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STRUCTURING INFORMATION IN TECHNICAL INHERITANCE WITH PDM SYSTEMS

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Abstract

Nowadays a product development process is often based on experience and collected product lifecycle information. The communication between machines and equipment and a consistency throughout the whole product lifecycle are enabled by Industry 4.0. In the Collaborative Research Center (CRC) 653 several aspect for communicative and intelligent products are developed. The CRC aims to develop smart products, so-called gentelligent products, which collect and store their lifecycle information inherently and give feedback to the development and production. In this publication it is shown how the development process is supported by the experience and information of gentelligent components supplied by Technical Inheritance. To provide relevant life cycle information for the development process the need of a product data management (PDM) system is shown. At the example of the Formular Student racing car RP09 the necessity of PDM for Technical Inheritance is shown to support the next generation development and its advantages discussed.

Keywords: Product Lifecycle Management (PLM), Product Data Management (PDM), Requirements, Design process, Technical Inheritance

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1 INTRODUCTION

Nowadays, product developers are working in a dynamic and digitized time, where information about technical systems and components can be collected and deployed (Kaufmann, 2015). In addition, the information are not only recorded, collected and deployed for a single product lifecycle phase, but also throughout the integrated product lifecycle (Gottwald, 2016). This creates data sets and data diversity, which need to be managed, structured and standardized (Lachmayer, 2016). This challenge needs to be overcome, especially in times of Industry 4.0.
With the aim of resource efficiency, Industry 4.0 leads to a decentralized, intelligent and networked production (Bauernhansl, 2014). The components search by themselves the fastest way through a production to a machine, machines equip themselves independently to the components and order spare parts by themselves (Kaufmann, 2015). In addition, Industry 4.0 not only enables communication between machines, but also between components (Lachmayer et al., 2016). However, beside the production, an integration of the development and usage phase is also necessary for the consistent realization of Industry 4.0.
In the Collaborative Research Center (CRC) 653 "Gentelligent Components in their Lifecycle" several aspects for communicative and intelligent products are developed. Through the integration of information technologies the abilities of technical systems are increased with regard to intelligence and become "smart". The CRC 653 aims to develop smart products, so-called gentelligent products, which collect and store their lifecycle information inherently and furthermore give feedback to the development and production. To improve gentelligent components the process of Technical Inheritance is developed. It is based on the biological principle to transfer information on the basis of evolutionary mechanisms (Lachmayer et al., 2012). Based on the analysed data and extracted information a next generation can be developed. This ensures a continuity in the product lifecycle.
In the CRC 653 the basic idea of Industry 4.0 is further developed to the "Industry 4.0 and more" approach. The received lifecycle information are reported back to the development and production. For this purpose, information and communication technologies have been developed, which enable the acquisition, storage and exchange of information in the various product lifecycle phases. This approach is called "Industry 4.0 and more", since the production process is not only in the focus, as often described in literature, but the whole product lifecycle, connected continuously through data acquisition, storage and recording. This also includes the development and maintenance phase, whereas new product generations are being developed based on production and utilization data from previous product generations (Denkena et al., 2016).
The "Industry 4.0 and more" approach gives the product developer access to consistently product lifecycle information and thus also the possibility to create a new product generation. For a targeted and efficient work in the product development, the product lifecycle information of the different generations need to be managed, structured and standardized. Nowadays product data management (PDM) systems help for this challenge in the context of a product lifecycle management solution. These PDM systems focus on the product development and the management of product data and documents, but not on an intergenerational development. Accumulated experiences and information can be collected, stored and made available to all developers and stakeholders in a central system. Hence, new developments can be derived on the basis of existing generation information, designs and solutions. The Technical Inheritance supports product development in this point since all product lifecycle information are provided and returned continuously. To build up an efficient generation development, the lifecycle information need to be connected to the development steps, therefore the PDM system needs to be connected with the lifecycle information. The needed information have to be identified from the different lifecycle phases and from the generations.
This paper discusses how the different information of the lifecycle phases of a gentelligent component are provided by Technical Inheritance and combined by a product data management systems, to provide an intergenerational development.

