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Component Development Using Topological Methods

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Abstract. The article aims to briefly summarize the design aids which can be used nowadays, such as topology optimization and generative design, which are common in integrated CAD systems. A case study is used to present the results and comparisons provided by the previously mentioned methods.

Keywords: Product Design Methodology, Topology Optimization, Generative Design.

Introduction

In case of designing machines and structures, the design task can be accomplished in different ways. These methods include the continuous development of the steps of design methodology developed in the last century. Various procedures and techniques related to the University of Miskolc play an important role in terms of machine design [1], [5] - [7]. Each design method has its own advantages and disadvantages, but the most appropriate one is determined by the qualification of the design staff and the type of task in question. The process is greatly influenced by its resource requirements, although efforts must be made to maintain the technical and technological level of the present age and to create the best use of it. It can be observed that in many areas of industry, the proportion of human labour is decreasing compared to the work of machinery and other means of production. This is inherent in the development process, in the hope of which we can provide a solution to a given task faster, more accurately and, if necessary, at less cost. A system where one merely communicates information and makes decisions while the equipment is working, seems to be a favourable way. Similar processes are taking place in the field of product design, thanks to the generative design module that became widespread in integrated CAD systems, as it serves as an example of the philosophy mentioned above. Design engineering is limited to provide accurate information and select from the results obtained.

1. The selected components

The case study demonstrates the design of a component made up of simple geometric elements using design methods, such as generative design, provided by the present age.

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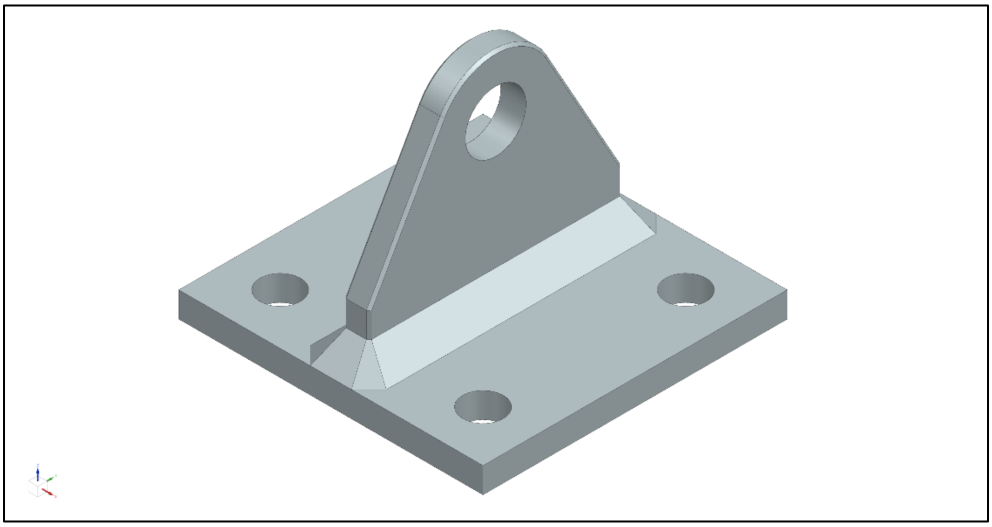

Figure 1. The reference part.

The initial part, which is a console, is screwed to a specific plane. A load can be hung in the mortise in the part, so the console is subjected to tensile stress. The part is fixed to the horizontal plane with four screws and during the test, it is assumed that the screw connection used is suitable to withstand the resulting stress states. A hook or pin can be inserted into the hole in the bottom of the part.

Name	stainless steel 1.4125
Yield point	689 [MPa]
Tensile strength	861,25 [MPa]
Young modulus	206,7 [GPa]
Poisson factor	0,27 [-]
Shear modulus	83900 [MPa]
Density	7,75 [g/cm3]

Table 1. Material properties of the part.

In order to make the results comparable, a preliminary finite element simulation is performed on the initial workpiece, so that the load capacity of the part becomes known. For finite element analysis Autodesk Inventor was used. During the test the maximum stress and maximum displacement arising under the load was searched. The point of attack of the load force and its direction were recorded on the part. Based on the geometric properties of the component, the direction of the specified load is considered critical which can be stated as static. Table 2 summarizes the results of the FEM analysis.

