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Application of Topological Methods in the Development of Vehicle Components

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Abstract. Many areas of the industry are characterized by continuous changes, which define new directions of development in product design. The development of computers and software, the spread of modern production tools and the development of material technology make it possible to expand traditional production technologies with modern processes. Integrated CAD systems have occupied their place in the product design and development process for decades, reforming classical design methods. Popular optimization procedures in integrated CAD systems, such as shape optimization, topological optimization and the new generative design process, provide effective solutions for design engineers in more and more industrial application areas. Experience shows that modern design methods can be used in many areas of industry. The appearance of metal powder printing and additive technology make it possible to test the designed prototypes or even to produce the final products. The following article aims to support the above with the help of a case study.

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

Introduction

Engineering design is intended to produce an acceptable result to a formulated problem both technically and economically. Before manufacturing a physical prototype, the part pre-inspected in a virtual context, the end of which is to reduce time and costs. This way is called virtual prototyping, which can be related to the parallelization of methodical design [1,2,3]. Likewise, additive manufacturing now is an arising technology that can be considered as the next industrial revolution. In fact, the use of this technology is projected to expand steadily [4,11]. Compared to traditional manufacturing technologies, additive technology offers lesser design freedom for both prototype and finished products and doesn't bear precious tools and molds. Likewise, computer-aided design CAD technologies, similar as generative design and topological methods [12-18] can further extend the applicability of additive manufacturing. Generative design tools are also showing growth and expansion in numerous areas of the industry. The main CAD system providers have also developed their own generative design systems, conforming to the trends [5,6,10]. Interactive design seems to connect with different engineering cultures [7]. Considering the freshness of additive manufacturing and generative design technologies, the methodology is presently allowed to be deficient. This paper seeks to answer the following research question (RQ): how effectively can the generative design methodology be applied to an appropriately designed part based on the methods explored?

1. The basis of the case study

The case study in this article is based on a previous competition development proposal, the main theme of which is an experiment in the development of chassis components for vehicles. The study aims to reduce the weight of the components in case of the wheel suspension system. Regarding vehicles designed for racing, this demand is even more emphasized as increasing the acceleration potential of the vehicle can be understood by increase of the traction force and/or reduce of the mass. As the role of mass reduction, especially the reduction of unsprung masses, is particularly important in case of vehicle components, that is why the chosen topic can be considered as appropriate for several reasons to examine the applicability of the given design method. The expected attributions can be provided by the chassis if the parts are rigid enough. The individual connection points were determined during the entire chassis design, which are located on different planes and axes which can be connected to each other, while it can generate complex and spectacular results.

2. The selected components

The wheel hub is one of the most important elements of the wheel suspension, which bears many functions. In fact, the main purpose of the part is to provide a connection between the wheel and the swingarms. Due to the mechanical connection, it has bearing points and mounting surfaces for the brakes and swingarms.

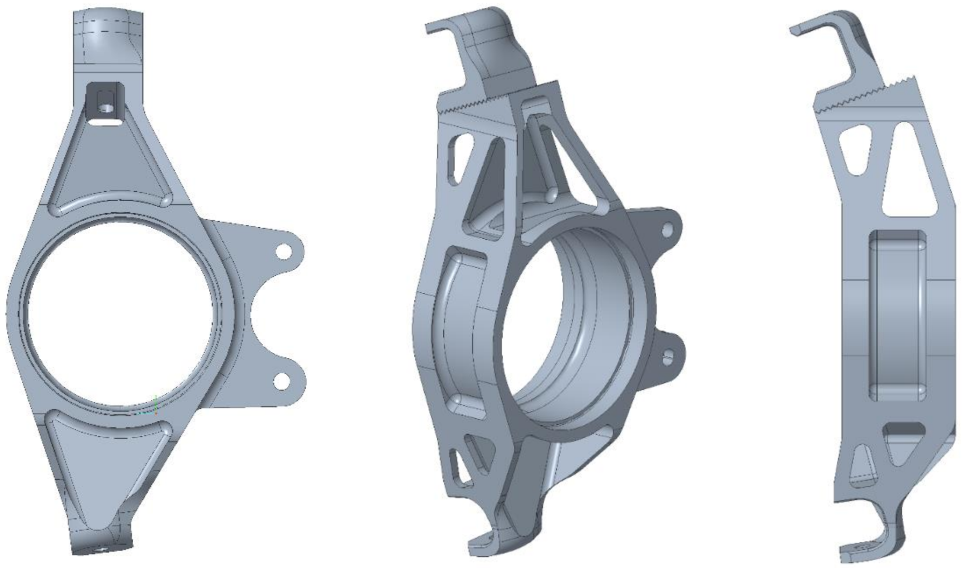

Figure 1. The original model of the wheel hub.

