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The Autogenetic Design Theory – an Evolutionary View of the Design Process

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Abstract

The main focus of the paper is to present the Autogenetic Design Theory (ADT) as an evolutionary view of the design process. It is aimed to be a basis for a better understanding of the nature of design process. Thus, the ADT can be used for modelling and for supporting the design activity as the substantial activity within the product development process. The ADT describes product development as a continuous development process of technique and technology. The basis of the ADT is to understand the evolution of products in analogy to the (technical) evolution of humans.

Evolution means gradual development, permanent adaptation, and optimisation to an aim that thereby changes itself. Both the development of a new product (new design) or the change of an existing product (adaptation design) can be described from the evolutionary view as a continuous optimisation of a basic solution by observing starting conditions, boundary conditions, and constraints (which may evolve themselves, too). The basic solution for a new design usually is a combination set of existing solutions ("new design of the second kind"). The basic solution for an adaptation is the product to be changed. Topics of the ADT are furthermore the description and the modelling of all procedures in the design process.

Keywords: evolutionary design, process modelling, descriptive model of designing

1 Introduction

Evolution means gradual development, permanent adaptation, and optimisation to an aim that thereby changes itself or the change (modification) of a worse state into a high/better one. Additionally the natural evolution is subjected to dynamic starting conditions, boundary conditions, and constraints exactly the same as each design. The development of a new product (new design) or the change of an existing product (adaptation design) can be described from the evolutionary view as a continuous optimisation of a basic solution by observing starting conditions, boundary conditions, and constraints [14]. The basic solution for a new design usually is a combination of existing solutions ("new design of the second kind"). The basic solution for an adaptation is the product to be changed. Contents of the Autogenetic Design Theory (ADT) are furthermore the description and modelling of all procedures in the design process [2] [25]. In this context the ADT describes and models all procedures within design with the evolutionary operators recombination, mutation, horizontal gene transfer (gene exchange over species barriers) and selection. One key element of the ADT is the transfer from terms and proceedings of the natural evolution theory into the design theory. With this approach, the evolution of individual products is knowingly regarded in the design process as well as the search for analogies to other specific fields are supported.

2 Procedures in product development

Product development[1] has a key role in today's enterprises. In this area, all product properties and up to 85% of the later product costs are specified, and an enormous responsibility for accruing costs is connected. This area is called "product defining range" or "engineering". It is to be recognised, that errors during the early phases of the product development process (e.g. in product design) lead to re-design and high additional costs in later phases (e.g. after production) [21].

The development of a new product is usually based on orders, customer's requests, market gaps, spontaneous innovative ideas, or enterprise guidelines, which define the product idea and/or the tasks during product planning. Product development is usually mentioned in the same meaning as design, and often literature describes product development equal to design. The design process activity corresponds to the product development activity, without the direct inclusion of prototyping and testing, which are necessary for a specific task. The importance of design is considerable for a company: The entrepreneurial success is determined by the success of its products. From organisational view, design is the substantial part of the product life cycle. From methodical view, design is an optimisation process constrained by given aims and by contradicting conditions. Requirements usually change along time (due to the fact that some new requirements are identified during development), so that a designed solution can be regarded as an optimum under the temporally available conditions [14].

2.1 Substantial tasks in the design process

In order to assure the execution of all (time and cost-critical) procedures for a successful product development in the necessary required quality (work procedures, use of certain procedures and tools), procedural models [1] [8] [13] and structural design methods [14] [15] [18] have existed for a long time. Their essential characteristic is to suggest a certain work sequence (or "work flow"), to handle a task and to use appropriate tools. In practice, one can note that this particular sequence (because of time constraints or it is of lacking knowledge of available methods and their possibilities) will not always observed. Apparently, the sequential operational sequence (which is postulated in most procedure models) does not support the engineer (product developer, technical designer) to fulfil his task efficiently enough. Rather, the engineer feels restricted in his creativity and looks for possible solutions in a reduced solution space only [6].

