Design Evolution by Integration of Life Cycle Information in Knowledge Repositories

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The gentelligent technology allows components to “feel” (collecting and saving) their loads over the product life cycle. Hence arise new challenges for the development process. The information about real loads can be used for an adaptive design of the next generation. Therefore the methods, tools and heuristics, the feedback of life cycle information and the optimization strategy have to be developed and merged to a “Design Evolution”. This considers the methodology of data handling and evolutionary mechanisms in the proceedings of the optimization. In this paper the approach for a Design Evolution is shown by a demonstrator of a wheel carrier by combining simulations and real load data. These information are integrated into a knowledge repository whereupon the Design Optimization reverts. The influence of handling these data on next generations of the wheel carrier is shown.

Key words: Design Methodology, Statistical Operations, Optimization, Evolution, Simulation

1. Introduction

Nowadays the periods between the developments of two generations of a technical system are getting shorter and more complex. Therefore in some projects new process cycles e.g. application of evolution strategies in product development are investigated [4,15]. Additionally technical systems are getting more specific and individual. Furthermore mechatronic systems are enabled for a self-optimization for an effective operation [6] as well as management systems for structural documentation of product utilization are developed [1,14]. Especially for this reason it’s very important to know the loads during the product life cycle. A possibility to collect such information represents the gentelligent technology which is developed in collaborate research center (CRC) 653 “Gentelligent Components in Their Lifecycle” [5]. Gentelligent means a combination of genetic and intelligence. This new technology enables mechanical components transmitting their load data during the manufacturing and usage phase [2]. Thus the requirements for the methods, heuristics and tools in the product development process are revised.

In this project the Technical Evolution is developed [12]. Technical Evolution means the design of gentelligent systems, which is adapted to their environment [10]. Gentelligent systems could be highly dynamically loaded mechanical components which collect information about their loads over the product life cycle [11]. The specifications and requirements for the methods, tools and heuristics for an integration of this technology in a product development process have to be elaborated. In addition the statistic methods for a reduction of data volume like cluster analysis [3,8] have to be investigate as well as the integration of this information in knowledge repositories. Furthermore suitable optimization strategies [7,16] have to be analyzed by using methods for multiobjectives [13] and knowledge based engineering [10]. The concept of the Design Evolution is the combination of these three research tasks.

2. Concept of Design Evolution

The three packages are “Design of Gentelligent Systems”, “Statistic Operator” and “Optimization Design” and are depicted in a simplified life cycle of gentelligent components including product development process and the Technical Evolution in figure 1.

