Parametric Modelling and Generative Design

A Multi-Step Machine Learning Approach for Design and Optimization of Network Tied-Arch Bridges

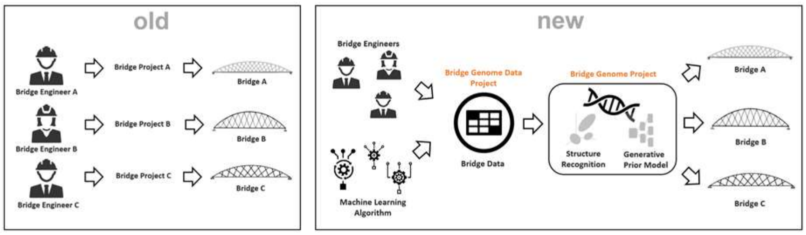
Institut für Baustatik und Konstruktion

Supervision: Prof. Dr. W. Kaufmann
Tutors: Dr. Michael A. Kraus, Georgios Klonaris

Student: Sophia Kuhn

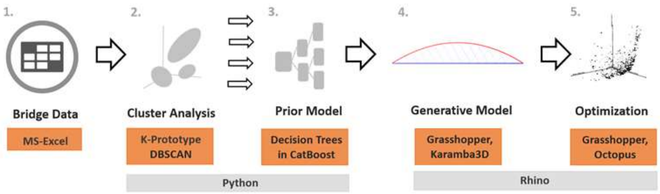
Introduction

Conceptual structural design today relies heavily on the intuition and experience of the structural engineer, often includes an investigation of similar reference projects, and is mostly a time-consuming and demanding task that is characterized by many iteration steps. This thesis hypothesizes that conceptual structural design as we know it today can be greatly assisted and improved by using modern machine learning (ML) methods.



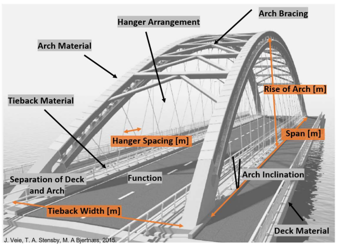
Overview

A multi-step ML approach to improve the design and optimization process of network tied-arch bridges was developed. It utilizes pre-processed data of existing bridges (1) and generates clusters of continuous and categorical bridge parameters (2) which are used to train a prior model (3). Based on the parameter predictions of the prior model a parametric structural model is generated (4) and subsequently optimized (5).



1. Bridge Data Set

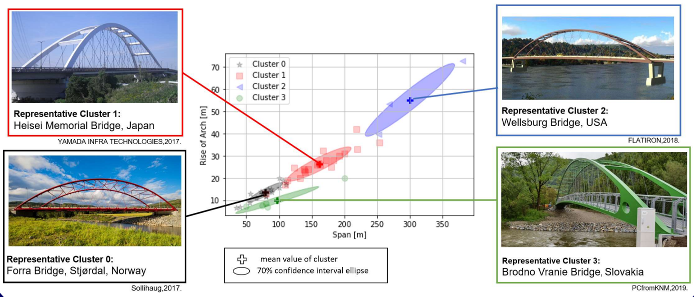
The basis forms a data set containing parameter information of existing network tied-arch bridges from all around the world. In order to appliy ML algorithms the data set containing both continuous and categorical data had to be preprocessed.



Continuous Parameter
Categorical Parameter

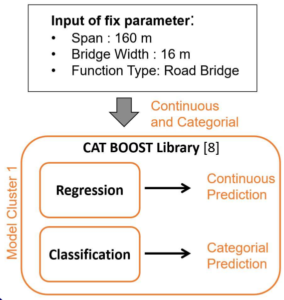
2. Cluster Analysis

Based on a pre-processed data set a cluster analysis is performed to find a structure within the data. Two unsupervised learning algorithms K-Prototype and DBSCAN have been successfully applied A consistent structure was identified by both algorithms showing strong similarities of all bridge parameters for network tied-arch bridges that are within similar span ranges.



3. Prior Model

A model is trained based on the available prior data that is capable of predicting suitable bridge parameters for a new project situation. The open-source CatBoost library was used due to its capability to handle mixed data types and applies regression and classification. It applies the supervised learning method of gradient boosted decision trees. The prior model is shown to provide well advised parameter predictions and therefore providing easy access to more complete information at an early stage.

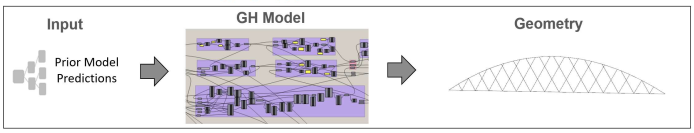


Output: Prediction Order	Predicted Values
1. Separation Deck –Arch (Yes/No)	No
2. Material Arch	Steel
3. Material Tiebacks	Steel
4. Material Deck	Steel-Concrete Composite
5. Rise of Arch	25.62 m
6. Hanger spacing	11.37 m
7. Hanger Arrangement	Parallel
8. Arch Inclination (Yes/No)	Yes
9. Arch Bracing	Cross Girder

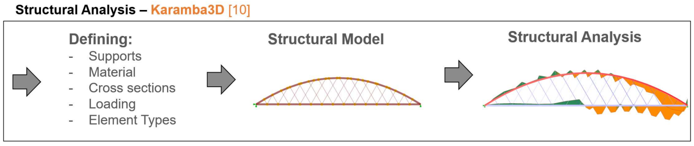
4. Generative Model

Based on the predictions made by the prior data model, a parametric structural model is constructed using Grasshopper and Karamba3D in the Rhino 7 environment. This Generative Model provides real-time structural analysis feedback for any parameter changes.

Parametric Geometry – Grasshopper (GH) [9]



Structural Analysis – Karamba3D [10]



5. Optimization

The plug-in Octopus is applied to conduct multi-objective optimizations of the bridge parameters using the genetic optimization algorithm HypE. Objective functions calculating material costs, structural efficiency, and aesthetic quality were applied. The use of machine learning algorithms to generate new bridge designs has been proven to reduce optimization time to find near optimum design solutions. Additionally, a first approach to include human aesthetic criteria was developed and successfully applied.

Conclusion and Outlook

In conclusion, the developed multi-step ML approach is found to be of valuable assistance to the structural engineer at the beginning of a structural design project. It improves the structural design and optimization process of network tied-arch bridges and provides a framework that can be directly applied to other suitable data sets of other frequently used structure types (e.g. hall constructions). The framework is capable of extracting and analyzing the knowledge saved in built structures of today and provides easy and fast access to this information. Predictions of the developed ML approach are based on detailed investigations of completed construction projects and therefore show a great potential to improve future construction projects by providing easy access to more complete information at an early stage. An identified limitation of the implemented approach is the small size of the data set the model is trained on. Additionally, the input of expertise and creativity by the structural engineer remain necessary as the machine learning model can adopt potential mistakes from the past and does not promote structural innovation.