Force	50 [kN]
Von Mises Stress	331,3 [MPa]
Displacement	0,091 [mm]

Table 2. The results of the FEM analysis.

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2. Application of topology optimization

To perform the topological optimization operation, it is advisable to create a new reference body model, which will be the modified geometry of the geometry of the reference part [8]-[11].

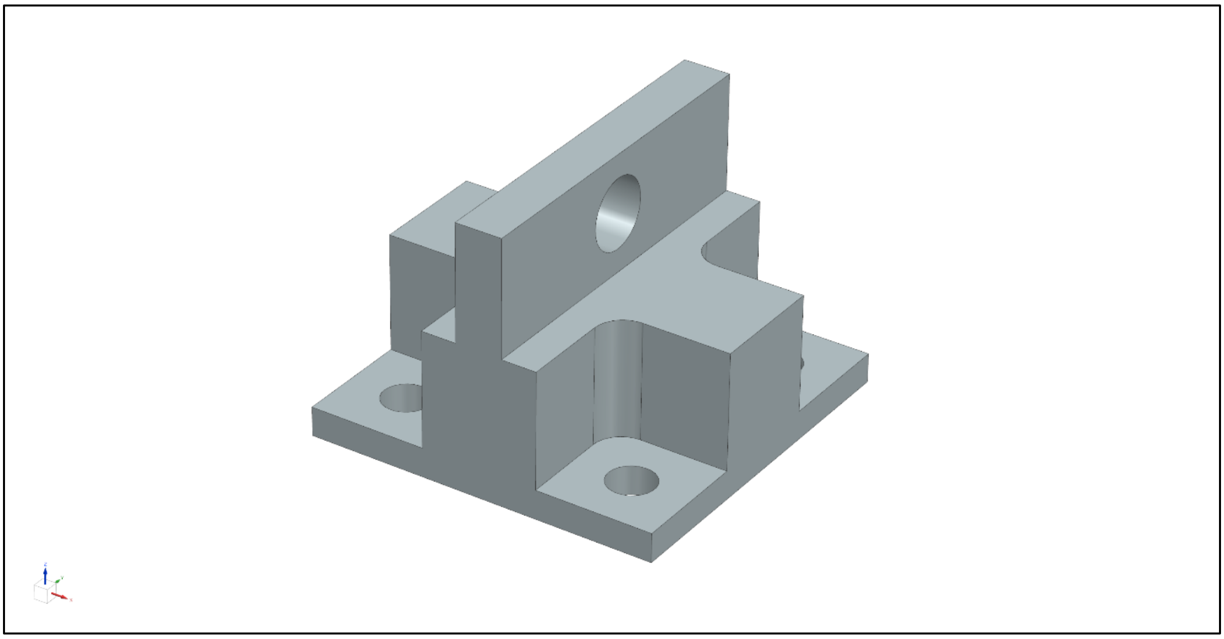

Figure 2. The modified model of the reference part.

The modifications made to the model increased the overall volume of the part, but the functional elements remained unchanged. It is important that areas, where the wall thickness is smaller than that of the original part on the model, are not created. Furthermore, it must be ensured that the mounting and loaded surfaces are the same as the previous model. The selected material is completely identical to the previously used stainless steel (1.4125). In the next step, the loading force of 50 [kN] was recorded, the direction and point of which are the same as those used in the previous FEM analysis. The fixing points were determined at the location of the four holes. At these points, it is necessary to create fixed volumes, which remain solid bodies during the optimization [2], [4]. For comparison, care should be taken to create fixed volumes of the same size during topology optimization and generative design. This means that for each hole we define a rotating body with an inner diameter of 13 [mm] and an outer diameter of 20 [mm]. For the 20 [mm] diameter hole, we created a 36 [mm] diameter cylinder. These auxiliary bodies are marked by green in the program. The software provides the possibility to specify a plane of symmetry and meshing settings, the appropriate settings of which can reduce the calculation time.

