THE IMPACT OF COMPUTER TOOL SYSTEMS ON DESIGN METHODOLOGY PROCESSES AND APPROACHES

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Abstract
The aim of technical design is that the method used and the process followed produce a tangible result that provides an optimal solution to a given technical problem. The goal is continuous development, planning and control, which requires a large amount of mental, physical and financial effort. The driving force behind the system is based on the market and social needs as well as the continuous development of technical sciences. These demands force the continuous renewal of products and parts so that they can be reborn with a new appearance and new functions. From an economic point of view, unexpected costs can be minimized in the early phase of the design process, therefore a well-chosen design approach and design tool system can be key to achieve the success of the final construction. With the help of the tools of computer technology, various planning support procedures could be created, which, in addition to the methods of classical design methodologies, made the work of design engineers easier.

Keywords: *product design methodology, design processes, design approaches*

1. Introduction

It can be observed that from everyday products to the components used in machines, continuous improvement and innovation are constant objectives. Along with market and social demands, the development of technical sciences constantly forces these products and components to be reborn day by day with new appearance and new functions. Continuous development, planning and simulation control require a large financial investment, which is accompanied by a great deal of mental and physical work. The invested resources are to keep pace with consumer demands and the great development of industry. Apart from this, the factual statement and view is valid that, based on economic aspects, the expected costs of solving design problems discovered in the construction activity, in the early phase of the design process, are the lowest, taking into account the entire life cycle of a product. Based on this logic, the constructor engineer has the greatest responsibility during the entire design and development process. Accordingly, we consider it a true statement that the greatest economic result can be achieved with the least investment through technical development. With the help of computer technology, various planning support procedures could be created, which reformed the methods, approaches and various systems of rules of classical planning methodologies. The expected properties and quality parameters of a manufactured product, component or other product are greatly influenced by the applied design method and the capability and quality of the production equipment used for production. In the previous decades a significant technical development can be observed in the field of production technology, although additive technology has developed and is becoming more and more widespread. These innovative procedures force the methodology and approach of related sciences to keep up with modern expectations, such as machine and product design.

2. Theoretical foundations of design methodology

In the technical world, the purpose of the design activity is to produce a result, that at the end of the process provides an optimal solution to a given technical problem in a way that it meets the current expectations of society taking into consideration the limits of the level of development of the technical sciences. The system of criteria forms a solution field that regulates the number of possible solutions and their effectiveness. In this solution space, engineering sciences can be considered to be constantly developing, however, this monotony is not characteristic of social needs, therefore the planning activity can be considered continuous due to the changing needs. To perform a successful technical design or development task, the design engineer must know the thread leading to the solution or the path that can provide solutions for the given task. A classic design process can basically be divided into two units: a conceptual design stage and a construction design stage. In case of the conceptual design process, there is a great need for human creativity, which facilitates the generation and analysis of a set of possible solutions. In this stage, technical products only form solutions expressed by their functional sub-units, so-called function structures, the production of which requires extensive professional experience and abstract thinking from the designer. In the construction design phase, more specific but comprehensive technical knowledge is necessary so that a successful concept can be transformed into a working and final solution in the construction phase. A technical solution may have many solutions, but they may differ based on suitability. The task of the design methodology is to describe an ideal path or process that can be easily followed and goes from the emergence of the technical problem to its solution. Over the past century, various approaches and design techniques have appeared, which are likely to provide a guideline throughout the entire design process.

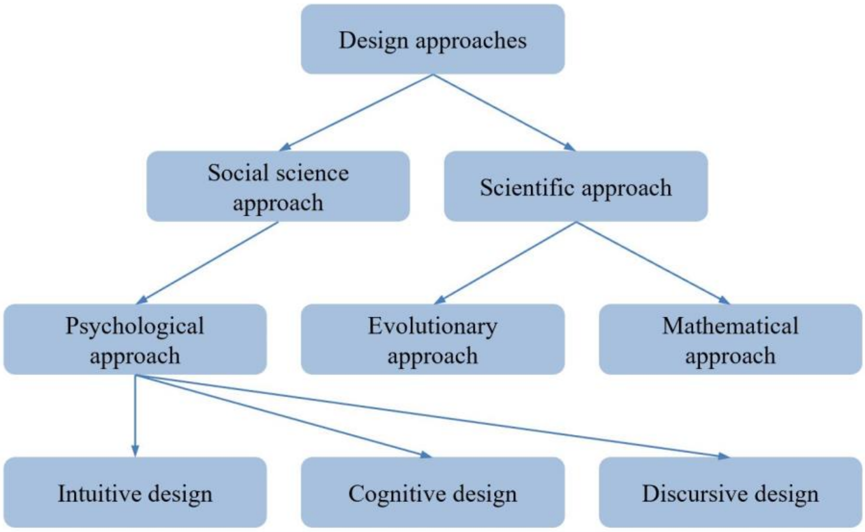

Figure 1. *Design approaches*

Figure 1 presents the typical methodological and design approaches in a graph-like representation. Basically, two main groups can be distinguished: the social science and the natural science approaches.