Creativity is important in the design process. It is described as a result of the reciprocal effects between logic and intuition. These statements are published in different models dealing with creative thinking process. This process is subdivided into individual components like available information, information processing (methods, proceedings), and emotions and motivations [10]. A well-known model of the mathematician POINCARE describes creative thinking processes in four phases. It consists of the preparation phase, the incubation phase (processing and taking up information), the illumination phase ("I see experience"), and the verification phase [16]. Both the cognitive processes and the possibility to think in a flexible way are substantial components of the creative thinking process.

1 Product development covers marketing, styling, development, design, and process planning. Product development can be described as the area, in which the global and complete product model is developed from the first idea (or market needs) and its appropriate requirements to the complete documentation of all further steps within the life cycle of the product.

The use of procedural models and design theories in practice can induce a restriction of creativity. This is to be considered within the ADT by an evaluation of the individual procedural models. In order to promote creativity, it is also important to ensure the possibility of information acquisition by training courses and team learning, horizontal and vertical qualification, and similar approaches [10]. These means lead to a higher understanding of selection and execution of existing methods and specification techniques (like e.g. QFD, FMEA, brainstorming), which support the creative process. The methodologies, which are used in the product development process, lead to a complex operational sequence that is influenced by factors like experience of the designer, his creativity, team ability, motivation and emotions. These factors are stamped by the applied methods, by the available tools, and by the consideration of regulations and standards [22] [23].

2.2 Designer's procedure

Based on the known requirements, the necessary functions, and because of his expert knowledge, the designer creates an appropriate solution (usually using isolated tools e.g. sketching, CAx Systems). This solution will be usually better than the preceding one. Due to his daily tasks it is not always possible to create further solutions and to evaluate these. Therefore the designer creates the "next-best" solution without knowing that he could have found better solutions defined by requirements, boundary and initial conditions of the solution space. In Figure 1, an abstract representation of the possible solution space is shown. Within the global solution space, the designer finds smaller subspaces only. He then refines the solutions found in the subspaces systematically by experience, knowledge and trial (and error, of course).

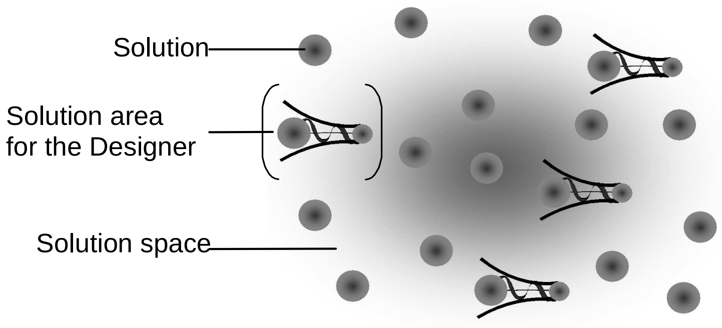

Figure 1: Designer's procedure

Searching for possible solutions in the solution space, optimising different alternatives, and finding the solution (which matches the requirements best) is a complicated, multi-criteria search and optimisation process. Usually, the designer tends to avoid this cumbersome work. Artificial intelligence offers a possibility of a multi-criteria search under changing conditions and allows to search the entire solution space and to find alternative solutions.

2.3 Application of design theories in practice

Empirical investigations in the area of the design methodology are usually aimed to create a better understanding of design. These studies, which were accomplished among other things by GUENTHER, offer the designer the necessary free space and do not impose a rigid procedure. GUENTHER divides designers in two categories. The first category (the so-called p-designers) describes designers with practical experience who, however, have not undergone any special training of design methodology at institutions of higher education. The other category (m-designers) includes designers with a very good background in education of methodical design. Using the behaviour pattern of both categories, the differences between the sequential methodical procedure and the intuitively practical procedure become visible. One of the results of the accomplished studies is that p-designers achieve a similar result in a noticeable shorter time compared to m-designers, by which the procedure of an m-designer is verifiable due to the use of methods. Unfortunately, the creative thinking process of a p-designer is not transparent for others (because of the poor quality of the procedure) [11].