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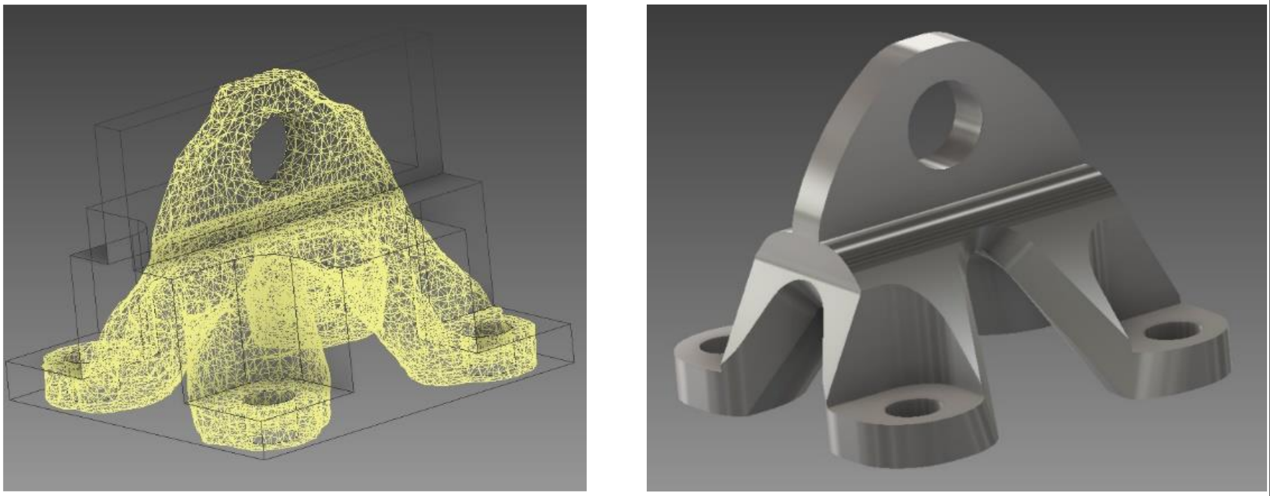

Figure 3. The result of topological optimization.

Figure 3 shows the solution of the topology optimization process. During the search for a solution, mass reduction was the main goal that was set in the program. The value of this design aspect can be defined as a percentage, which in this case we set as the optimization goal. The value used is 13 [%], which is relative to the original model. These adjusted parameters provide a component with a weight of 0.91 [kg]. It can be observed on the meshed model that the surface of the resulting geometry is very uneven. Due to the chip separation production technology, they were replaced by surface planes. A very important factor is whether the created geometry corresponds to the loads. The answer to the question was obtained with the help of finite element simulation.

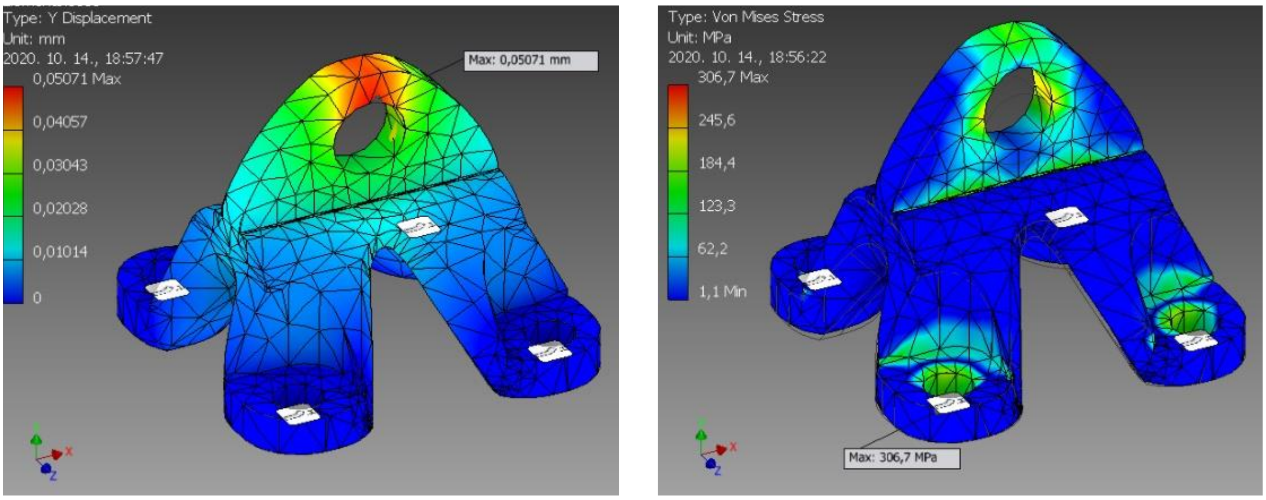

Figure 4. Deformation and stress state on the optimized part.