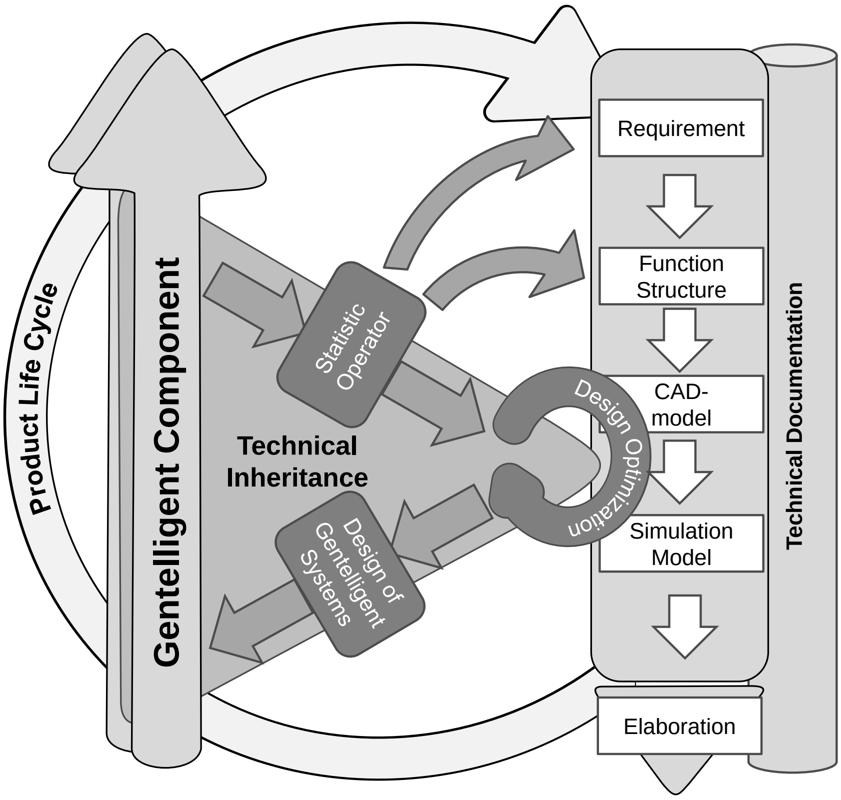


Figure.1 Concept of Design Evolution

The first package “Design of Gentelligent Systems” deals with the development specifications for the gentelligent technology. At the beginning the focus lies on the analysis of the position of the gentelligent technology in the component for a purposeful feedback of product life cycle information. Therefor the methods and tools in such a development process have to be analyzed and adapted for a user-friendly assignment. On this account the gentelligent was investigated for its applications areas and is conditioned in form of a design catalog. Also the first analysis for a process description is done for a demonstrator component in the Unified Modeling Language (UML). There is a high potential for a better understanding for a development with the gentelligent technology.

In the second package “Statistic Operator” methods of data processing are analyzed. Here the focus lies on methods for cluster analysis. By this methods the data volume can be reduced for a better handling in the “Design Optimization” as well as the significant loads could be detected. Beyond the methods are robust against measurement errors. The information about the significant loads can be used for different tasks, for example for adaption design. In that way these information were stored in knowledge repositories. To implement other tasks by the “Statistic Operator” like concept modification within the development process of the next generation other mechanism and statistical methods have to be developed.

In the third package “Design Optimization” several optimization strategies are analyzed. These imply topology and parameter optimization. In this project the optimization by generative parameter models is used because complex components can be linked up over effective areas and manufacturing as functional restrictions could be considered. For the minimization of a multi-objective function genetic algorithms are well suited. In this project the challenges are the development of methods for assembly optimization as well as the consideration of life cycle data in the optimization process.

The combination of these three research packages enables a Design Evolution for mechanical systems by integration of product life cycle information into knowledge repositories. These are the interfaces between “Statistic Operator” and “Design Optimization”.

3. Data Combination and their Statistical Analysis

a race car from the Formula Student Team called “HorsePower” of the Leibniz Universität Hannover is one of the demonstrators in the content of the CRC 653. In the feasibility study for this project the wheel suspension especially the wheel carrier is focused on. First a multi-body simulation model of the race car was created in AdamsCar depicted on the left in figure 2.