2 PRODUCT GENERATION DEVELOPMENT WITH PDM/PLM

The basic proceeding in a development and construction process depends on the degree of novelty and the existing experience with the assigned task (Pahl and Beitz, 2013). Weber also says that two different approaches exist in product development. On the one hand, a solution can be developed, which has never existed before and is further developed in the subsequent development process. On the other hand, an existing solution can be used so that at least one partial solution for the new product is used, further developed or newly developed, thus has never occurred in this context (Weber and Husung, 2015). For both ways to develop a product, there are already firmly established procedures.

2.1 The concept of Technical Inheritance

In order to implement these two proceedings, consistent, structured and continuously information about the product are required. Not only are the geometric information of interest, but also the remaining product lifecycle information. In the CRC 653 different sensors have been developed, which can either be applied or integrated on or in a component (Gottwald, 2016). Both ways result with the possibility, that lifecycle information, e.g. loads, can be stored inherently in the component. In this way a thorough understanding of a monitored component can be created, which is necessary for the further development of a product. The Technical Inheritance process for an intergenerational product development is depicted in Figure 1.

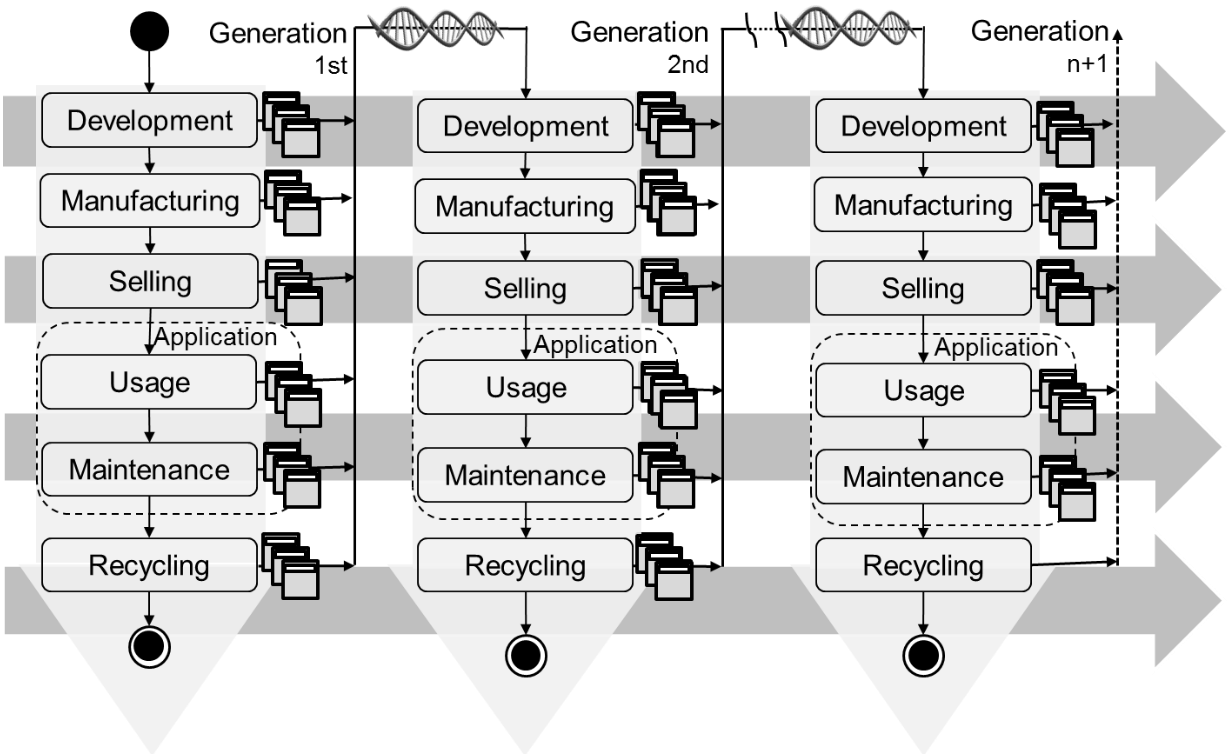

Figure 1. Intergenerational development process (Lachmayer, 2014)

In Figure 1 it is shown, that the product lifecycle is always going through product generation to product generation. In each phase, data is generated and recorded, which can influence the next product generation. The application is differentiated into usage and maintenance. In this paper the Technical Inheritance with the development phase, the production phase and maintenance phase is focused.