In Figure 4, it can be observed that the maximum stress developed due to the load is 306.7 [MPa], which is adequate with the applied safety factor. The maximum value of the deformation is 0.05 [mm].

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3. Development of the part by generative design

In the second stage of the case study, the design process of the component is created by the generative design method and its results, and their evaluation are presented. The modelling steps were made in the Autodesk Inventor program and the generative design module was used in the Autodesk Fusion 360 program. In the preparation phase, the fixed and limiting volumes were defined. To a large extent, it can be stated that similar steps must be followed as in the case of topological optimization. Accordingly, each setting corresponds to what you have seen before. The size and shape of the limiting geometries, the raw material, the constraints, and the load forces are the same as the parameters defined during the topological optimization. After setting the appropriate values, it is necessary to start an automatic check function. During the process, the software goes through the settings and if it finds a contradiction, it indicates it to the user of the program [3]. This can happen if the created material has incomplete properties or if the right material is not selected for the selected process. After these control functions, the design procedure can be started, which does not burden our own computer, but takes place entirely on a cloud-based storage location. Accordingly, after starting the process, the capacity of our computer is not needed.

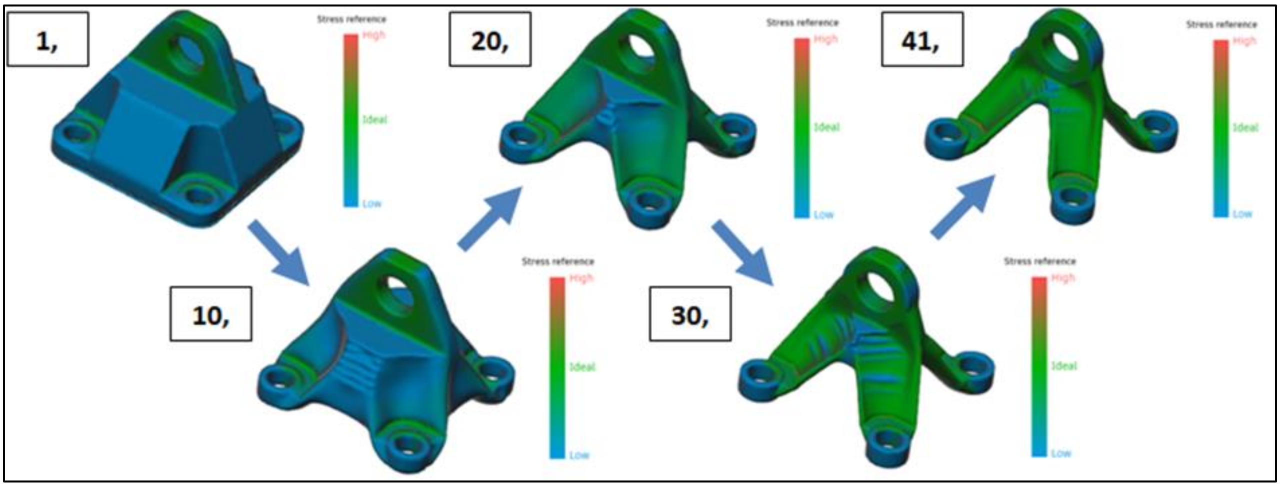

Figure 5. Iteration steps of the generation process.

It is a great advantage that the program provides many raw materials and production technologies, these solutions are available in large numbers. It is advisable to filter and select the individual solutions in different ways as early as possible. If the generation of solutions starts in a given direction, after opening the part, the result of the iterations created can be viewed and selected as a possible solution. In many cases, the process of generating the geometry is favourable, but the final state does not fully meet the expectations, then the intermediate elements can be used. The development of the components can be seen in Figure 6. It is possible to observe the state of tension, which allows us to obtain information about the mechanical properties of individual results without other tests.