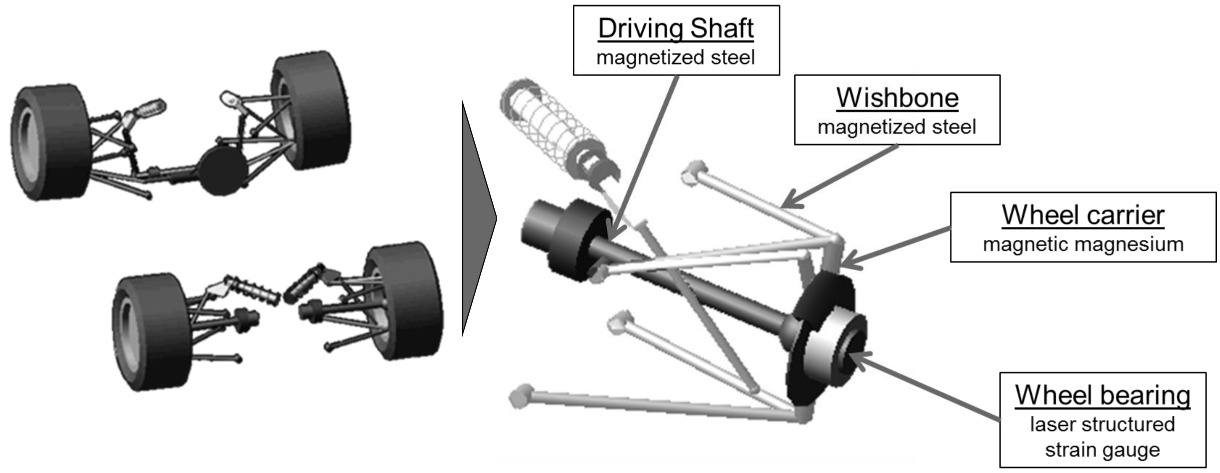


Figure.2 Simulation Model of Wheel Suspension of Race Car RP09

The focused section of the wheel suspension is depicted on the right side. The possible gentelligent components are marked. The driving shaft and wishbone can be made from magnetized steel. The wheel bearing can be equipped with laser structured strain gauge. The focused wheel carrier consists of magnetic magnesium [2].With the simulation model load data during a drive can be generated for the wheel carrier. The three suspension points which link the wheel carrier with the wishbones and spring strut are of special interest. To gain the forces in the real race car a transformation of the measurement data is necessary. Therefore two points were located where applied strains could be measured by the gentelligent technology in the first package “Design of Gentelligent Systems”. These applied strains were converted into force at the suspension point between wheel carrier and wishbone, depicted in figure 3.

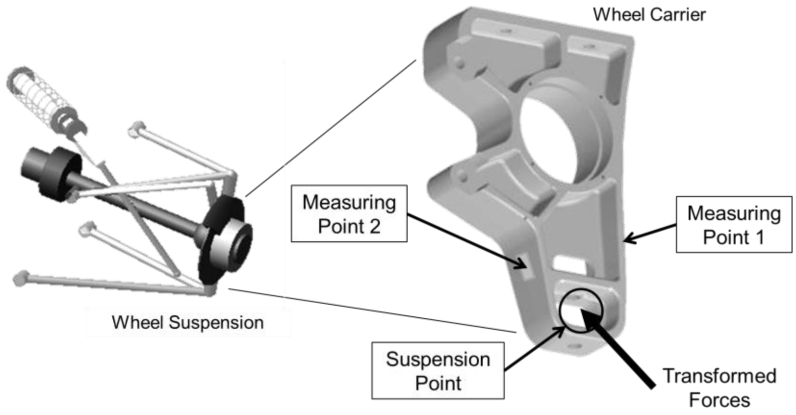


Figure.3 Wheel Carrier with Measuring Points

The translation is realized by a linear regression of forces from multi-body simulation and applied strains of FEM-Simulation. The conversion occurred by the following formula:

$$\begin{pmatrix} Fx \\ Fy \\ Fz \end{pmatrix}^T = \begin{pmatrix} \epsilon_{1,x} \\ \epsilon_{1,y} \\ \epsilon_{2,y} \end{pmatrix}^T * 10^7 \begin{pmatrix} -0.1692986 & -0.1806184 & -0.0684381 \\ -0.4256452 & -0.4040402 & 0.2738836 \\ 0.0539143 & 0.1451508 & 0.0128671 \end{pmatrix}$$

The determined error of this calculation is 1% at a load of 200 N and 10% at a load of 1600 N. This failure range is acceptable for a transformation from applied strains to force at the suspension point. In figure 4 the force progression of this suspension point is depicted for the simulated and translated version.

