Topology Optimization of a Bracket

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Introduction

This project entails the topology optimization of a bracket using the open-source finite element software FEniCS. The requirements for this project is to use the Method of Moving Asymptotes (MMA) to iteratively adjust the design variables, guided by asymptotes, in order of moving towards an optimized solution. Furthermore, a robust optimization approach as well as a double-filtering technique is required, where parallelization has been useful to shorten computation time.

The dimensions of the bracket are as shown in Fig. 1. The thickness of the part is 20 mm, however the topology optimization is performed in 2D to save computational effort. The meshing and boundary conditions are as shown in Fig. 2, where the part is fixed on the leftmost part (marked in red) and a force in the negative y-direction of F = -1000 N is applied to the bottom half of the hole (marked in white).

Fig. 1

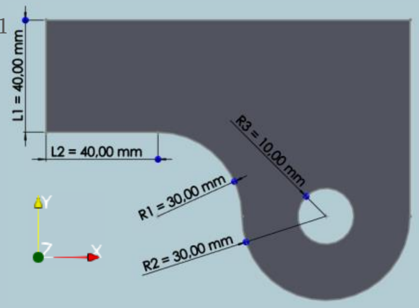
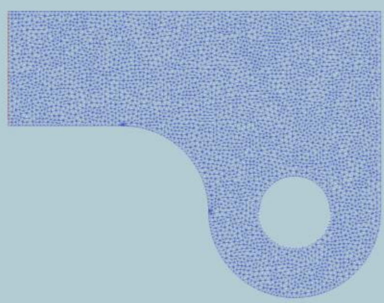


Fig. 2



The topology optimized geometry is constrained to allow a maximum volume fraction of 0.5, whilst minimizing compliance. The topology optimization applies a value of ρ between 0 and 1 to every element, where ρ=0 corresponds to an empty element and ρ=1 is an element with material. However, to avoid intermediate values of ρ to achieve a geometry with clean, sharp boundaries, (as well as fixing issues such as checkerboarding and mesh dependency problems), a Helmholtz filtering, Eq. 1, and Heaviside projection, Eq. 2, is performed.

$$-r^2\nabla^2\tilde{\rho}+\tilde{\rho}=\rho, \qquad \frac{\partial\tilde{\rho}}{\partial \mathbf{n}}=0$$

Eq. 1

$$H(\beta,\eta,\tilde{\rho})=\frac{\tanh(\beta\eta)+\tanh(\beta(\tilde{\rho}-\eta))}{\tanh(\beta\eta)+\tanh(\beta(1-\eta))}$$

Eq. 2

Results: Effect of β and η on the projection

The effect of β and η on the projection will now be investigated. The Heaviside function in Eq. 2 has been plotted for different β values in Fig. 3 and for different η values in Fig. 4.

Fig. 3

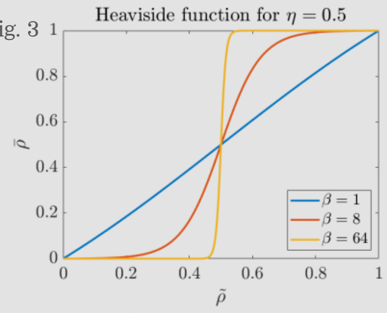
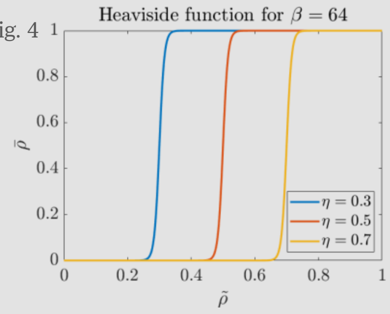


Fig. 4



From these figures it can be seen that β controls the steepness and η translates the Heaviside function. Firstly for the topology optimized structure, by altering the value of β it can be seen that as β increases the amount of intermediate values increase, and sharper boundaries are created. The β-value is altered in Figs. 5-8, where η = 0.3 for all:

Fig. 5

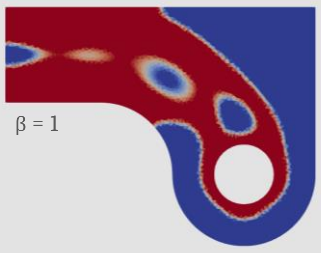


Fig. 6

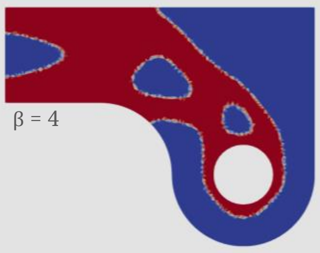


Fig. 7

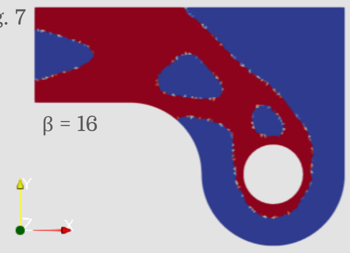
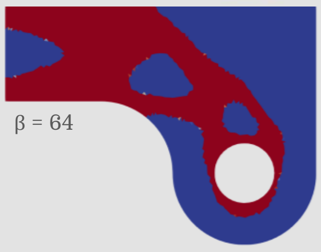


Fig. 8



Results: Effect of η, double-filtering and robustness

Figs. 5-8 have been created using a robust implementation, which performs the topology optimization for three values of η, an eroded case; η=0.3, a nominal case η=0.5 and a dilated case η=0.7. In Figs. 5-8 eroded cases are shown, and in Figs. 9 & 10 the nominal and dilated cases are seen:

Fig. 9

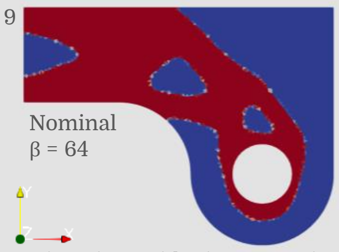
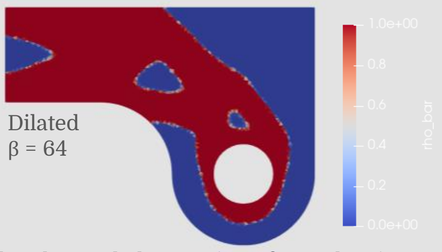


Fig. 10



Comparing Fig. 8 with Figs. 9 & 10 it can be seen that the eroded case, Fig. 8, favors leaving more elements empty, which is as expected from Fig. 4.

