Use of Generative Design Tools in the Production of Design Products using 3D Printing Technology

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***Abstract* – Generative design uses machine learning to emulate nature's evolutionary approach to design. Designers and engineers put design parameters such as material, size, weight, strength, manufacturing methods and costs into generative design software that explores all possible solution combinations and quickly generates hundreds or even thousands of design options. The article describes the production of a design backrest of the chair by combining several rapidly developing technologies. The selected backrest of the chair was digitized and subsequently subjected to design modifications in the Generative Design module of the Creo Parametric 7.0 system. The new design of the product was produced by means of a 3D printer to point out the possibility of saving the used production material of the design properties of the product while maintaining the required strength properties in the waste-free production method by additive technology.**

***Keywords* – Additive production, Digitization, Generative design, Optimization, Creo Parametric 7.0.**

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1. Introduction

One of the main goals of generative design is to save time in the design process, save material by creating the most efficient structures and save money by developing the most cost-effective production method.

The process, combined with the performance of digital computers, which can handle a large number of possible solution permutations, allows designers to create and test entirely new capabilities that go beyond manufactured capabilities, leading to the most efficient and optimized design. [1] Generative design thus opens up many new design possibilities, as it creates unique and innovative solutions that are often built outside of human imagination. [2] We can state that by developing this design approach, there is the potential for a complete change in the way designs are made. The products designed by this progressive generative design technology offer new possibilities for creating complex designs that are difficult to create with the construction tools used so far. [3] These tools are gradually becoming part of the design of many products that people use in everyday situations.

At present, the emphasis in many spheres is on progressive computer technologies. [4] For generative design, the main positive feature is the ability to simultaneously create, evaluate options and display the entire solution process before the designer commits to the most appropriate design alternative. The software allows adding material only where it is needed. Production processes such as 3D printing technology are perfectly suited for the production of organic molds. Organic shapes are now increasingly used in the world because these shapes are perceived as optimized compared to traditional designs [5], [6]. Aircraft, cars, spacecraft and other weight-dependent segments will be made easier thanks to this rapidly evolving technology. The assumption is that in the future it will be possible to create a number of products so that their production adapts to the growth of the global middle class and so that they are better adapted to the consumer. Many products are created in less time; less waste is used from the used material or fuel [7], [8]. Energy consumption will be reduced and industry will have less of a negative impact on the planet. The output of generative design can be images, sounds, architectural models, animations and much more. It is therefore a quick way to explore the possibilities of design used in various fields such as art, architecture, engineering and other design industries [9], [10]. Although technology has advanced, in general, many software applications still seek to achieve one goal - to display a man-made design more usefully and accurately. This means that computer technology and software are still dependent on humans [11], [12]. Even if the designer is experienced and creative, he still works within the limits of the human mind. With this new idea comes a generative design that aims to broaden these boundaries and horizons.

2. Use of Generative Design Today

The greatest use of generative design is mainly in companies engaged in custom industrial production. Such companies are characterized by a small series of production and a large proportion of purchased parts. Great pressure to be put in place to ensure the shortest possible innovation cycle. Experience shows that up to 80 % of data and experience from previous projects can be used for new product development in this type of company. However, it is essential that the data as well as the experience gained are available in such a format that they can be used in the context of a new contract [13], [14].

Lightning Motorcycles engineers teamed up with Autodesk Research Center, led by Andreas Bastian, to optimize motorcycle swing. Lightning Motorcycles has previously tried to alleviate the swing of the motorcycle's vertical swivel arm using composite 3D printing technologies. Although the designs theoretically worked, the properties of the materials did not withstand the forces developed when used on such a powerful machine. Component optimization using generative design, which we can see in Figure 1, should allow an overall improvement in the performance of the motorcycle. Previously proposed generative projects had clear objectives in that the components analyzed have to be light and structurally optimized. The requirement was that the optimized arm would meet the required qualitative and quantitative criteria to maintain a driving experience. At the same time, care had to be taken to reduce the overall weight and maintain the required performance.

