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Technical Evolution Process - An Approach for Product Development and Optimization

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Abstract

The question how to combine conceptual changes with optimization strategies and life cycle information to implement semi-automatical design changes regarding real environmental conditions in product development is still a challenge. The presented approach of an evolution-based development outlines a framework to get one step closer to computer-aided design variation. Instancing the bicycle important aspects like product representation, optimization strategies as well as the invariance of feedback variables are focused in detail.

Keywords: Technical Evolution, Optimization, Engineering Design.

Motivation

Product lifecycles are very short today and product complexity causes a constant increase in development effort. In many cases the concept of technical evolution can be utilized underlying that product development is similar to the evolution of nature - where requirements change in a way that the well adapted survive bequeathing their gens while others become extinct [1]. Developing new products engineers pursue the intent of optimal adaption in request to the requirements to achieve sustained success for their company. Although evolution of technology seems to be similar to evolution of nature in reference to long-range development the mechanisms of enhancements are different. Considering evolution of nature a new individual is generated by selection, recombination and mutation. An improvement of individual properties is only effected after a large number of inheritance terms. Non-improving properties are eliminated by selection during the life of an individual. Considering the process of product development in this context a selection of products during its life cycle by the customers is not feasible. The number of product individual is smaller than in nature as well as the time of development steps is considerably shorter. Thus application of evolution mechanisms in product development process makes only sense by a computer aided evolution process where various evolution steps are accomplishable before finishing the development. This approach is still successfully used e.g. in solving optimization problems by genetic algorithms [1,2,3,13].

Requirements for an evolution-based product development process

In focus to complex product optimization by application of evolution mechanisms there is still a particular challenge attributed by the following questions:

- How can we represent the product and its variations be presented in reference to design and physical properties by a computational product model in a way which facilitates fundamental conceptual changes?
- How can detailed information be acquired about the environmental conditions a product generation is impacted during its life cycle?
- How can design variants be evaluated by simulation methods in reference to advanced changes of environmental conditions?

Summarized these questions can be concentrated to the domains of modelling, feedback of life cycle data and advanced product evaluation. For all these aspects aplenty computer aided engineering tools are available: The shape of a product can be modelled by computer aided design tools which can be linked to simulation methods like finite elements or multi body systems. Thus the boundaries for virtual simulation can be determined by laboratory experiments. All these tools are well-suited for development and evaluation of a single product generation with a limited feasibility of variations. Exploration of an enhanced design space in reference to conceptual changes as well as consideration of optimization of assemblies and component on a detailed level is not available yet. Thus an extended approach for product development considering the presented aspects is necessary.

Concept

Extending the existing product development process which consists of specification, conceptual design and embodiment design by a process of inheritance, shown in figure 1, a feedback of life cycle data is established [10]. To get detailed information about the environmental conditions it is necessary to equip products “gentelligent” in a way they are able to measure e.g. loads or temperatures. The product itself decides whether these

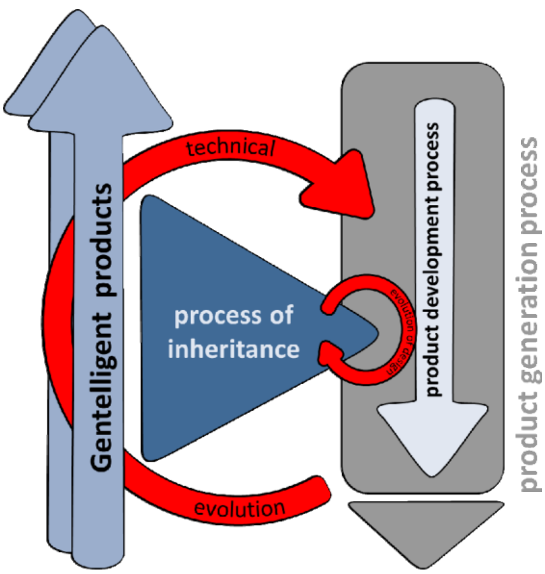

Figure 1 Evolution-based product development approach

information are critical and important for further product development. This can be provided by monitoring systems, system integrated intelligence and prospective component integrated sensor technologies e.g. "gentelligent components" developed by the german Collaborative Research Centre 653. Implementing the data processing as well as the measurement as a physical part of the component, data handling and storage reduction can be handled by the component itself. For feedback information to the product development process some already existing maintenance terms can be utilized. The process of inheritance also contains statistical operations to get information about critical conditions as well as transforming measurement data of many product individuals into information feasible for development engineers [7,8,9]. Furthermore the evolution-based product development approach contains two different operations to link life cycle information and product development information of the current product generation to the development process of one of the next generations. Analysing these aspects two different types of information feedback can be identified:

- **Analysis of technical evolution:** By analysing the product history it is possible to get detailed information about the relation between requirements, individual solutions and technical and social impact. Instancing the evolution history of a well-established product for example a bicycle there are the following issues:
    - Outline of the history of important development steps.
    - Analysis of fundamental conceptual improvements focused to initiation mechanism e.g. the change of requirements.
    - Identification of problems responsible of persistence in the respective development step.
    - Analysis of optimization mechanism in focus to the well-known optimization strategies.

