Design process optimisation and form finding using parametric 3D modelling and simulation tools

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Abstract

The first possibilities for engineers to analyse membrane structures were based on physical modelling; now approximately 60 years later this task is nearly completely overtaken by computer simulations. Through the years the software has improved by using better form finding algorithms, resulting in highly advanced software.

Given the growing complexity of lightweight membrane structures and the increasing time pressure to develop projects, one must constantly search for new optimizations. Even while designing lightweight membrane structure is a highly interactive process, there are opportunities to improve the process.

This paper deals with the question of how new or already existing software can be used to create a more efficient automated process for standardized lightweight structures.

Using new modelling techniques, the form finding can be transformed from a manual to an automated process. The explored process is called "generative modelling", a modelling technique consisting of algorithms based on parameters. This approach is converting the manual design steps in subsequent processing steps using parametric input.

This process optimisation using various interconnecting software packages, such as Rhinoceros, Grasshopper, GSA, Formfinder and EASY leads to various design templates and a case study, which will be described within the paper. Further on a review about various form finding and analysis methods has been carried out and will be presented as well.

Keywords: Lightweight structures, Optimisation, Generative modelling, Parametric form finding

1   Introduction

Designing lightweight membrane structures is a highly interactive process between the engineer and the architect. This multidisciplinary design process is supported by highly developed software to analyse these kinds of structures.
The first ways for engineers to analyse membrane structures were based on physical modelling, now approximately 60 years later this task has almost been completely overtaken by computer simulations.

By implementing and connecting new modelling techniques, simulation tools and interconnecting software in this process, manual steps are transformed to automated steps. This creates the possibility to optimize the design process of standardized membrane structures.

Every membrane structure is built up using basic membrane shapes like: saddle or hypar shaped structures. Through experience and practise, designing and constructing four point hypar shaped membrane structures became more standardized. However, despite the fact that these structures are more standardized, the design approach often requires a great amount of time: finding the right geometry and using several separate simulation and modelling tools.

This paper describes a study of optimizing the whole design approach for these standardized membranes structures using new parametric modelling techniques, simulation tools and interconnected software packages. This will establish a total subsequent process using parametric input.

2   Definition and application of generative modelling

Generative modelling is a modelling technique based on parameters combined with algorithms. This technique differs from commonly used modelling methods.

Using standard "Computer Aided Design" (CAD), a shape is built up: starting with a simple level of geometry (points and lines) and expanding this geometry till the desired model is reached. In standard modelling systems, 3D objects are defined and created of simple geometric primitives. The modelled geometry is not connected and is not influencing each other.
To define the geometry in space, the user is defining points and curves as fixed parameters. Beginning with a fixed parameter (defined as x, y and z coordinate) and from there each element is built up separately.

Generative modelling is a change in how shapes are built-up. The change with this drafting method is the transformation from just drawing points and lines to connected operations. A shape is described by a series of processing steps, rather than just the result of manually applying operations.
This method is very general and can be used for any shape representation that offers a set of mathematical generating functions. [2]
Using generative modelling to approach standardized membrane shapes offers possibilities compared to CAD techniques. With this method one is able to create

generative design templates, where according to the input (parameters), the right shape automatically is found and created.

These design templates can be used to find and create the specific shape of a four point hypar, according to three-dimensional input. Also templates can be established for standardized membrane details, with parametric input according to the membrane geometry, forces in the membrane surface and supporting structure.
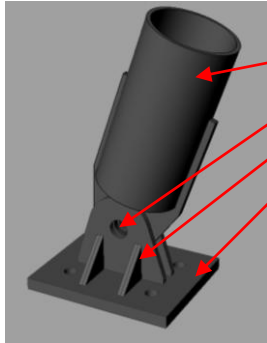
Example parameters:
1. Profile size
2. Pin size
3. Stiffeners size
4. Plate size and bolds
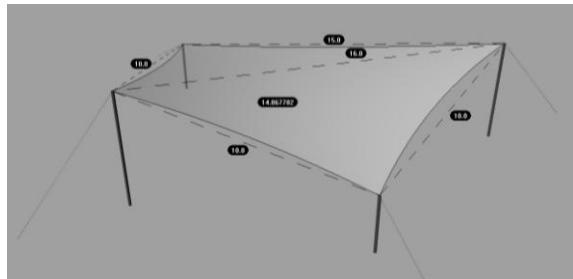
Figure 1. Example of parameterized membrane detail.

Figure 2. Example of parameterized four point hypar structure.

3   Software and simulation tools

Parametric tools
The parametric tools used for the generative design templates are Rhinoceros and plug-in Grasshopper.

Rhinoceros is a standard modelling package specialised in NURBS and complex shapes. It is used as basic modelling software for parametric 3D modelling and simulation optimizations.
Rhinoceros has the capability to export and import almost any modelling extension known today, which makes it possible to connect it easily to other software packages.
On top of the manual drafting tools, Rhinoceros offers an Application Programming Interface (API) option. API offers the possibility for other developers to work with the program and extend the use with plug-ins programmed by second party developers.