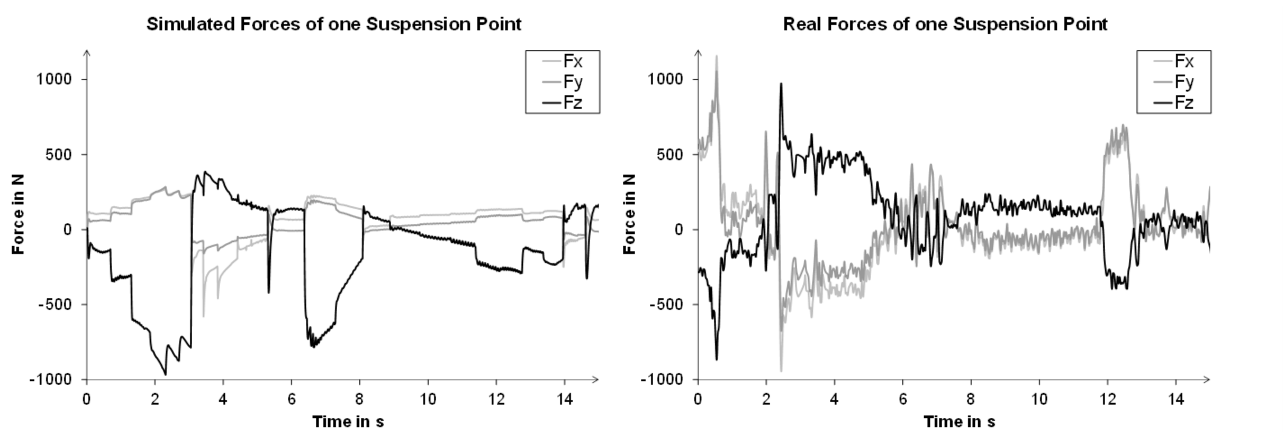
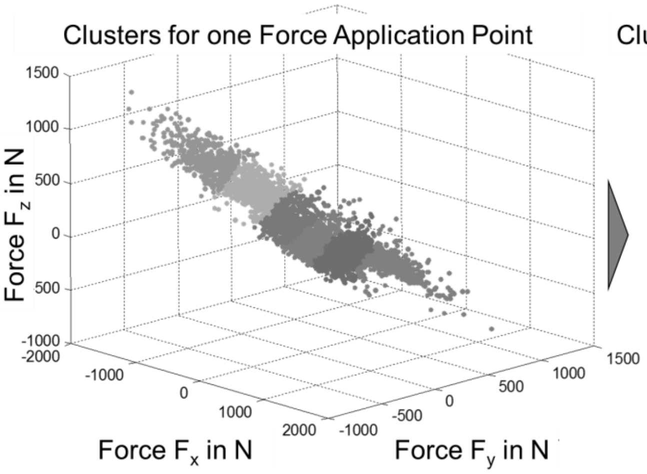


Figure.4 Comparison of simulated and real force progression

On the left side the progression of the measured and transformed forces for one suspension point is depicted. Whereas the progression of the simulated forces is pictured on the other side. The ranges of the simulated and real forces are similar to each other. Beyond the dependencies between the forces progression behaves similar. The comparison between these two graphs confirmed the assumption. This allows, that real and simulated force data could be used for the optimization. A reduction of the data volume is necessary before.

Further data processing involves a statistical analysis. The data sets of simulated and real force at the three suspension points are combined for the analysis. This is necessary because only one suspension point can be measured at the moment. The other reason is that for an equivalent informative over the loads during the product life cycle a huge number of data sets have to be considered. In the case of signal processing in an uncertainty one way of structuring and grouping data is cluster analysis.

The k-means and the k-medoids cluster analysis methods are applied. It could be shown that the k-medoids method needs more calculating cycles than the k-means but it’s more resistant against measurement deviations. In that way the combined data set from simulation and real race car were clustered. The result of the cluster analysis for the suspension point from the real applied strain data is depicted on the left in figure 5. The significant load cases for all three suspension point are presented on the right side.



Clustercentres for three Force Application Points

Cluster	F_{x1}	F_{y1}	F_{z1}	F_{x2}	F_{y2}	F_{z2}	F_{x3}	F_{y3}	F_{z3}
1	-182,8	151,4	53,5	313,9	-170,7	655,9	182,8	-151,4	-53,05
2	470,8	-383,6	136,8	-431,1	-98,9	747,4	-480,8	383,6	-136,8
3	45,4	66,9	1,6	-75,24	138,6	408,9	-45,5	66,9	-1,6
4	-454,7	-430,5	150,6	-134,7	397,9	641,9	454,7	430,5	-150,6
5	311,2	407,9	138,3	-58,2	-450,7	788,7	-311,2	-407,9	-138,3
6	-800,4	-799,1	301,4	590,9	30,8	853,4	800,4	-799,1	-301,4

Figure.5 Cluster analyses with six significant load cases for three force application points

Six significant load cases were chosen in association with the dynamics of a wheel suspension. There exist the vertical, lateral and longitudinal dynamics. These information about the loads are stored in knowledge repositories and are the basis for the adaption of the next generation.