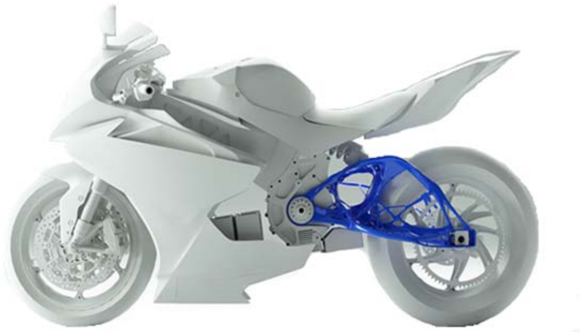

Figure 1. Swivel arm developed by generative design technology by Lightning Motorcycles

Generative design is not limited to product development, but it can also be applied to larger projects, such as the design of entire buildings or offices. One of the larger projects took place at the maRS Innovation District in Toronto, where designers used generative design tools to create a floor plan for an office environment that would not be possible with conventional design and manufacturing methods. The architects used generative design to take into account the logistics needs and needs of employees, including the requirements of the working environment. After successful data collection, the generative design software created 10,000 options for various workplace layout solutions. The designers then categorized these layout options in a compromise manner. The designers agreed that without the use of the software, it would not be possible to obtain such positive results even with many years of experience in the field of design.

In 2018, Starck teamed up with Kartell and the creator of Autodesk generative software to implement a joint chair design project based on generative algorithms. It was one of the first commercial products designed by generative AI technology. Starck provided the chair with an overall vision and advanced generative design algorithms that created a myriad of design options while meeting Kartell's requirements for plastic injection molding technology. Examples of the finally designed chairs can be seen in Figure 2.

Figure 2. Plastic chairs created using generative design tools

Generative design also affects industries such as textiles and footwear, where designers have a wide range of uses, as it is not necessary to pay as much attention to strength, force load and other parameters as in the engineering or space industry. Some designers have used generative design to create various pieces of clothing, shoes, masks, glasses and other design accessories, which have mostly been made using 3D printing. An example is the Under Armor sports shoes, which were created in collaboration with Autodesk. The aim of the project was to produce the lightest possible sports shoes. At the beginning of the design, the designers gradually gained information about what the shoe currently looks like and then inserted it into a generative design tool that created an organic-looking bottom of the shoe. The shoe was made using 3D printing technology, provides athletes with stability and sufficiently absorbs shocks when running or walking. Although the time required for design and production using generative design technology has been reduced, the production costs themselves have increased compared to traditional production, which is reflected in the increased price of these sports shoes. In Figure 3, it is possible to see several proposed design accessories created by generative design tools.

Figure 3. Fashion design accessories created using generative design technology

3. Use of the Generative Design Module in the PTC Creo Parametric 7.0 Software

Creo Parametric software developed by PTC is a universal comprehensive CAD/CAM/CAE software designed for modeling, simulation, analysis and a range of other design functions. With Creo Parametric, users can create and develop complex and detailed designs. The latest versions of the software also include a module for creating generative design. This module is located in the software environment under the Applications - Generative Design tools tab. Before starting a generative study, it is necessary to define several input parameters of the model. The parameters will ensure that the result that the study produces is of the required quality and meets the physical and material requirements. Among the basic tools that need to be set up when creating a generative study in the Creo Parametric 7.0 system are:

Design spaces – defines the parts of the study that are involved in optimization and are needed to define a generative study. These include:

- Starting Geometry – marking the body as the initial geometry. This is the first step in defining a generative study. The part of the component marked as the initial geometry becomes partially transparent; this allows a better view of the remaining parts contained inside. Only one body needs to be marked as the initial geometry. The resulting design is contained within the initial geometry.
- Preserved Geometry – represents the parts that are included in the generated designs, but their geometry remains unchanged. The required loads and constraints can be applied to the preserved geometric surfaces. Preserved parts should not intersect or touch each other. If this is not the case, these parts should be merged.
- Excluded Geometry – the parts marked as excluded geometry are represented in the final generated designs as empty volumes without any materials. The omitted parts act as obstacles, so the study addresses them, but not within their volume. No load or constraint can be applied to components marked as excluded geometry. The excluded geometry should be contained within or go through the initial geometry.
- Undesignated Bodies – these parts are not marked as initial geometry, preserved geometry or excluded geometry. Unmarked parts affect the generated design, but are not part of the final design. These surfaces may be subject to loads and constraints, and may transfer loads and constraints to other parts to which they are firmly attached.

In the group of tools labeled Physics, it is possible to select the constraints and loads that we want to apply in the study. One can apply them separately or create a node by selecting the Add Load Case function. The result is calculated separately for each load case. However, the resulting design is generated taking into account all load cases associated with the model. These include:

Structural constraints:

- Fixed Constraint – by removing all degrees of freedom. The selected part is prevented from moving and deforming.
- Displacement Constraint – this restriction will allow the selected part to move only in a certain direction, in other directions it will not be allowed to move.
- Planar Constraint – allows full planar motion for planar surfaces, but limits out-of-plane displacement.