In the social science branch, we are talking about psychological approach, which can be divided into three different approaches: intuitive, cognitive and discursive. The natural science approaches are made up of the evolutionary and mathematical approaches. In the following, the individual subsections introduce the views and methods shown in *Figure 1*.

2.1. Intuitive design model

The design approach based on intuition can be considered one of the earliest design models, which is also commonly called as the Anglo-Saxon design. Intuition can be characterized by a specific human thinking, during which human reflection recognizes the truth and finds the right solution by skipping logical steps. Intuition is operated by the vegetative nervous system, which cannot be induced by human intention, hence the time required for proper intuition can be uncertain. Intuition is the result of a spontaneous and involuntary action. Selye and Pólya can be considered as the most significant researchers in the field of this topic (Selye, 1967; Pólya, 2000). This model contains internal feedback, due to which the designer has to make an uncertain journey from understanding the task to solving it, so the process takes an uncertain amount of time. The intuitive process is very well explained and illustrated by the model created by Tajnafői (Tajnafői, 1974). The intuitive school of design strives for a good design by creating a model for a given problem but tries to develop it as accurately as possible. Based on these, the characteristic of the Anglo-Saxon school of design is that it solves the task with the best approximation, by guiding the design along a few lines, but sets up a complex model and, if necessary, continuously refines it. The main role is played by theoretical orientation and intuition, which can be helped by various techniques. At the end of the process, the quality of the design and the expected design time are greatly influenced by the personal qualities, professional aptitude, creativity and talent of the design engineer. Based on this, it can be summarized that the amount of time for the design is inversely proportional to the designer's professional knowledge and talent, and then the expected quality of the design is proportional to the engineer's individual abilities (Takács et al., 2011).

2.2. Cognitive design model

The structure of the cognitive design process can be compared to the one of intuitive design systems, as this work method also relies on a set of intuitions. The essential difference is that in the cognitive design method we are talking about a partially open, progressive system, in which local cycles take place at some levels of the task's solutions. Based on the basic idea, a model is set up at various levels of the task solution. Intuition plays an important role, as new ideas are constantly needed. However, the important characteristics of the prescriptive approach also appear, that is, the design itself progresses by following exact steps. The quality of the results obtained during the process cannot be determined in advance, but the expected design time is more predictable, since the process is open and largely characterized by forward progress. The cognitive approach, or the cognitive design school by another name, strives for a good construction by setting up models at the various solution levels of the task and refining them through a series of iterations. The cognitive design school solves the tasks with the best approximation for each design stage. The method is characterized by the fact that it guides the design along a few lines, but sets up several models and, if necessary, constantly refines them. The preferred way of thinking is based on intuition, combined with a strong theoretical orientation. Intuition techniques and various methods are used by the designer. There are internal cycles at various levels of design. The problem of conceptual design and structural design is separated. It is not necessarily important that the same designer solves the task at both levels. The design process is usually faster than with an intuitive design model.

