GSDesign manual

12/12/2020

This document is a manual for the use of GSDesign, a **2D graphic statics based design tool** developed as part of the TU Delft Building Engineering masters' thesis 'StructuralComponents 8' by Floris Bruinsma.

GSDesign is a design tool where you have to provide your own initial structural sketch as a starting point. It enforces structural engineers to think by themselves to come up with a self-defined, logical, topology. Only after this initial definition can the tool come into play to explore the design and optimize it, creating a workflow that combines the engineers gut-feeling with the power of computation. Although optimization is involved in this process, it must be clear that the developed tool does not perform a typical topology optimization.

If you are taking part in the user experiment you are kindly requested to follow all three sections. If you are just interested in trying out GSDesign, only sections 1 and 2 are relevant. Participants of the user experiment are expected to be comfortable and handy in the use of Grasshopper, since the developed tool is based in this environment. Furthermore, during the tutorial and the experiment use will be made of Galapagos; an evolutionary optimization component embedded in Grasshopper. Galapagos is very user-friendly and works by connecting the Genome input to sliders whose value influence the design, and the Fitness input to a fitness value, as illustrated in the tutorial file of section 2.

Content

1. Installation (5 minutes)

First of all, please download the GSDesign tool, tutorial files, and the accompanying files for the user experiment via the following link. After opening the link, right-click the GSDesign.zip file and choose '*Download*'.

[GSDesign-zip]

The GSDesign tool consists of 2 parts: the main functionality is developed into a grasshopper plugin (**GSDesign-0.1.gha**), while some extra visualization logic is defined as Grasshopper clusters which are stored in a separate file (**GSDesignClusters.gh**). The cluster file can be opened in Grasshopper and used directly, while the plugin needs to be installed. Please follow these instructions:

1. Open Rhino 6 (Rhino 7 should also work, but has not been tested yet)
2. Open Grasshopper by typing `Grasshopper` into the Rhino command line, or by clicking the icon.
3. In Grasshopper, go to *File > Special Folders > Components Folder*
4. Copy the **GSDesign-0.1.gha** file into this folder. For windows: make sure that the file is unblocked by right clicking the file, selecting *properties*, ticking '*unblock*', and selecting *ok*.
5. Restart Rhino
6. GSDesign should now be added as an extra plugin, and should show up like displayed in figure 1. If you receive an error message similar to the one in figure 2, you should update Rhino. Version 6.31.20315.17001 or higher is required.