Further empirical studies on the use of design methodology in the Swedish and the British industry determined that the methodical proceedings are generally known in companies. But they were rarely used during real design processes [12]. Studies in the context of the development of the ADT lead to similar results. Most companies invest much time on product specification and on requirements engineering, but after that, the design process is driven by the experience of the designer and the team. Many of the companies, which were asked, acquire their requirements for the product in the early phases of the product development, but do not continue this consistently. That is a process without transparency. By these analyses and the examined procedural models the ADT shows the analogy of proceeding to the natural evolution. The aim is open the designer an evolutionary view to the design process and new possibilities of problem solving.

3 Analogies between product development and human evolution

Procedures in product development form a complex operational sequence, which are affected by many factors, like level of knowledge and experience of the engineer, his creativity, team ability, motivation and emotions in practice, the application of methods and appropriate tools, work techniques and the consideration of regulations and standards. The procedure of determining requirements and their extension during the design process can be compared to the (tool making) procedures of early modern humans [19]. Early humans improved their tools intuitively by trying, pictorial thinking, getting feedback and forming them according to their needs. Today's product development can be regarded in the same way.

For example, humans of the Palaeolithic age developed javelins in a modular way in order to replace the spearhead easily. This development took place during a period of 15,000 years and it was only possible due to the traditional experience (pictures, mechanical skills, etc.) [19]. The evolution of humans runs similar to the evolution of a product. Products are developed by the traditional experience and under the respective requirements. For this reason it is possible to adapt products by changing requirements and boundary conditions.

3.1 From morphology of the humans to morphology of the products

By today’s state of the evolution research the upright gait of humans was developed by the Australopithecus (“Lucy”). This way to go was developed by the requirement to form the family (social adjustment, protection) and to collect the food for the family’s members. The development of the upright gait entailed changes in the structure of skeleton and in the function of some muscles [19]. The comparative behaviour research (Ethologic) determined different “engines” of the evolution for morphologic changes like this. Such driving forces can be the instinct, adaptive behaviour, optimal behaviour and sexual selection [26].

On the other side the behaviour of the individuals, who represent the phenotype (Stature), has an influence on the composition of the genotype (DNA), too. The genotype again is responsible to transfer information from one generation to the next generation. Unfortunately in the evolution research it is not clarified, in which way the transfer from phenotype to the genotype take place. The development time (beginning time and end time) is an essential factor on molecular level to form the phenotype. An example is the development of vertebrate animal extremities, which are similar by all vertebrate animals in the early phases of their development. Duration and length of the formation of the individual cell populations affect for example the creation of the hand skeleton or foot skeleton. The phenotype is the crucial size for the selection of the individuals. The evaluation by selection of the partner exclusively takes place due to the development of the phenotype [26].

3.2 Driving forces of product development

Instinctive, and adaptive, and optimal behaviour as well as selection are the driving forces of the natural evolution and also of product development [26]. Instinct is described as behaviour, which fosters frequently further investigations or analyses. Instinct is generated, while processing a task and lead to further investigations and promotes thereby the creative way of thinking. The creative way of thinking that is also based on the designer's experiences plays a crucial role in the phase of the determination of the principal solution. Both the designer's instinct and his creative way of thinking cause the application of the evolutionary operators mutation (new ideas) and recombination (known ideas). The adaptive behaviour leads to the recombination of existing solution types and thus to the ongoing adaptation of the solution according to the requirements. On the other hand, optimal behaviour is described in evolution research as a transfer of models from other sciences. This can be assigned to the design process too and this causes a so-called horizontal gene transfer during the design process. When detailing the solution, it is necessary to use the evolutionary operator "selection". In the context of a selection, an evaluation of the solutions must take place. At this stage, the possibility to apply well-known procedures is offered to the designer [24].

The genealogical tree of human evolution can be compared also with a genealogical tree of the evolution of a product. Human evolution adjusts its "product", when changes in the social environment or in the environment of humans take place. One of these adjustments is the upright gait, which caused different changes of the skeleton and muscle structure.

