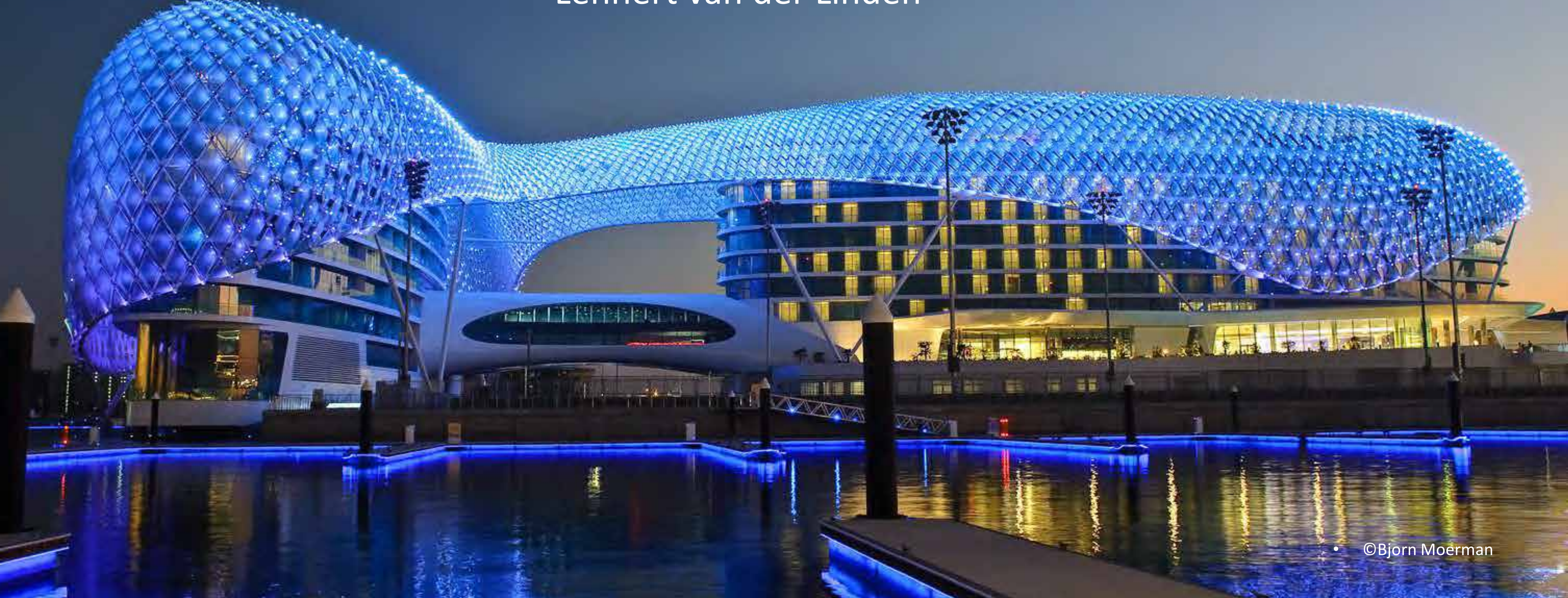
PARAMETRIC DESIGN AND ENGINEERING

Technische Universiteit Delft

Lennert van der Linden



- ©Bjorn Moerman

PARAMETRISCH ONTWERPEN

We kennen het van…


Zaha Hadid Architects


© Department of Public Works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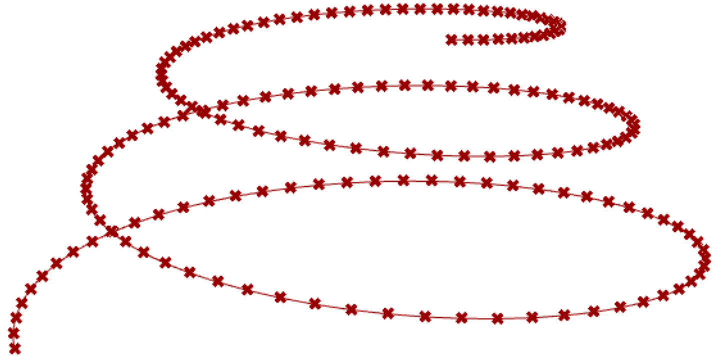
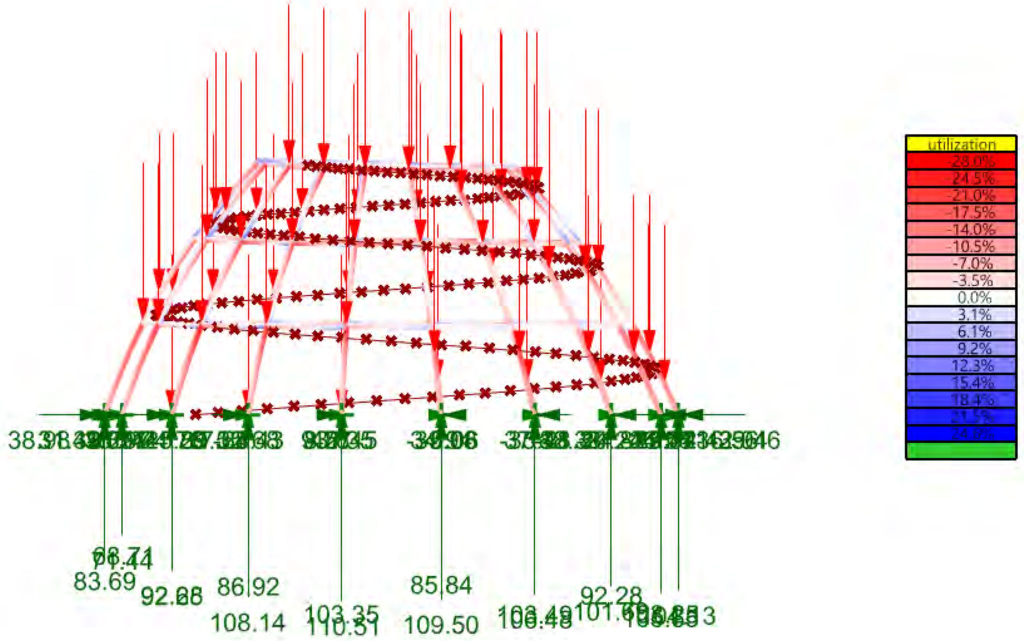
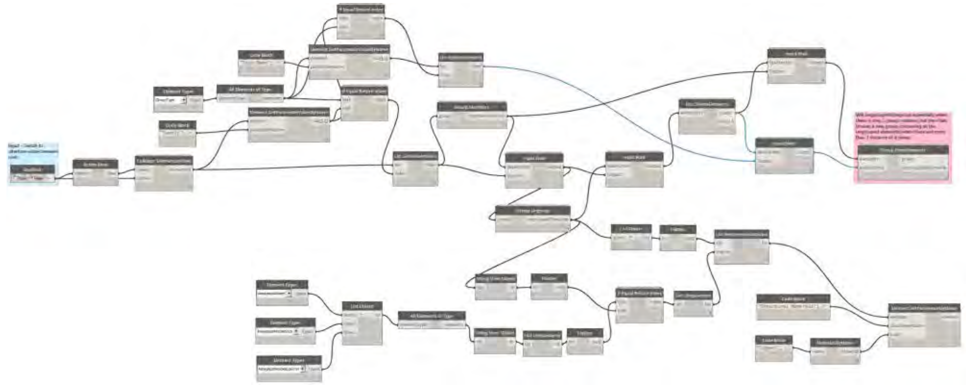
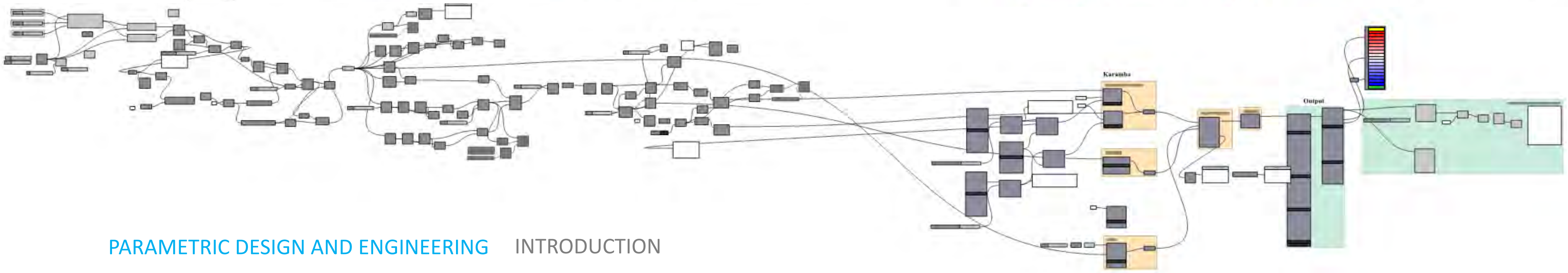
PYLON
Foto: Christian Richters, Gijs Dragt