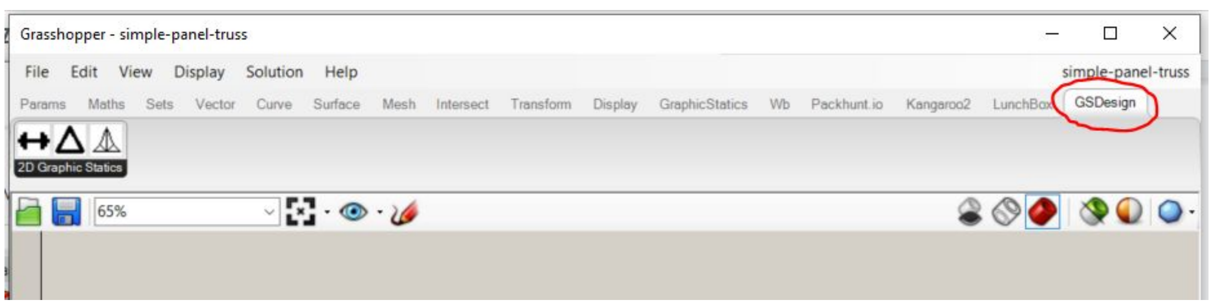


Figure 1: Grasshopper interface with GSDesign plugin properly installed

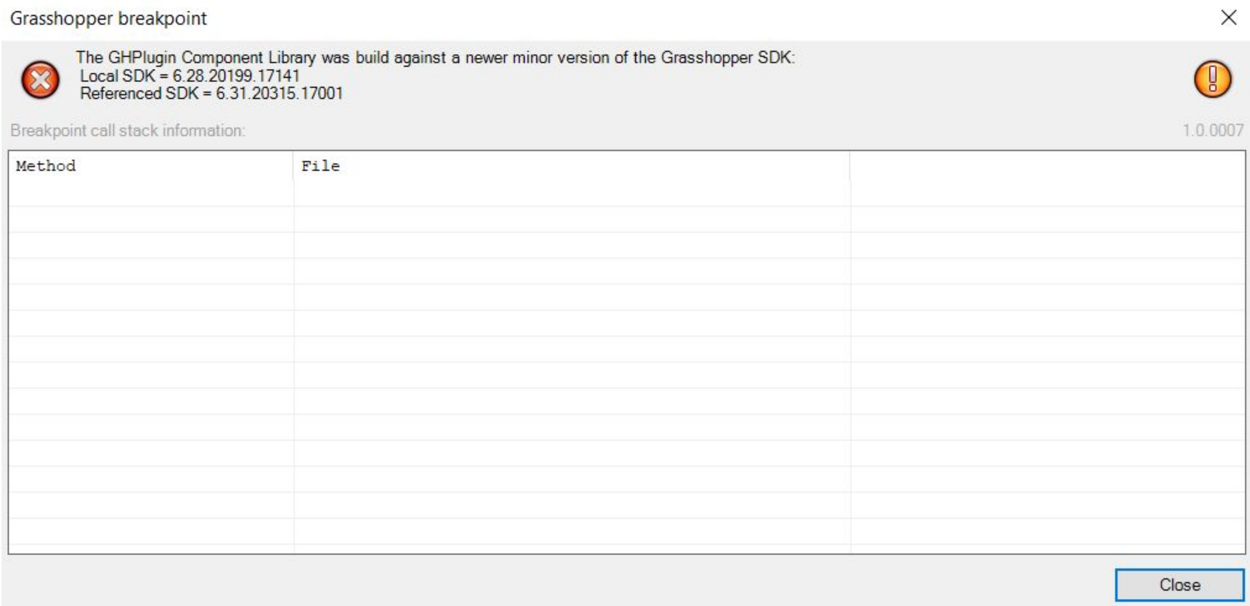
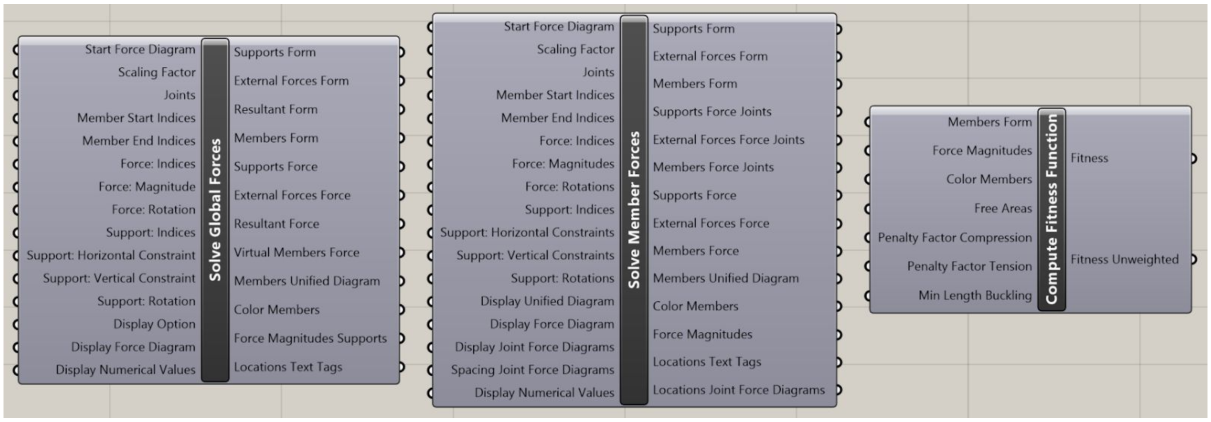
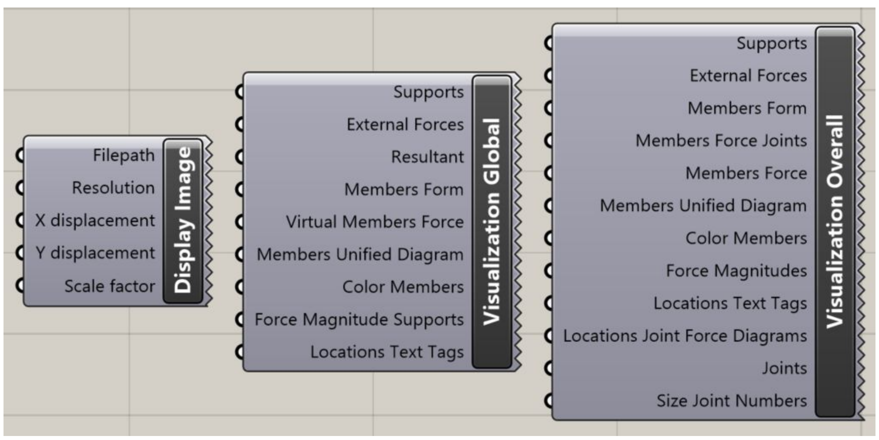