The constant intensification of emission regulation can be described as a driving force in the automotive engineering design process. Within the next years, the EURO 4 and (S)ULEV regulations, which lead to zero emission vehicles, have to be realized [5]. These guidelines explain the strong activities in automotive engineering to improve existing fuel injection procedures, to reduce vehicle weights for reaching smaller consumption values and exhaust emissions. Influences like these foster a transfer of well-known developments to other fields of activities and to a development of completely new products. Noting this, the evolution process of a product is smoothing comparable with the evolution of humans.

4 Summary and practical application of ADT

In the automotive industry, the global overproduction, increasing stress of competition, and globalisation generate increased market dynamics and falling product prices. Additionally there are increasing requirements during the ongoing development of the product caused by rising customer's requirements and intensified legal regulations (e.g. safety standards and emission regulations). Therefore is it very important for the automotive companies to develop consumption optimized and environmental compatible engines, which are of improved performance and which fulfil the emission regulations.

Within automotive industry there was the task to increase the efficiency of the catalyst of a four-cylinder-engine. The aim was to increase the converted pollutants while the building space restrictions are considered. The building space restrictions serve as degrees of freedom for the development of an exhaust system with a pollutant conversion of 100 per cent.

For solving this task, the design system NOA [20], which applies evolutionary algorithms [17] as procedures for a solution search and which has been developed at the Chair of Information Technologies in Mechanical Engineering in Magdeburg, was used. The possible solution space is described by the requirements were scanned by the design system NOA. Due to the geometrical changes lead to a new incoming flow to the catalyst surface. The resulting exhaust system reached a higher efficiency of the catalyst. The black geometry in figure 2 shows the new model of the exhaust system. The task was successfully solved. Discussing the results with the designers offered a completely new view to the problem. In previous analyses (by the supported designers) such variants were rejected due to the expected high-pressure loss, but the designer could be lead to new creative ideas by the procedure of the ADT.

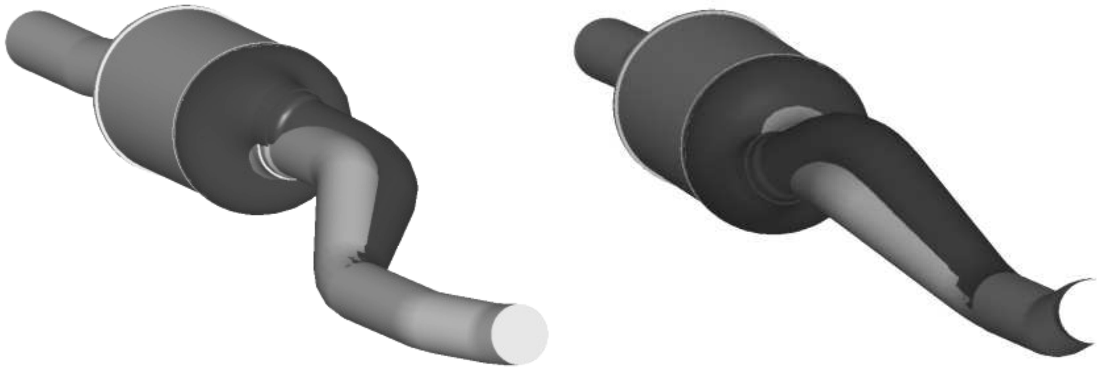

Figure 2: The new designed exhaust system

The main focus of the paper is to present the Autogenetic Design Theory (ADT) as an evolutionary view of the design process [3]. It is aimed to be a basis for a better understanding of the nature of the design process. Thus, the ADT can be used for modelling and for supporting the design activity as the substantial activity within the product development process. The basis of the ADT is to describe the evolution of products in analogy to the natural evolution.

There are several methods and tools that allow the designer to expand the solution space and support his creative thinking processes. The procedures in ADT are characterised by the evolutionary operators and the driving “engines” (forces) of the evolution in the individual phases of the design process. In the ADT, artificial intelligence and chaos theory could form the bridge between product development and biological evolution.

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