  When including the results of these analyses to a knowledge based product model current product development can be extended. Thus the changes between different concepts can be calculated based on rules and experience data which should be part of the product optimization process [4,5]. In contrast to the measured life cycle data the analysis of technical evolution can be characterized as the subjective path in this approach which is responsible to identify the elements to model a product evolution in reference to physical characteristics and shape[5].

- **Evolution of design:** By linking the life cycle data transformed by the process of inheritance to applicable development information to a product model which is the basis for design variants an objective path can be established in the evolution-based product development approach. Compared to the subjective path this objective one is established to initialize a product variant with defined parameters interrelated to real environmental conditions as well as to define boundaries for an evaluation process e.g. by loads for a mechanical finite element based stress analysis. This linking is a precondition for an extended optimization approach because without detailed feedback data no application related design evolution is possible. Summarized the evolution of design describes the linking of life cycle information to an applicable optimization strategy [9].

In conclusion the presented evolution-based product development approach provides the fundamental operations which are required for conceptual changes expanding the commonly used optimization strategies.

Methods

Focusing the presented operations as well as the challenge of application transfering this approach to existing products important aspects are determined in detail. Instancing the bicycle the approach is reflected by further advisement respective a feasible product representation, optimization strategies and the classification of feedback variables.

Product representation for conceptual variation

Analysing the development of computational product models it can be noticed that the models are primarily related to the geometry of components especially to generate manufacturing documents. Increasing the application of computational simulation methods like finite elements and multi body system analysis functional modelling of systems and subsystems as well as the evaluation of these product representations became available. In the further development of computer aided engineering tools an improved exchange between simulation and geometry models was accomplished. In contrast to this development the representation of concepts is not commonly used although the conceptual development step impacts the complete product design as well as the fulfilments of specification [14].
Thus different layers of computational product representation, shown in figure 2, are basically for conceptual optimization. Engineering design grammars are well suited for the product representation on conceptual level because the degrees of freedom are manageable although the design variation is fundamentally. But in focus to the presented approach a continuous automatic data exchange of parameters and constraints between different layers of representation necessary for optimization is still a challenge. For identification of product related grammar based design elements the analysis of product evolution is fundamental. Analysing the bicycle for example the identification of the wheel as an inherent element is appropriate because different arrangements as well as design parameters approve a wide range