The 3D model of the part under consideration was designed on the base of traditional design styles. The raw material of the element is 6061 Aluminum with a density of 2.7 [g / cm3], a yield point of 275 [MPa] and a tensile strength of 310 [MPa]. The overall size of the stump stand is 280x150x60 [mm] and the weight of the current design is 1.25 [kg]. The indicated axis can be manufactured using traditional cutting operations. The entire element features cuts and pockets, which are said to be the tools of traditional design and manufacturing methodologies.

3. The generative design process in iCAD system

Generative design is a design process in which an algorithm optimizes the shape of the element for a particular boundary condition. The design of the shape is not a manual design task. The developer determines the functional boundary conditions of the part, adds it into the software, which calculates the shape of the optimized part according to the specified criteria during iteration processes [6, 10]. Lately, several papers have been devoted to the description of generative design processes [8, 9], on the base of which the outlined task is answered.

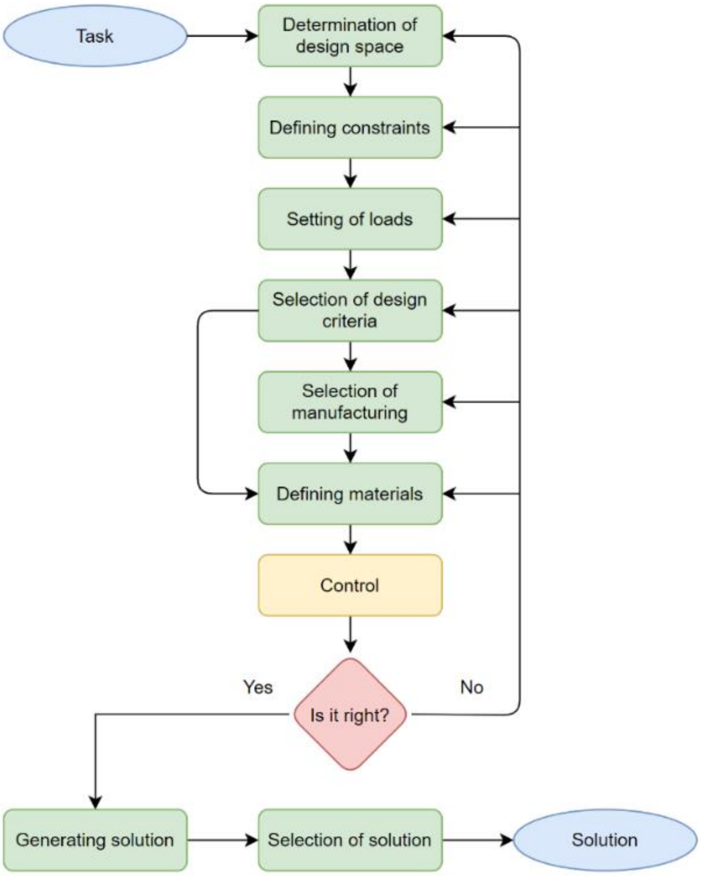

Figure 2. Steps of the generative design process [9].

It is advisable to carry out the design process step by step on the basis of the indicated flowchart, as this is the only way to get an effective result based on preliminary exploration. The presented case study in the paper is solved in the Generative Design Support module of the Fusion 360 Integrated Design System. Examination of the installation environment of the chassis parts is analysed in the Design Module, while the mass optimization task is performed using the Generative Design Module and the final check of the results can be carried out in the Simulation Module.

3.1. Determination of design space

Following the defined design process, the installation environment of the component must be examined in the first step. Based on the results, the necessary and limiting volumes must be constructed, which the method can use in the subsequent steps. The undercarriage is a complex structure, consisting of many components, for which a suitable connection surface must be created. In this case, these body models are designed through traditional modelling, which is not an automatic process. This process can be the creative part of the design, as in this case the designer can significantly intervene in the specifics of the emerging geometry.