4. Design Optimization

The knowledge repository allows an overview of the different load cases products experienced during their life cycle. The comparability is guaranteed by constant force application points in the suspension. The significant load cases have to be included into the requirements of the technical system. This leads to the restrictions of the multi-objective function.

The goals are distinguished in two parts. One focus is the light weight construction. The second is the equable stress distribution inside the wheel carrier. The stresses are depended on loads and the shape of the component. The shape is associated with the light weight construction. In the knowledge repository n-significant load cases are stored. These could be evaluated considering the objective by e.g. their appearance or usage location. Therefore the weight of the loads is chosen considering their occurrence. A simplified information flow is depicted in figure 6.

To adapt the wheel carrier to the significant loads a generative parameter models which is used in this Design Optimization is developed. This model is restricted by design guidelines of manufacturing as well as functional constraints. To minimize the multi-objective function a genetic algorithm is applied.

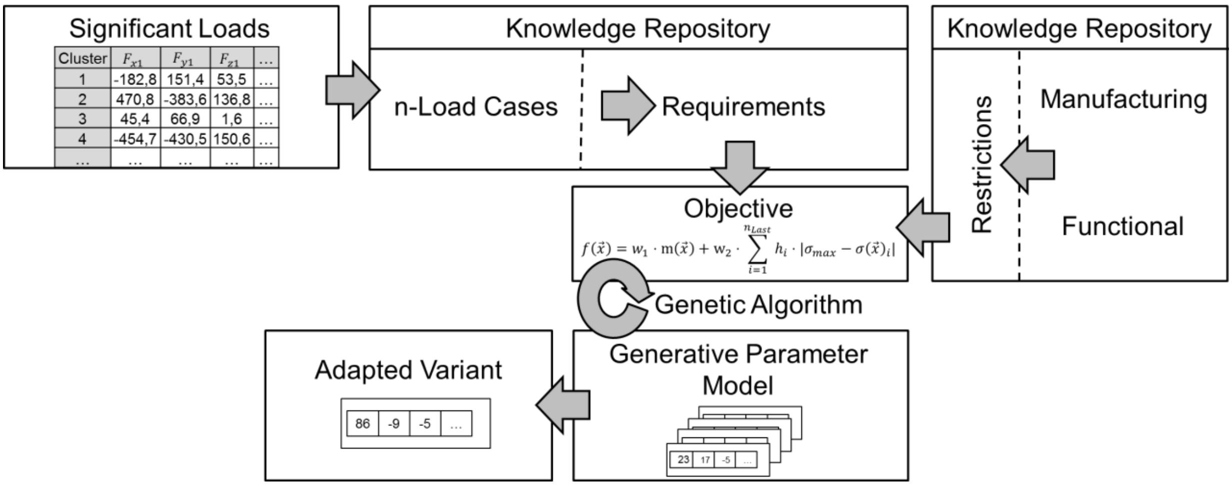


Figure.6 Integration of product life cycle information into a knowledge repository

A simplified process of an iteration, which represent the operations between the objective and the generative parameter Model is depicted in figure 6. If the value of fitness reaches the required objective a new adapted gentelligent variant is developed.

The generative parameter model of the wheel carrier consists of three basic elements. There are suspension points which are connected to the wheel bearing element by linking elements. These elements are developed in a parameter set for the wheel carrier. The generative parameter model includes the structural and the shape design, depicted in figure 7. The structural design implements the dimension of the whole component with the restrictions for the tie points.