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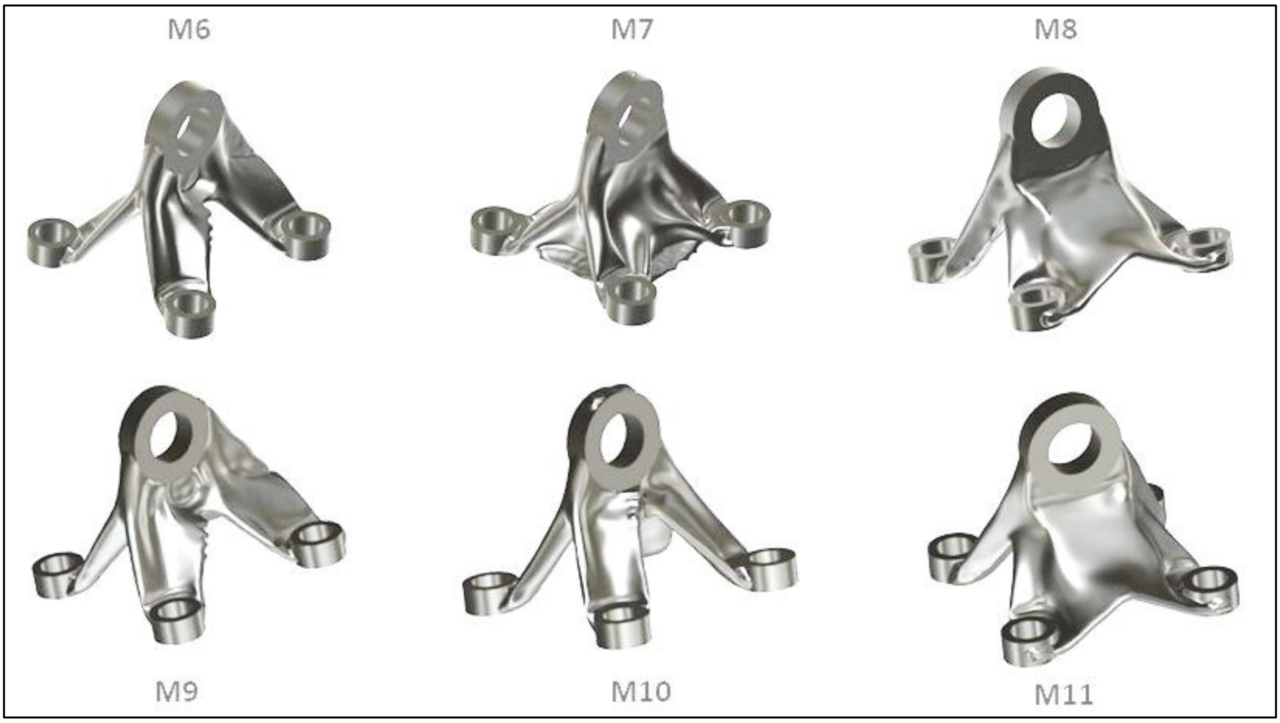

Figure 6. Results of the generative design process.

After the generation process and the selection of steps, the method resulted in six parts. The number of iteration steps used by the program is two hundred and forty, each of which has one possible solution. After that, the components must be individually selected. The software is able to perform comparisons between individual solutions by assigning different aspects and conditions. It displays them graphically with the help of diagrams.