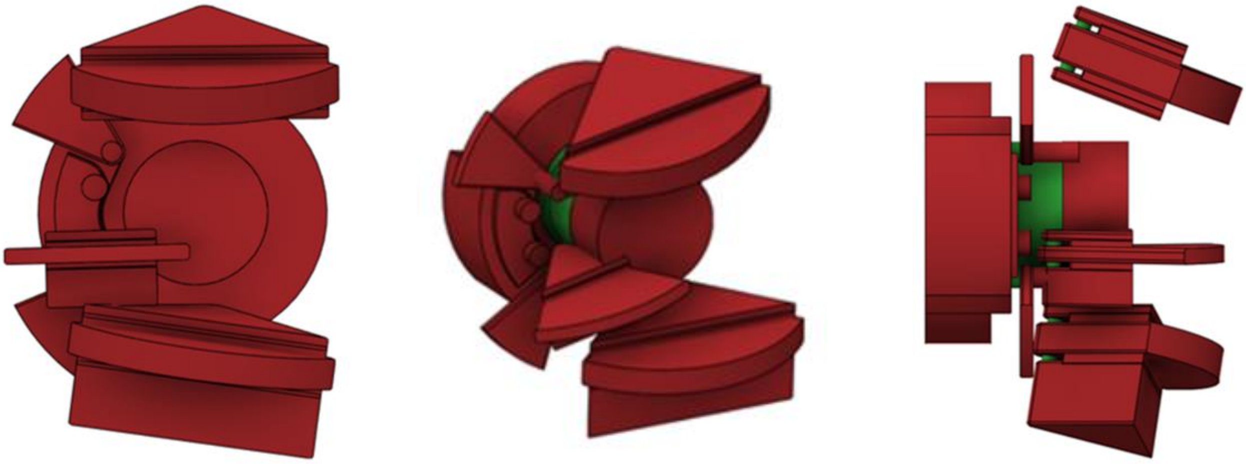

Figure 3. Determination of design space.

The models shown in Figure 3 represent the volumes for the chassis. It is advisable to start the modelling by creating the volumes to be kept. In the next step, the reverse of this must be done, so volume elements must be created that limit the design space. The colour green indicates the mandatory zone and the red one the forbidden zone. Care must be taken during the process, the best solution may be to define the restrictions using the results of a kinematic simulation.

3.2. Definition of loads and constraints

In the next step, constraints and loads are specified, which must be created on the volume parts that are to be preserved.

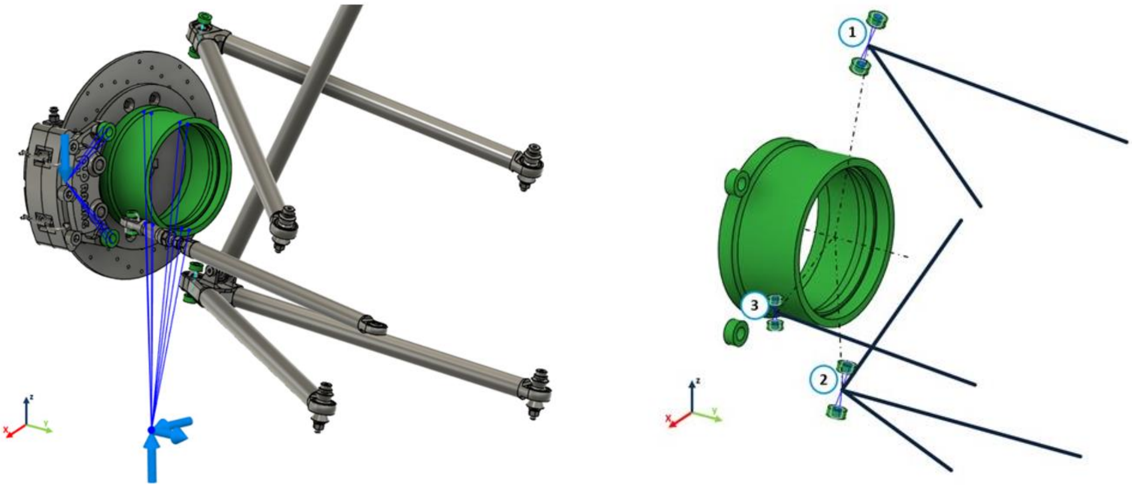

Figure 4. Definition of constraints and loads.