The shape design is subdivided into two parts. First the effective area which describes the kinematic coupling between two elements of the model is examined. In this case there is a static kinematic coupling of the wheel

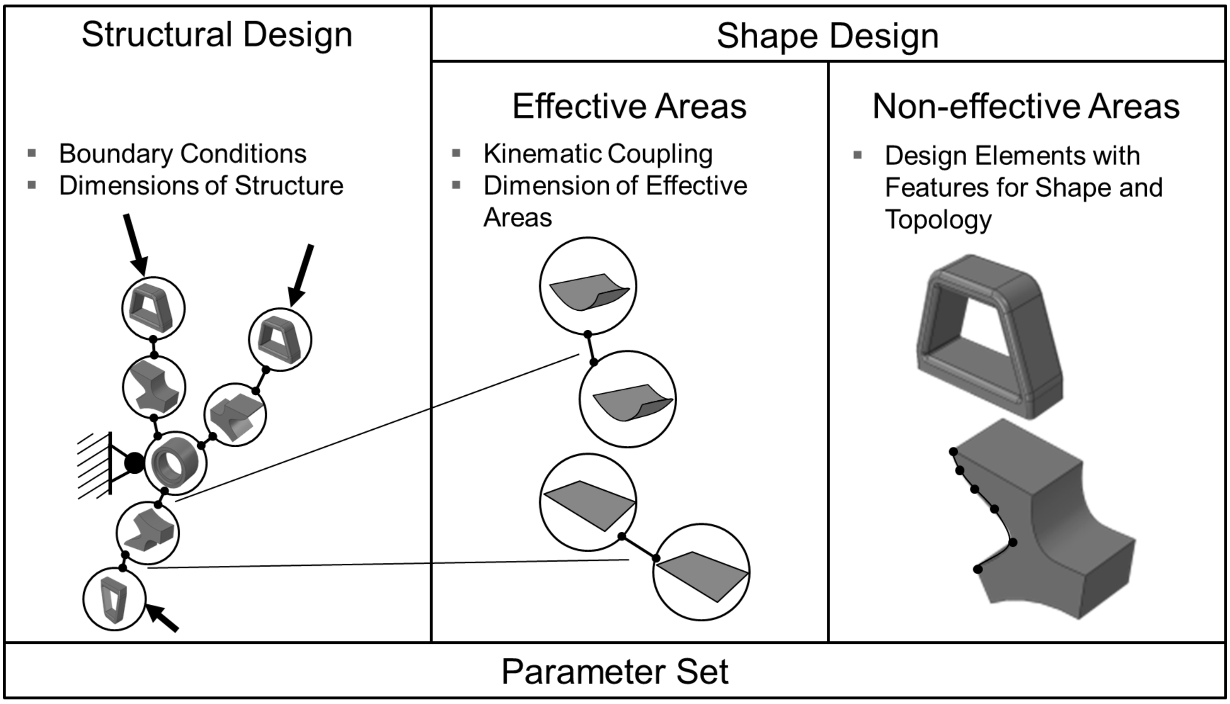


Figure.7 Generative Parameter Model of the wheel carrier

carrier. Also the dependency of the dimension is declared. If one element changes the shape of an effective area it must be guaranteed that the counterpart changes in the same dimension.

Second part of the shape design are the non-effective areas. Here the focus lies on manufacturable restrictions. The parameter sets for these areas are linked up with features for shape and topology considering the manufacturing conditions.

