Topology Optimization of 3D Printed Lattice Structures using Machine Learning Algorithms

Loukas Athinaios-Athinadis, 1059811

Diploma Thesis

Supervisor: Loutas Theodoros

Applied Mechanics Laboratory

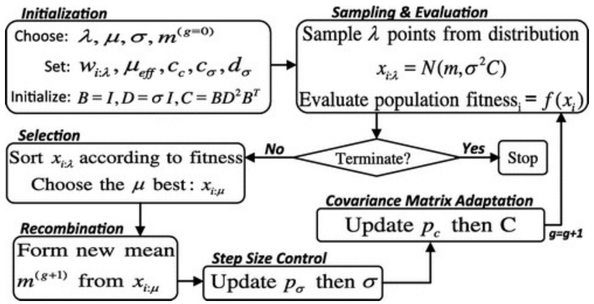
1. Introduction

The rapid advances in technology in recent decades have resulted in the demand for materials with improved mechanical behavior. Lattice structures are a new promising class of materials with unusual properties and performance. Using Machine Learning, the obstacle of finding the best lattice design can be addressed.

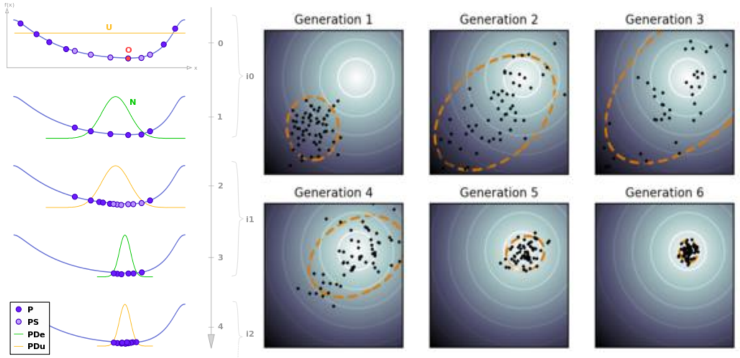
In the present thesis, the topology optimization through the Covariance Matrix Adaptation Evolution Strategy algorithm (CMA-ES) of lattices subjected to compressive loads is presented. Two different optimizations were performed, the first one focusing on the minimization of the mass-to-shear-strength ratio while the second one on the mass-to-resilience ratio. The procedure involved the use of the programs nTopology (3D design of the lattice) and Abaqus (compression simulation). The combination and communication of the algorithm with the programs was performed using code in Python programming language. For each optimization 10 iterations were performed, considering 4 candidate models in each one (40 models in total per optimization). Finally, the optimal model was 3D printed and subjected to a compression test to verify the results.

2. Machine Learning: CMA-ES algorithm

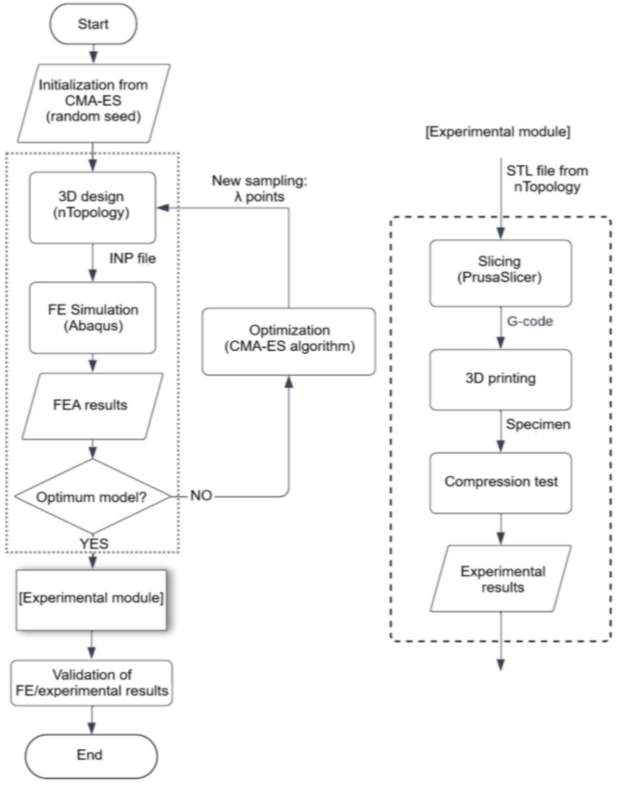
CMA-ES workflow:



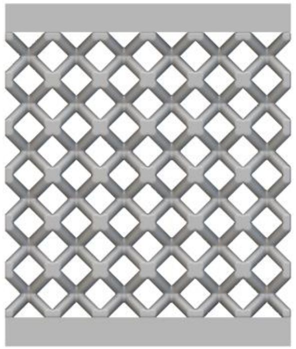
Optimization with sampling λ points from normal distribution with covariance matrix C:

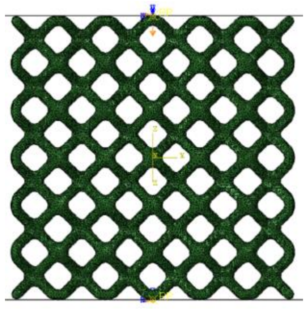


3. Optimization process



4. 3D model & FE model

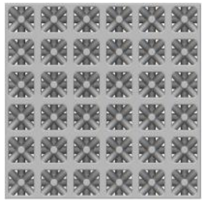

3D model in nTopology

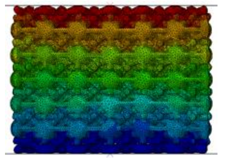

FE model in Abaqus

5. Results

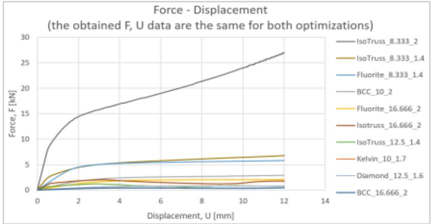
5.1 Optimum model (IsoTruss_8.333_2):

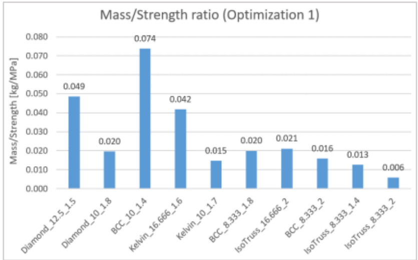
(the optimum model is the same for both optimizations)

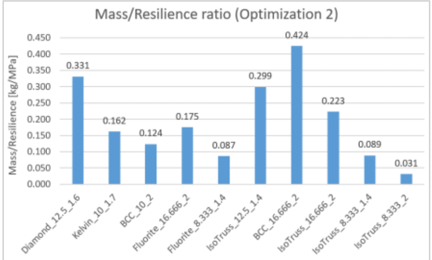

3D optimum model in nTopology


Deformed optimum model in Abaqus

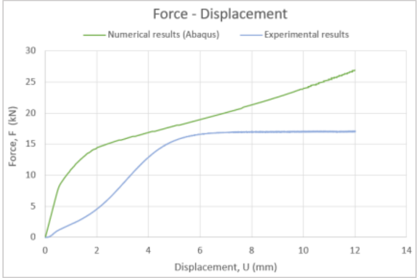
5.2 Comparison of 10 models for each optimization:

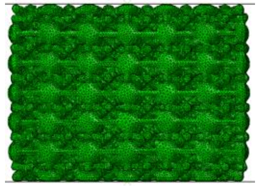






5.3 Experimental validation of the optimum model (IsoTruss_8.333_2):




Deformed model in Abaqus


Deformed model after compression test

6. Conclusions

1) Both optimizations output the same model as optimum:
Cell: Iso-truss, cell side dimension: 8.333mm, strut thickness: 2mm

2) An increase in strength of up to 293% was observed, compared to the second-best solution.

3) The objective functions (mass/strength, mass/resilience) improved by -54% and -64% respectively, compared to the second-best solution.

4) It is worth noting that with an increase in structure's relative density, the improvement in strength significantly outweighs the simultaneous negative effect of mass increase.

5) The experimental results of the optimum model show a significant deviation of 92% in strength from the FE results. This leads to the conclusion that FDM printing method is inappropriate for manufacturing lattices of this scale due to the existence of multiple defects in the specimen structure. As a recommendation for future studies, SLA printing method might provide more accurate results.