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GENERATIVE DESIGN: AN OVERVIEW AND ITS RELATIONSHIP TO ARTIFICIAL INTELLIGENCE

ESZTER BORSODI[1] –ÁGNES TAKÁCS[2]

University of Miskolc, Department of Machine and Product Design,
H-3515 Miskolc-Egyetemváros
[1]*borsodies@gmail.com,* [2]*takacs.agnes@uni-miskolc.hu*
[1]*https://orcid.org/0000-0002-3955-2182*, [2]*https://orcid.org/0000-0002-3210-6964*

Abstract: The paper deals with generative design. It presents the definition and the process of generative design and mentions the differences from traditional design method. The application areas are also discussed with real life examples and collection of possible application cases. Furthermore, the article analyses the connection between Artificial Intelligence and generative design and gives a suggestion for adapting Deep Learning in the evaluation and selection phase.

Keywords: *generative design, Artificial Intelligence, Machine Learning, Deep Learning*

1. INTRODUCTION

Generative design was developed in the 1990's, but software supporting this design method are appeared in the 2010's [1]. The computing capacity back in the past was not enough for run these complicated algorithms, but nowadays with the power of cloud computing this problem is solved. The development of additive manufacturing technologies also supported the realization of structures with complex geometry created by generative design.

Generative design is mainly based on nature-mimicking algorithms and operate similar to the evolutionary process [2]. To achieve this, generative design implements Artificial Intelligence. With these properties, generative design can create the best solutions for different consumer needs and redefine the engineering design.

2. GENERATIVE DESIGN

2.1. Definition

According to the general definition of generative design, parameters are given in a programme, which creates all versions of the output that meet the input criteria. Generative design is used in many areas, the output can be, for example, sound, image or 3D model [3]. In this paper, generative design means the production of 3D models by generative design in CAD software.

Approached from this aspect, it can be defined as a design process which iteratively, with the help of an algorithm creates all the models that are optimized for the requirements we set [4].

2.2. The process of generative design

There are programmes especially created for generative design (e.g., Generate from Frustrum), CAE software supporting generative design (e.g., OptiStruct from Altair) and parametric design systems with a generative design module (e.g., Fusion 360 from Autodesk from) [5]. The steps of generative design are illustrated in *Figure 1*, which is based on the Autodesk Fusion 360 Generative Design framework, but other generative programmes work similarly.

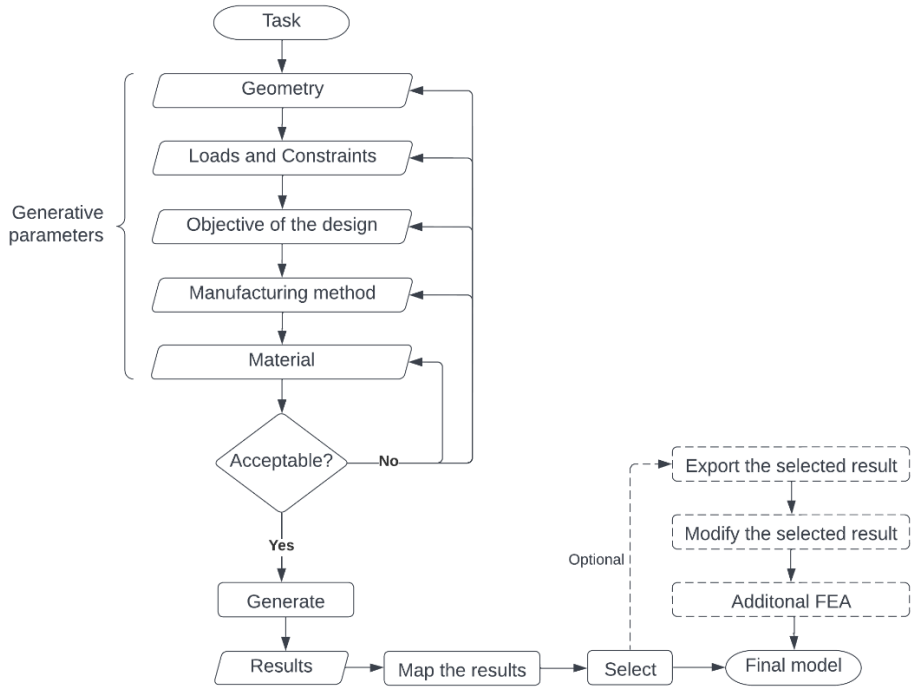

Figure 1. *Flowchart of the generative design method*

First, we need to define the initial geometry. The starting geometry can be specified from scratch by selecting the areas to be retained and the areas of empty spaces, or we can import a traditionally designed 3D model (in this case we also have to mark off preserve and obstacle regions). The next step is defining the location and magnitude of the constraints and loads acting on the areas to be preserved. After that, objective of the design (maximize stiffness or minimize mass) can be selected. This is followed by the choosing of the manufacturing method,

so that the programme takes into account the characteristics of different production technologies when generating the model, thus reducing the production costs. The last step in specifying the generative parameters is selecting the material.

The software checks the entered data before generation and warns in case of incorrect or missing information. If the result of the check is positive, the generation process can come, which provides a number of 3D models corresponding to the input parameters. The generation process takes place in the cloud, and then the designer's computer receives the results. We can filter these outputs according to different properties and choose the one that best meets our requirements. It is possible to export the selected model and modify it using traditional CAD tools, but in this case additional FEA is recommended after the editing.