Figure 2: Error message indicating that Rhino should be updated

2. Functionality (15 minutes)

As mentioned, GSDesign consists of components and Grasshopper clusters. The two images below show all the components (top), and clusters (bottom) available within the tool. As mentioned before, the clusters can be obtained by opening the **GSDesignClusters.gh** file.





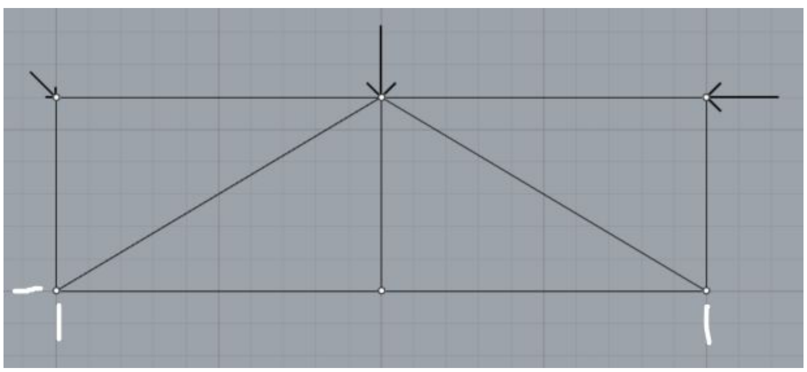
The functionality of each element is as follows:

- **Solve Global Forces** (component): Finds the resultant of all external forces, creates and solves a global form and force diagram, and thereby finds the support reactions.
- **Visualization Global** (cluster): visualizes the results of **Solve Global Forces**.
- **Solve Member Forces** (component): Incorporates the same functionality of **Solve Global Forces**, but then proceeds to solve all individual joints in the actual structure, finding all member forces. Output is focussed on the overall results and does not include the global diagram or the force resultant.
- **Visualization Overall** (cluster): Visualizes the results of the **Solve Member Forces**.
- **Compute Fitness Function** (component): Computes a fitness function, based on the total load path SUM(F_i * L_i), incorporating also other design input like areas that need to remain free, a penalty factor for either tension or compression elements, and a factor that can include buckling behaviour. The total load path calculated by SUM(F_i * L_i) is a

basic representation of the necessary structural material volume, assuming a constant stress distribution. SUM(F_i * L_i) multiplies the length of each member *i* by the force it carries and adds this to the total summation, resulting in one value that indicates the structural material use, therefore quantifying the efficiency of the design.

- **Display Image** (cluster): imports a jpg or png image and lets the user scale and move it to a preferred location on the canvas. Can be used to import an initial design sketch, which can then be manually traced in Rhino.

SimpleHoweTruss-tutorial.gh contains a tutorial file showcasing how these components can be used to obtain valuable design information. The design case that is used here is that of a simple Howe Truss, defined as in the image below, with black arrows depicting external forces, and white lines depicting the yet unknown support reactions. The tutorial file must be opened in combination with the Rhino file **SimpleHoweTruss-tutorial.3dm**



The Grasshopper tutorial file contains multiple groups showing the functionality of GSDesign step-by-step. The content of these groups will be explained here:

Solve Global Forces

This group shows how the **Solve Global Forces** component can be used in combination with the **Visualize Global** cluster. The reader is encouraged to play around, change certain inputs and observe how the design and visualization changes. To analyze which index a certain point has in a list (which must be known in order to define the members), the Point List component can be used. The grey line and arrow in the visualization represent the resultant force of the three external forces.

