Analysis of software solutions for creating models by a generative design approach

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Abstract. With the constant development of new technologies and designs, the idea of a generative design approach arose. Generative design allows to create an infinite number of new designs in a relatively short time without the constraints associated with the imagination of the designer. Designs created by a generative design approach create optimized products that meet the specific needs of their end users. The parts created in this way are often lighter, stronger and less expensive in terms of their subsequent production. Generative design software applications are often more intuitive to work with than traditional CAD systems, and no additional knowledge associated with operating the software is required. The main goal of generative design is to save time in the design process, save material by creating optimal structures, and thus save money by developing cost-effective products. The product software only adds material where it is needed, which is typical of the additive production of organic shapes and forms. The product created in this way is more efficient for production compared to the traditional design and production approach. The article points out the current state of development of this rapidly expanding design technology with a description of software solutions used for the implementation of a generative design approach on illustrative examples of created design products.

1. Introduction

One of the main reasons and often associated with solving problems that the customer turns to the designer is the choice and the process of designing a suitable design. This process is basically based on experiments and errors within the specified parameters. However, processes using traditional methods require many iterations to achieve the optimal design required by the customer\cite{1}. With this solution comes the idea of a generative design approach. Generative design (GD) allows to create an infinite number of new designs in a much shorter time compared to the traditional design approach. The design is not limited by the imagination or experience of the designer in comparison to the traditional design development cycle\cite{2},\cite{3}. Designs using generative design create optimized parts that meet the specific needs of end users. Designs made in this way are usually lighter in weight, stronger in strength and more efficient to use. Also, software applications of generative design are often more intuitive and do not require significant additional knowledge of operating the software. With increasing advances in technologies such as additive manufacturing, robotics, artificial intelligent algorithms and increasing hardware performance, the generative design approach is becoming an increasingly lucrative choice in the design process in various industries\cite{4}.
2. Methods of generative design

Generative design is one of the new areas of software CAD engineering, in which the designer works with AI algorithms to generate and evaluate hundreds of potential designs for the final product idea. It is therefore the ability of CAD applications to autonomously generate a number of design alternatives with respect to specified constraints. All these boundary conditions can be processed by the software independently and create the final design without the advice or interaction of the designer [5]. After completing the software calculations, engineers can choose which designs they want to examine in more detail and work with. Overall, this speeds up the design process and expands design options. With the advent of cloud storage, software has access to a tremendous amount of computing power. Some software applications already work autonomously, so they no longer need human intervention to enter commands. The designer simply needs to describe the problem and the software then works autonomously to find the optimal solution. [6]

The basic methods of GD include:

- **Forms synthesis** – allows designers to enter certain object parameters, e.g. expected objectives and constraints. Complex algorithms use the latest developments in AI technology and create a myriad of design solutions from which they select those that appear to be optimal and present the results obtained to the designer. This method is used in most generative software.

- **Grid and surface optimization** – this method uses an existing structure. Instead of creating new objects, generative software is used to optimize the surface structure of the object, making the object stronger and lighter. Algorithms of this method are used e.g. in complex asymmetric grids and nets, in optimizing strength or minimizing the material used.

- **Trabecular structures** – used mainly in medical engineering. This method measures and distributes microscopic pores across solid materials to imitate bone structure. The design created allows the patient to treat more quickly after limb implantation.

- **Topological optimization** – a method used to design the most suitable geometric shape of a body or assembly under known boundary conditions. In practice, by using it, it is possible to design the shape of the product with significant volume savings and thus reduce its weight. Optimized products in most cases have a shape that is difficult to produce or economically inefficient by conventional production methods. For this reason, in many cases the technology of additive production is a suitable method of production. [7], [8]

2.1. Use of generative design in the world

Creating new concepts requires progressively more flexibility. To achieve this flexibility, special tools and methods are used, which facilitate the creation of 3D geometry parameterization and can then be easily modified and functionally evaluated [9]. Traditional tools are just as expensive because they are not flexible which reduces the cost of experiments. Technologies such as GD and additive manufacturing can support endless design solutions with minimal capital investment [10]. For some specific types of engineering problems, generative algorithms outperform human engineering teams in handling complex design tasks [11]. Currently, the most common use of generative design algorithms is topological optimization. These applications are common wherever the primary focus is on weight loss, e.g. when designing the internal components of work tools (to improve ergonomics), sports equipment (to increase performance), vehicles and aircraft (to reduce fuel consumption or increase payload) or in the case of any product whose transport weight is a significant factor [12]. If the material is the main criterion, higher structural efficiency can lead to significant savings in terms of both costs and sustainability. [13]