- Cylindrical Constraint – is designed for cylindrical surfaces. The constraint occurs in the axial, radial and tangential directions.

Structural loads:

- Force Load – the force load acting on the specified area can be defined by entering values in the X, Y, Z directions in the positive and negative directions of the vector.
- Moment Load – a load that acts in the twisting direction and can be positive or negative.
- Pressure Loads – loads acting on the surfaces of the three-dimensional model. A positive pressure load always acts at any point relative to the normal direction of the surface, even if the surface is curved.
- Centrifugal Load – the resulting load acting in the opposite direction to the direction of the centrifugal and tangential velocities. The definition of the centrifugal load is determined by the vector component of the angular velocity or by the direction vector and magnitude.
- Linear Acceleration Load
  Design criteria – it incorporates study objectives, manufacturing and geometric constraints, as well as material settings. Multiple design criteria can be defined for a generative study, but only one can be active at a time. Only active design criteria are taken into account during the generation of proposals. The target weight with preserved geometry is taken into account.

Study settings – using these settings it is possible to increase the quality of the generated results. The Fidelity function defines the accuracy of the results on a scale from 1-10. If the model contains small elements, e.g. sharp edges or thin layers; for better quality, it is advisable to use the Minimum element size function. By applying the Maximum iterations function, we can obtain better results, even if the duration of the study increases.

The generative study is started with the Optimize function. The duration of a generative study depends on the settings and the complexity of the component. This process can sometimes be quite lengthy. A generative study in Creo Parametric 7.0 allows creating interesting design proposals. The generative studio is easy to set up and is suitable for less experienced designers. The disadvantage compared to other software is that the study will provide only one final component that cannot be compared with another result of the generative study. On the other hand, the great advantage is the short duration of the processes of generating new designs, which allows trying a larger number of combinations of settings in a short time. Different study settings also meet the requirements for creating complex components.

4. Design of a Chair Backrest Component with Generative Design Tools

In order to demonstrate the application of generative optimized design techniques, a plastic backrest on an office chair was chosen. For the needs of digitizing the backrest, a hand-held scanner ZScanner 700 was used. The selected scanner is able to record the spatial characteristics of the scanned bodies with an accuracy of up to 0.05 mm. Due to the dark surface of the component, it was necessary to apply an opaque coating to it before scanning. The chalk spray used makes it easier to recognize the projected laser pattern on the body surface. It can be easily removed after the scanning without damaging the surface finish. During scanning, the scanner requires the recognition of suitably spaced reference marks, based on which it can unambiguously determine its position in space in the digitization process and then place the measured data correctly. In this case, the reference marks were not placed on the surface of the backrest, but a pad with a pre-prepared pattern was used, which can be seen in Figure 4. During the scan, the backrest did not move relative to the pad, but to capture all views, the scan was repeated with different saves 5 times.

Figure 4. The process of scanning the chair backrest for CAD model creation

The unification of individual views and their cleaning was realized in the environment of the software VXelements 6, which is shown in Figure 5. Common surfaces were used to determine the correct position of the partial scans instead of position points always for overlapping views.

Figure 5. The process of unifying views

The resulting shell in STL format was imported into the Creo Parametric 7.0 software environment, where the surface was converted into a parametric volumetric model by implementing reverse engineering techniques. Thanks to the precise shape reconstruction, it is possible to perform accurate analyzes after defining parameters such as material, external assumed load, fixing of the part in the functional assembly. Defining the parameters can be seen in the following Figure 6.

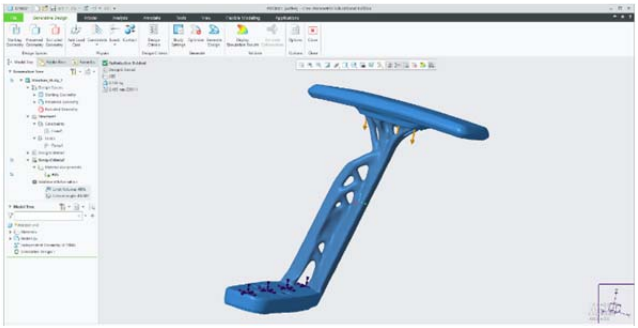

Figure 6. The process of unifying views

The Multibody Design function allows one body to be divided into several parts within one running session and to assign different parameters to individual parts. For this example, the backrest was divided into three basic parts, which can be seen in Figure 7. The three basic selected parts included the base for connecting the overall structure of the backrest: 1. backrest base, 2. backrest arm, 3. seat back.