During the development phase information about the design are generated. Also data from the production phase and maintenance phase are analysed concerning differences and changes during the product lifecycle. With the help of a Generative Design Approach (Sauthoff and Lachmayer, 2014) combined with usage information new geometric product designs are developed for the next generation. The new generations are optimal adapted to particular usage information (Lachmayer et al., 2015).

During the production phase it is resorted to a concept of knowledge-based process planning. At first the process plans are generated, based on the construction data. In the next step the working steps are selected, while considering the current production state. Process signals are evaluated by a process monitoring systems during machining. In the last step a production protocol can be stored inherently in the component and is available during the whole lifecycle. To reproduce optimum process results, component specific process information will be combined with additional manufacturing data and fed back to process planning (Denkena et al., 2014).

The application phase includes the maintenance phase. Here, with the help of a component status-driven maintenance, the remaining life of a component is determined. The maintenance can be clarified at a control loop consisting of an experience base, a comparison, a diagnosis and a prognosis module (Van Thiel and Nyhuis, 2010). This requires the current state of the component and the future probability of failure. The experience base is stored in the form of a database, each monitored component being recreated as a new data set in the database, until enough different data sets are available and the greatest possible number of profiles is covered. Then, components are compared with the stored data sets and checked for conformity. In case of agreement, a life expectancy forecast is prepared and suitable maintenance measures are defined. In the event of a lack of conformity, adapted maintenance actions are taken (Winkens and Nyhuis, 2015).

A flexible data format, which can be used and adapted for storage and transformation of the information during the lifecycle of the product, is used in the CRC 653. The information, which describe the parameters of the product defined by the product developer or the descriptive characteristics, such as operation or production information, need to be stored and accessible for the next generation development. Therefore a standardized data exchange, the hierarchical Gentelligent Markup Language (GIML) had been developed. As a basis for the representation of gentelligent information the Extensible Markup Language (XML) had been used (Denkena et al., 2016).

A major challenge with the product lifecycle data and information is structuring and organization in a central system. Without a kind of product data management, the large amounts of data are quickly no longer manageable and chaotic. A product data management system supports the structuring and organization. Therefore it makes sense to have a product lifecycle management, but also a suitable product data management in order to make the collected data and information transparent and always accessible.

2.2 Characteristics and Possibilities of modern PDM Systems

A product data management system is nowadays used for the administration of computer-generated 3D models, drawing data and further development and product documents. By extending the functionalities to the lifecycle consideration of a product, PDM is laid the cornerstone of product lifecycle management (PLM). PDM is a database-based software component that is provided to the developer as a tool in product creation and serves as an integration platform for various production systems (e.g. CAx-Systems or text processing Systems) (VDI 2219, 2016). In this way, information about products and their development process consistencies can be stored, managed and achieved transparently. PDM systems thus form the backbone of the development and design process, since they enable data integration across all development process steps (Eigner and Stelzer, 2001). Basic functions of PDM technologies are (Arnold et al., 2005; Eigner and Stelzer, 2001; Feldhusen and Gebhardt, 2008; VDMA, 2005):

- Application functions:
  To the application functions belongs the document management for general documents, drawings and models. The part management and product structure management is also a part of the first function group. To structure and organize the parts classifications systems can be implemented in PDM System and is also one of the basic functions. As an administrative function workflows can be implemented and managed with a PDM system. The project management complements the basic functions of PDM technologies.
- Handling functions:
  With the handling functions it is possible to do recording or copying data in a PDM system. Documents or models can be checked in or checked out. Different versions and revisions can be defined.
- Administration functions:
  To the administration functions belong the user and permission management. Also the data backup and long-term archive are basic functions of PDM technologies. The data import and export and the system configuration are part of the administration functions.