An example of the use of GD technology in practice is the design of the caliper designed by Redstack. The part was designed to be easy and cheap to manufacture. In this study, the designers used the original caliper model and then modified it using generative software. The result of the optimization is a symmetrical design that is 50% lighter than the original solution design. [14]

Due to the nature of GD, this method of construction is ideal for the automotive industry. Every kilogram of material saved on a component is directly related to a real improvement in the overall
performance of the vehicle. Electric Company Arcimoto Inc., XponentialWorks and ParaMatters are collaborating on the design and retrofitting of lightweight components for their fun utility vehicle. The partners hope to achieve cost reductions, improved efficiency and effectiveness, and ultimately to achieve the goal of a more environmentally friendly approach. [15]

Figure 1. Fun utility vehicle from Electric Company Arcimoto and partners. [15]

General Motors and Autodesk have used GD technology to remodel a car seat belt holder. The software has created more than 150 valid design options based on engineer boundary conditions and parameters such as connection points, force and weight. The research team focused on a new design, the organic structure of which is difficult to imagine and model in parametric software. The new seat console is 40% lighter and 20% structurally stronger compared to the original design. It consolidates eight different parts of the structure into one 3D printed part, which is one of the significant advantages of using GD in the production of components. [16]

Figure 2. Car seat belt holder developed by General Motors. [16]

Autodesk also collaborated on a project with VW California's innovation and engineering center to maximize the car's power while reducing its weight. Car weight reduction using GD technology was first used in this project on the wheels of a VW 1962 microbus. Lighter wheels not only reduce the overall weight of the vehicle, but also reduce rolling resistance on the tires. The new wheels created by GD software are 18% lighter than the original wheel sets. Through software, the total development time from design to production was reduced from 1.5 years to several months. The same process was subsequently applied to the rear-view mirror arms. [17]

Figure 3. Volkswagen 1962 microbus. [17]

Generative technologies have significantly increased the degree of creative freedom that many companies have in their approach to component design but not without undue complications. Reducing the weight of the structure affects all other mechanical aspects of the design. The lighter material
naturally has different design tolerances and manufacturers must take these variations into account in order to meet strict safety standards and durability, all while maintaining reduced weight. In an automotive environment where these standards compete for the manufacturer’s attention, simulation of these complex parts is essential. [18], [19]

Airbus also uses GD to re-evaluate other components of structural aircraft including the leading edge of the A320 vertical tail plane. The purpose of the A320 vertical stabilizer is to provide directional stability and reduce aerodynamic inefficiencies caused by side-to-side movement. GD enables the research team to evaluate hundreds of design alternatives, all of which meet the goals of stiffness, stability, and component weight. [20]

Figure 4. The internal construction of the A320 aircraft from the Airbus company. [20]

3. Current state in the field of software solutions of generative design approach

Autodesk – Fusion 360

Fusion 360 is a cloud-based CAD/CAM software for collaborative product development enabling product research and design through collaboration between users. The software allows to create 3D designs, collaborate, manage data, create toolpaths, run simulations to validate designs, and more. It supports various file types which facilitates the import and export of created projects. The software works on a "pay-per-design" basis which means that a fee must be paid for each generated model. Payment is made by obtaining cloud credits (1 credit = $ 1). Fusion 360 also has various tools integrated such as CAD, CAM, FEA and drawing documentation. This option allows to easily transfer the project through the selected design phases to the presentation graphics without the need to change software packages. It is also possible to create various analysis and simulations.

ParaMatters – CogniCad

ParaMatters first officially introduced CogniCAD in 2018 where the launch attracted significant attention for its unique software capabilities. CogniCad is a cloud-based pay-per-design platform capable of performing a number of tasks that benefit additive manufacturing including autonomous topology optimization, component consolidation and lightening. Intuitive software simply requires users to import their CAD files into the platform and define load and design criteria. The software then generates and optimizes the model. CogniCAD offers users a variety of load simulations and analysis including thermal loads, various normal and gravitational forces, moments that the software can perform directly on models or over remote points. It also allows the design of production programs in the CAM module and many other options including the definition of applied pressure, flexibility, stiffness and deformation constraints of the proposed models. CogniCAD also allows automatically generate additive-ready models such as high-performance and lightweight structures for the aerospace and automotive industries.

