

Heuristic Methods Aiding Ergonomic Design

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Abstract. The increasing complexity of the world of technology and the technical components surrounding humans increases the need for ergonomic measures. However, these activities often have only a corrective character, and therefore, despite (or perhaps because of) the possibility of computer support, their results are not satisfactory. When solving problems, very often it is difficult to give up the well-worn strategies or hypotheses, even though they turn out to be ineffective. During the design process a specific attitude is formed towards a certain kind of conduct, which certainly makes it difficult to adopt new and effective strategies, which in turn inhibits creativity. Moreover, it appears that in many cases a functional solution is not determined by a systematic evaluation of all possible solutions, and the initially adopted concept's primary reasons often have been removed. Therefore, in this article, it was decided to take on the subject of the possibility of using heuristic methods in ergonomic design. In the article, described is the use of specific methods and design situations requiring a new approach. Also presented are the limitations of heuristic methods for ergonomic design and the possibility of their fusion in typical design processes.

Keywords: ergonomic design, heuristic methods, design, ergonomics.

1 Introduction

Ergonomic design has become a very broad concept. It encompasses all of the areas of human functioning, from complex megasystems consisting of networks of interconnected human-technical systems [4] to simple hand tools [5]. In addition to its initial application in the development of working conditions, ergonomic design is very widely used in designing an environment suitable for people with disabilities [5]. The need to take into account human needs in creating technical objects was mentioned for the first time in the mid-twentieth century, and following that for the first time used was the term ergonomic design, a new kind of design that takes into account the so-called "human factor" [21]. It was at this time noted that in order to solve problems related to human activity it is not enough to have intuition, experience, and "common sense," as was thought thus far, and one should rely on scientific principles, as in the case of machine design [1]. However, the search for ergonomic solutions that will meet the criterion of an important and deliberate change according to the primary functions of the design process [3] is a complicated process, and thus far not one that

can be fully described by a computer algorithm. In addition, in viewing the design process as a creation of a suitable system designed to meet a specific need or to fulfill a specific function [17], assigning quantitative characteristics to technical objects seems too shallow of an approach to the design process.

Also, it is worth noting that studies show that the human factor criteria are effectively incorporated into the design process in the early stages, i.e. until the end of the preliminary design, or at all stages prior to the preparation of system documentation. This is due to the fact that it is during the early stages of design that determined are the issues essential for the functioning of the system, such as the type of applied technologies or the level of automation and robotization of processes [12, pp. 38-39]. Subsequent design decisions, for example those taken at the detailed design stage and at later stages can correct the earlier shortcomings in the area of ergonomic criteria only to a small degree, and the extent of possible changes in the project is determined by the previously undertaken decisions of strategic importance [22;12, pp. 38-39]. Therefore heuristic procedures, being one of the first stages of design, are able to have a much greater effect on the ergonomic quality of products than the following structured design activities.

2 The Search for Solutions as the Primary Function of Design Processes

The unchanging stages in the design process are analysis, synthesis, and evaluation, which simplified, can be defined as: breaking down the problem into parts, assembling the parts in a new way, and studying the consequences of introducing the new system into practice [13, p. 82]. Such described design processes require a very complex testing apparatus, which will allow a broad approach especially to the disintegration of the problem into its components and then a new approach to them.

In almost all cases, the appropriate formulation of the design problem allows one to transition to a group of optimal solutions, whereas an inadequate or unreliable approach will cause the design solution to be characterized by a greater or lesser error. However, only the following stages of designing involving the search for solutions that will meet a need described in the design process allow one to attain solutions of the described quality.

The search for solutions should therefore meet the following requirements in order to achieve an optimal ergonomic solution [on the basis of 11, p. 324]:

- solutions which arose before the full formulation of the problem may be defective – not fully analyzed parameters describing the problem,
- analyze all of the possible solutions, because then there is a greater probability of finding better solutions,
- at the beginning do not specify the abilities and limitations in terms of achieving ideal solutions because the limitations may turn out to be only illusory
- regardless of how many solutions have already been invented, one can always find one that is newer and better – search for it as long as time permits,