In the case of traditional design, only a few concepts are created. After that, the adequacy with given parameters and manufacturability of the conceptual models are examined, and during this several modifications or redesigns may be necessary. In contrast, generative design reduces the time of product development and market launch because it creates a large number of models that meet the given requirements and takes into account the manufacturability.

2.3. Application areas

Generative design has already been used successfully by several companies. Airbus created a partition wall for the A320 aircraft with generative design. The algorithm of the wall's frame imitates the growth pattern of the slime mold, and the algorithm of the frame's inner structure was based on the lattice structure of the mammal bones which densely fills the space with material at the stress points, while less densely elsewhere. General Motors produced automotive parts, Under Armor created lightweight running shoes using generative design. NASA has also used this design method, for example, they designed a space exploration lander *(Figure 2)* with generative design.

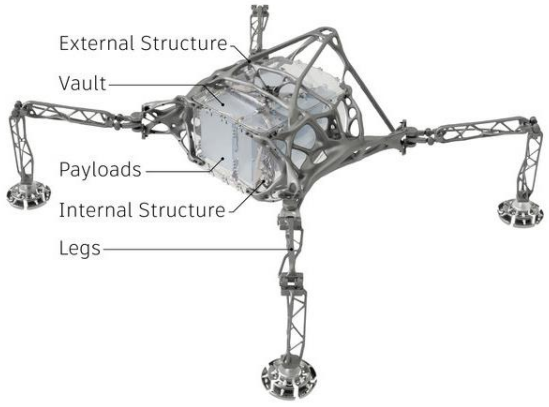

Figure 2. *Space exploration lander created with generative design by NASA*

Several studies have already dealt with the practical application of generative design, for example Seregi and Ficzere designed a weight-reduced drone frame using this method [6].

Considering the characteristics of the generative design, engineers can exploit the potential of this method in the following cases:

- Industries, where minimizing mass but achieve same performance is the key issue (e.g.: automotive industry, aviation industry, space industry, competitive sports)
- When the goal is to reduce fuel consumption thus emissions (e.g.: aviation industry)
- When the goal is to reduce material usage thus material costs
- When sustainability is an important factor
- When the goal is to increase performance and load capacity
- When the product is unique and exposed to special loads, and it is sufficient to produce it in small series
- When reduction of product development time and quick market launch is important
- When highly automatized design process is required
- When unique, nature imitated design is the goal
- When we want consolidate parts, which also simplifies supply chains and maintenance
- Design tasks with high complexity

3. Connection between generative design and Artificial Intelligence

3.1. Fundamentals of Artificial Intelligence, Machine Learning, and Deep Learning

Artificial Intelligence (AI) is a technique demonstrated by machines which imitates human thinking and behaviour with algorithms to solve problems as humans would do, or with even better performance [7]. The ability to learn is part of the intelligent behaviour, AI's subfield, Machine Learning focuses on this topic.

Machine Learning (ML) trains computers with mathematical data models without direct human supervision. It uses algorithms to identify patterns in the data, and then makes predictions based on the observed patterns and/or improves itself. [8]

Deep Learning (DL) is an advanced type of machine learning that uses multilayers of algorithmic networks, called neural networks, inspired by the structure of the human brain. A deep artificial network consists of nested neural nodes, and each question answered leads to another connected questions in the nested hierarchy. The difference between ML and DL is Deep Learning automatically perceives the identification properties, while these features have to be given by human in the case of Machine Learning. [9]

3.2. Generative design and Artificial Intelligence

According to the Autodesk Generative Design Primer open-source project, generative design and Machine Learning are not the same, but generative design relies on Machine Learning. Machine Learning finds patterns and predicts, while generative design creates models.

The programme makes an initial model with random input values in the beginning of the generative process and after that continuously optimizes it according to the given requirements. If large amount of data available, Deep Learning can be a great support of generative design to create better initial design based on accurate historical dataset.

3.3. Application of Artificial Intelligence in the evaluation and selection phase of generative design

After the generation process, we have to select from the models. This raises a tough question: which one should we choose, since they all meet our requirements of geometry, mechanical properties, material and manufacturing method? Artificial Intelligence can play a role in this phase as well, because if a sufficient amount of data is accessible, Deep Learning can help the choice between concepts.

The data is the key point here: we have to provide information about factors that was not included in the generative parameters, because generative design focuses on the performance. These data can derive from the life-cycle analysis of similar parts, from the following areas:

- Mechanical and other kind of test results.
- Experiences of manufacturing.
- Maintenance, service.
- Logistics and transportation.
- Packaging.
- Assembling, disassembling.
- Recyclability.
- Ergonomic aspect.
- Economic aspects (e.g.: marketability).
- Customer feedback.
- Experiences from long-term usage.

4. SUMMARY

The most important features of generative design were briefly described above. The generative design process based on the Autodesk Fusion 360 Generative Design framework was presented. Practical applications of generative design were mentioned, and the areas of possible applications were collected according to the properties of this method. It can be highlighted that generative design method could be used if we want to achieve a lower weight or better mechanical properties. The article also presented the connection between generative design and

Artificial Intelligence, and finally we made suggestions regarding the further application of Deep Learning related to generative design.
Further task could be to develop an Artificial Intelligence based evaluation system for the selection phase of the generative design method.

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