$$r = a + b \cdot \theta^{1/c}$$







EEN OVERZICHT VAN HET VAK

IN VOGELVLUCHT

WAAROM IN HET ONDERWIJS?

- Veranderingen
- Marktbrede interesse
- Verwachtingen

LEERDOELEN

- Het ontwikkelen van een parametrische ontwerp denkwijze

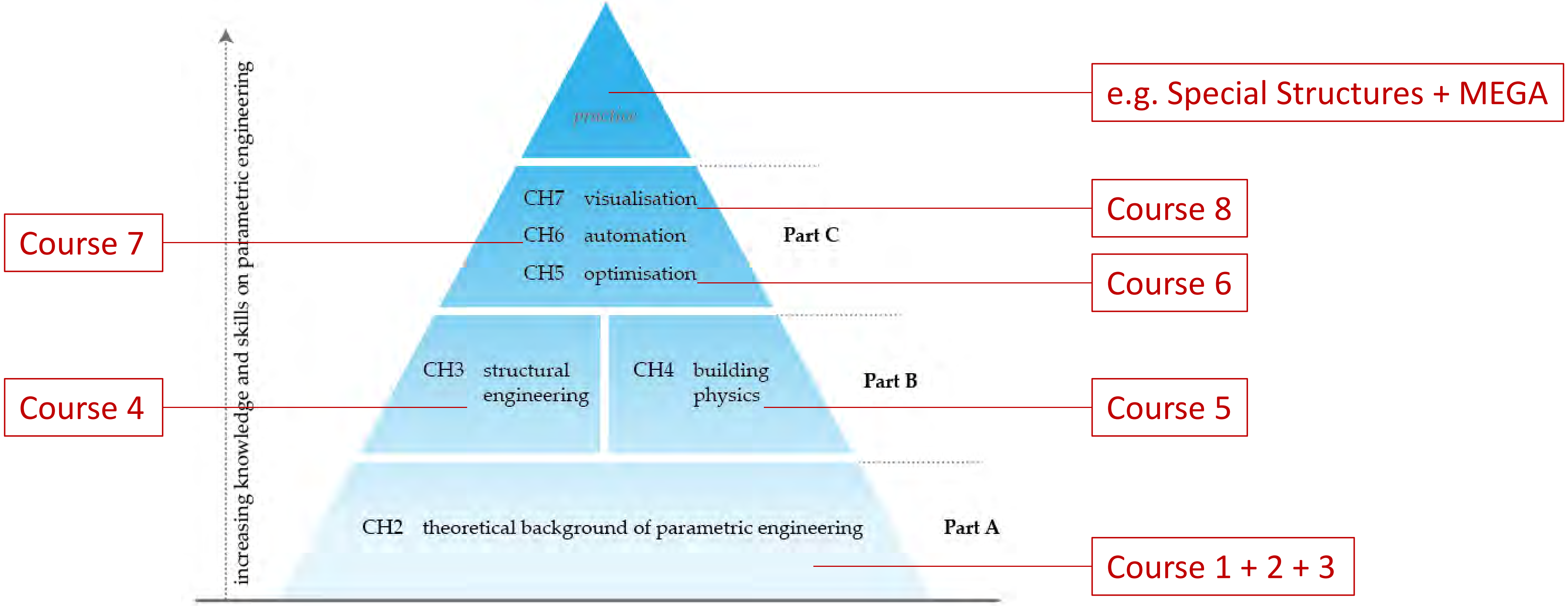
- Het opzetten van parametrische modellen en het manipuleren van geometrie
- Het koppelen van parametrische geometrie aan rekensoftware
- Het toepassen van optimalisatie algoritmes
- Het verifiëren van computer resultaten

ORGANISATIE

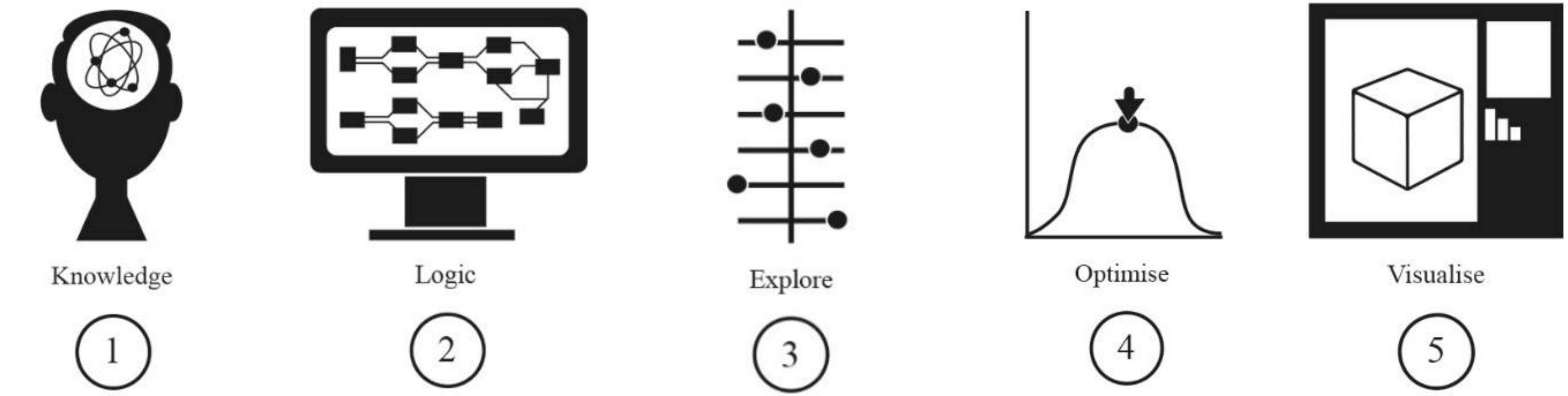
- Hoofddocent
  - Lennert van der Linden — TU Delft & Arup