A PDM system supports the development of products and ensures that all stakeholders are on the same level of information. Thus, product describing information (metadata), e.g. part numbers, versions, creation date and release date, validity status, originator, etc. can be managed via a PDM system. This makes it easier to search for specific information and / or data sets (Pahl and Beitz, 2013). An overview of the current PDM systems on the market can be found at Ulrich (Ulrich, 2016).

In contrast to PDM is PLM a strategic component for a company that is mapped in a PLM process. Individual process steps of the product lifecycle are integrated, supported and combined. While PDM has a strong focus on product data, PLM focuses on the management of all data, processes and applications of the entire lifecycle of a product.
In Figure 2 it is shown, how PDM and PLM are assigned to the different lifecycle phases.

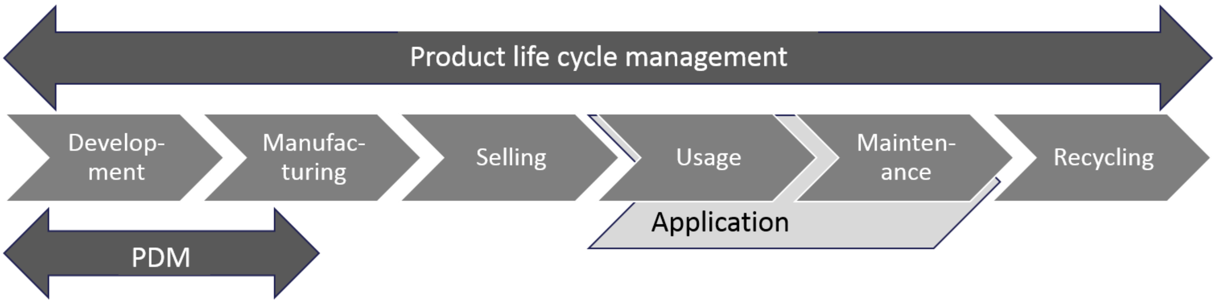

Figure 2. PDM and PLM in a product lifecycle (after VDI2219, 2016)

While working in a PDM system developers avoid to work with outdated information or with different information states, since validity dates are managed (Müller et al., 2012). Sources of error are reduced and eliminated.
PDM and PLM systems are established technologies in the development departments and through a whole company value added chain. But there is no consistency in the product lifecycle for the planning and simulation of components or processes within the framework of Industry 4.0. Also monitoring during the application is not fully supported by an available PLM approach (Abramovici, 2007).

2.3 Technical Inheritance supported by a PDM System

With a combination of Technical Inheritance and a PDM system, the various data and information sources of the different lifecycle phases can be combined in one central system and are available to each participant. In Figure 3 the concept of the lifecycle information delivered by the Technical Inheritance and stored and organized in a PDM system is shown.

