Parametric Modelling and Generative Design of Concrete Structures

Investigation and Evaluation of Generative Design Toolboxes for the Bridge Design Case

Leitung Prof. Dr. W. Kaufmann

Betreuung Dr. Michael Kraus
Georgios Klonaris

Studierende Nathalie Chiaverio

Institut für Baustatik und Konstruktion

Introduction

The design of structures, and especially the bridge design case, involves a lot of different design parameters. Together with possible objectives and performance goals, this can lead to a vast amount of different design options. Recently, there is an increasing interest in finding options of performing early design space exploration instead of simply validating initial design choices. As a consequence of the steadily growing use of Artificial Intelligence (AI), Generative Design has become a possible approach for the described problem.

Problem Statement and Objectives

This thesis investigates and evaluates different existing Generative Design toolboxes for the bridge design case. The idea of creating a continuous workflow has already been investigated in the last years. One major part of the thesis forms the examination of the toolbox *Design Space Exploration.* Besides others, it offers a multi-objective optimisation feature based on the genetic algorithm NSGA-II. In the thesis, it is also looked at the tool *Octopus*, which uses the evolutionary algorithms HypE and SPEA2. Moreover, other optimisation features are analysed.

Methods

The investigated toolboxes are all plugins for *Grasshopper*, which is a parametric programming language for the 3D-modelling software *Rhinoceros 3D*. Therefore, in order to test the tools, a *Grasshopper* model of the floor system of a bridge is implemented. The used reference bridge is the Blennerhassett Island Bridge, which is located in West Virginia.

Figure 1: Blennerhassett Island Bridge, arch only

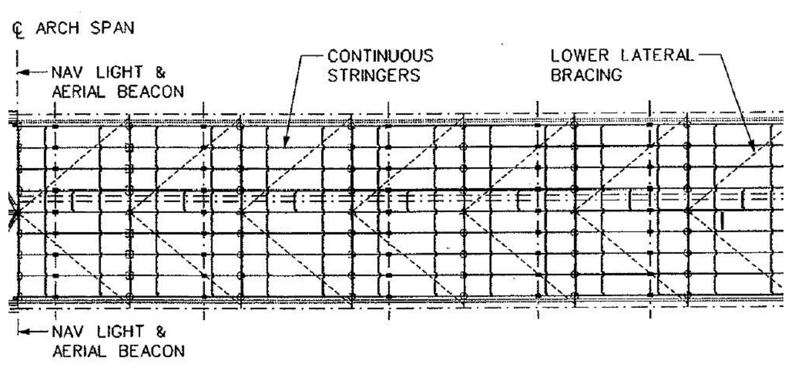

Figure 2: Floor system of the bridge

For the application of the toolboxes, design variables and objective functions need to be defined. The parameters that are varied, as well as the objectives are shown in Figure 3. In order to achieve the utilisation goal, a loss function is introduced. The loss function punishes the values, which do not have a utilisation of 1. With the help of asymmetry, invalid designs can be penalised more.

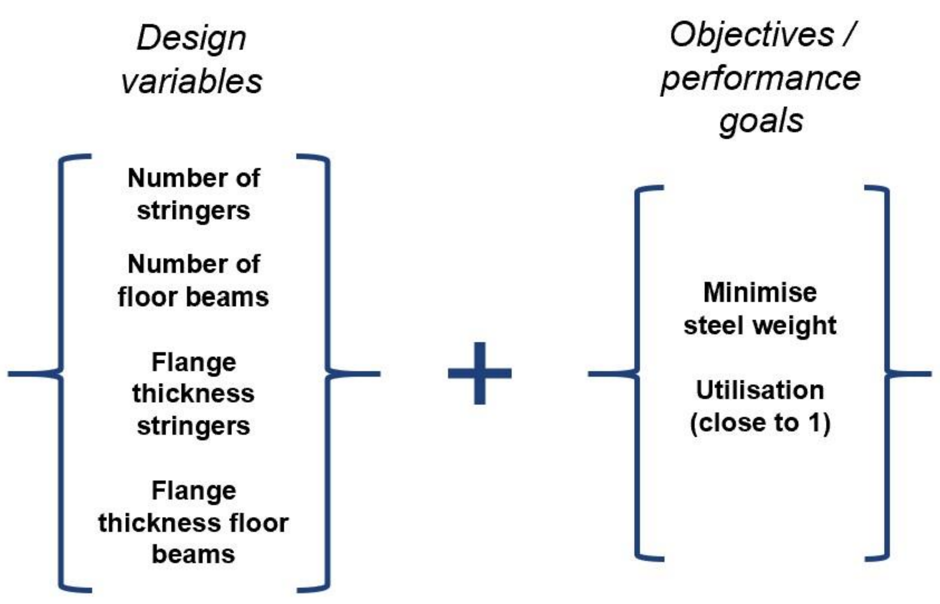

Figure 3: Design variables and objectives

Results

Figure 4 illustrates the data generated by the *DSE.* The design points are distributed in the entire design space, while there is a small accumulation of the data in the low steel weight area. The optimal result with a valid utilisation has a decreased steel weight of around 10 % compared to the base case, which is marked in red. Figure 5 underlines the high amount of data with an utilisation ≥ 1, in fact around 71 % of all data is not valid.