SolidThinking – Altair Inspire

Altair Inspire is a well-known comprehensive software designed for various engineering areas of design. This software accelerates the creation, optimization, study of structurally effective parts and assemblies and reduces the time to market. A clear multifunctional graphical user interface which is intuitive even for beginners helps to create and modify the geometry of models. The structural analysis module called Altair SimSolid provides the ability to quickly and accurately analyze large assemblies and complex components. Altair MotionSolve dynamic motion simulation is an excellent tool for motion and force analysis using the simulation of multiple bodies at once. It also includes the Altair OptiStruct tool which serves as an industry standard for creating structural efficiency, topological optimization for generative design of practical, feasible and production geometry.
Dassault Systèmes – xGenerative design

CATIA xGenerative Design is a generative modelling application that works in a computer's web browser environment. It uniquely combines graphical visual scripting and interactive 3D modelling with the ability to use one or the other design solution interchangeably at any time. This new intuitive and intelligent approach allows creative people in the architecture, engineering and other design industries to quickly design, explore and validate variants of complex, repetitive and irregular shapes or patterns.

McNeel & Associates – Rhinoceros

Rhinoceros is commercial 3D CAD software developed by the American private company Robert McNeel & Associates which was founded in 1980. The software is based on the NURBS mathematical model which uses computer graphics to create a mathematically accurate representation of curves and surfaces in free form compared to applications based on polygonal networks. Rhinoceros is used in CAD, CAM design, rapid prototyping, 3D printing, reverse engineering, and the architectural and industrial design industries. The add-on as a visual scripting language for Rhino is Grasshopper. Grasshopper is a visual programming tool with an environment embedded as an application in Rhinoceros software. The program was created by David Rutten at Robert McNeel & Associates. Grasshopper has become part of the standard toolkit for Rhinoceros in version 6.0 and later. Grasshopper is primarily used to create generative algorithms.

4. Design of components by generative design tools

For an illustrative presentation of the work in the GD software environment a simplified model of the car's front bumper with several holes for the headlights and the car's cooling space was chosen and created. An example of a model created in the Fusion 360 software environment is shown in Figure 5.

Figure 5. Car front bumper model.

Design procedures were applied to the created front bumper model using a generative design approach using Autodesk Fusion 360, Paramaters CogniCad and SolidThinking Altair Inspire software. Two iterations were created in each of the selected software. In the first iteration, only the central part of the bumper was used. In the second iteration, all the front surfaces of the bumper were selected including the areas with holes for the car's headlights.

4.1. Fusion 360

The first GD iteration created using Fusion 360 software

As a first step in the design of the GD approach using Fusion 360 software, the choice of bumper center surfaces to which the generative design software calculations will be applied. The second step was to select areas that will be taken as obstacles and will be ignored (suppressed) during generation. The next step was to define the forces that will act on the bumper model during use. For clarity, a force of 500 N placed in the center of the bumper was used as a load simulating the normal operation of the car.
Figure 6. Defining the forces acting on the bumper in Fusion 360 software.

Subsequently, the lower hole was selected for the installation of the radiator which was locked using the function "structural constraints" thus ensuring the locking of the possibility of manipulation of a given element of the model during generation. Following the approval of the conditions for setting up the model the process of generating and calculating the model was started through the "generate" function.

The result of the first iteration of the design was a final design focused on optimizing the middle part of the car bumper. The process of generating a model is relatively demanding in terms of computational power as well as the time required for its conversion. The generation time was approximately 15 hours but during the generation the software can be turned off and the process takes place on the company's cloud server.

Figure 7. The resulting design of the first iteration of GD in Fusion 360 software.

The second iteration of GD created using Fusion 360 software

In the second iteration, the design parts of the whole bumper were selected except for all the holes which were marked as obstacles and were suppressed in the calculation process. The other parameters already entered from the first iteration of the GD process remained unchanged. The overall setup was performed without reporting problems in the control table of the defined model and generation parameters. The resulting design of the second iteration can be seen in figure 8. The second iteration brought several interesting to extreme proposals for the solution of the car bumper model.
4.2. CogniCad

The first iteration of GD using CogniCad software was similar to the previous software. The first step was to import and define a material (Al 6061 –T6) that would be suitable for the car's operating conditions if the bumper component was manufactured. In the next step, all the middle parts of the bumper model that were used in the generation were selected. These areas are shown in blue in the software on the model. In the third step, non-design surfaces were selected, i.e. side surfaces that were suppressed during generation. These areas are shown in green in the software on the model.