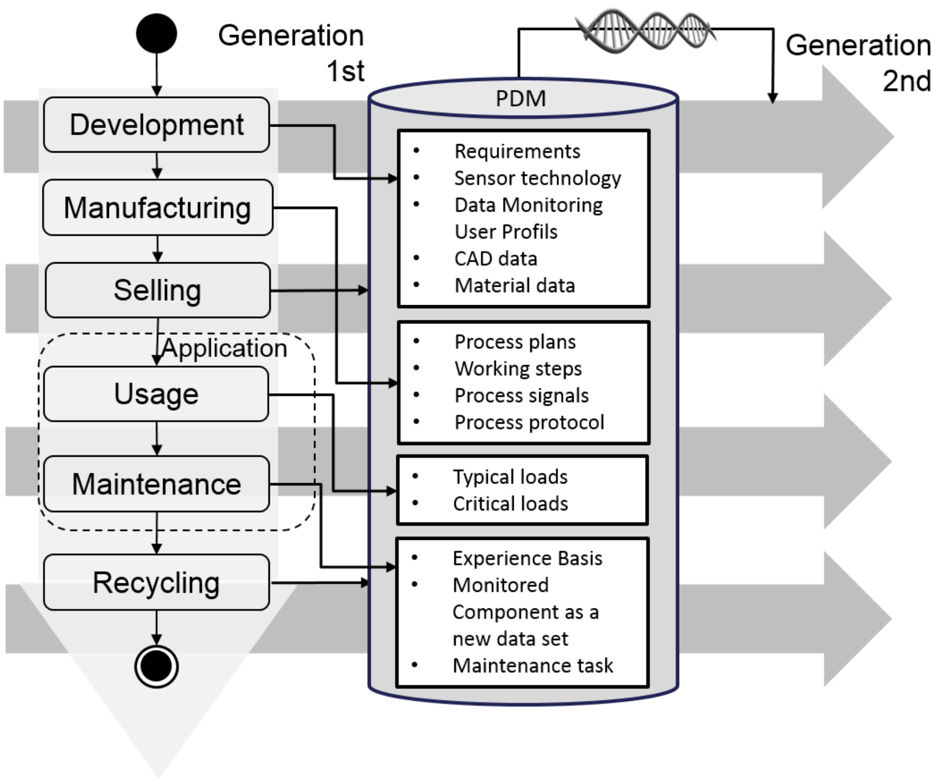

Figure 3. Lifecycle Data from Technical Inheritance in a PDM System

All development-relevant information of the different lifecycle phases for an exemplary generation return into a PDM system, so that all necessary information are available for new generation development. From the development phase, the presented design parameters, user profiles as well as material characteristics are added. The production phase stores process plans, working steps and process protocols. Form the usage phase the typical and critical loads are stored and the maintenance implements the experience basis and new data sets. From generation to generation, the information and knowledge base about the individual products, their behaviour and their use expand. On this information and knowledge base can be referenced for a new generation development or adaption.

3 DATA ACQUISITION FOR FEEDBACK IN A PDM SYSTEM

According to the German VDI guideline 2221, a design process starts with the clarification and specification of the task and recorded in a list of requirements as a work result (VDI 2221, 1993). Functional structures are then created and the product is developed more and more. However, in order to shorten the time of a design process, previous products and their realization are searched according to the same or similar requirements. Another criterion that can be looked for in the development are failure hypotheses, according how a component has been designed and calculated. Failure hypotheses are e.g. dynamic fracture, thermal aging or tribological abrasion. The development phase is not only taken into account, but also al other lifecycle phases, in order to ensure the greatest possible coverage. In this way known and existing solutions or partial solutions can be adopted or adapted. The reuse of solutions or partial solutions leads to a considerable resource saving and results in shorter development times.

3.1 Sensors for Failure Hypothesis

In order to acquire data and information from all lifecycle phases, different sensors need to be integrated into or on a product or component. Various measuring sensors can be used to record a measurand. For the determination of a sensor a process approach has been developed.