Figure 4 presents the points and surfaces where the forces should be placed and their orientation. The right side of the figure provides help in how the constraints must be defined at each connection point. In this step, attention have to be paid to what movements are restricted at each point. The load forces were determined empirically, they always depend on the weight and engine power of the construction of the given age, so these parameters can change from year to year. The loads for the given construction are summarized in the table below, which can be considered as maximum values.

Name of the load	Extent of the load	Surface affected by force
Fx	2150 [N]	Abutment surface of wheel bearing
Fy	3150 [N]	Abutment surface of wheel bearing
Fz	2575 [N]	Abutment surface of wheel bearing
Ft,braking	6000 [N]	Surface of the caliper mounting points

Table 1. Loads affecting wheel hub.

In order to ensure sufficient safety, during the test we take into account the case with the highest load, when all of the listed forces load the body at once. The software calculates the optimal geometry based on von Mises stress. Unfortunately, it is not possible to define dynamic effects.

3.3. Definition of design objective functions

In Fusion 360, the "objectives" function can be used to select optimization goals and constraints, which can be either maximization of stiffness or minimization of mass. In the current case study, the stiffness maximization objective function is selected. The weight requirement is a maximum of 0.85 [kg] and the required minimum safety factor is 2. The conditions can be further tightened by prescribing various production technologies. In the following, at least one raw material must be assigned to the model. The software can only handle linearly elastic material models. Among the additive manufacturing technologies, the "SLM" (Stereo Lithography) and "EBM" (Electron Beam Melting) processes were selected, which are associated with Aluminum (AlSi10Mg) and Titanium (6Al-4V), which are also suitable for milling operations.

3.4. Evaluation and selection of solutions

Different charts are available to review and compare solution options. The tabular view helps to arrange the solutions in order. Furthermore, it is possible to modify certain aspects, such as weight, cost and deformation.

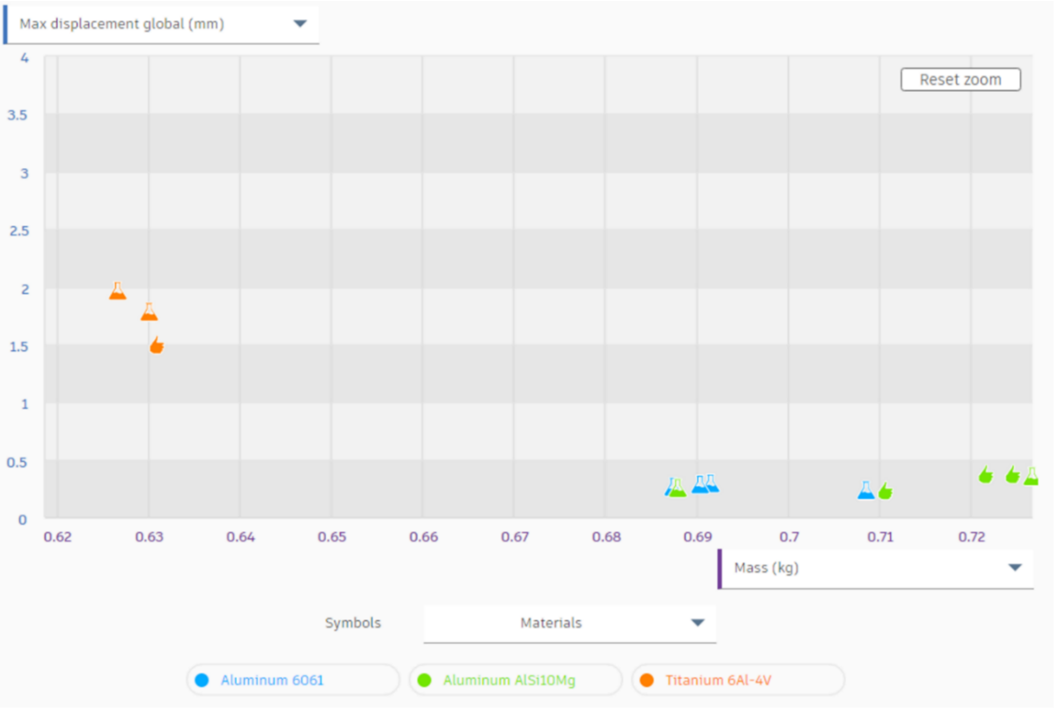

Figure 5. Evaluation of solutions based on different raw materials.