- Gastdocenten
  - Andreja Andrejevic en Jasper Spiegeler — OMRT
  - Roy Crielaard — Heijmans
  - Matthijs Beekman en Roel Winter — VIKTOR
  - Rick Titulaer — Arup

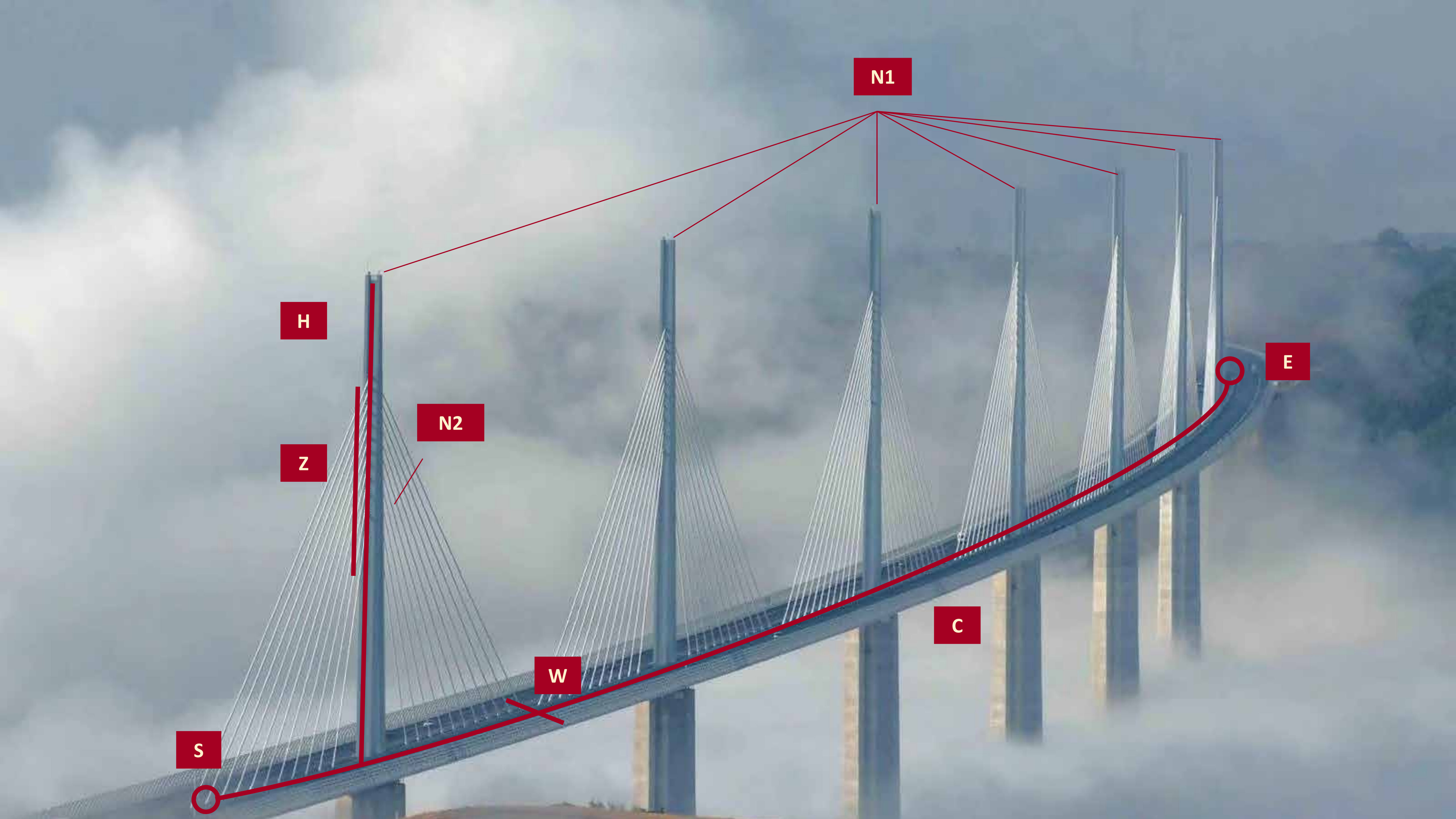
STRUCTUUR


e.g. Special Structures + MEGA
CH7 visualisation
CH6 automation
CH5 optimisation
Part C
Course 8
Course 7
Course 6
CH3 structural engineering
CH4 building physics
Part B
Course 4
Course 5
CH2 theoretical background of parametric engineering
Part A
Course 1 + 2 + 3
increasing knowledge and skills on parametric engineering