- do not be limited to search for solutions in various areas of information, the designer should rely on his or her own ingenuity,
- the greater the amount of knowledge, the greater the chance for a successful generation of solutions to the problem,
- the belief “this is how it must be” is the enemy of creativity, while a sense of security and persistent love to stick with what has survived years confines the ring of ideas,
- increase to a maximum the number of unique solutions which will be analyzed,
- expand to a maximum the boundaries of the possible solutions by eliminating the illusory limitations,
- before determining the group of sought solutions one should not describe the problem in detail, because it can turn out to be an obstacle that discredits the optimal solution,
- do not prematurely eliminate solutions even if they seem ridiculous, useless, or wasteful, because it may be only an illusory feature,
- gather all possible solutions from all available sources – from literature, patents, and other technical fields or beyond, because
- combine the ability to use the resource of known solutions with the ability to create one’s own original ideas, because often the best solutions are beyond the knowledge of textbooks or traditional practice,
- focus attention on the methodology of finding solutions because the "hit and miss" approach is a method characterized by the unnecessary return to similar solutions, with low effectiveness,
- do not look for a new solution by modifying the existing solution, rather search for an option that differs substantially from it; the evolution of a design results in an unnecessary duplication of errors from previous solutions,
- do not continuously use the same way of solving a problem, a habit will lead to the narrowing and stiffening of the ways of thinking, it becomes an obstacle to innovative thinking,
- when searching for new solutions one should rely on his or her own imagination, but simultaneously the designer should not allow emotional involvement in his or her solutions, since other much better competing solutions may exist.

In particular, the last of the rules show that the right approach to the design problem will result in obtaining a suitably wide perspective, which gives one the chance to obtain a solution with a much higher ergonomic quality. Such an approach, however, requires methods that do not restrict, but expand, the number of possible solutions. Hence, the interest in heuristic methods.

3 Methods Applied in Ergonomic Design

Although industry and academia agree that the human aspect is very important for the success of a product, and also for the safety of its functioning, there are few methods and tools that help designers with such factors during the synthesis stage of the design

process [20]. This assumption is true, of course, not taking into account a number of executive programs, such as CATIA, which function only as a tool to support the process of ergonomic design in the automotive industry [24]. One of the few available examples is the “behavioral design approach” (BDA), which integrates user behavior with product data as design work. By defined behavioral tasks to be done by the user and product, a set of solutions could be considered before choosing a final solution. Similar in terms of the approach method is discovering the ergonomic needs of users through observation and analysis of the ways of product usage by different user groups [9]. However, this approach does not meet the adopted criterion of the design process – the possibility of a broad search for possible solutions, based on the accepted needs of the user [20].

Certainly, one of the most promising methods that can be used in the design processes is Reverse Engineering, which allows for the duplication of an already existing product. Its main feature is the mapping of existing objects through virtual points located in space [19]. This allows for easy transfer of existing objects into the virtual space, and hence one can not only copy technical objects, but also biological objects, yielding a reproduction of objects such as designed handles. This method works well in the design of simple design solutions for a fixed group of recipients, but is not applicable to the design of more complex solutions.

During further seeking of methods supporting ergonomic design mentioned should be a wide group of simulation solutions, whose task is to assess the ergonomic solutions prior to implementation. As an example of this approach provided is a simulator of assembly and maintenance operations under a constrained environment, which determines the accessibility and the other ergonomic issues, such as muscle effort and its related fatigue. Based on a single objective optimization method, trajectory planning for different operators could be generated automatically [14].

However, the presented methods do not meet the adopted design criterion, the broad search for solutions. Hence the interest in heuristic methods that can be used to solve ergonomic problems.

4 Heuristic Methods Finding Application in Ergonomic Design

Without a doubt, there are a number of universal heuristic methods, which can be used in any properly conducted design method. It is worth to recall what they are used for and what these heuristic methods consist of. Heuristics is the science of methods of detection of new facts and the relationships between them (from the Greek *heurisko* – to find) [21]. In most cases, heuristic methods are used to overcome the limitations of thought and to open the designer to new areas that were previously overlooked [21].

The most frequently quoted and at the same time applied inventive heuristic is Brain Storming. Its creation is attributed to Alex Osborne in the 40’s of the last century, but historians have found its prototypes even a thousand years before our era in Asia. The idea is to stimulate the brainstorming session participants (meeting) to freely report a large number of possible ideas. This approach is based on the assumption that a large number of ideas will include at least a few that are good [3; 18]. It is true

that the effectiveness of this method is challenged [3], however, in its defense it can be given that it is an excellent opportunity to get to know the opinion of the other people on the problem, which is almost always a necessary step in the design procedure. An example of the application of this technique may be the method cited in “Sociotechnical design for a sustainable world,” which consists of three stages [7]:

- matrix that cross-matches basic needs and the available forms of waste and thereby induces, by brainstorming, the development of design opportunities,
- four matrices for identifying the ergonomic demands of the three human users (the primary, the intermediate, and end users) and the environment, and
- matrix that evaluates the design alternatives in terms of sustainability, quality, and cost.

A method similar in structure to the brainstorm is Synectics, whose name is derived from Greek and means to connect into one piece parts or elements different from each other and which seemingly have nothing in common. The method was developed by William J. Gordon and involves the taming of strangeness and the transformation from the ordinary to the bizarre, which enables the achievement of the five mental states necessary to respond in a creative way: engagement and detachment, rejection of premature solutions, speculation, object autonomy, and hedonic response [3, p. 99]. For design processes with a focus on human needs this method seems to be particularly useful at the very early stages of designing a specific solution.