Figure 5. shows the evaluation of each solution according to the material and the deformation caused by the load. The colors indicate the individual raw materials.

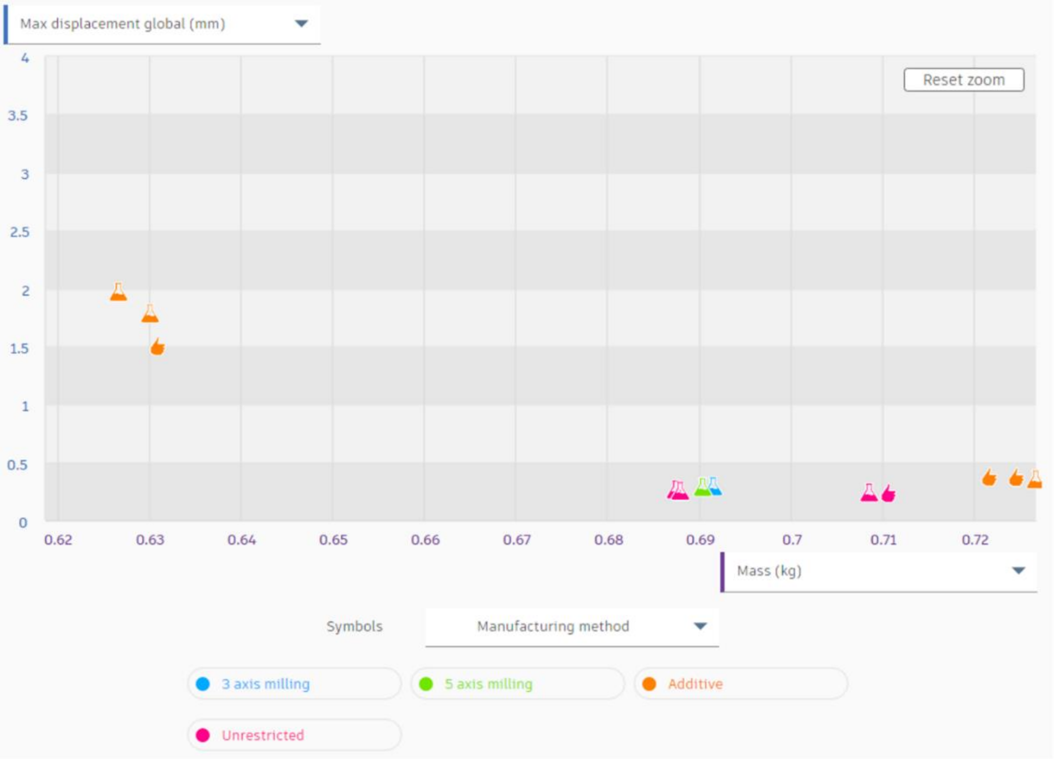

Figure 6. Evaluation of different production technology solutions depending on mass and maximum displacement.

Figure 6. shows the evaluation of each solution according to the material and the deformation caused by the load. The colors indicate the processing method.

Based on the obtained results, it can be concluded that the solutions with the smallest mass can only be achieved with additive manufacturing technology. The raw material of these solutions is Titanium, but they have the largest deformation in the loaded state. If the basic material is replaced with Aluminum, we get stiffer but heavier parts.

Figure 7. Selected solution I, solution II, solution III.

Three constructions were selected among the generated solutions. The parameters of each solution are summarized in Table 2. One of the easiest and also the most difficult solutions were selected from the entire set, which represent the extreme cases. The construction chosen from the middle field can be made with Aluminum raw material and traditional cutting technology. The results show that the cutting technology has no negative effect on the obtained results only in extreme cases. The second concept became the final solution, which also meets the requirements for weight reduction and strength. In the case of the smallest mass solution, one would have to work with expensive raw materials, which are combined with expensive production technology.

	Solution I.	Solution II.	Solution III.
Manufacturing technology	Additive Y+	5D milling	Additive Y+
Raw material	Ti 6Al-4V	Al 6061	Al 6061
Mass	0.76	0.695	0.825
Deformation	0.7	0.29	0.18
Safety factor	4.5	6.46	5.5

Table 2. Analysis of solutions.