THEORIE



ACHTERGROND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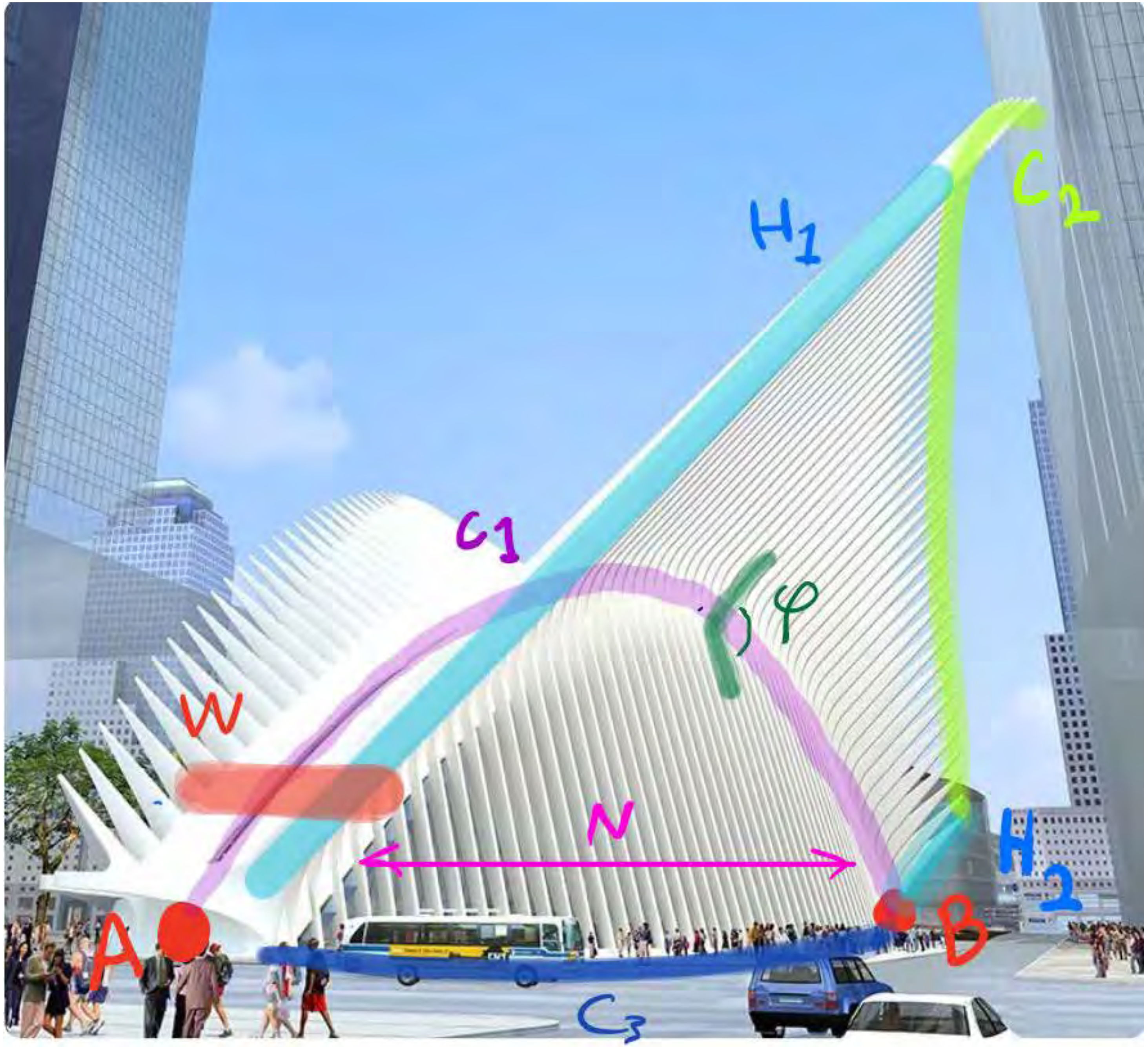
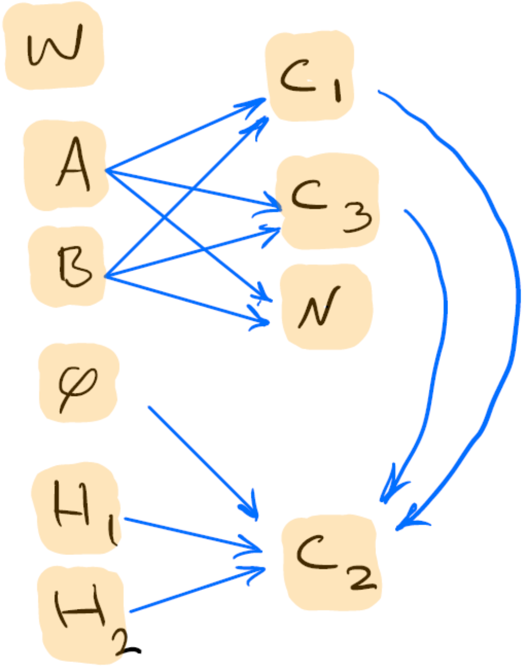
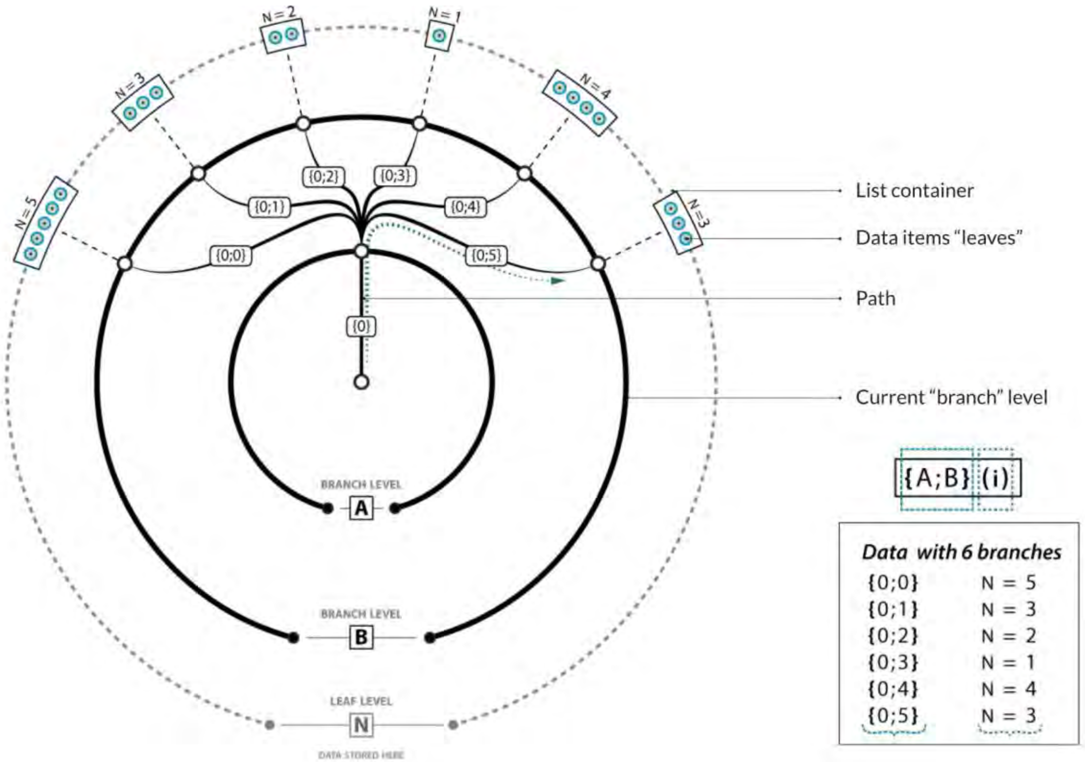