Subsequently, the option of using an intelligent force distribution option was selected with which the software itself evaluates, suggests the position and magnitude of the forces for model generation. When choosing an intelligent force distribution option it was also necessary to define that the model would be created for the automotive industry so that the software could independently determine the distribution of forces on the surface of the investigated model. In the next step, the lower cross-section was selected for the "boundary conditions" function to ensure the position that the given cross-section is not further worked on and remains without design changes. In the last step, the option of reducing the material by 40% and the method of generating the model with the choice of model parameters and storage location were chosen.
The first GD iteration created using CogniCad software

Compared to Fusion 360, CogniCad generates only one model but the result is a sufficiently optimized product.

![Image of the first iteration in CogniCad software](image1.png)

**Figure 10.** The resulting design of the first iteration in the CogniCad software.

The second iteration of GD created using CogniCad software

The second iteration is very similar to the first. The difference is only in the choice of design areas where the whole model was chosen including the side parts of the model around the holes for mounting the headlights. Both holes for the headlights were selected using the "boundary conditions" function. With this function the holes were secured against position change and further manipulation during generation. The resulting model after generating the second iteration is similar to the first but the software also reduced the material in the selected side faces of the model.

![Image of the second iteration in CogniCad software](image2.png)

**Figure 11.** The resulting design of the second iteration in the CogniCad software.

4.3. Altair Inspire

The first iteration of GD using Altair Inspire software

The first iteration procedure consists of the same steps as the previous software. The first area of the bumper model was also selected in the first step which will be modified using generative algorithms. In the next step the areas that remain to be generated by the suppressed and applied forces were selected which are indicated in the software by red arrows. Subsequently, in the model generation window the option to reduce the material to 10% was selected and the generation was started.

![Image of the first iteration parameters in Altair Inspire software](image3.png)

**Figure 12.** Selection of first iteration parameters in Altair Inspire software.

The resulting design of the first iteration using Altair Inspire is shown in Figure 13. Altair Inspire software algorithms are more focused on topological optimization than on the design itself which was also reflected in the resulting model.
The second iteration of GD using Altair Inspire software

In the second iteration, the side surfaces of the model with holes for the headlights were also inserted into the algorithm. Subsequently, the option to reduce the material to 10% was again selected and generation was started. The resulting design of the second iteration in Altair Inspire software is shown in figure 14. The resulting design is radical in many respects (shape and material) and would need to be worked on more in boundary conditions, as the material utilization has been reduced to 10% compared to the original model.

5. Evaluation and comparison of software supporting GD

User preferences or experience from previous software are also an important factor in choosing software. A big disadvantage of using Fusion 360 and CogniCad software is their price for each model generation. This basically means that if a user who works with over-experimental products and does not have much experience with generative software can often repeatedly try to generate which can be costly. Another negative factor is the time required to generate. For some complicated geometries the generation can take more than fifteen hours. In Tab. 1 it is possible to see the comparison based on the selected comparison criteria of the individual software.

|                               | Autodesk Fusion 360 | CogniCAD   | Altair Inspire |
|-------------------------------|----------------------|------------|---------------|
| Graphical interface           | Yes                  | Yes        | Yes           |
| Possibility of strength and other analysis | Yes | Yes        | Yes           |
| Participation of the module for model creation and editing | Yes | No         | Yes           |
| Possibility to import the model in *.step and *.stl format | Yes | Yes        | Yes           |
| Long generation time of one iteration | Yes | Yes        | No            |
| Possibility of generating multiple models in one iteration | Yes | No         | No            |
| Ability to transfer a file using cloud storage technology | Yes | Yes        | No            |
| Possibility to use a consolidated model | Yes | No         | No            |
| Possibility of a one-time purchase of a software license | No | No         | Yes           |

When working with Fusion 360 software its great advantage was the graphical interface and variety of tools. After the creation of the basic design of the car bumper there was no problem associated with the working transition to the GD module and the subsequent use of its functions. The downside of this software was the lengthy time required to generate a single design. CogniCAD software also included a
very intuitive graphical interface which made it easy and transparent to go through the individual steps of GD. The biggest negative was the relatively small number of tools for editing and manipulating the model. Altair Inspire includes innovative graphical ways to select parameters and constraints which is very efficient and fast for the user. However, some knowledge is required before the initial launch of this software as the software does not have such a high degree of automation compared to the software already described.

6. Conclusion
Although artificial intelligence still works on the principle of logic 1 and 0, the development of generative technologies is constantly growing and many software applications are already starting to work autonomously where you just enter what the designer wants to create and the software then performs the necessary calculations and creates several designs. This article describes the approaches and presents model proposals created by generative design technology their current use which extends to various industries as well as the advantages and disadvantages associated with its use in practice. Furthermore, three selected software supporting GD were presented pointing to the optimization and generation of the car bumper model with a description of the new design and a comparison of the design approach in the individual software.