2.3. Discursive design model

The discursive process is a controlled engineering activity that follows a properly developed method. The individual German Engineering Schools started researching the regularities in design tasks, the main goal of which was to break down the design process into various levels and functional units and to systematize previously discovered experiences and working solutions. The novel method development has many researchers (Hansen, 1965; Rodenacker, 1967; Koller, 1969; Koller, 1994; Roth, 1982; Althsuller et al., 1956; Deciu et al., 2005), but the joint work of Pahl and Beitz can be considered the most significant study, as it provides one of the best summaries in the science of discursive design techniques (Pahl et al., 2007). Methodical planning is characterized by the fact that the design takes place through a scheme, during which a large number of variants are developed to solve the partial tasks. The basic principle of methodical design is to take into account the documented knowledge of others in order to find a solution. The entire process is divided into distinct subtasks and does not contain negative feedback, so it can be defined as a monotonically progressive process. During the procedure, the number of possible solutions increases, and then the methodical selection and evaluation process begins in the second stage. The number of so-called artificial solutions based on the combination depends on the number of functions explored and used, as well as the number of solution elements assigned to the functions. If there are too many solution elements, the so-called "combinatorial explosion" phenomenon may occur. This means that the number of solution options exceeds the level that is still comprehensible for the human brain. The limits of handling combinatorial explosion can be handled by computer support. Human intuitive abilities were relegated to the background, as they looked for solutions in the set of previously developed working solutions. This type of design school strives for the best design by trying to select the best from a large number of possible results. The discursive design process depends to a small extent on intuition, therefore the expected quality of the design does not depend on the intuitive abilities of the designer, but only on the number of solution elements of the design (Takács et al., 2011). The planning time requirement is inversely proportional, and the quality of the solution is relative to the designer's professional ability. In the system, individual creativity and talent can be considered constant.

2.4. Evolutionary design approach

Genetic algorithms can be associated with the name of John Holland, but David Edward Goldberg also achieved great success in this field of research (Holland, 1992; Darwin, 1872). A genetic algorithm is an optimization technique based on the principles of natural selection that searches for the input value of an optimization problem that provides the "best" output value. In a mathematical sense, it means the maximization or minimization of the objective function, in which the set of possible solutions is called the search space. Accordingly, the goal of optimization is to find a specific point or set of points in the search space (Erdősné et al., 2012; David et al., 1986). In genetic algorithms, there are a number of possible solutions to a given problem, and then these go through recombination and mutation, as in natural genetics. New individuals are created during the process, which is repeated over several generations. Each individual has a fitness value, which is determined based on the objective function. The fittest individuals have a better chance to produce offspring, which is consistent with C. R. Darwin's theory of evolution. Thus, over generations, better and better solutions are continuously developed until we reach the stopping criterion. In many cases, genetic algorithms are faster and more efficient than traditional methods. It contains a list of "good" solutions, not just a single solution. The problem is always solved, which is also improved over time. Assuming a stochastic process, there is no guarantee that the solution is optimal and of the best quality. The process starts with an initial population that can be randomly generated. The so-called parents are selected from the population for later mating. Thanks to the applied crossover and mutation operators, new offspring are generated. Finally, these offspring replace the existing individuals in the population and the process repeats itself. In this way, genetic algorithms try to mimic human evolution to some extent (Mitchell et al., 1996; Szabó, 2023).

2.5. Mathematical design approach

The mathematical approach of the engineering design process favours the tools of various optimization procedures that can provide exact solutions for precisely formulated engineering problems. During the production of a final product from a concept sketch, a number of design aspects and criteria are validated. In most cases, these can be linked to operational, economic, production, use and safety aspects. The designer strives to create a product that best meets the expectations based on the given criteria. The goal is to find a qualitative and quantitative combination of design aspects that fulfils the most favourable conditions (Takács, 2017). In reality, a design process usually does not take place along a linear direction, but certain elements of it have to be repeated. This stage is the optimization part of the design process. It is an important factor that the elaboration of individual elements of the entire process has a great impact on the final result, therefore the control of individual steps is inevitable. Recently, a significant increase in the use of 3D iCAD systems and numerical structural analysis tools has been observed in industrial design and development, as these tools cover an increasingly large part of the design processes. Computer-aided design procedures can be used in the early stages of the process, thus reducing the time bringing the product to market. Recent simulation tools make it possible for some of the physical tests and experiments to become negligible. An important feature is that numerical simulation tools and optimization procedures play a significant role in the development of a product, but the entire design process cannot be automated. A classic optimization process mostly refers to a well-defined part of the entire object to be designed, which means solving a sub-problem through optimization. Classical structural optimization tasks can be solved using analytical and numerical methods, however, in many cases, analytical methods are not suitable for the analysis of complex engineering problems, so they are used for verification in most cases. With the help of numerical procedures, a near-optimal solution can be achieved by iteratively changing the initial model, which is used to conduct a systematic search procedure, the aim of which is to find a more favourable structural model. The search procedure lasts until the optimization condition is satisfied, during which we get sufficiently close to the optimal solution (Erdősné et al., 2012).

3. The relationship between computer design tools and classical machine design

Reformation of the image of traditional design processes is because of the increasing importance of computer aided engineering design, as in the last decades, computers have become one of the most important tools of engineering design.