Solve Member Forces

This group shows how the **Solve Member Forces** component can be used in combination with the **Visualize Overall** cluster. As can be seen the inputs are mostly similar to those of the

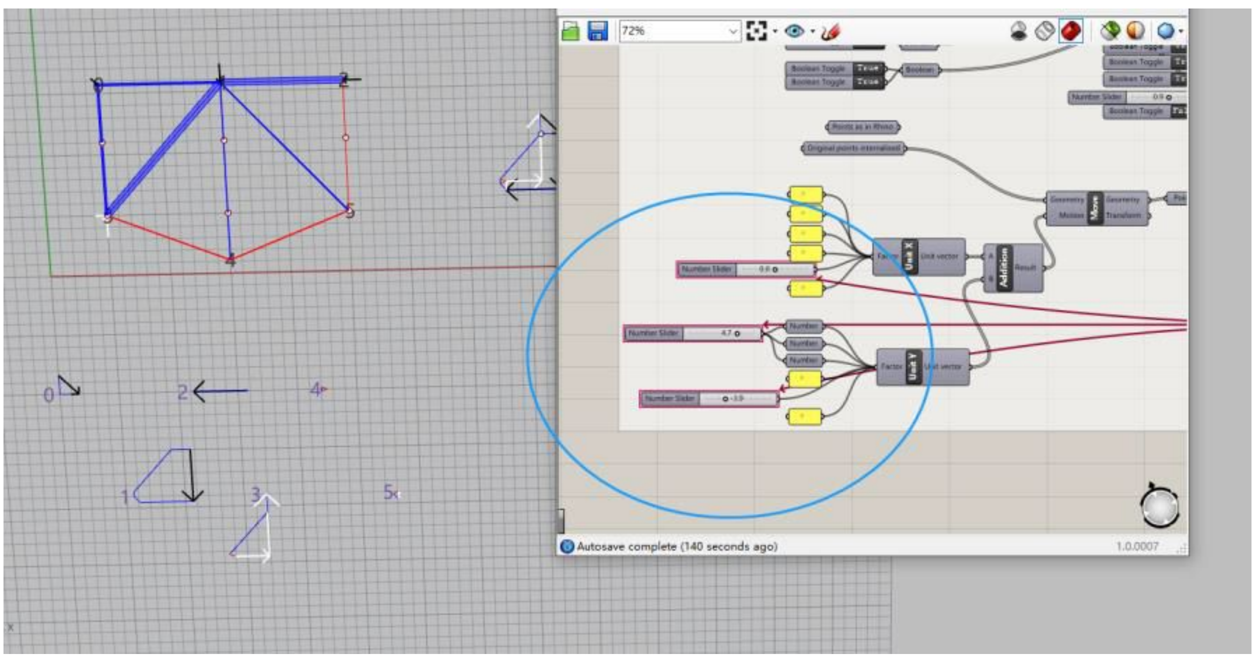
Solve Global Forces component, and are therefore linked from the original input definition in order to not repeat ourselves.

In order to enable the display of the Visualisation Overall cluster in the Rhino viewer, right click the cluster and select *preview*. With the same method the Visualization Global display can be hidden.

Again the reader is encouraged to play around with all the inputs, in order to understand the functionality of this component + cluster.