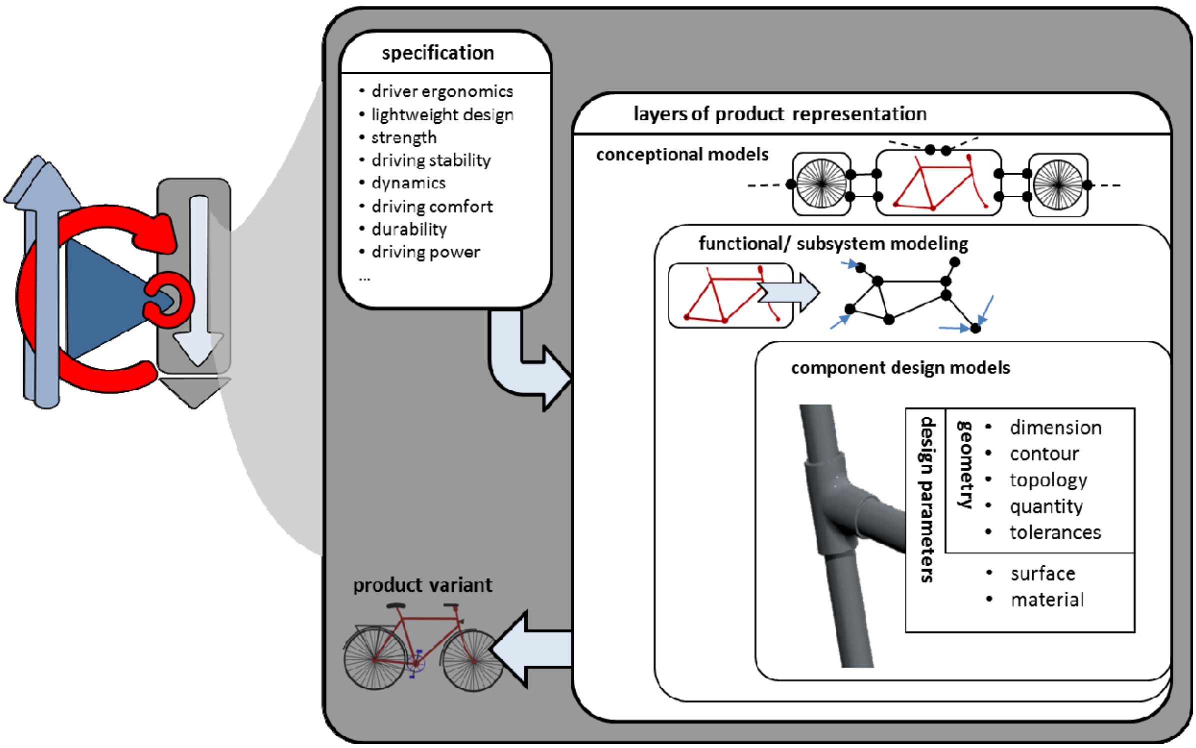

Figure 2 Layers of product representation instancing a bicycle

of variation with mostly applicably solutions. Summarized the definition of deliberated product representation layers and the appropriated degrees of freedom characterizes the conceptual design space as well as the definition of inherent design elements [4,5,6]

Optimization strategies

In the context of the presented approach product development can be seen as an optimization problem. Due to the aspect that the existing computer aided product models are primarily established for representation of shape and not for representation of functional optimization mechanisms this kind of representation is ineffective for an evolution-based approach. Nevertheless there is a wide range of well-suited optimization strategies which are successfully used for shape and system optimization on different levels of product representation. Thus it is reasonable to analyse these strategies in context to conceptual changes and integration of product life cycle data. The fundamental concepts of optimization strategies in reference to product representation on the functional system level and the embodiment level of shape are presented in figure 3. These strategies can be applied in every layer in the order of topology, contour and parameter optimization. While topology optimization enables the variation of fundamental structure elements within a layer parameter optimization varies the related parameter values for the purpose to find the well adapted value constellation. This way to link topology, contour and parameter optimization is commonly used in product development. Focusing a bicycle frame, shown in figure 3, modelled by a truss structure the different implications can be analysed. While the concept of truss quantity and connection is optimized by topological variation, the best-suited arrangement of nodes is computed by contour optimization. Inherent properties of the truss elements itself e.g. material, cross-sectional area and profile are configured by parameter optimization simultaneously. The shape of the bicycle frame represented on the component design layer is optimized by the same strategies [11,12].