3.1. Parallel design process

Recently the number of available software technologies has been multiplied, as the specialized fields of research require different CAE target software. Different specializations may require different design methods, which are distinguished by diverse principles, since in addition to compliance with functions, a number of criteria must meet, such as material saving, economy, manufacturability, reliability and operational accuracy. These must meet the systems of criteria, which in technical practice are usually called a technical design, which is a documented, feasible engineering concept. Thanks to the use of computerized design tools, a so-called parallel design process can be implemented.

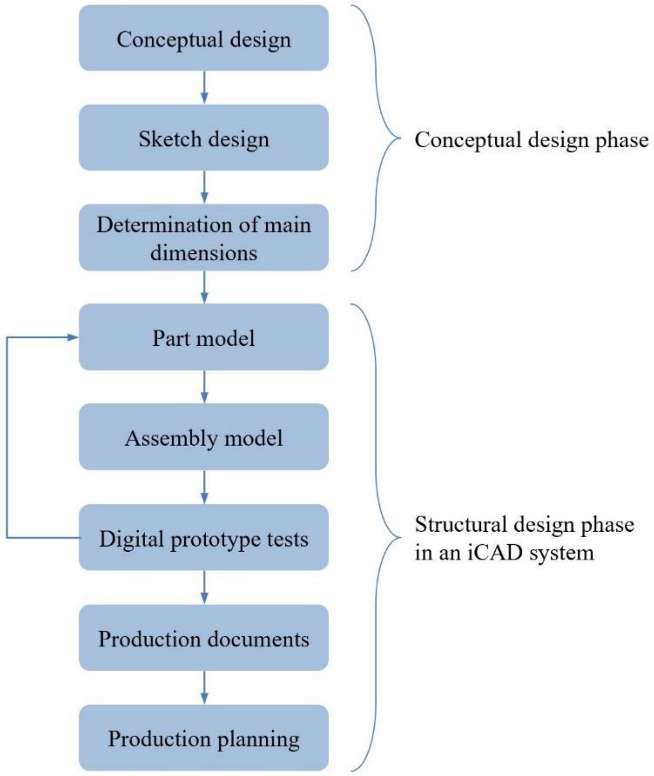

Figure 2. *Parallel design process*

Figure 2 shows the parallel design process, the main feature of which is the use of iCAD (Integrated Computer Aided Design) systems. The process can be divided into two main units, which are conceptual design and structural design. The structural design phase is entirely carried out in the iCAD system, so the partial tasks are parallel. In the conceptual stage, the operating principles are developed, and the individual elements are spatially arranged, after which a 3D model is created together with the determination of the main dimensions. In many cases, a parametric model is invented that can be used by CAE's integrated dimensioning modules. The structural design phase begins with the creation of 3D CAD models, followed by digital prototyping. The process also allows checking of models and assembly, for example assembly testing, crash testing and various VEM analyses. These verification steps can result in feedback in the process. The final production documents can be automatically generated in the iCAD system. Designing in the iCAD system results in the need for fewer prototypes and sample pieces, since many properties of the components can be tested and checked with a high degree of safety in the software environment with the appropriate simulations, so the development can be more time and cost-effective (Takács et al., 2011; Hegedűs, 2015; Hegedűs et al., 2012).

3.2. Generative design process

Generative design is considered a novelty in mechanical engineering design tasks, however, thanks to the spread of additive and hybrid manufacturing technology, it has appeared increasingly widely in integrated mechanical engineering design systems in recent years. The main characteristics of generative design are artificial intelligence-based software and machine learning, with the help of which the shape of a part to be designed is determined by simulation methods, taking into consideration the expected requirements. It optimizes design outcome objectives using a variety of methods, such as minimum cost and/or weight.