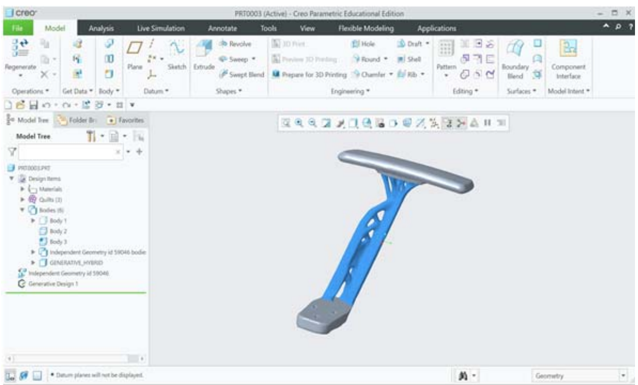

Figure 7. Dividing the model into required parts with the Multibody Design function

The shape optimization process involved only 2 selected parts. The "backrest base" part remained unchanged, as it required precise positioning and rigidity of the holes for attachment to the chair. The third part "seat back" was also neglected, as with an optimized, slightly deformed surface, edges may be formed which could cause abrasions on the support or reduce the overall sitting comfort. The second part "backrest arm" was optimized depending on the assumed maximum load of 500 N acting perpendicular to the backrest surface. The direction of the future layering of the material and the density of the filling were taken into account during the simulation.

The resulting optimized design was processed for additive production with the application of FDM technology in the software application Simplyfy3D ver. 4. The g-code for the Creality CR-10 MAX production facility was created in the software, which has a sufficiently large working space (450 x 450 x 470 mm) so that it can produce the given design in one working cycle without the need to connect smaller parts. The settings were optimized for PTG material and a print nozzle with a diameter of 0.8 mm.

Other selected parameters of the 3D printing production process are:

- Print layer height: 0.52 mm
- Number of top/bottom layers: 4 layers
- External perimeters: 3
- Filling: 100 %
- Nozzle temperature: 240°C
- Heated pad temperature: 70°C
- Average print speed: 40 mm/s

After setting the required parameters, the verification of spatial printing was followed by a simulation, which we can see in Figure 8.

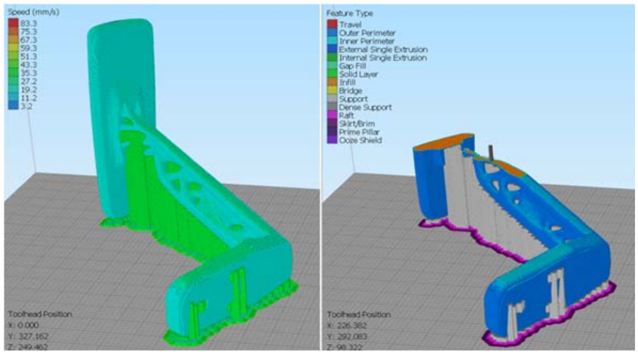

Figure 8. Simulation of the spatial printing of a model used for editing with generative design tools

Depending on the defined production parameters of the component production, 284 m of material with a diameter of 1.75 mm was consumed, which represented 19 hours of working time of the 3D printing process. For comparison, if the same conditions are chosen and a printing nozzle with a diameter of 0.4 mm and a layer height of 0.22 mm is used, the total production time would be extended up to 61 hours. The final manufactured chair backrest component designed and optimized by the generative design approach in the Creo Parametric 7.0 system is shown in Figure 9.

Figure 9. Final assembly of a chair backrest designed with generative design tools and manufactured using 3D printing technology

5. Conclusion

The idea in the past that computers will become a full-fledged and substitutable part of designers in the design process could be a bit unimaginable for some people. However, researchers have used this claim many times in various technological innovations. With today's advanced technologies used on a daily basis, people are still involved in design development. It is generative design that can also be the result of cooperation between the human intellect and computational power. Design technology has still not progressed to the level of the average person's intelligence.