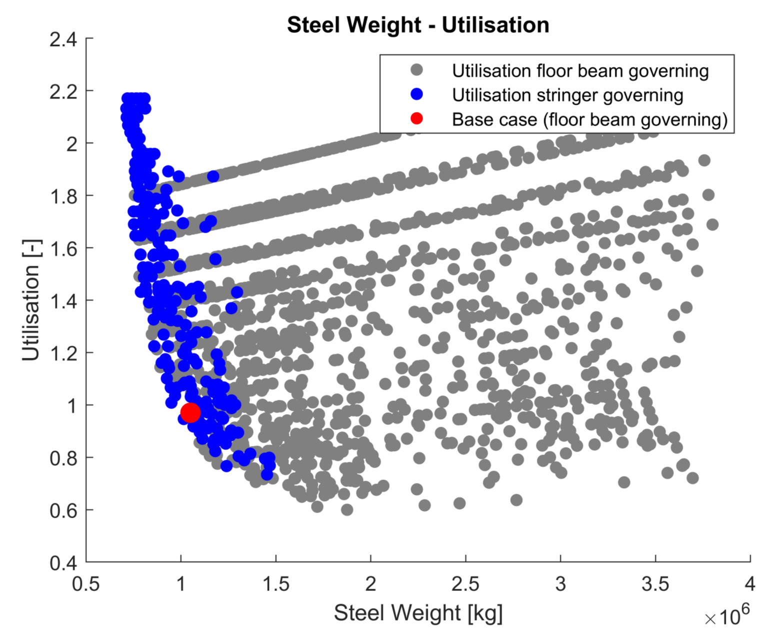

Figure 4: Data generated by *DSE*

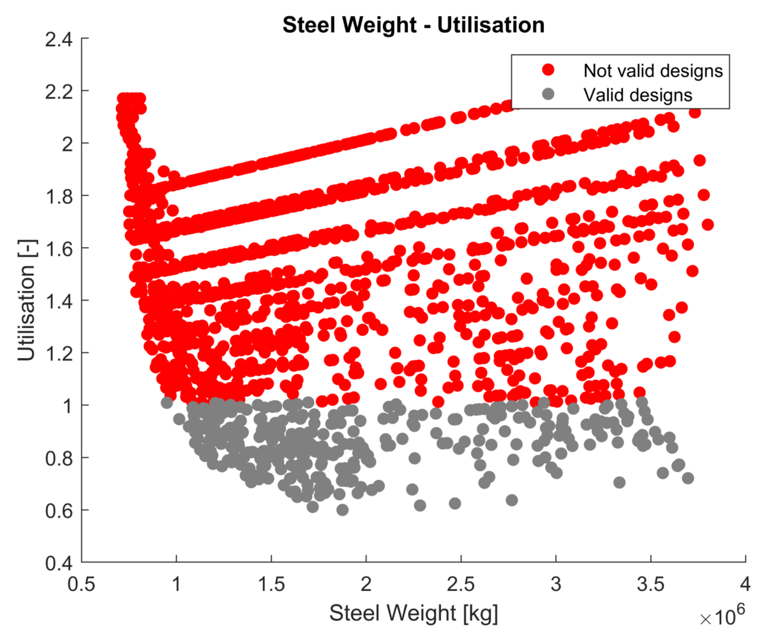

Figure 5: Valid and not valid designs, generated by *DSE*

The high amount of invalid designs is likely to be a result of the used algorithm. However, the definition of the objectives, as well as the implementation are also critical for the generated output.

Figure 6 presents the data generated by *Octopus*. The pareto front, the region with optimal designs, is much more pronounced than for the *DSE.* Moreover, the number of invalid designs is only around 19 %. For optimisation purposes in the engineering field, the used algorithm of *Octopus* seems to be more suitable than the NSGA-II.

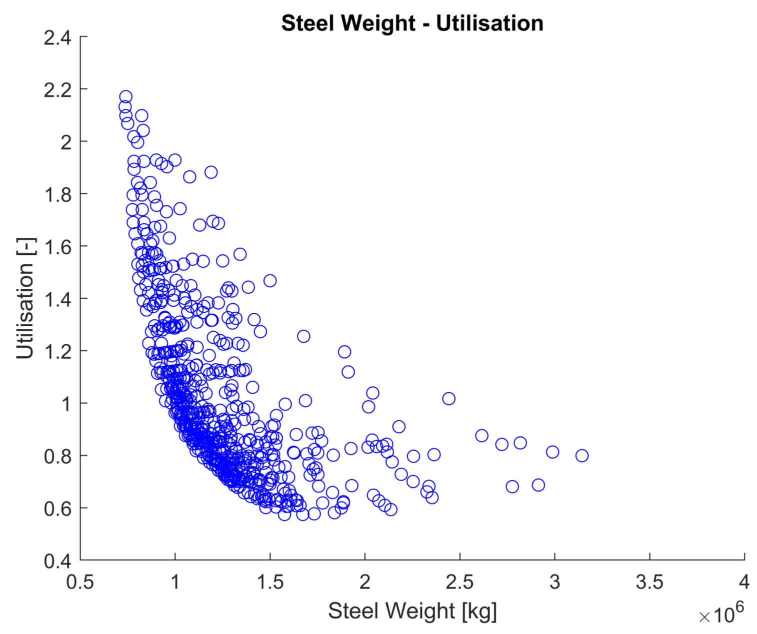

Figure 6: Data generated by *Octopus*

Conclusion and Outlook

In conclusion, the use of Generative Design toolboxes can be beneficial for the conventional design process in the engineering field. They can enable the generation of various design options and automate the iterative process of finding a design optimum. From an economical and a social point of view, the choice of an appropriate optimisation algorithm is crucial, though. Using an algorithm that is not suitable can lead to a high amount of wasted computing effort and in the end, the disadvantages can even predominate the advantages.

As an outlook, the further investigation of the loss function in order to reduce the invalidity ratio is an important factor to be examined again more closely. In the end, the overall aim should be the identification of the best suitable multi-objective optimisation algorithm. Thus, it would be possible to develop a new Generative Design tool, which supports the engineer in the design and optimisation process of concrete structures and bridges in the best possible way.