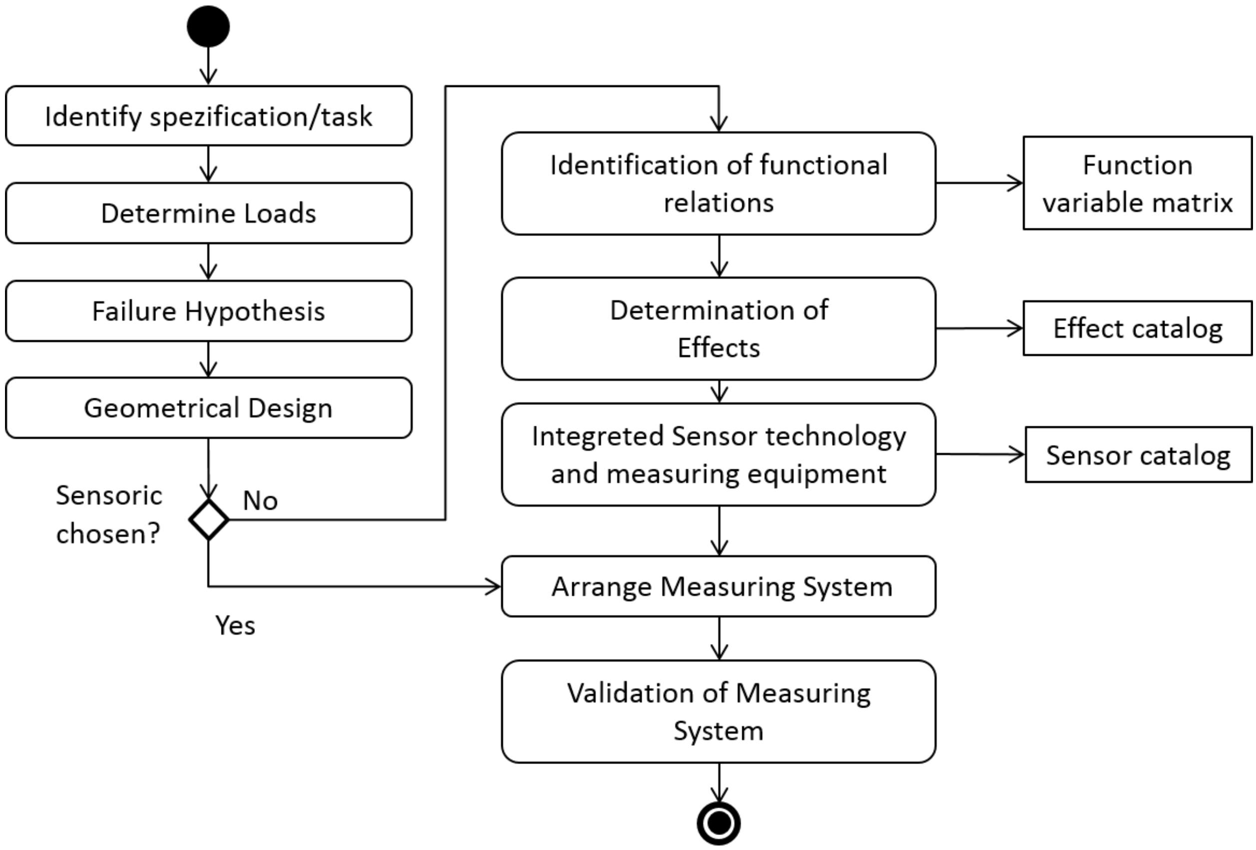

Figure 4. Process for sensor integration

As shown in Figure 4 the specification and task of the component has to be identified. Afterwards the loads are determined and the failure hypothesis is established. Failure hypotheses are different perspectives of calculating or designing a product. With the establishment and calculation e.g. of the dynamic fracture, a statement can be made how much reversal of load a component can sustain with a certain force. However, with the failure hypotheses alone it is not possible to determine, why the supposed force is occurred. The sensors developed in the CRC 653 help to make a statement about the causes for the failure hypotheses.

With the considered failure hypothesis the geometric design can be established. If the sensor system is already chosen, the measuring system can be arranged. If not, the functional relations have to be considered.

The functional relations and the physical functions specify power, e.g. angular momentum, angular velocity or stress, and quantity, e.g. mass, spring stiffness or coefficient of friction, in a system need to be identified. The interactions that link the physical functions variables are called target functions (Roth, 2000). The linking of several target functions results in a function structure (Roth, 2001). In a function variable matrix, in which the row and column contain the function variables, related effects are contained (Roth, 2000). Effects are the legality provided by nature to effectuate something. Physical, chemical, biological or other relations are known as "effects" and can be assigned to a target function.

For the function variable matrix one or more effect is stored with the mathematical description in an effect catalogue for each matching pairing. By setting up the functional variables, the assignment of effects to the target functions, an active principle can be derived in the next step. These active principles are documented in a principle sketch and serves as a basis at the beginning of the design phase. Through the active principles all interactions so far are taken into account of a technical system or component. As a result, the interactions in a damage case can also be identified in a next step.

In the following step, the measuring sensors are selected based on the identified principles. In the CRC 653 various sensors have been developed for different meas02urand and recorded in a sensor catalogue (Gottwald, 2016). Through the understanding of the system and the interactions, a measuring sensor can be selected, which determine a possible cause for a dynamic fracture. With the active principles and measuring sensors a system or component organisation is set up. The sensors collect and store the information about the components lifecycle during the different phases. The sensors enable the Technical Inheritance to give a data feedback to other phases or the PDM system.