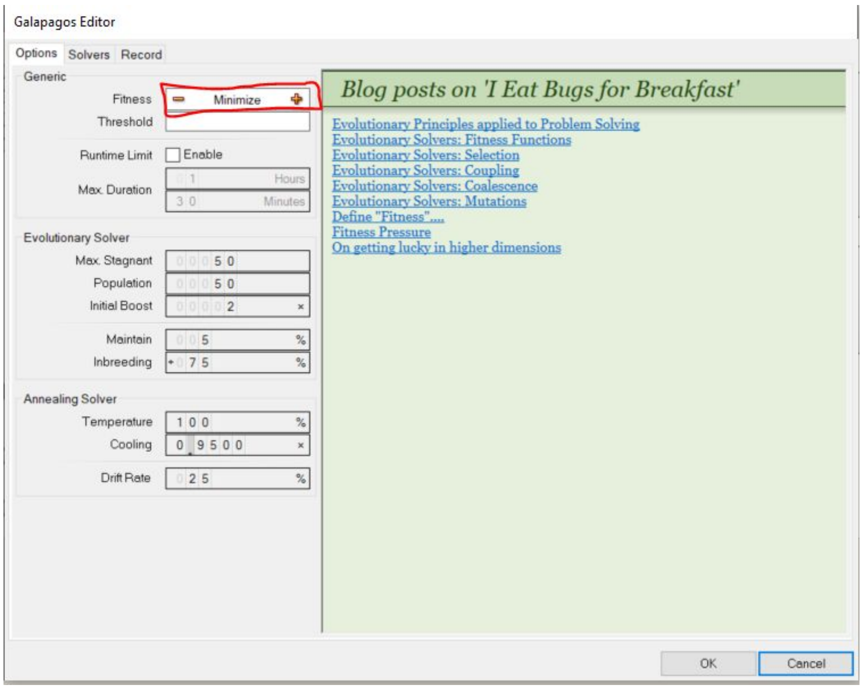
Optimization 1

This group shows a simple optimization setup where three parameters are defined that manipulate the locations of the joints that make up the structure. These parameters are shown in the figure below. The top slider manipulates the x-value of joint 4, the middle slider manipulates the y-value of joints 0, 1 and 2, and the bottom slider manipulates the y-value of joint 4. Apart from this, the locations of the joints are fixed.

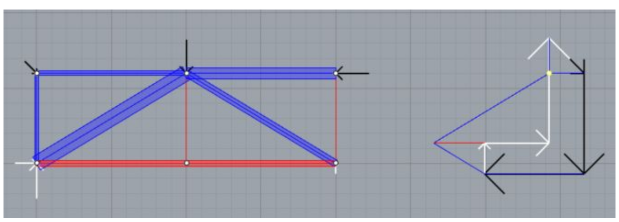


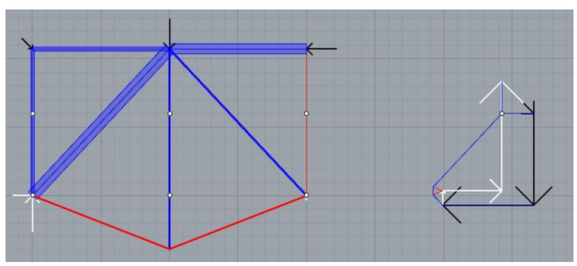
The **Compute Fitness Function** is introduced here and uses three inputs of the Solve Member Forces component to compute the ‘’fitness” of the design. No additional inputs have been defined, so the component only computes the pure load path value.

Galapagos is used to optimize the structure based on the fitness value, using the defined parameters. By double-clicking the Galapagos component, one can access the Galapagos optimization interface, and start an optimization sequence by going to the *solvers* tab and clicking *Start Solver*. For both this optimization and the next one, the advised Galapagos settings are displayed in the figure below. Most important is that the Fitness value must be minimized instead of maximized.



The results should be as in the images below. With the start situation on the left, and the (for these specific parameters) optimized design on the right.



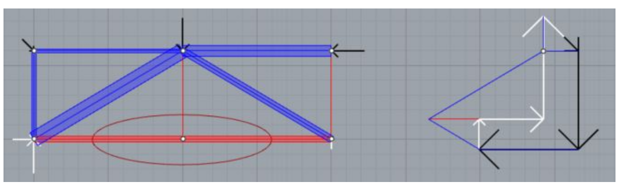


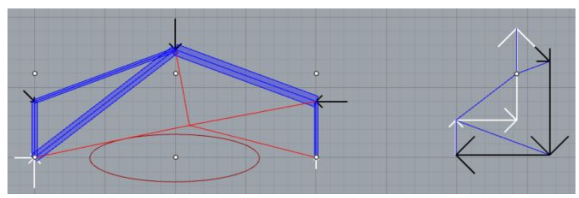
Optimization 2

For this optimization sequence, two extra things have been incorporated:

- A curve has been added to the Free Areas input of the Compute Fitness Function component, which contains an oval shape (right-click the curve component and select *preview*, if you don't see it), wherein no structural elements are allowed.
- The parameterization of the locations of certain points is now accompanied with a parameterization of certain members. Two number sliders can be set to either one or zero, which results in a different connectivity of the joints.

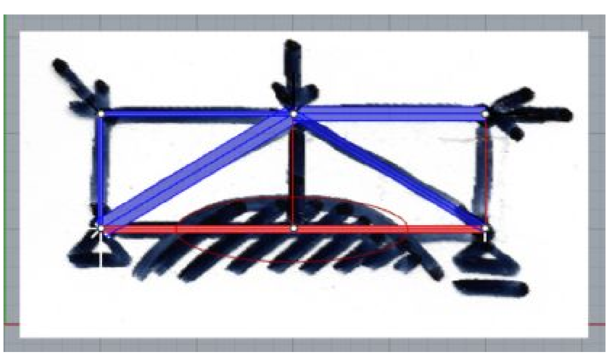
The reader is encouraged to try out these new parameters and check the optimization setup. When all is clear, an optimization can be carried out, which should (with this specific setup) converge towards a design similar to the image below on the right. It is worth noting that a heuristic optimization algorithm is used, which means that your outcome could slightly differ from the one shown here.