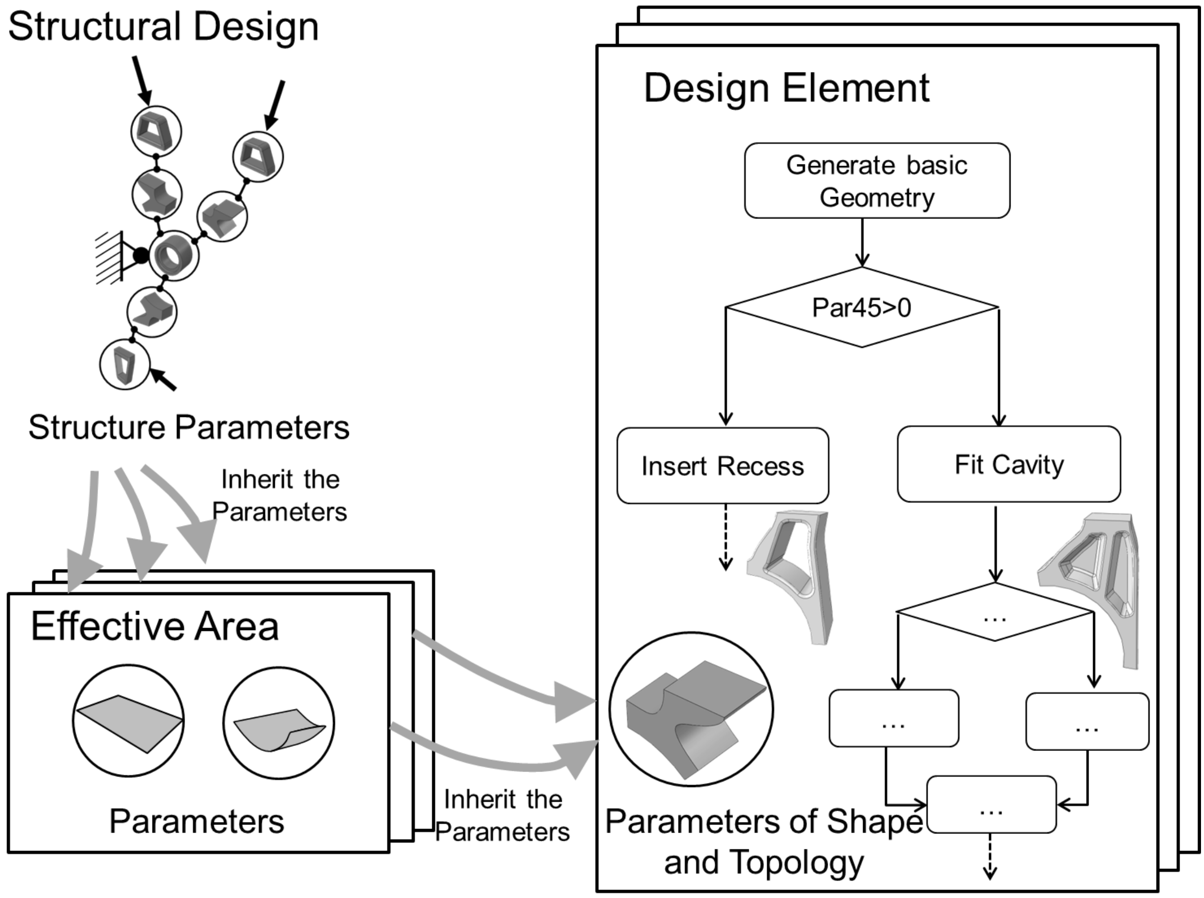


Figure.8 Inheritance of Parameters in the Generative Parameter Model

The inheritance of the parameters set based on the genetic algorithm. There are some fundamental operators in this process of the evolutionary mechanism recombination, mutation and selection. Therefor the parameter set of the individual design elements are modified by such operators.

To secure that the elements don’t go below of a manufacturable thickness the constraints for the parameters are set by the developer. The variance of topology transformation is parametrized too. The process of the inheritance and topology variation of the shape design is depicted in figure 8.

For the estimation of the generative parametric model the fitness of the multi-objective function is calculated. Different Results of new generative parameter models of the wheel carrier are depicted in figure 9. These are possibilities for the next generation. By changing the design of the new generation the positions of the gentelligent technology has to be adapted by the “Design of Gentelligent Systems” because the load distributions changes.