3.2 Application

The Formular Student race car RP09 of the Leibniz Universität Hannover represent one of the demonstrators of the CRC 653. To collect lifecycle data, especially applied loads, gentelligent technologies are integrated into the race car's components.

For each year a new race car is being developed. The requirements must always be considered for each of the new developments. This can be the different race tracks, the various climatic conditions or changing drivers within the team. The lifecycle information from the previous generations help for the new development. The data from the phases are collected and entered into the standardized data exchange format GIML. These are transmitted from the different phases in a PDM system. Within the framework of the CRC the authors use the PDM system Autodesk Professional.

The focus in the development process is to create a new product generation of gentelligent components, which are significantly better adapted to the environmental requirements. The goal-oriented collected information are the basis for the new generation design. The design evolution process includes the steps of data analysis, modelling of component geometry, geometry optimization and finally the design of a new component generation, shown in Figure 5. During the development phase in the CRC 653 this design process is projected on a wheel carrier of the RP09.

Firstly the detected lifecycle data are transferred with the standarzied data exchange GIML to the development phase. During the analysis the lifecycle data is clustered and represented in Newton and the load direction with the use of a Python script. The next step of creating a new design is choosing the so-called parameterized skeleton which provides the location and connecting surfaces according to the developed Generative Design Approach (GDA) (Sauthoff, 2014; Lachmayer, 2016). The authors use the CAD-System Autodesk Inventor for the GDA. Next is the choice of the appropriate standard basic design elements form a database, also stored in the CAD-system Autodesk Inventor. The design elements includes manufacturing restrictions and have a fixed number of design areas, a number which is determined in advance. In the case requirements corresponding to these areas are unchanged the separate design areas can be defined as inherited objects to the next component generation (Mozgova et al., 2016). The new product model is then given with the help of a Python script into the optimization in the FEM system Abaqus. During the optimization phase the CAD parametric model is interconnected with a simulation environment in Abaqus. With the help of a genetic optimization algorithms a geometric and a conceptual product design is generated and optimal adapted on the particular load cases. This design evolution process results in optimized and adapted wheel carrier for the RP09 for each generation. This development process can be repeated for each new generation and its design process. The information generated and collected in the development phase e.g. load cases, parametric skeleton and design elements or the FEM solutions, are structured, unified and standardized with a classification system, which are used to arrange objects according to their features, for the storage in a PDM System. This guarantees an eased retrieval and a traceability over the time and changing engineers and user. The classification systems contains a primary key, which order and standardized the information of the development and manufacturing phase in a numerical code (Scheidel et al., 2016). The component geometry, material information, the force application points and gentelligent technologies can be classified with the developed classification system. The classification system orders and structure the lifecycle information and transfer them to the PDM System. There it helps to have a continuous structure and a lossless exchange between the different lifecycle phases and different user.