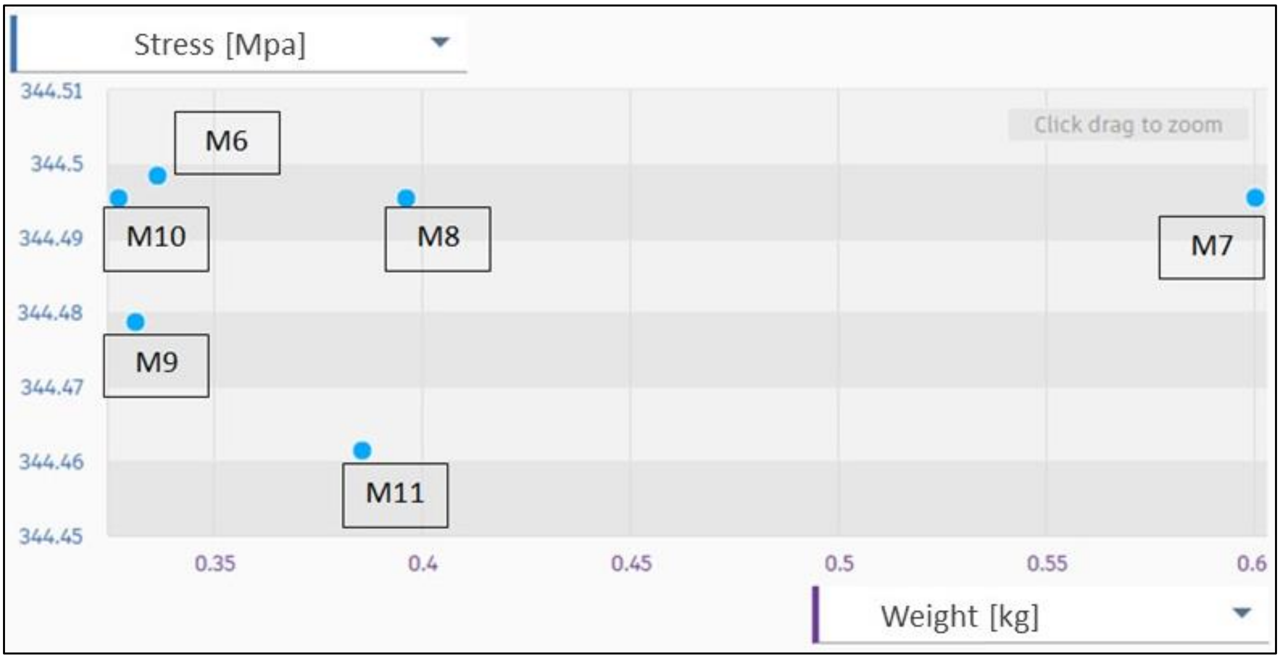

Figure 7. Classification based on mass and stress condition.

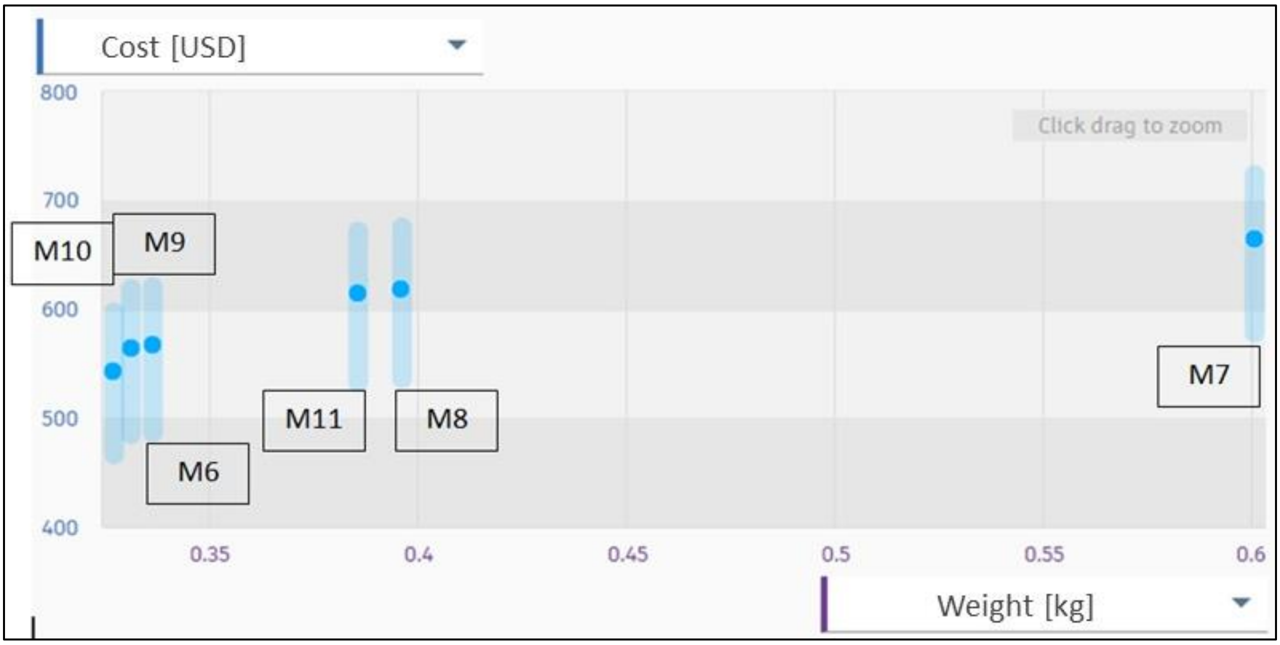

Figure 8. Classification based on weight and production cost.

