Design and modeling of new technologies with advanced morphological approach as CAI method

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Abstract. Innovation processes are highly dynamic and competitive. Their effectiveness depends on the speed of reaction to changes in the market and economic situation. Therefore, there is a need for a comprehensive software to support the innovation process throughout the product life cycle. The latest tendency in design research show that great efforts are being made to implementation of CAI (Computer Aided Innovations) as part of CADx systems. This paper presents and discusses a heuristic discursive Advanced Morphological Approach (AMA) for solving the design problems on conceptual stage in uncertain conditions. This approach allows you to search for innovative solutions at the early design stages, form variant clusters, generate a variety of sub-optimal variants, choose the most rational alternatives and compare them. It is based on the provisions of the system, cluster analysis and morphological methods.

1. Introduction
Within the three phases of system design (Conceptual, Preliminary and Detailed), the Conceptual Design Phase is the most challenging one: a high number of decisions have to be taken with a long-term and irreversible impact. The Conceptual Design Phase involves the generation of solutions, of engineering concepts and of design principles to satisfy the functional requirements for a given design problem. As more than only one solution of a problem exists, improved designs can be identified within the defined design space if the set of potential Engineering Solution (ES) can be enlarged compared to present possibilities [1-3]. Innovative ES can be found by creative search, using individual experience and knowledge (intuitive methods) or using discursive methods. Discursive methods can be part of specialized computer-aided design (CADx) systems (figure 1). Traditional CADx systems are mainly used for calculating or optimizing already known models and consist of CAD/CAM/CAE systems [4-6]:
• CAD-Computer Aided Design
• CAM-Computer Aided Manufacturing
• CAE-Computer Aided Engineering
Combining these methods with CAI will allow you to create a single overall design system and greatly improve the efficiency of the ES development. The development time and cost are also significantly reduced. This will increase the competitiveness of the products created.
2. Computer aided innovations

Using CAI from a practical point of view helps to decrease uncertainty by development and researches at the early stages of design. This approach allows for thorough and comprehensive research of new engineering solutions. This limits the number of changes to the system being created at the manufacturing stage (figure 2). This results are lower costs, shorter implementation times, and increased competitiveness. In CAI development very often an interdisciplinary investigation are required.

Figure 1. CAI system significance at the conceptual design stage.

Figure 2. Project cost change with traditional design methods and CAI oriented.
3. Morphological approach
Morphology analysis (morphological box) invented by Swiss astrophysicist Fritz Zwicky [7]. As a problem-structuring and problem-solving methods, morphology analysis was designed for multi-dimensional, non-quantifiable problems where causal modeling and simulation do not function well, or at all [8]. The combination of all possible variants then generates the final design concept [9]. Morphological analysis has been successfully applied to form a matrix of system options (figure 3).

![Diagram of Morphological Approach](image_url)

**Figure 3.** The sequence of system configuration forming.
More recently, morphological analysis has applied the researchers in the field of future studies, engineering system analysis and strategy modeling [10]. The morphological approach is widely used in Germany. The Society of German Engineers has developed two sets of rules for engineers: VDI 2222 "Design methods: methodical development of engineering principles" and VDI 2221 "Design methods of technical systems and products" in which it is recommended to use the morphological approaches to find new innovative ES [11,12].

The morphological box method is performed in the following order.

- Give a precise problem formulation and a general description of the research object.
- Form important attributes (properties, functions) of the object. The set of features ensures the existence and functioning of the object of research.
- Each attribute is assigned possible implementation options.
- Set of generated variants is reduced to a morphological matrix or morphological box.
- Choice and analysis solutions from the morphological box and determine their value.

Advantages of morphological analysis:

- equivalence of all elements of the analyzed system;
- clarity of the task statement;
- removing restrictions in the analysis of the system options under study;
- synthesis of new systems
- developing existing systems

The disadvantage of the method is the abundance of options, from which it is difficult to choose the best one. For objects with a large number of elements and many variants, the table becomes cumbersome and the method becomes time-consuming. Some of the major problems of application of classical methods of morphological analysis are: poor access to support software which can address the combination explosion generated by multi-parameter problem spaces inherent in the use of morphological analysis; insufficiently flexible processes that address users’ operational constraints; seen to be overly generic, disguising identification of specific application areas of interest [13]. Morphological analysis does not allow to determine whether all possible options are considered.

4. Advanced morphological approach

The advanced morphological approach are used for the following purposes:

- Problem definition and formulation
- To generate a better understanding of problems or systems
- Investigations of existing or developing systems

The AMA is based on cluster analysis, set theory, set of rules and modeling [3,14,15]. In the proposed AMA method and software "Okkam", conceptual design is conducted in 10 steps (figure 4): synthesis of the morphological matrix (1), definition of a system of criteria (2), weighting of options (3) and selection of reference variants (4), generation (5) and selection of variants (6) using estimates of each variant and comparison with others, clustering of variants based on similarity measure and creation the solution space (7), analysis of clusters and solutions (8), analysis of the design risk, variants and selection (9), synthesis of anticipation models, parametric modeling and optimization stage (10) [2,3].
In step (7) the clustering of variants takes place as shown in figure 5. Clusters can be generated by grouping solutions e.g.

Having a nearly similar Hamming distance. It is also used as a measure of likeness or similarity. If reference variants, i.e.

Realized ES with known options for the criteria as defined in the morphological matrix, are included they can be used as starting points for clusters [2,3].

**Figure 4.** Block diagram of advanced morphological approach.

![Block diagram of advanced morphological approach](image)

**Figure 5.** The variants is space solutions.

![The variants is space solutions](image)
The AMA method has a significant advantages over traditional methods, which can be grouped into the following groups:

Constructive criteria (Constructive perfection)
- System analysis and search of engineering solution principles, weaknesses, optimization definition, development potentials, etc.
- Analyze essential parameters of a system
- Structure or behavior of a system analyze
- Generation of alternative solutions
- Models of basic solution concepts
- Reduction system weight
- Synthesized bionic structures
- Cost reduction of individualization and personalize of the product

Economic criterion
- Reduction system modeling and design time
- Minimizing the production cost
- Time reduction between design and production
- Reducing the cost of manufacturing parts
- Reduced material consumption
- Improving quality and reducing the level of defects
- Improving the efficiency of resource use
- Completely "paperless" manufacturing of parts

Operational (consumer) excellence
- Improving product functionality and durability
- Update components to extend the service life of the product

Ecological compatibility
- Increasing the product longevity
- Reduction of energy intensity of manufacturing
- Increasing the efficiency of using materials
- Using of secondary materials and waste

The AMA method let maximize the economic, engineering and environmental efficiency of engineering systems and technologies.

5. Conclusion
This paper presents an advanced morphological approach as part of CAI method. The AMA is a heuristic discursive approach for solving the design problems on conceptual stage in uncertain conditions.

AMA have the main advantages:
- System-oriented or holistic Thinking
- Clear orientation of all actions towards goals
- Precise problem definition and formulation

The method and software "Okkam"allows:
- The better understanding of problems or systems
- To generate and analyzed computational the morphological set of variants
- Use existing or developing systems and technologies

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