Display Image

The display image group shows how the **Display Image** cluster can be used to import a jpg or png image of a design sketch to the Rhino canvas, to then trace that design digitally. This would therefore normally be done at the beginning of a design process in GSDesign. To see the image, you must define the file path entry so that it matches the location of the **SimpleHoweTruss-sketch.jpg** on your computer, and be sure to set the preview of the cluster on. To define the file path, right-click the File Path component and choose '*select one existing file*', and select the **SimpleHoweTruss-sketch.jpg** file.



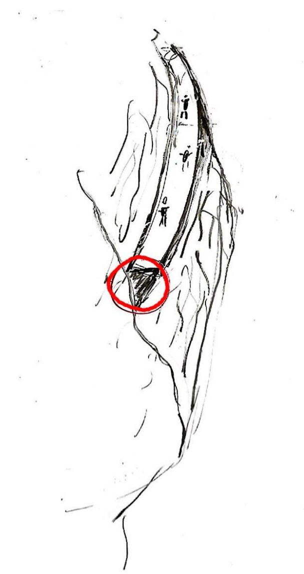
3. User Experiment (75 minutes)

First of all thank you very much for participating in this user experiment!!

The experiment concerns a design exercise, and consists of 2 parts. In the first part a 'conventional' design process is followed where the participants are asked to make a design manually, using their own expertise and insight. In the second part they attempt to construct an improved or new design in the GSDesign tool, using the manual design of the first step as a starting point.