The aim of the paper was to point out the ease of designing GD tools without the need for many years of experience of the designer to work with the software, tools, defining parameters, functions and ways of working for the effective use of GD software. The article also draws attention to the negative aspects of the use of this design technology as the generated designs can often be imperfect or too shape and material insufficient for their production. Ultimately, this can have an impact on the time required to regenerate the design thus increasing the costs associated with the process of creating optimized models. With the constant and rapid development of technology the world is becoming more complex which is closely related to the growing demand for these innovative products which are optimized in shape and interesting in design. Generative design will play a key role in solving many problems that designers would not otherwise be able to solve on their own.

References
[1] Straka L and Dittrich G 2020 Design of manufacturing process of mould for Die Casting by EDM technology with the computer aided. International Journal of Engineering and Management Sciences, vol. 5, no. 2, pp. 57-63.
[2] Poor P and Basl J 2018 Czech Republic and processes of Industry 4.0 implementation. Proceedings of the 29th International DAAAM Symposium 2018, pp. 0454-0459.
[3] Poor P, Basl J and Zenisek D 2020 Assessing the predictive maintenance readiness of enterprises in West Bohemian region. Procedia Manufacturing, vol. 42, pp. 422-428.
[4] Zoubek M, Poor P, Broum T, Basl J and Simon M 2021 Industry 4.0 maturity model assessing environmental attributes of manufacturing company. Applied Sciences, vol. 11, no. 11, pp. 1-24.
[5] Guo X and Cheng G D 2010 Recent development in structural design and optimization. Acta Mechanica Sinica, vol. 26, pp. 807–823.
[6] Howarth D 2017 Generative design software will give designers "superpowers" Available: https://www.dezeen.com/2017/02/06/generative-design-software-will-give-designers-superpowers-autodesk-university/
[7] Langelaar M 2016 Topology optimization of 3D self-supporting structures for additive manufacturing. Additive manufacturing, vol. 12, Part A, pp. 60-70.
[8] Ngo T D, Kashani A, Imbalzano G, Nguyen K and Hui D. 2018 Additive manufacturing (3D printing): A review of materials, methods, applications and challenges. Compos, vol.143, p. 172–196.
[9] Monkova K, Zetkova I, Kucerova L, Zetek M, Monka P P and Dana M 2019 Study of 3D printing direction and effects of heat treatment on mechanical properties of MS1 maraging steel.
Leary M 2020 Design for additive manufacturing. Amsterdam: Elsevier, p. 358, ISBN 978-0-1281-6721-2.

Gibson I, Rosen D and Stucker B 2015 Additive manufacturing technologies. New York: Springer, p. 498, ISBN 978-1-4419-1119-3.

Monkova K, Monka P P, Zetkova I, Zetek M, and Hanzl P 2017 Influence of sample orientation on young’s modulus and fracture surface at DMLS technology. ICSID 2017, pp. 1-4.

Valicek J, Harnicarova M, Kopal I, Palkova Z, Kusnerova M, Panda A and Sepelak V 2017 Identification of upper and lower level Yield strength in materials. Materials, vol. 10, no. 9, pp. 1-20.

Akella R 2018 What generative design really is, what it isn’t, and why it’s the future of manufacturing. Available: https://adsknews.autodesk.com/stories/why-generative-design-is-the-future-of-manufacturing

A2K Technologies: Generative Design and its Applications. Available: https://www.a2kstore.com/generative-design-and-its-applications

Zelinski P 2020 Generative design to bring weight and cost savings for micromobility FUV. Available: https://www.additivemanufacturing.media/articles/generative-design-to-bring-weight-and-cost-savings-for-micromobility-fuv

General Motors: Driving a lighter, more efficient future of automotive part design. Available: https://www.autodesk.com/customer-stories/general-motors-generative-design

Deplazes, R. 2019 Autodesk collaborates with Volkswagen Group on generative design in electric showcase vehicle. Available: https://adsknews.autodesk.com/news/autodesk-volkswagen-generative-design-electric-showcase-vehicle

Panda A, Nahornyi V, Pandova I, Harnicarova M, Kusnerova M, Valicek J and Kmec J 2019 Development of the method for predicting the resource of mechanical systems. The International Journal of Advanced Manufacturing Technology, vol. 105, no. 1-4, pp. 1563-1571.

Stejskal T, Dovica M, Svetlik J and Demec P 2019 Experimental assessment of the static stiffness of machine parts and structures by changing the magnitude of the hysteresis as a function of loading. Open Engineering, vol. 9, no. 1, pp. 655-659.

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