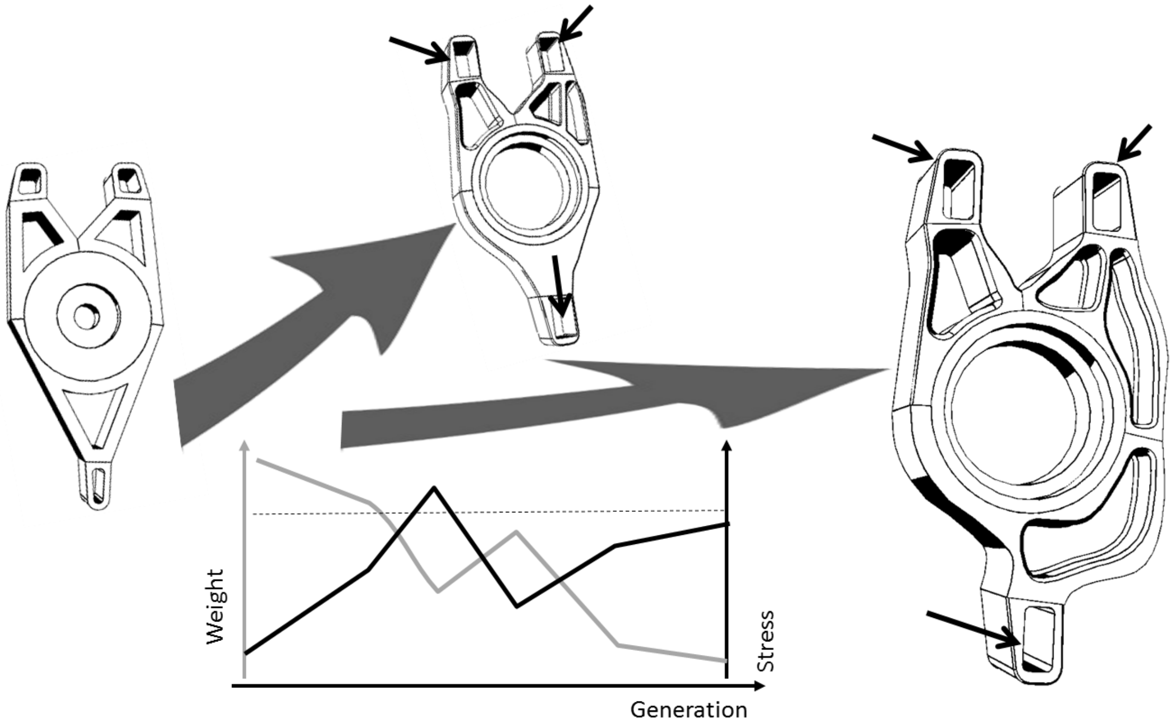


Figure.9 New Generations as function of the load cases

5. Conclusions

With the combination of the research packages “Design of Gentelligent Systems”, “Statistic Operator” and “Design Optimization” it’s possible to adapt gentelligent components to their environment. The challenge of suitable feedback strategy for the wheel carrier is solved by linear regression and a translation model. Thus the strains which are collected during the product life cycle are converted into forces at the suspension points. Therefor a multibody simulation model of the race car was developed. This model is used to get more data sets of forces during the life cycle of wheel carriers in different situations. In the package “Statistical Operator” datasets of real and simulated forces at the wheel carrier are being analyzed by cluster analysis. The k-means and k-medoids methods are appropriate operations to reduce the data volume. At the end the k-medoids method is on account of its properties the selected method to detect the significant loads. These product life cycle information are stored in a knowledge repository which provides the data basis for configuration of the multicriterial objective function in the “Design Optimization. In this package various optimization strategies were investigated. Considering the adaptive design to develop a following generation of a component the generative parameter models found to be a suitable means. The restrictions of manufacturing and function of the component are integrated. Beyond the genetic algorithm is used to optimize the gentelligent wheel carrier based on product life cycle data.

After demonstrating the potential of the gentelligent technology for adaptive designs of the next generation based on virtual and real load data it is necessary to validate the proceedings on a test bench. Inter-generational test have to be arranged. Based on this the methods, tools and heuristics will have been adapted for a Design Evolution of assemblies. Therefore the specifications describing the development process have to be work out. One possibility is to use activity diagrams of the Unified Modeling Language to demonstrate the feasibility of the approach. In addition the knowledge repositories will have been investigated for handling gentelligent product life cycle information of assemblies. The mechanism for a targeted feedback of product life cycle has to be defined too. By implementing gentelligent assembly systems the generative parameter models have to be enabled with dynamic kinematic couplings. Additionally the restrictions have to be adapted. The vision is a development environment for the gentelligent technology which allows a Technical Evolution.

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