4. Summary

In the article the development of the field of product design, which forms the basis of generative design, was presented. The factors affecting the spread of the generative design process were also intoduced. The article proposed the steps of the currently explored design process of generative design, the accuracy and applicability of which was examined within the framework of a case study. The study presented the work processes of each step in an integrated CAD system. By going through all the necessary steps, the article can present effective solutions for the stated design needs. Some elements of the solutions obtained during the used design method are compared in Table 2. Numerical data prove that the given method can be used for the purpose of weight reduction, regardless of the production methods.

References

[1] Takács, Gy., Zsiga, Z., Szabóné Makó, I., Hegedűs, Gy.: Methodical design of production tools, Nemzeti Tankönyvkiadó, (2011), Miskolc (in Hungarian)

[2] Hegedűs, Gy.: Application of Knowledge-Based Design in Computer Aided Product Development Lecture Notes in Mechanical Engineering, pp. 109-114., (2017)

[3] Hegedűs, Gy.: The application of methodical design to industrial measuring machine development, PhD Students Forum, 2002: Proceedings of Faculty of Mechanical Engineer-ing (2002), Miskolc (in Hungarian)

[4] Wohlers, T., Campbell, R. I., Huff, R., Diegel, O., & Kowen, J.: Wohlers report 2019: 3D printing and additive manufacturing state of the industry. Wohlers Associates (2019)

[5] Szabó, K.; Hegedűs, Gy.: Brief Overview of Generative Design Support Software, DESIGN OF MACHINES AND STRUCTURES 10: 2 pp. 123-132., 10 p. (2020), doi: 10.32972/dms.2020.023

[6] Szabó, K., Hegedűs, Gy.: Brief Overview of Generative Design Support Software, MULTIDISZCIPLINÁRIS TUDOMÁNYOK (2020), (in Hungarian) doi: 10.35925/j.multi.2020.3.39

[7] Fischer, X., Nadeau, J.-P.: Research in Interactive Design (Vol. 3): Virtual, Interactive and Integrated Product Design and Manufacturing for Industrial Innovation. Springer, Berlin (2011)

[8] Szabó, K., Hegedűs, Gy.: Steps of Generative Design in Integrated CAD Systems, MULTIDISZCIPLINÁRIS TUDOMÁNYOK (2020), (in Hungarian) doi.org/10.35925/j.multi.2020.4.43

[9] Szabó, K., Hegedűs, Gy.: Steps of Generative Design in Integrated CAD Systems DESIGN OF MACHINES AND STRUCTURES 11, No. 1 (2021), pp. 53-58. DOI: 10.32972/dms.2021.007

[10] Gönczi, D.: Essential features of topological Optimization tasks in Abaqus Final Program System, MULTIDISZCIPLINÁRIS TUDOMÁNYOK 11. (2021) 4 sz. pp. 177-187 (in Hungarian) doi.: 10.35925/j.multi.2021.4.22

[11] Frazier, W.E.: Metal additive manufacturing: a review. J. Mater. Eng. Perform. 23, 1917–1928 (2014)

[12] Zuo, K., Chen, L., Zhang, Y., Yang, J.: Study of key algorithms in topology optimization, Int J Adv Manuf Technol, 787–796 (2007), doi: 10.1007/s00170-005-0387-0

[13] Bendsøe, M.: Optimization of Structural Topology, Shape, And Material, Springer, Berlin, 1995, ISBN 978-3-662-03117-9, doi: 10.1007/978-3-662-03115-5

[14] Trautmann, L.: Product customization and generative design, Multidiszciplináris Tudományok (2021), doi: https://doi.org/10.35925/j.multi.2021.4.10

[15] Novotny, A., Sokolowski, J.: Topological Derivative In Shape Optimization, Springer, Berlin, 2013, ISBN 978-3-642-35244-7, https://doi.org/10.1007/978-3-642-35245-4

[16] Rozvany, G.: Aims, scope, methods, history and unified terminology of computer-aided topology optimization in structural mechanics, Struct Multidisc Optim 21, 90–108 (2001). https://doi.org/10.1007/s001580050174

[17] Huang, X., Xie, Y.: Evolutionary Topology Optimization Of Continuum Structures, Wiley, Chichester, 2010, ISBN 978-0-470-74653-0

[18] Tajs-Zielińska, K., Bochenek, B.: A heuristic approach to optimization of structural topology including self-weight, AIP Conference Proceedings 1922, 020001 (2018); https://doi.org/10.1063/1.5019028