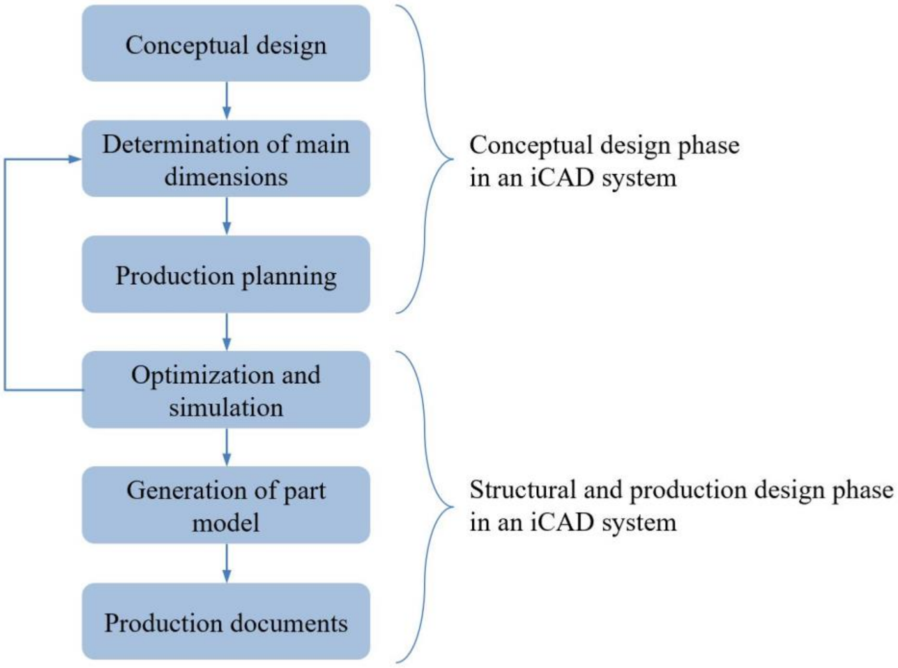

Figure 3. *Generative design process*

The innovative generative design process differs from traditional methods in a way that the generative algorithm evaluates and changes the product model for the next analysis iteration without user intervention, which results in many more solution variants for the given functional expectations. In the traditional parallel design process, additional user-driven iterations may be necessary until the given concept can reach the production stage that concludes the process. An essential characteristic of generative design is that it can be applied even at an early stage of the design process, without an existing conceptual plan being available. Thanks to this, the method creates completely new solutions by taking manufacturability aspects into account, thereby significantly reducing the time required for the examination of the digital prototype associated with component testing. Verification simulations and various analyses are integrated into the design process, which are performed automatically by the software. The result of generative design is greatly influenced by the choice of production technology, which can be chip removal, additive manufacturing and moulding. The software only produces solutions that correspond to the selected procedure. It is a great advantage that, assuming additive and hybrid processing, it is possible to combine products consisting of several components by combining functions, which were previously not possible due to traditional production technology. These properties can mean additional cost savings in terms of subsequent use (Cadalyst, 2018; Szabó et al., 2020; Zou et al., 2007; Bendsøe, 1995; Rozvany, 2001; Borsodi et al., 2022).

4. Summary

Among the various methodological principles, the intuitive model can be considered the earliest noted technique. The cognitive approach appeared later, followed by the discursive methods. The method and approach used for design has always been greatly influenced by the technical development of the given era, which is determined the various tool systems available for designers and constructors. In the beginning, the analogy of the processes and solutions observed in nature provided help in the design tasks, so that the intuitions arising from the stored knowledge could provide effective solutions to individual design problems. In terms of development of the discipline, it was found that the intuition linked to the person brings uncertainty into the system by the fact that the intuition can be greatly influenced by the individual experience and creativity of the designer. In the science of planning, it has always been important to estimate the time required for the process and the expected quality of the design, which required a methodological development direction in which human-related uncertainty is reduced in the process. In case of the intuitive design model, the focus is on having the right intuition, but the quality of the design and the amount of time required for development cannot be estimated in advance. In case of the discursive design model, the role of intuition is almost reduced, thereby reducing the degree of uncertainty, so the success of the design and the amount of time spent can be easily defined. On the other hand, the basis of these characteristics is that the tool system of methodical design shows a significant and continuous expansion, which is parallel to the development of various iCAD systems. The latest member of the design tool system is the generative design module, which is increasingly integrated into individual iCAD systems. The researchers and developers of the topic refer to the design problem solution provided by the generative design method as a so-called paradigm shift, because it reforms the classical social science and natural science design and construction approaches. These viewpoints have clearly made distinguishable design processes, thought processes and tool systems, but the continuous development observed in the world of technical design and development shows a kind of blurring within the individual approaches, in connection with which we can make the statement that the different methods mostly complement each other more and more. The generative design module is basically an optimization software that uses the procedures for structural optimization from the set of individual mathematical approaches. The basic functionality of the software is complemented by the integration with the genetic algorithms used in the evolution tool system, which tries to describe the evolutionary processes found in nature as precisely as possible and integrate them into the computer design processes. So, the discursive design model can be considered the direction of development, since the target software integrated into the tool system of the process includes the elements of different approaches or methods, so the discursive approach can be considered a kind of design multidiscipline.

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