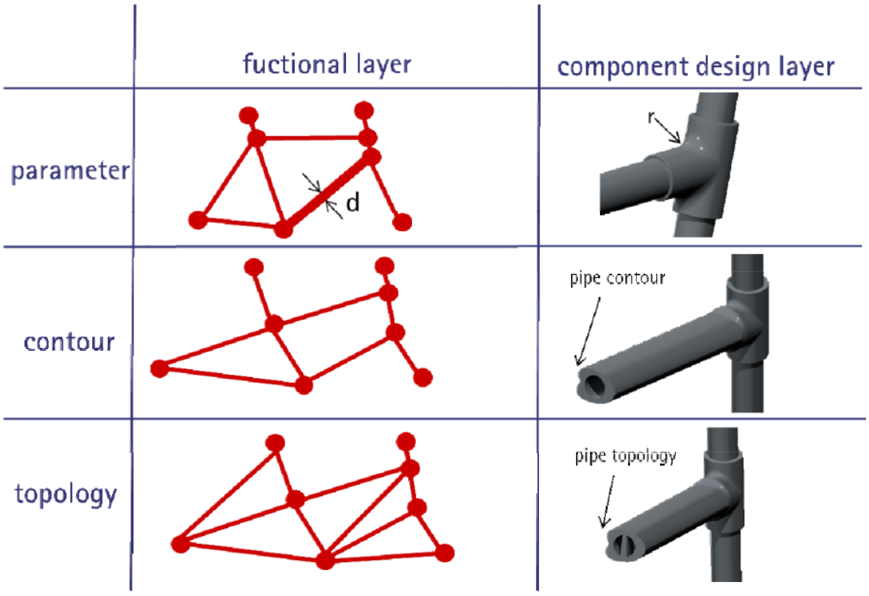

Figure 3 Levels of optimization strategies

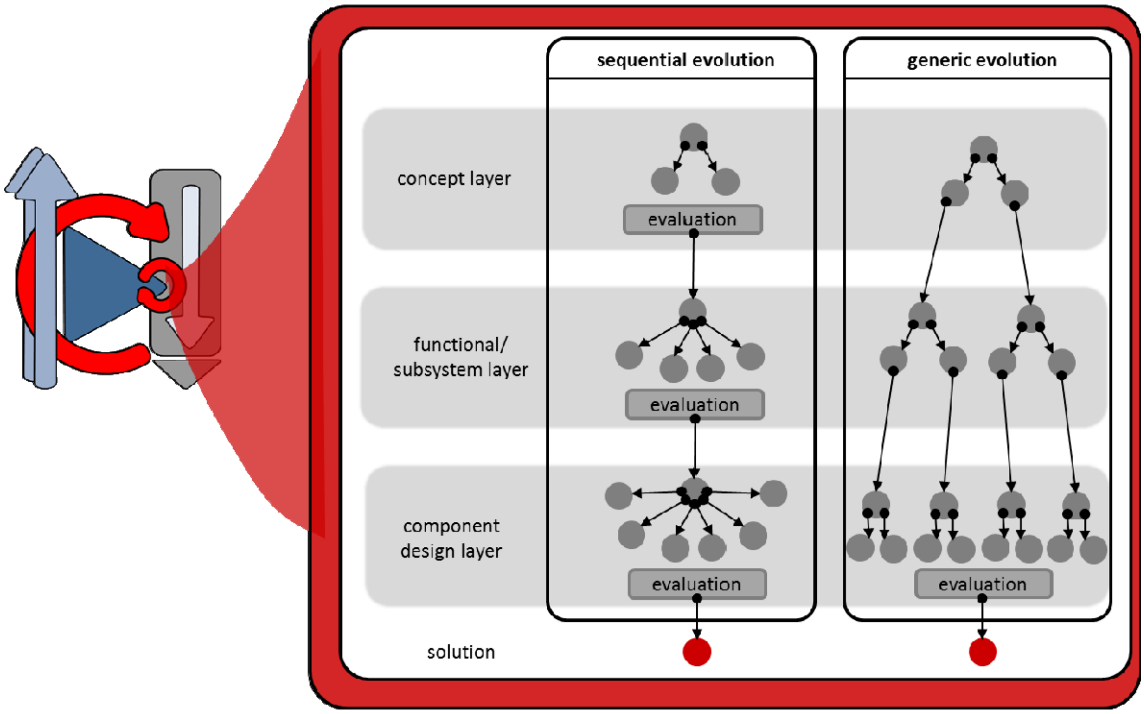

Figure 4 Different layer-orientated optimization approaches

Focusing the optimization process in context of the evolution-based development approach linking the different layers to a global optimization approach has to be considered. Thus two different approaches for a layer orientated optimization, shown in figure 4, are examined exemplary. Following the concept of genetic algorithm global optimization can be differed in a sequential evolution approach and a generic evolution approach: Using a sequenial procedure several variants are generated in every layer. Specification constraints as well as regarding life cycle information are cxonsidered by an evaluation modul and only one optimized individual is tranfered to the next layer. The quantity of variants generated in every layer depends on the appropriate degrees of freedom. In contrast to layer orienteted evaluation the generic evolution approach only consists of one evaluation modul but the quantity of evaluation candidates increases. Application of the approaches mainly depends on the degrees of freedom as well as the computational effort of evaluation e.g. a simulation because the generic evolution approach requires many calculations on the component design level where normally a huge computational effort is necessary. Otherwise there are products whose global charactestic is fundamentally influenced by details on the components design level. In this case a sequential evolution is partially impossible [13].

Invariance of feedback variables

In addition to product representation and optimization the feedback of objective life cycle information is an essential element of the evolution-based product development process. Considering the aspect of different layers of product representation life cycle information related to a component have to be integrated as constraints in the right layer and have to be linked to the inherent element in this layer additionally. Furthermore the level of design variation applicable in the related layer has to be consistent with the feedback information. Thus the feedback information have to be invariant to the design variation. Instancing a bicycle frame this requirement can be demonstrated: Measuring the stress at several critical joints at the frame of the bicycle during its application analysis of real impact is possible.