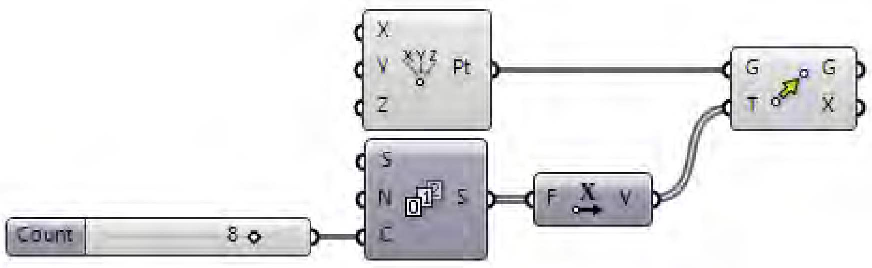
TU Delft

SOFTWARE

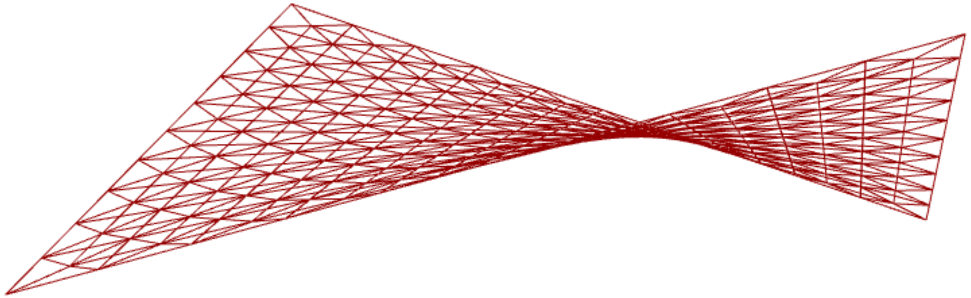
Rhinoceros® 6



SOFTWARE

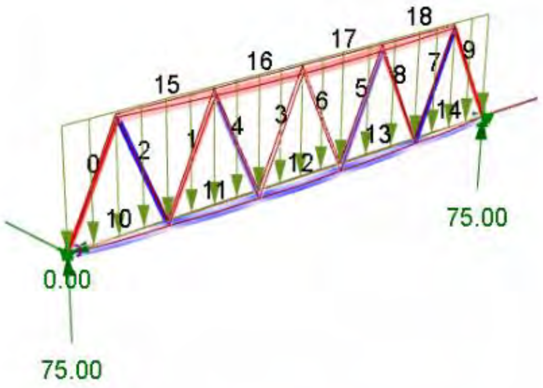


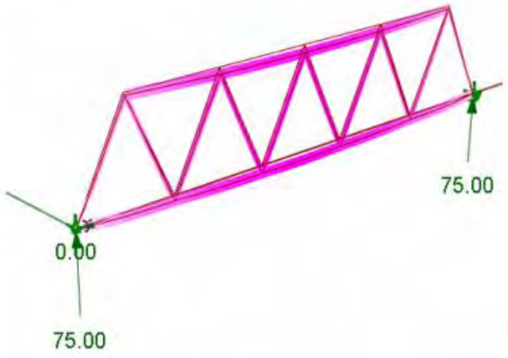
SOFTWARE

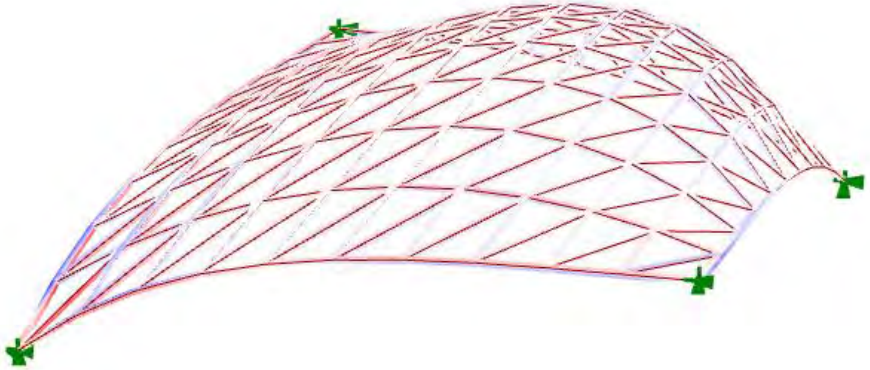


CONSTRUCTIEF ONTWERPEN

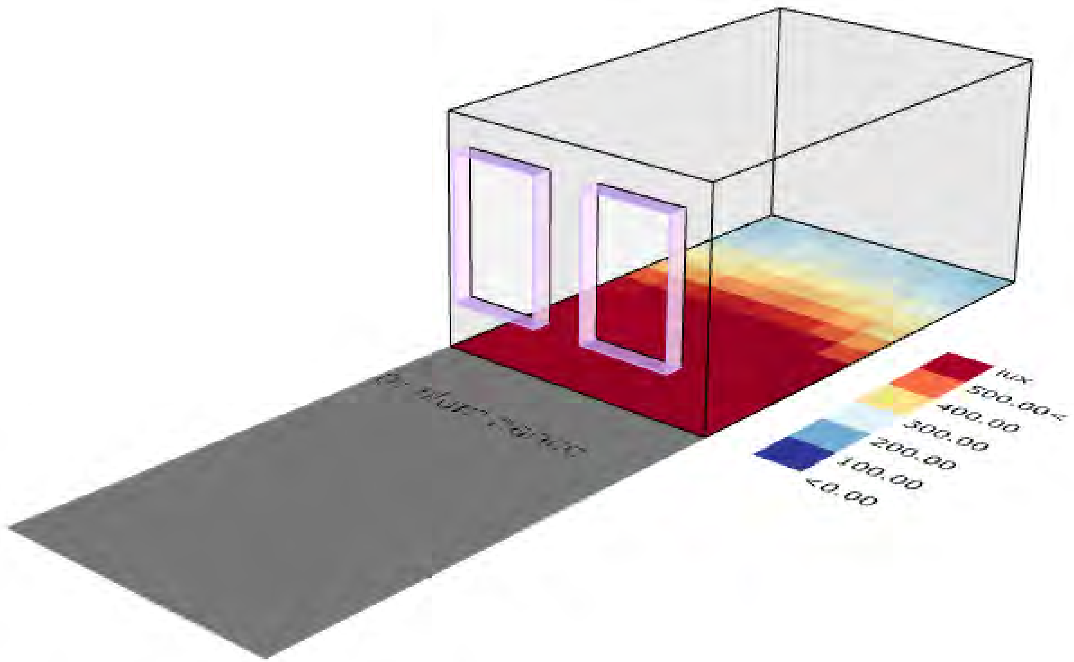
Karamba 3D
parametric engineering



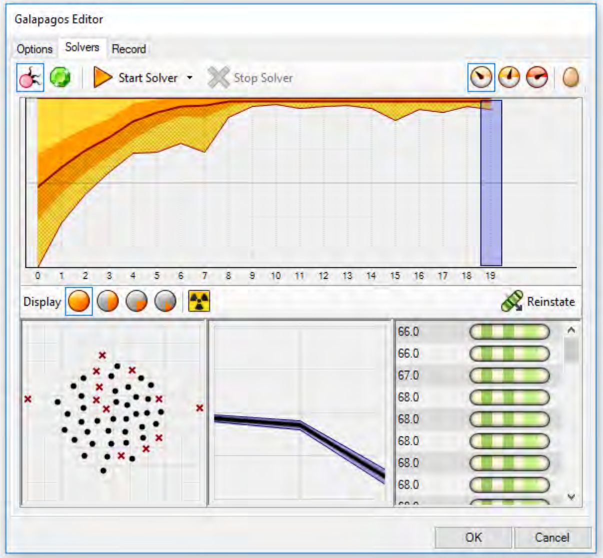


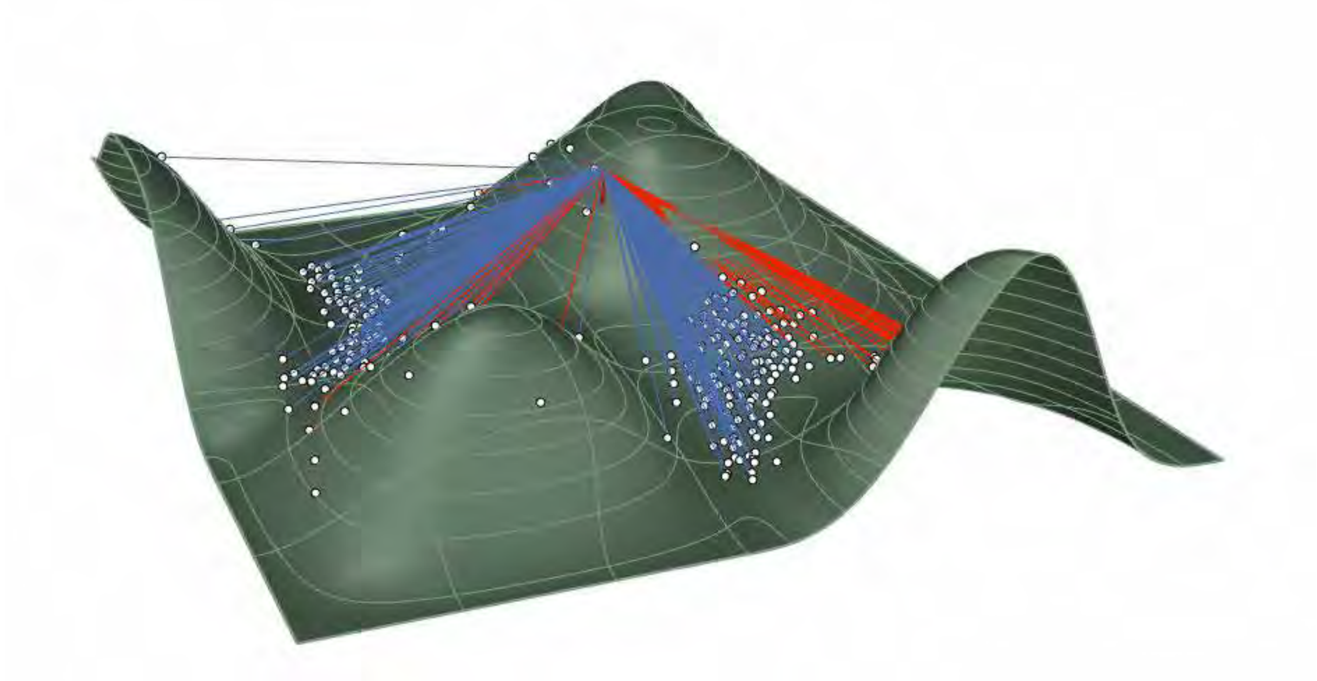


BOUWFYSICA

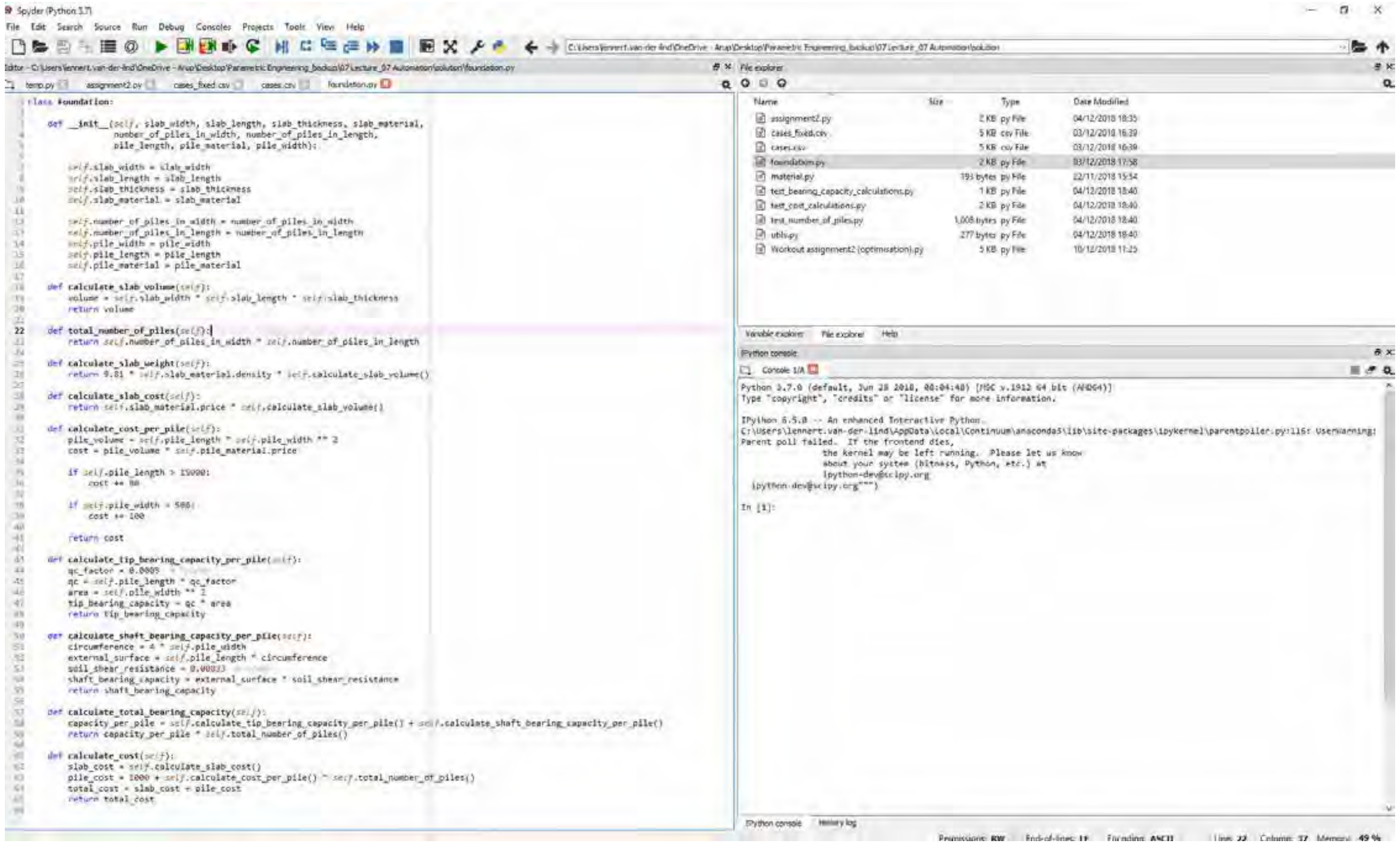


OPTIMALISATIE

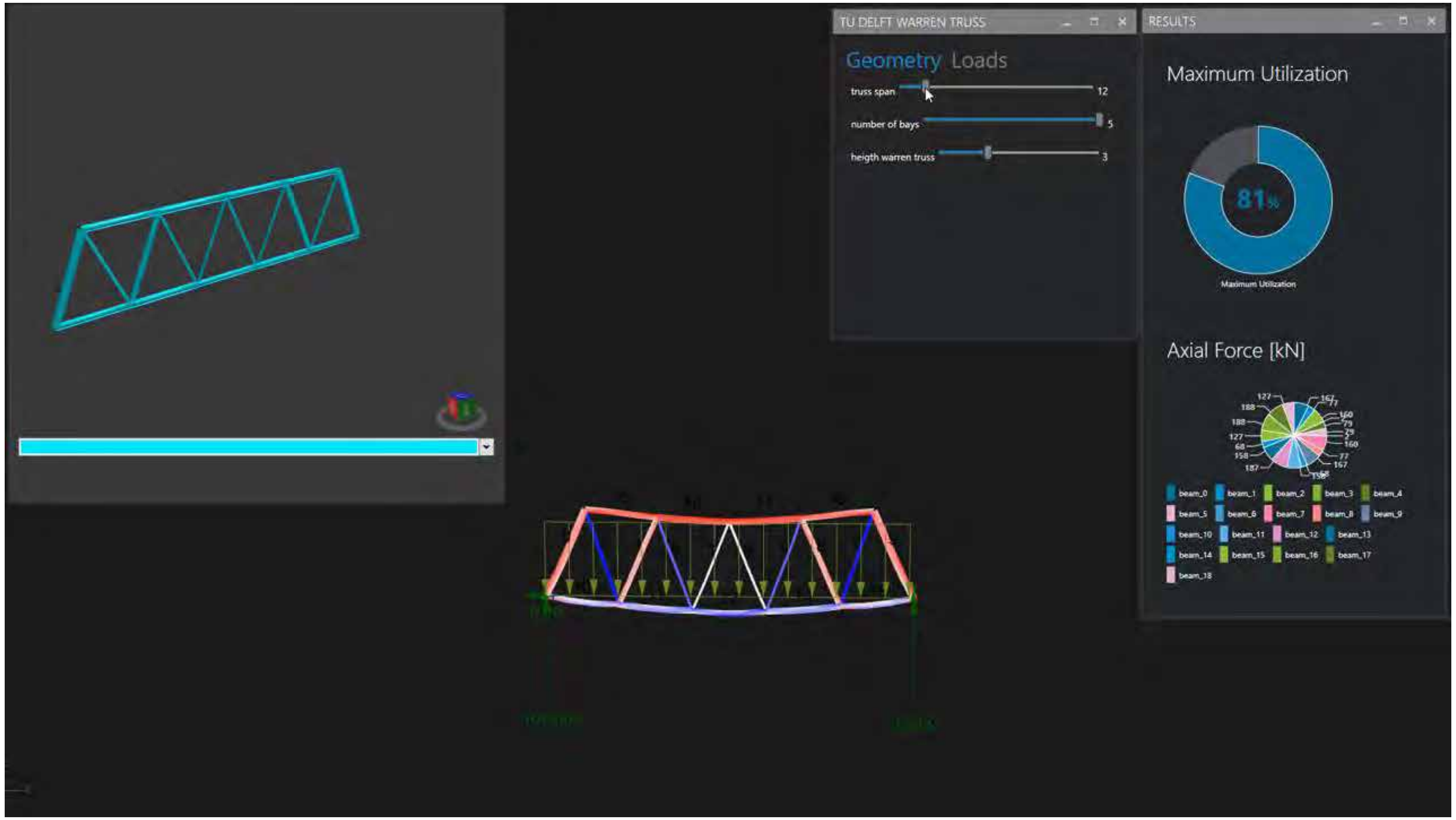




AUTOMATISEREN + SCRIPTEN



VISUALISATIE



GROEPSOPDRACHT

Academisch jaar 2018-2019

La Defense Hotspring Resort

CIE 4210 - Parametric Design & Engineering

0. Render of the building in its environment

In the context of a fictive project for a mixed-used high-rise building in La Défense, Paris, our designing team is making use of parametric tools to offer the client their bid proposal, including an exploration of different geometries, a structural analysis and a building physics analysis.

1. Exploded view of the mixed-used building

Inspiration & Concept

Given the plot's location[4], we chose to develop a building monumental enough to fit into its environment next to the CNIT and the *Grande Arche de La Défense*. Two inspiration led to the final geometry of the structure : a toroidal hotel in China[2] and a high-rise grid-shell bearing structure in London[3].

2. Sheraton Huzhou Hot Spring Resort (c) http://everythingchapel.com

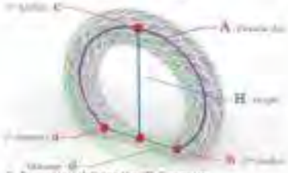
3. The Gherkin Tower (c) https://www.emporis.com

4. Project plot (c) www.flickr.com

Geometry

Taking the Sheraton hotel as an example for the structure definition, we chose three parameters[5] (*H*, *a* & *b*) to define the volume of the building and three more for its cross section[6] (*R*, *N* & *r*). Doing so allowed us to explore a large amount of geometries, locations and visuals.

a and *b*, the two anchor points of the torus are restrained in the available area of the plot[4] (shown in blue). The pedestrian bridge running through the plot gives an extra limitation to the height *H*.



5. Parameters defining the 3D-Geometry

6. Parameters defining the cross-section

Workflow

The advantages of using a parameterized definition like the one we used for this project are numerous and are well illustrated by the workflow we used[6].