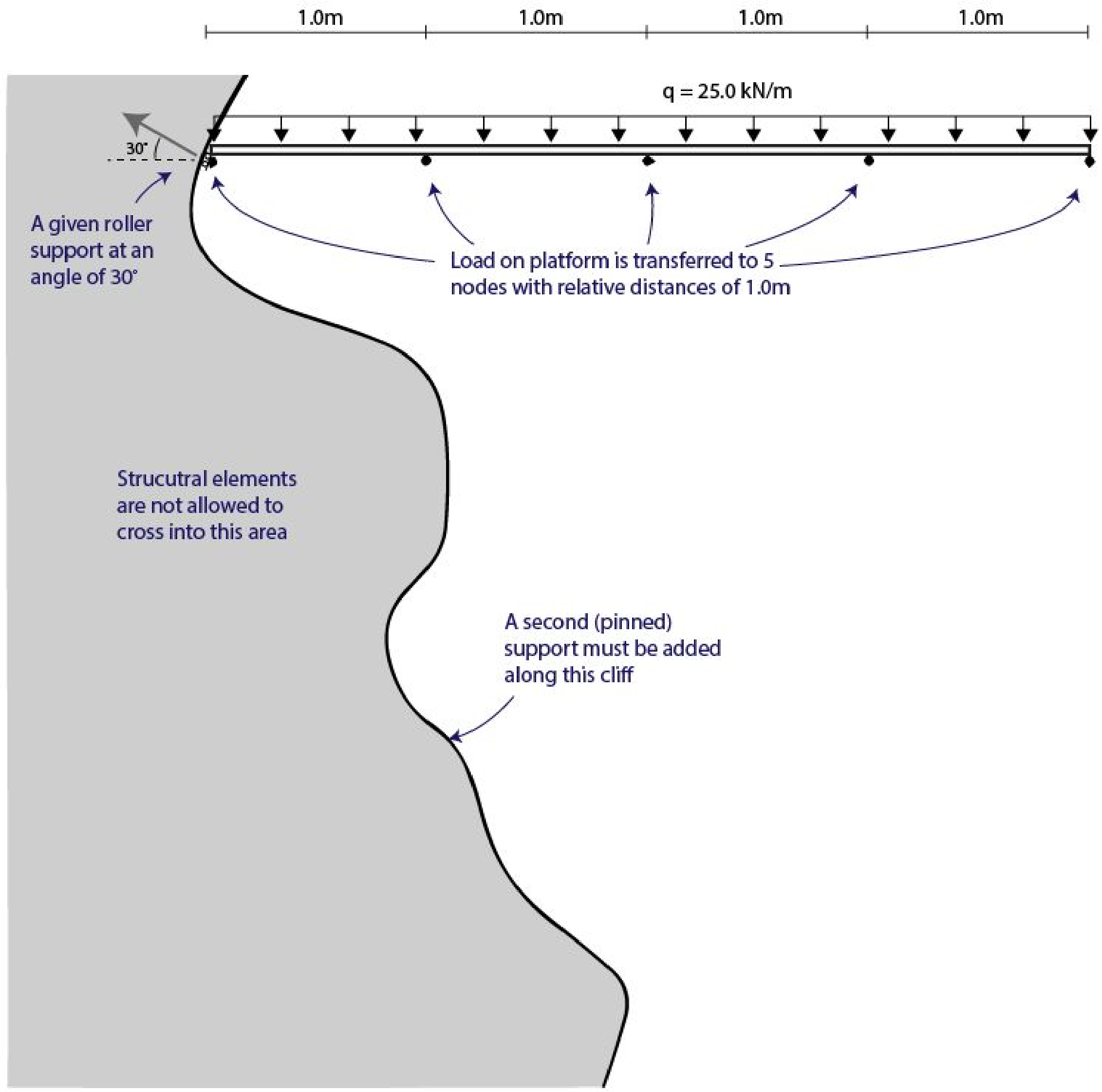
Setup of design case

The design case concerns a structure that supports a platform along a cliff.
The figures below show a picture of the construction of such a structure (left), and a sketch of the design situation in 3D (right).



A 2D structure must be created, which is assumed to be supported out of plane, however buckling of members between nodes must be taken into consideration.

The image on the next page shows the whole setup of the design problem. It concerns a 4m wide platform, bearing a distributed load. 5 nodes have been defined on which the load on the platform is transferred. The node on the left-hand side is also the first support, which is a roller at an angle of 30 degrees. The second (pin) support must be placed on the outline of the cliff, which is also given. An additional requirement is that no structural elements are allowed to go through the rock.



In order to allow proper comparison and to be able to digitalize the designs in the GSDesign tool, the following requirements apply:

- The design must be a truss-system, meaning that it consists only of **straight normal-force bearing elements**, connected by **pin joints**.
- The design must **statically determinate**, which for 2D trusses means that: **$m + r - 2j = 0$** (m = number of members, r = number of support reactions (3), j = number of joints)

Apart from the mentioned requirements, participants are free in their designs and can add as many nodes as they want. The main design objective of the experiment is:

<u>To design a structure that transfers the loads to the supports as efficiently as possible.</u>

Experiment instructions

Step 1: manual design

1. Print **UserExperiment-StartingPoint.pdf** on paper multiple times (5 minutes), or - if you prefer to make your sketch digitally - open the file in a suitable program.
2. Make one or multiple designs on the printed paper or digital environment. The following rules apply:
   a. You have **15 minutes** to complete this step, please time yourself!
   b. The use of any additional analog or digital tools besides (digital) pen and paper is allowed.
3. When time is up or when you feel that you are done, please document the final design(s) by scanning or taking a photo. Save the designs as jpg or png on your computer. (5 minutes)

Step 2: GSDesign

Now the goal is to take the designs during step 1 as a starting point to further explore possible solutions. The idea is to digitalize the design(s) of step 1 and optimize them using the previously described method. During this design process, you may be inspired to try out different designs in GSDesign, please do so if time permits.

1. Open **UserExperiment-CliffsideCantilever.3dm** and, after you started Grasshopper, **UserExperiment-CliffsideCantilever.gh**. These files contain a starting point for this specific case from where you can start designing. Please read the instructions in the file and make sure that you understand the workflow to define a new design, depicted by the numbered steps. (10 minutes)
2. Start designing! The following rules apply:
   a. You have **30 minutes** to complete this step, please time yourself!
   b. Please **save every meaningful newly created design** as a new (logically named) file. (also Rhino file if relevant)
3. When the time limit is up, please pick your final design and other relevant designs and save those Rhino and Grasshopper files in a handy spot on your computer.

Step 3: Submit results (5 minutes)

Take all the relevant files from steps 1 and 2, place them in one folder and send that folder via wetransfer to florisbruinsma@white-lioness.com.

Step 4: Questionnaire (5 minutes)

As a final step, please fill in this questionnaire. The questions mainly concern your experience in the experiment, and have the objective to get a view on the practical value and user friendliness of the tool.

Thank you!