Graduation Plan

Master of Science Architecture, Urbanism & Building Sciences

Graduation Plan: All tracks

Submit your Graduation Plan to the Board of Examiners (Examencommissie-BK@tudelft.nl), Mentors and Delegate of the Board of Examiners one week before P2 at the latest.

The graduation plan consists of at least the following data/segments:

Personal information	
Name	Stella Pavlidou
Student number	5385571

Studio		
Name / Theme	Building Technology - Sustainable Structures	
Main mentor	Dr. Charalampos Andriotis	Structural Design and Mechanics
Second mentor	Dr. Michela Turrin	Design Informatics
Argumentation of choice of the studio	Topology exploration is a topic I was particularly interested in before applying for my Master's degree. During MEGA course I was introduced to the concept of multi-objective optimization and decided that I wanted to be more involved in this area. AI is an innovative technology that will change the way we design and configure solutions. Exploring the possibilities of integrating AI into the concept of Generative Design and Topology Optimization was a topic that combined all the fields that interested me and would allow me to expand my knowledge and learn new computational tools.	

Graduation project	
Title of the graduation project	Deep Generative Design A deep learning framework for optimized shell structures
Goal	
Location:	-
The posed problem,	The topology of shell structures is critical and affects cost, assembly time, structural performance, and aesthetics. Designers and engineers need conceptual and practical tools to explore it. There are many variants that describe a design and exploring the design space for optimum solutions is a time-consuming process. Generative Models

	that integrate Artificial Intelligence can minimize the number of variants in a smaller sized space and could potentially be integrated in an optimization workflow.
research questions and	Main Question According to the problem statement, mentioned above, the main research question is if an AI based framework can generate new structurally effective solutions, in relation to the dataset that was used for training. This would prove that AI can be a powerful creative assistant for designers and engineers, and could potentially help expand the possibilities of generative design. **Sub-question** • Can a Variational Autoencoder be trained to generate mesh tessellations? • What form of data can be used to train a Variational Autoencoder to generate mesh tessellations? • Can a surrogate model learn to predict the structural performance of encoded data occurring from samples describing truss shell structures? • Can a surrogate model learn to predict the structural performance of decoded data occurring from samples describing truss shell structures? • Can a Gradient Descent Optimizer propagate back to

	encoded data to search for optimum solutions?
design assignment in which these result.	The purpose of this thesis is to prove that AI can be a powerful assisting tool for designers and engineers. A helpful AI workflow would request for certain boundary conditions as an input (such as shape, structural performance, etc) and produce effective solutions. Due to time limitation this thesis is restricted in terms of input criteria. The criterion for the suggested workflow is structural performance for mesh shell patterns with specific boundaries. This workflow includes a generative model able to produce mesh tessellations with a specific boundary and a surrogate model able to predict a design's structural performance. The architecture of the generative model is that of the Variational Autoencoder, an Artificial Neural Network architecture introduced by Diederik P. Kingma and Max Welling (Kingma & Welling, 2014). A Gradient Descent Optimizer is integrated in the workflow to search the design space for effective solutions. A training dataset is needed that according to bibliography should exceed 1000 samples. The samples need pre-processing to be used in training machine learning models. Appropriate options for the form of the training dataset will be explored. Computational power is crucial in training machine learning models. For

	this reason, TU Delft's supercomputer "Delftblue" is used.

[This should be formulated in such a way that the graduation project can answer these questions.
The definition of the problem has to be significant to a clearly defined area of research and design.]

Process

Method description

Literature Review: The first step is to investigate existed research examples. The methods for pattern generation in shells structures must be defined. Then existed research for generative design and optimization using AI models will be reviewed. During this process, the computational tools that will be used have to be specified. To familiarize with these tools and models, an experimentation with existed tutorials is needed.

Design the Training and Optimization Framework: Based on the literature review a framework will be proposed that might be altered slightly during the training process

The proposed steps are:

- Create the dataset and measure its structural performance (performance indicators will be displacement, utilization and the structure's mass), using Finite Element Method software (FEM).
- Train a Variational Autoencoder with the produced data.
- Decoded Data is used to train a surrogate model that is able to predict a design's structural performance.
- Use a Gradient Based Optimizer that propagates back to the encoded data to search for best solutions.
- Produced results are assessed to see if more effective solutions are generated.

Literature and general practical preference

The first step is to investigate existed research examples. The methods for pattern generation in shells structures must be defined. Then existed research for generative design and optimization using AI models will be reviewed.
During this process, the computational tools that will be used have to be specified. This involves, programming languages (Python, Grasshopper), FEM software(Karamba3D), AI models (VAEs, surrogate models, gradient descent algorithms).To familiarize with these tools and models an experimentation with existed tutorials is needed.

Key References

Shell structures:
Oval, R., Rippmann, M., Mesnil, R., Mele, T. Van, Baverel, O., & Block, P. (2019). Automation in Construction Feature-based topology fi nding of patterns for shell structures. Automation in Construction, 103(May 2018), 185–201. https://doi.org/10.1016/j.autcon.2019.02.008

Deep Learning Framework:
Gladstone, R. J., Nabian, M. A., Keshavarzzadeh, V., & Meidani, H. (2021). Robust Topology Optimization Using Variational Autoencoders. 1–20. http://arxiv.org/abs/2107.10661

Reflection

1. What is the relation between your graduation (project) topic, the studio topic (if applicable), your master track (A,U,BT,LA,MBE), and your master programme (MSc AUBS)?

The "Building Technology" Master Track covers topics linked to both to architectural design and engineering. It encourages students to follow a wide range of courses; structural design, generative design, climate design, construction detailing, computational design, all approached in relation to sustainability, efficiency and interrelationship. This is because interdisciplinary thinking is key to creating innovative solutions to real-time problems.

Over the last years, computational design has enabled new possibilities of design exploration, with respect to qualitive and quantitative criteria. The integration of generative computational tools in the early stages of design was a breakthrough for the architectural community, allowing designers to find the ideal cross-section where architectural concept, engineering requirements, sustainability and efficiency are met.

The current graduation thesis attempts to broaden the possibilities of generative design through Artificial Intelligence (AI) for a common design task: topology exploration and optimization. In this direction computer science, generative design and structural optimization are combined through a generative workflow, to test if AI can contribute to assisting efficiently designers and engineers in the early decision-making stage of topology exploration.

2. What is the relevance of your graduation work in the larger social, professional and scientific framework.

In an urban context facing population growth and displacement, while existing and aging infrastructure must be adapted to climate change, the construction industry faces the need to take immediate action. Designing workflows that allow fast and easy exploration of the design space, but also make no compromises regarding the quality of the result with respect to qualitative and quantitative criteria, is the key to addressing current design challenges.

The topology exploration for shell structures that occur from mesh tessellations is a time consuming process operated in the early stages of design. To generate solutions initial parameters have to be specified and there are countless variables on which the structure's outcome depends. This projects suggests an AI workflow able to minimize the variables that describe a shell structure, predicts its structural performance and search for structural optimum solutions. The results of the research are encouraging for expanding the capabilities of generative design though AI integration, easing the decision making process and improving an optimization workflow.