Indeed, once the geometry of the structure is carefully defined using a reasonable number of parameters, it is possible to efficiently split the workload without being limited by the interactions between the different tasks. By stating what the inputs and outputs are for each of the steps, each task can be developed in depth independently. Once an update is required, it is only needed to update the inputs of each task with the new outputs from its dependencies.

In the case of this project, these tasks include the geometrical definition, the structural modelization, analysis and optimization and the building physics (location, orientation and sunlight & energy analysis).

7. Parametric design & engineering workflow

8. (a) Gridshell pattern exploration

8. (b) Gridshell pattern exploration

8. (c) Gridshell pattern exploration

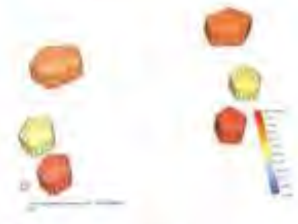
8. (d) Gridshell pattern exploration

Exploration

Apart from the geometrical parameters defining the structure, the pattern defining the gridshell bearing all the loads applied on the structure can be explored further. This pattern is defined using two series of 0 & 1, one vertical and one horizontal, expressing which vertices of a mesh covering the facade have to be selected to act as end points for the grid shell elements.

By varying these series, it is possible to change the density of steel in the structure, create interesting visuals and make use of specific structural properties.[8]

9. Sun path diagram



10. Energy analysis results (in kWh/m²)

Analysis

As one might have expected, analysis are one of the subject where parameterized projects really shine. In the case of our project, these analysis are divided into two main categories : the building physics analysis and the structural analysis.

The radiation received by the building resulting from the sun path diagram[9] is useful for a sunlight analysis[14] which presents the natural daylight perceived in a building and the performance of the building and its dependency to artificial lights. At last, depending on the building's functions, the energy analysis[10] analyses the amount of energy needed to operate it.

Gridshell are known to contain a lot of distinct elements and such a structure, especially when the pattern isn't regular[8], will be difficult to analyse by hand. With a parametric design, it is possible to quickly assess the structural performance of such a structure : the utilization of each elements[11] for all the load cases of the ultimate limite state and the global deflection[12] for each of the load cases defined in the service limite state.