Generative design is becoming increasingly important, especially thanks to new programming environments and scripting capabilities that have enabled relatively easy implementation of ideas even for designers with little programming experience. In addition, this process can create solutions to essentially complex problems that would otherwise be exhausting for the designer's work. This activity is facilitated by the tools of commercially available CAD packages. Not only are generative tools more accessible, but many custom design software packages already include tools that use generative design technology. It is also important to remember the ways in which generative design can free the human designer from stereotypical tasks in creating better and more creative solutions. A computer can go through hundreds of design iterations at a time when only one designer would create one. However, generative design still requires much more human design than an autonomous generation of concepts to find the best mechanical configuration. This means that artificial intelligence technology still cannot automatically design goals, parameters and ways of creating a design without the participation of a designer.

Many products will become more affordable due to reduced research and development costs. Creative design will be able to prosper and inventions should appear as simple and optimized concepts that any designer can create. Generative design will also be able to save on production costs, as almost all test procedures are included in the initial generative design process. This means that no major modifications are required at later stages of production. Engineers and designers will be able to think beyond the scope of their previous ideas and experiences. As with all new technologies, generative design technology will become much more affordable over time, leading to an increase in creative and unpredictable innovation in product design and development.

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References

[1]. Langelaar, M. (2016). Topology optimization of 3D self-supporting structures for additive manufacturing. *Additive manufacturing*, *12*, 60-70.

[2]. Nomura, T., Dede, E. M., Lee, J., Yamasaki, S., Matsumori, T., Kawamoto, A., & Kikuchi, N. (2015). General topology optimization method with continuous and discrete orientation design using isoparametric projection. *International Journal for Numerical Methods in Engineering*, *101*(8), 571-605.

[3]. Vojtko, I., Kočiško, M., Janak, M., & Fečová, V. (2013). The new design of robot arm. In *2013 IEEE 11th International Symposium on Applied Machine Intelligence and Informatics (SAMI)* (pp. 53-56). IEEE.

[4]. Svetlík, J., Baron, P., Dobránsky, J., & Kočiško, M. (2014). Implementation of computer system for support of technological preparation of production for technologies of surface processing. In *Applied Mechanics and Materials* (Vol. 613, pp. 418-425). Trans Tech Publications Ltd.

[5]. Ansola, R., Canales, J., Tarrago, J. A., & Rasmussen, J. (2002). On simultaneous shape and material layout optimization of shell structures. *Structural and multidisciplinary optimization*, *24*(3), 175-184.

[6]. Monkova, K., Monka, P. P., Šuba, O., Žaludek, M., Kozak, D., & Vanca, J. (2021). Influence of the material volume of a lattice structure on bending properties. In *MATEC Web of Conferences* (Vol. 349, p. 04003). EDP Sciences.

[7]. Svetlík, J., Hrivniak, L., Šašala, M., & Stejskal, T. (2021, November). Application of continuous carbon fiber reinforced composites in a modular system. In *IOP Conference Series: Materials Science and Engineering* (Vol. 1199, No. 1, p. 012092). IOP Publishing.

[8]. Setoodeh, S., Abdalla, M. M., & Gürdal, Z. (2005). Combined topology and fiber path design of composite layers using cellular automata. *Structural and Multidisciplinary Optimization*, *30*(6), 413-421.

[9]. Ngo, T. D., Kashani, A., Imbalzano, G., Nguyen, K. T., & Hui, D. (2018). Additive manufacturing (3D printing): A review of materials, methods, applications and challenges. *Composites Part B: Engineering*, *143*, 172-196.

[10]. Gibson, I., Rosen, D. W., Stucker, B., Khorasani, M., Rosen, D., Stucker, B., & Khorasani, M. (2021). *Additive manufacturing technologies* (Vol. 17). Cham, Switzerland: Springer.

[11]. Monkova, K., Zetkova, I., Kučerová, L., Zetek, M., Monka, P., & Daňa, M. (2019). Study of 3D printing direction and effects of heat treatment on mechanical properties of MS1 maraging steel. *Archive of Applied Mechanics*, *89*(5), 791-804.

[12]. Liu, H., Liu, Z., & Hao, S. (2021). Design of a throat-extended FDM extruder for multi-axis 3D printing. *Strojniški vestnik*, *67*(4), 180-190.

[13]. Panda, A., Nahornyi, V., Pandová, I., Harničárová, M., Kušnerová, M., Valíček, J., & Kmec, J. (2019). Development of the method for predicting the resource of mechanical systems. *The International Journal of Advanced Manufacturing Technology*, *105*(1), 1563-1571.

[14]. Dey, A., & Yodo, N. (2019). A systematic survey of FDM process parameter optimization and their influence on part characteristics. *Journal of Manufacturing and Materials Processing*, *3*(3), 64.