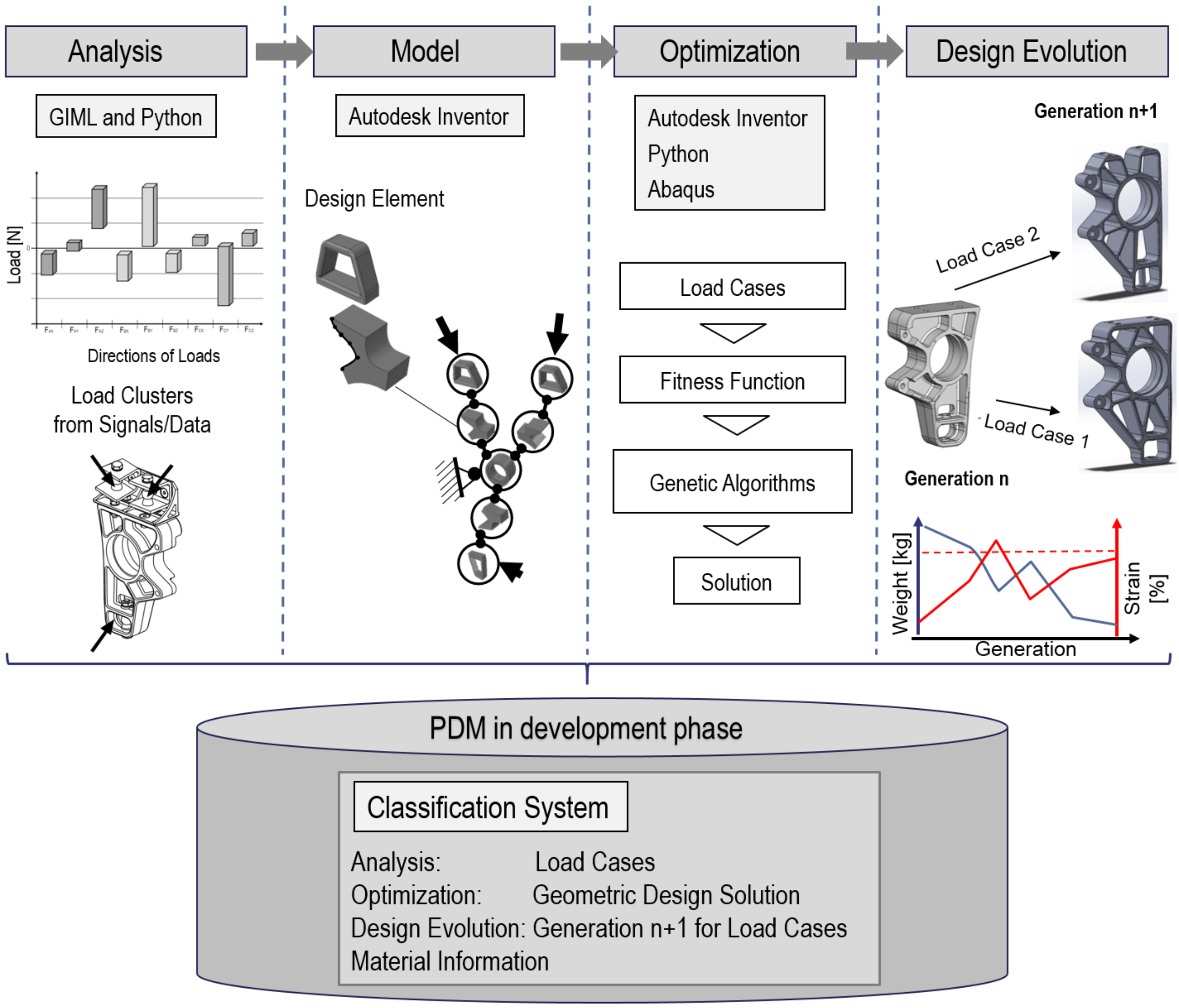

Figure 5. Product development Data for a wheel carrier in a PDM System

The development process for a new wheel carrier generation generates data and information, which are not only relevant in the development phase, but also for subsequent lifecycle phases. The analysis of the data and measured signals results in a load cluster with the significant load cases. These load cases are stored in a PDM system. The modelling process determines the used design elements and the conceptual and geometric design. For a new generation the used design elements and the whole design can be interesting, so these information are also stored in the PDM System. The optimization results in a design, which is adapted to the environmental conditions. The optimized model is adapted to the particular load cases of different usage phases. These different generation are also stored in the PDM system, because these are the relevant models for the subsequent phases, e.g. manufacturing or maintenance. All lifecycle phases have now access to the determined wheel carrier models and generate fitting process plans, working steps, e.g. for the manufacturing phase, or on new maintenance tasks.

4 CONCLUSION

Information flows during the lifecycle of a product in the CRC 653 are presented. The CRC approach, Technical Inheritance, is based in the storage and transfer of the assembled and verified information of gentelligent components in their lifecycle. It is shown, that Product Data Management complements the Technical Inheritance approach for an efficient next generation product development. With the help of a PDM System development relevant information, like requirements, failure hypothesis or used sensor technology, can be found, compared and if applicable reused in a product development process. A new product generation is performed on the basis of the collected lifecycle information. It is presented how these collected information can be structured and organized in a Product Data Management System. In the example of the Formula Student race car, it is shown which lifecycle information for a new development help for a new wheel carrier generation. The subject of further investigations are the implementation of the numerical classification system into the PDM System Autodesk Vault Professional.

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