11. Element utilization diagram

12. Element deflection diagram (in m)

13. Windflow (Feb 15 16:00 & Jun 16 15:00) & Windpressure

14. Sunlight analysis (in hours per day)

15. Initial cross sections (cm²) & total weight (t of steel)

16. Optimized cross sections (cm²) & total weight (t of steel)

Optimization

Lastly, given specific optimization criteria, it is possible to run through a large set of solutions and select the most optimized one.

For instance, to minimize the shadow projected on the pedestrian bridge, it is possible to search, among all possible locations within the available plot, the set of two anchor points minimizing it[17].

Another example is the optimization of the quantity of steel by exploring, for each element, 20 cross-sections that satisfy the requirements regarding displacements and utilization[15,16].

17. Sunlight hours optimization

Reflection

In this project, limitations arose which prevented the implementation of deeper analyses. Computational times as well as complex models led to some issues that required simplifications. While they were not extreme, some information and accuracy could have been lost because of it.

Parametric design is an incredibly robust tool, which combined with the proper knowledge and vision has led to amazing projects that are defining the way the building sector will grow in the future.

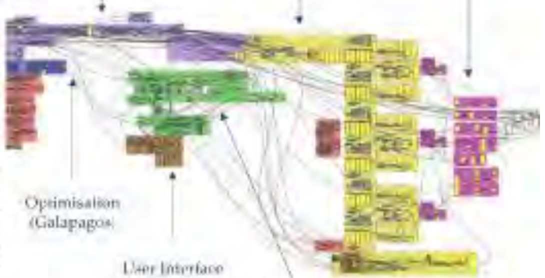
HONEYCOMB BUILDING

PROJECT INSPIRATION

Sino Steel International Plaza is a construction project located in the city of Tianjin, China. The main design idea of the building is to break with the basic concept of how a business district should look like, by creating a natural, organic and futuristic design. The structure consists of load bearing hexagonal façade panels, which reduces the need for an internal structure, creating a bigger internal space. The project also incorporates energy efficiency into the building by optimizing the window size dimensions to maintain a comfortable internal temperature. The window openings were arranged according to wind and solar directions. As part of the honeycomb building design, the team decided to incorporate the load bearing façade hexagonal panels.