So far for the robust implementation a double-filtering approach has been used, which performs the filtering and projection twice. This is found to create geometries which are more likely to have the same topology than the ones in a single-filtering robust approach. The dilated and eroded designs for β = 64 for a single-filtering robust approach is shown in Figs. 11 & 12.

Fig. 11

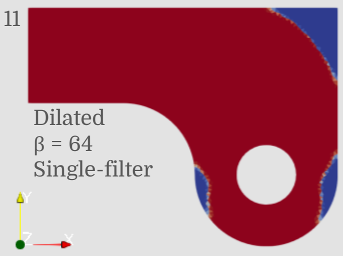
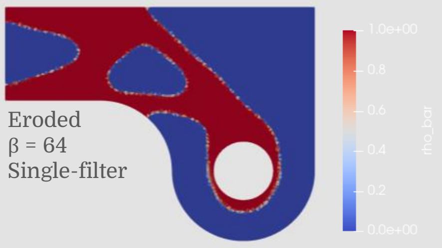


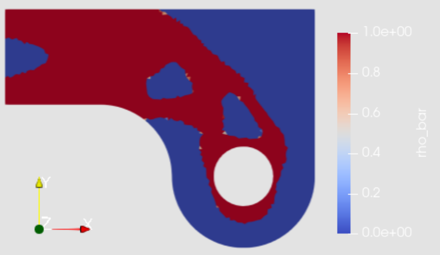
Fig. 12



It can be seen that using the single-filtering approach the difference between the dilated and eroded designs are vastly more different than when using the double-filtered approach shown in Fig 10 & Fig. 8 for dilated and eroded cases. Additionally, it is worth noting that the boundaries in the eroded case are significantly less sharp in the single-filtered case, Fig. 12, compared to the double-filtered case, Fig. 8.

The robust method not only tries different η-values, but also has a slightly different implementation compared to a non-robust method, since the robust method optimizes for a worst-case scenario of the design using what is known as a min-max formulation. Here the geometry has been created <u>without</u> this min-max formulation using a single-filtered non-robust approach:

Fig. 13
Non-robust
Single-filter
β = 64
η = 0.3 (same as eroded)



Results: Parameters of MMA – adjusting kmax

The method used for the optimization is the MMA as previously mentioned. It contains an inner and outer loop, where it solves a number of sub-problems in the inner-iterations after which it moves an index in the outer loop. You can alter the efficiency and/or accuracy of your MMA-algorithm for your specific problem by changing different parameters of the MMA-algorithm, to e.g. make it take smaller steps for solving more complicated problems (at the cost of computational time) or adjusting the number of maximum number of inner and/or outer steps.

In this case the effect of adjusting the maximum outer loop iterations, kmax, is investigated, for the double-filtering, robust case. Here for k = 10 (k is the iteration step):

Fig. 14

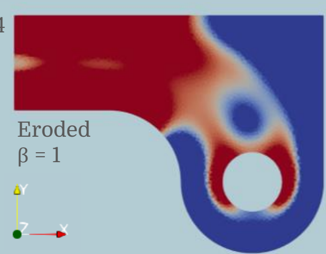
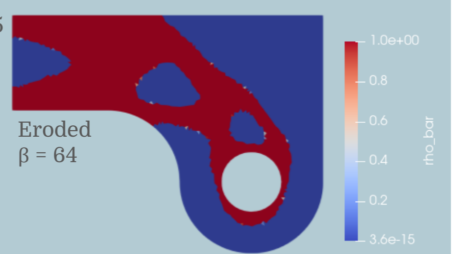


Fig. 15



Comparing the two eroded cases where β = 64, Fig. 15 & Fig. 8, where k = 10, and k = 25 respectively, no large difference can be seen. However, at lower β-values such as β=1 when comparing Fig. 14 & Fig. 5 also with k = 10, and k = 25 respectively, a large difference can be seen, since for k = 10, the solution has not converged yet. As such it is important to choose a sufficiently large kmax value to ensure convergence

Concluding remarks

In this project different methods of topology optimization of a simple bracket structure has been performed. The effect of filtering and projecting to allow more or less material to be empty or full has been investigated, as well as the effects of double-filtering, robustness and adjusting the maximum amount of outer iterations in the MMA-algorithm.

It has been found that, the β, η, kmax and double-filtering definitely has a significant effect on the topology optimized structure. When comparing the non-robust and the robust method only small differences were found, and thus for such a simple case both these methods produced useable results in a practical sense. Robustness are more important in more complicated cases, to avoid issues such as single-node connections in compliant mechanisms.

Sources and inspirations

- The equations and theory used stems from the course "Topology Optimization"
- The idea for the project was inspired by a similar project from the course "Design for Manufacturing and Reliability"
- The python codes: mma.py, parallel.py and filter_and_project.py are provided from the "Topology Optimization" course.
- The python codes: bracket_mma.py and cantilever_bracket.py are built upon provided codes from the "Topology Optimization" course
- The template for the research poster is provided by "posternerd.com"