Linking these stress information to an optimization process of the frame design variation at joints is not reliably possible because the joints itself are no longer a reference for optimization. For the bicycle frame invariance is accomplished by utilising the measured stress information to calculate the load forces the frame is impacted during its life cycle. Linking information about critical load force conditions as boundaries to an optimization strategy topology, contour and parameters of the bicycle frame can be completely varied if the joints of force application are fixed. If a variation of these joints is arranged additionally the load forces of the circumjacent components have to be calculated because the load forces at the bicycle frame joints are no longer invariant state variables of design variation. Thus invariance of life cycle feedback information is a fundamental property for linking them to a representation layer.

Results

Extending the common used way of product development with systematic linking of life cycle information, different layers of product representation and optimization strategies the potential of product quality improvement as well as adaption in reference to environmental conditions increases. Presenting the evolution-based development approach a framework is proposed considering the challenge accrued by this extension. Instancing the bicycle fundamental methods, shown summarized in figure 5, are illustrated in detail focusing on the analysis of difficulties regarding practical application of the approach.

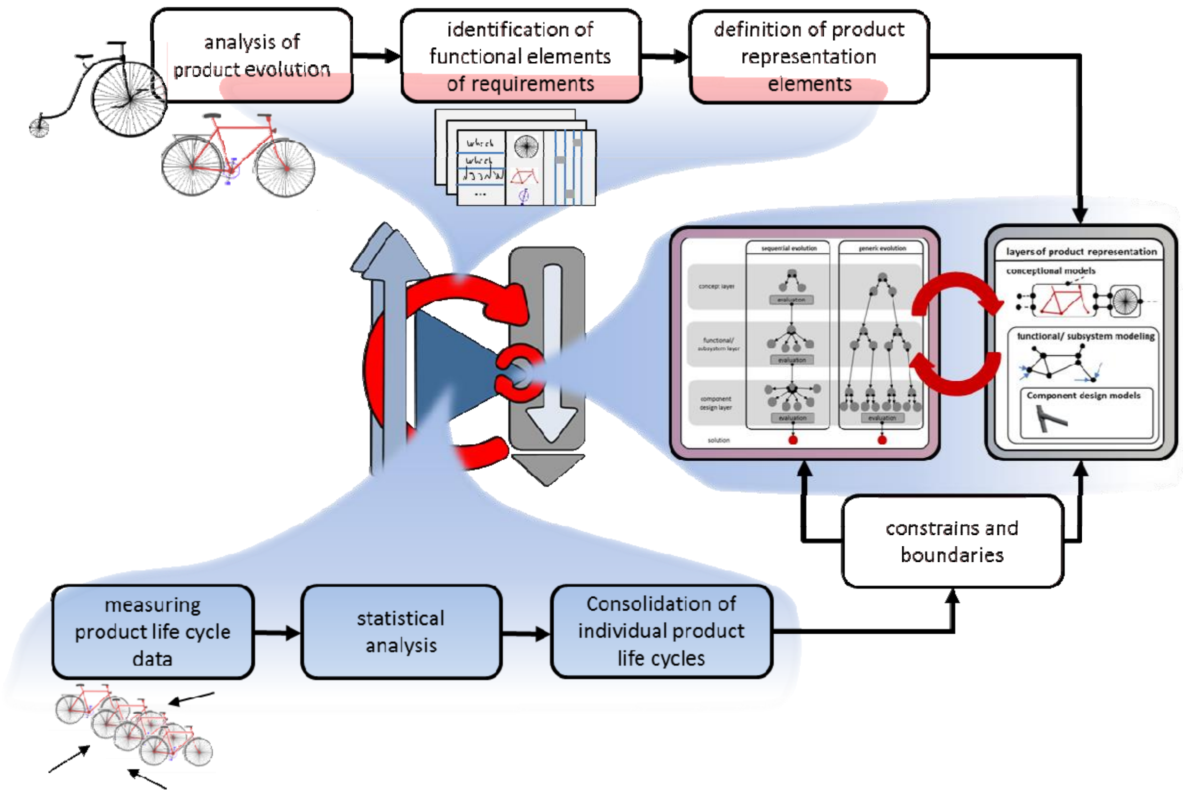

Figure 5 Evolution-based product development approach in detail

Conclusions

Applying the presented approach of evolution-based product development helps to customize, adapt or create next product generations of designs more precisely with less effort. The basic technologies and ideas are available and will be discussed but on the way to link them and to adapt these to specific products, markets and environments as well as to prove their performance there still is a lot of research to do.

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