WORKFLOW

The development of the final design requires the interaction of different parametric tools and plugins. The general geometry is developed using a Grasshopper script describing the input parameters and their relationship, which are then optimised using the Galapagos, Honeybee and Ladybug plugins. After the parametric geometry is completed, the structure is analysed using the Karamba 3D plugin, which develops a list of maximum allowable window openings based on the allowable deflections. Daylight and view assessments are performed using Ladybug and Honeybee. Results obtained from the structural analysis and the building physics assessments are compared and specific design characteristics are calculated. With the Colibri plugin, the different designs are transformed into data for Design Explorer. Here the client will have the possibility to find the optimal design per tower.

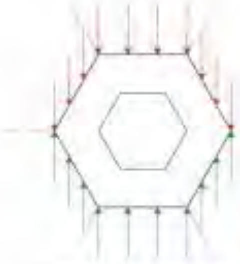


PARAMETRIC GEOMETRY

Parametric design can be defined as the development of a geometry based on the definition of initial parameters and the relationship they have with each other. For the Honeycomb Building some design assumptions are made consisting of the number of towers, number of panels per façade, which determine the base diameter of the tower, and the floor height, that determines the diameter of the facade panels. After establishing the relationship between the parameters, the output parameters obtained consists of the façade area, floor area and the location of window openings. Using this data, the main goal of the script is to determine the opening size of each individual window.

OPTIMISATION

In order to develop the final building design, an optimisation analysis is performed which searched for the optimal geometry by changing the height and location of each tower. A Rhino file with the city plan of Rotterdam is used in order to determine the plot location. A Honeybee plugin is used in order to input the sun and shadow, while a Ladybug plugin adds the location of the geometry into the analysis. The Galapagos plugin is used to perform the analysis which searches for the best configuration of parameters to maximise the floor area, while minimising the façade area and making sure that the building will not project any shadow on the considered area.



STRUCTURAL ANALYSIS

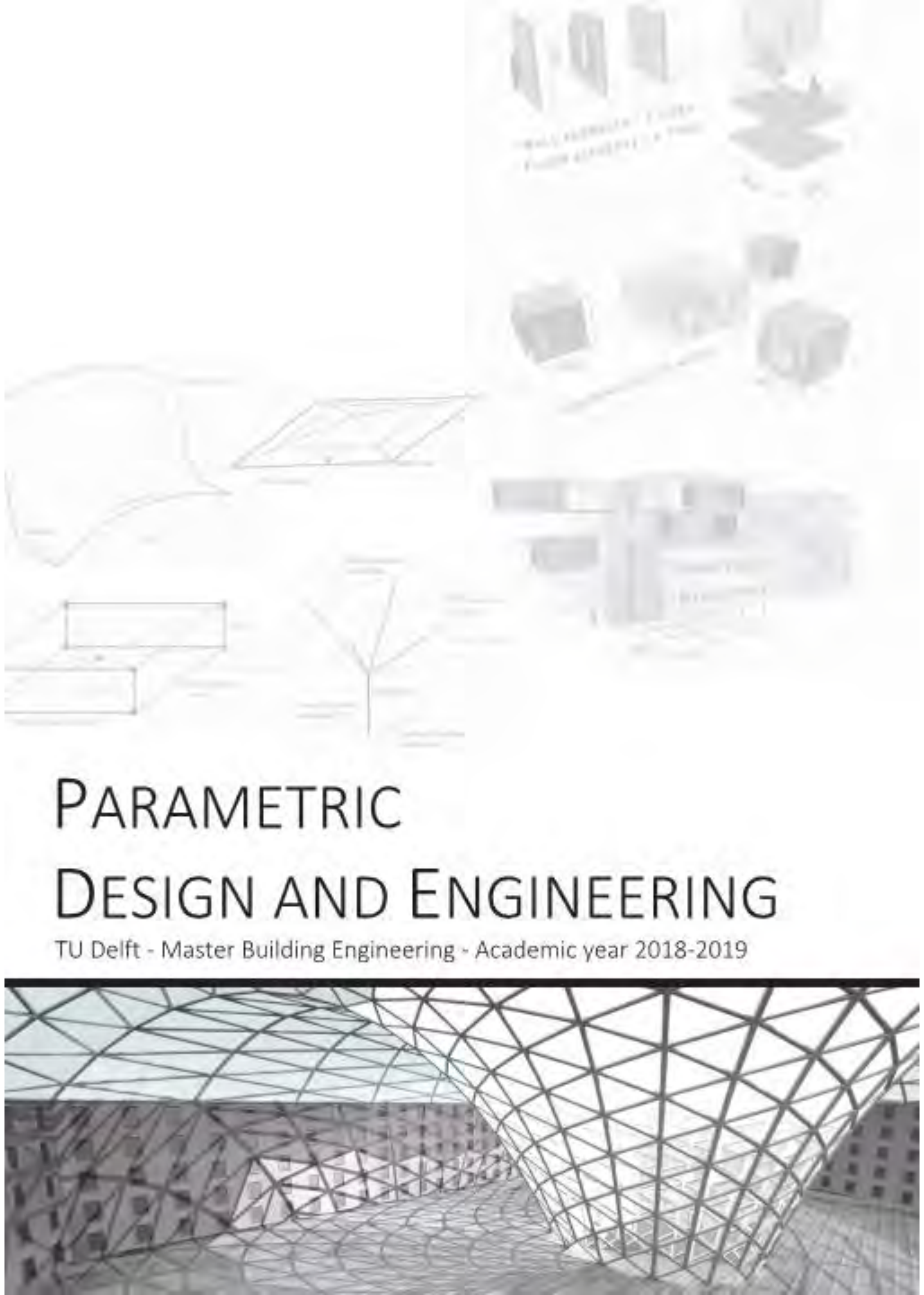
In order to determine the feasibility of the design, the team analysed the most critical façade panels for allowable deflection and unity check. The main goal is to determine the maximum allowable opening size for every window. The load applied to each panel is determined based on the weight of the façade elements on top, making the bottom panels the critical ones. Karamba 3D, a Grasshopper plugin, is used in order to perform a shell analysis on the panels. The final result consists of an analysis of the deflected panel and its unity check, as well as a list of the maximum allowable opening size for every window in the building. This list is used to calculate how many panels need to be adjusted in the considered designs and is a design characteristic in Design Explorer. An user interface is developed using Human UI, which allows the user to select any panel and perform the structural analysis.

DAYLIGHT AND VIEW ASSESSMENT

Using a python script, a set of 60 different combinations of opening sizes for top and bottom floor of one tower is created. After that, multiple Honeybee components are used to perform a daylight assessment. The daylight analysis consists of a computation of the average illuminance per floor per building, which is applied to all the possible designs. With this data, a linear interpolation is made for all floors in the building. Finally, the opening sizes are reduced to 10 standard sizes. The view analysis is based on an optimal design for view quality based on height and orientation. To make an comparison between the daylight and the view, all possible combination between a set of 10 design for top and bottom floor are considered. For these combinations, the deviation between daylight and view is computed. Finally, all data is exported to the Design Explorer, which creates an interface for the user that can be used to search for the optimal solution based on the client's desired parameters.

REFLECTION

The Honeycomb Building is a very complex design which analyses and optimises the structure based on building physics, structural analysis and relationship with its surroundings. A design like this, using a traditional approach would require the collaboration of different teams increasing the design time and cost. Having a parametric design allows the design to be flexible and adaptable to changes, which could lead to weeks of delays with a traditional design approach.



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PARAMETRIC DESIGN AND ENGINEERING

Dank voor uw aandacht