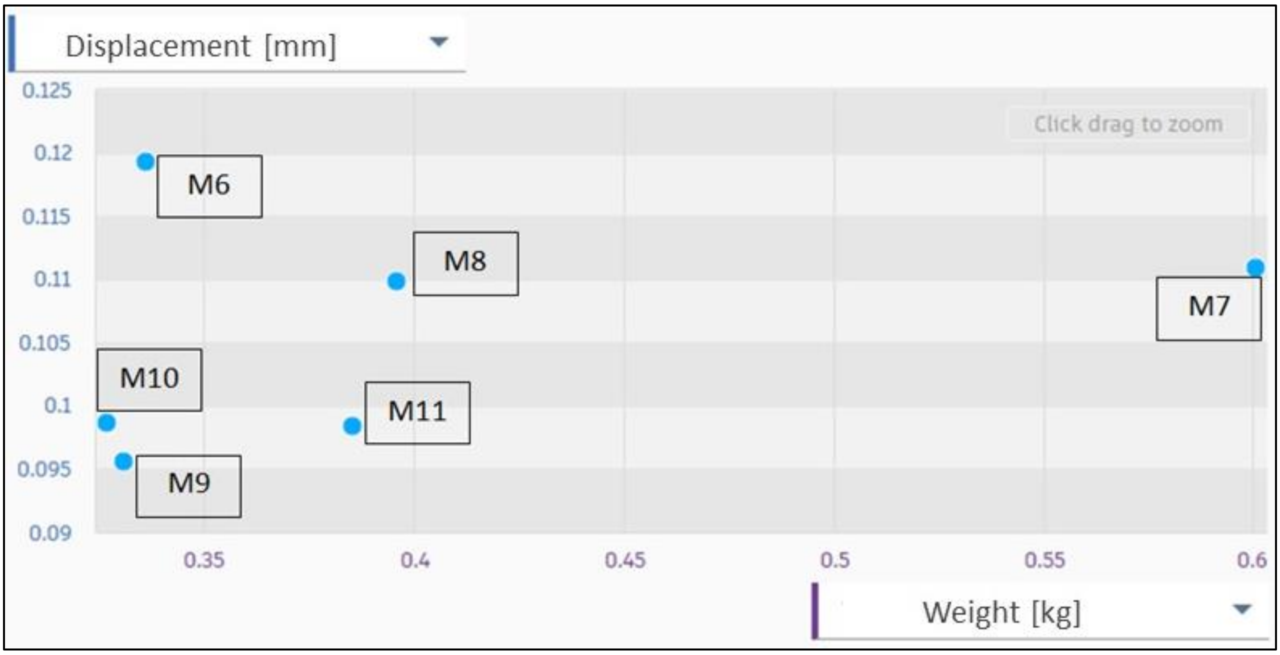

Figure 9. Classification based on mass and deformation.

During the evaluations, it was possible to come to the conclusion that solutions M9 and M10 proved to be suitable constructions due to their advantageous properties. These solutions represent minimal costs, but the M10 solution has the lowest weight and manufacturing cost. According to this, the final solution of the part produced by the generative design method is the M10 construction. Based on the results obtained during the study, Table 3 summarizes the properties of each concept.

	Traditional design	Topology optimization	Generative design
Quantity	Large series	Small series	Unique
Variations	1 [pc]	1 [pc]	240 [pc]
Machining	Cutting and welding	5D Milling	Additive manufacturing
Strength	331 [MPa]	306 [MPa]	344 [MPa]
Deformation	0,09 [mm]	0,05 [mm]	0,09 [mm]
Weight	1,07 [kg]	0,91 [kg]	0,32 [kg]
Weight loss	0%	17%	70%
Amount of waste	Medium	Big	Minimal
Cost	~12000 HUF	~55000 HUF	~220000 HUF

Table 3. Summary of the results.

4. Summary

The case study presents the process and problematic areas of modern product design. It compares three components created by different techniques, which were made in different software. If we are talking about a large series, a component designed using the classic method may be more suitable. The part created with the help of topological optimization is manufactured using 5D milling. In this case, the amount of waste generated during production is high, so this method is recommended for small series. In many cases, the production of a part designed with the generative design method can only be carried out using additive technology, which has low productivity but high machine costs. An important parameter is that the amount of waste generated during production is small. The use of the component produced in this way is recommended when weight reduction and the use of special or difficult-to-cut materials are important parameters.

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