In terms of chaotic methods, which also bring tangible results, mentioned should be SCAMPER and functional analysis. While it is difficult to measure the ergonomic effects of the application of both of these methods it is due to the much greater emphasis in the functional analysis method on the analysis of the problem that gives a better understanding of the complex relationship between the human – technical object [6]. The SCAMPER method is used for solving ergonomic problems, where the methodological approach to the design problem does not give the expected results, and in order to find the solution one needs to mentally “test” the range of solutions. SCAMPER is an acronym derived from the first letters of the names of the steps you can take towards creating a concept of a new solution in terms of a product (substitute, combine, adopt, modify/distort, put to other purpose, eliminate, rearrange/reverse) [3, pp. 97].

Functional analysis (also known as Zwicky morphology) gives more opportunities to perceive previously not considered combinations by simulating a combination of different parameter values. The application of this method in ergonomic design is found particularly in the case of simple and not very complicated systems, where the number of individual variations allows one to analyze the problem. In the case of a larger number of parameters of a given object the multiplied number of variants precludes their consideration, without limitation of the aspects under consideration.

The downside to all the previously mentioned methods is their high flexibility, but this is due to the need to elicit an accordingly broad view. However, there are many more scientific approaches used in design, of a heuristic approach, as exemplified by the ant colony optimization algorithm, which in combination with ergonomic requirements allowed for the development of new ergonomic solutions in the field of keyboards [23].

One of the more formal, but with a heuristic nature, methods is TRIZ. This method is rarely used in relation to ergonomic design – only 8 appearances in the SCOPUS database – which seems to be particularly surprising because of the very useful tool called: Altshuller invention patterns, which allow to synthetically consider the possibilities, depending on your problem. The aim of TRIZ methods is to direct the search for solutions in order to minimize the unnecessary effort of searching by designating a vector for the search. This method is applicable, despite the significant passage of time since its invention, in significantly reducing the time to seek a solution by eliminating the “hit or miss” method [3, p. 66]. Contemporary applications include, among others, the design of ergonomic hand tools [15].

5 Heuristic Rules for Ergonomic Design

Basing on one’s own experiences as well as from interviews with designers, and the review of design methods, one can conclude that ergonomics is an object of interest in the later stages of the design process, when one cannot get a significant improvement in the quality of ergonomic solutions. It is therefore necessary to create a model of conduct that will allow to respond reasonably early to questions about the ergonomic cost of solutions. It is extremely difficult because at this stage the measures to meet specific needs which will determine the mode of action of the product on the user are not defined.

To avoid the effects described above one should be guided by the following principles during the initial, heuristically supported, stages of the design process:

- particularly in the early stages of design when choosing the general concept of a solution the participation of persons involved in ergonomics should be sought,
- for each considered solution the ergonomic costs should be considered, taking into account the most detrimental effects of the applied solution and the probability of their occurrence and to take into further consideration those which provide a suitably low ergonomic risk,
- heuristic thinking should be applied not only to the technical solution of a specified problem, but also to the interface between the solution and the user,
- new solutions require a thorough rethinking of the whole construction in terms of ergonomic functions, it may indeed be proven that the described solutions resulted from circumstances which no longer exist,
- one should look for solutions similar to the original ways of functioning of man; nature had millions of years to prepare humankind for the conditions under which we lived until recently, while we have done it for just a few millennia,
- one should notice the human co-existence at all of the life stages of the proposed solutions, as well as after their completion.

These rules do not cover all of the sound design practices and also are an addition to universal design or concurrent design methods [2]. In addition, ergonomic design requires a number of organizational changes within the company performing them. One of the changes is an alteration of organizational culture and acceptance of participation of employees in designing and implementing new solutions. [16]. In the end all design methods need to enable an optimal choice of product parameters by decreasing product sensitivity to the occurrence of disturbances in a manufacturing process, and to achieve the lowest quality loss while keeping planned production costs [8].

6 Conclusion

It should be noted that low ergonomic quality also causes reduced product quality, and to improve the ergonomic quality one should proactively consider ergonomic requirements already in early design phases of new product and assembly concepts [10]. The ever increasing interest in the evolution of ergonomic and safe products, and thus, among others, the working conditions associated with working with them, is due to the possibility of obtaining the desired economic benefits [10].

It is also worth noting additionally that the very idea of taking into account ergonomic requirements may seem contrary to heuristic concepts, which require an appropriately wide approach to the design process and accomplishing a very wide search of all possible solutions, including those that would be at first rejected. However, one should keep in mind that the discovery methods based on heuristic mechanisms such as TRIZ, rely on positive directing [3, p. 66] and in such a sense the directing of the search to favorable areas in terms of ergonomics will bring considerably better results in the final solutions for the operating or servicing them human.

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