembly and starting up of the tool, the first prototypes of the lever will be produced, based purely on the matrix material. If these early prototypes are satisfactory, the lever – including the sensors, reinforcement components and actuators – will be produced and optimised regarding the necessary parameters of the forging process. It has been demonstrated that the process is not a sequential process. It includes a lot of possible iterations. For example, if the produced prototypes of the HIKE are not sufficient initially, the production parameters can be adapted (e.g. the temperature of the tool). If this is not sufficient, the tool and/or its cavity has/have to be changed. If this is also not sufficient, the whole concept of the lever has to be changed.

On the right hand side of Figure 3, an excerpt of the detailed selection process of the sensors is presented for the concept of sensors which are forged into the lever. For the sake of clarity, the identified inputs and outputs of the process steps are not shown. Based on identified sensor types and sensors, suitable sensors will be selected and have to be tested in order to examine whether the sensor is still functional or damaged by the temperature and pressure of the manufacturing process or not. If the sensor is damaged, additional constructive measurements to keep the sensor functional are performed and then the sensor is tested again. In the case that those constructive measurements are not possible or not sufficient, another sensor type or sensor has to be tested. If there are no alternative sensors, the sensors cannot be forged and have to be assembled subsequently.

5 DISCUSSION OF THE RESULTS

In this section, the presented results are critically discussed. At first, it has to be checked whether the research questions were answered or not. The operationalised research questions regarding the approach to capture processes were directly answered based on approaches from the field of process management. These approaches were adapted for the capture of development processes of HIKE. The question of the development process of HIKE was answered for the HIKE lever and two more HIKE which are not presented in this paper. Furthermore, by using the adapted approach for the capturing, the inputs and outputs of every process step could also be identified. Hence, the selected and performed approach could be successfully applied. The captured process was checked and corrected by the developer regarding its consistency and completeness. However, these results cannot be transferred to another HIKE. In order to define a generalised process for HIKE, which describes the development of different HIKE, the capture of more HIKE development processes is necessary. For this three more HIKE development processes will be captured next. However, during these subsequent steps, another adaption of the captured development processes regarding their level of detail might be necessary. One reason for this can be the different level of detail of the captured processes. Only if all captured processes have the same level of detail, which allows conclusions about the cooperation of the involved developers, a generalised process can be defined. After the generalised process is derived from the captured processes the necessary support for the definition of a reference process can be determined. Both, the generalised as well as the reference process can be evaluated by developing another HIKE. This kind of evaluation is not expedient for the process of the HIKE lever because only another HIKE lever can be developed. Keeping the overall aim in mind, to enable companies to develop HIKE on their own, companies are still not able to develop HIKEs using only the results of this paper. However, the paper presents the necessary basics as well as first results in order to define a reference process for the development of HIKE.

6 CONCLUSION AND OUTLOOK

Based on the results and their discussion, some conclusions regarding the research approach can be drawn. Firstly, the consideration of the actual processes is one important aspect for the definition of a reference process. This is a direct consequence from the literature. Secondly, the adaption of the approaches from the literature for the capture of a development process of a completely new HIKE is possible. However, the processes described in the literature are primarily for the optimisation and improvement of existing and previously defined processes in companies. In the case of the development of the HIKE, the processes do not represent development processes which are captured in companies. Hence the comparison with processes captured from companies is difficult. Furthermore, the captured processes describe development processes under consideration of a well-known superior system (the demonstrator). This is only one possible scenario for the development of design elements. Thirdly, resulting from this, defining a reference process purely by considering the actual processes is not sufficient. The capture of the actual development process is only one aspect for this definition. Based on the results presented in this paper, more development processes of HIKE have to be captured in the next step so that a better overview of the development under consideration of different departments is possible. For this, the existing approach can be used, but might be adapted and extended iteratively based on the results of the next steps. The necessary level of detail can finally be confirmed if it is possible to merge the partial processes for a single HIKE and secondly if it is possible to define a generalised process for all captured development processes. The merging of the different partial processes will be performed based on the identified inputs and outputs of each process step as well as the identified interfaces between process steps. The generalised process describes the summarised processes of all captured HIKE processes. For this, the different process steps have to be analysed, abstracted and then summarised, so that the generalised process does not only describe the development of a specific HIKE, but rather the general procedure of how the HIKE were captured.

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