One of these API's is Grasshopper, a graphical algorithm editor. It is a generative modelling design tool that operates as a Rhinoceros plug-in. The power of this drafting method with Grasshopper is the use of parameters. This program has the ability to create parametric models capable of working as programmed templates.
It is possible to start a template with algorithms and different kind of parameters, in the same way as membrane detail in figure 1. Together they can turn a fixed design into a parametric design that can be explored in numerous simulation environments.

A various amount of these simulation tools are working through plug-ins or interconnected with Grasshopper.

The advantage of these design templates is the fact that they give a direct graphical output in the interface of Rhinoceros and one is able to work from a single basic template.
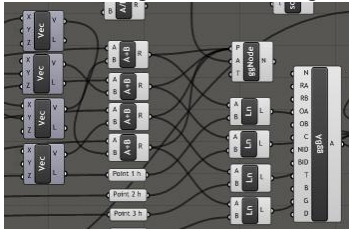
Grasshopper works by combining different operators, modelling and programming commands, to each other with parameters as input. Figure 3 shows an example of a few operators linked together inside Grasshopper. [1]

Figure 3. Operators inside Grasshopper

Simulation tools

In this study the simulation tools Oasys GSA suite and Technet GmbH EASY are used to demonstrate and substantiate the optimizations.

GSA suite is a FEA software package developed by Arup's software department Oasys. Besides the possibility to calculate conventional structures like buildings and bridges, it also includes a form finding solver based on dynamic relaxation.

EASY is a total engineering package specialist for designing and calculating lightweight surface structures, developed by Technet GmbH. This program includes options for form finding, statical analysis and generation of cutting patterns based on the force density method.

Interconnected software packages

The connection between generative modelling and simulation tools is made with the software package ssiGSA, developed by Geometry Gym. This tool works inside Grasshopper and connects the program to the simulation tool GSA suite.

This ssiGSA tool creates the opportunity to interact and exchange generative models with GSA suite related to structural analysis. Not only has it got the opportunity to export a generative model to the structural analysis program. It extracts the solver functions from GSA suite with a possibility to use them inside a generative model.

This means one is able to use the form finding solver (gsrelax solver) of GSA suite inside of Grasshopper.

The connection between generative modelling and simulation tool EASY can be made using CSV files or DXF files.

4 Case study: design process optimisation of a 4 point hypar sail

Using a case study, the interconnection and optimisation between generative modelling and simulation tools is explained. In this study the subsequent design process from finding the right three-dimensional shape towards parametric form finding and structural analysis, including parametric membrane details, is shown.

The case study will be compared with a standard design approach, using CAD modelling in combination with the simulation tool EASY.

The first case includes a generative modelling template, created by the authors, to find the geometry of a four point hypar and export it as DXF or CSV files towards the simulation tool EASY. Inside EASY the form finding process is done manually, while for this program there is no interconnected software plug-in available yet connecting the simulation tool to generative modelling software.

Secondly, a study including the generative modelling template is performed, now interconnected with GSA suite using the ssiGSA tool. It shows the optimisation throughout the whole design approach including parametric form finding and possible structural analysis.

In both studies the input is 3D dimensions for a standardized four point hypar shape. Figure 4 shows the steps of the two researched studies.

	Study 1		Study 2
1.	Finding geometry using generative modelling.	1.	Finding geometry using generative modelling.
2.	Calculate length link connection with membrane inside generative modelling template.	2.	Defining form finding, supporting structure (columns, backstay cables), loadcases and analysis tasks settings inside generative modelling template.
3.	Export geometry as DXF.	3.	Parametric form finding + automatic import structure, loadcases and analysis tasks inside GSA suite.
4.	Import DXF in EASY and Define form finding setting + form finding.	4.	Statical analysis inside GSA suite.
5.	Detailing supporting structure using parametric details.	5.	Detailing supporting structure using parametric details.

Figure 4. Processing steps of both case studies.

Step 1. Figure 5 shows the dimensions of the four point hypar sail for the both studies. Using a generative design template which can be seen on figure 7, the 3D geometry of the shape is found automatically, controlled and shown graphical in the used modelling software. Figure 6 shows the graphical output of the shape.
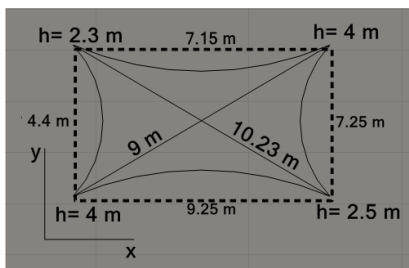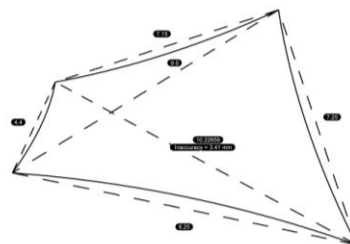

Figure 5. 3D input 4 point hypar sail.

Figure 6. Output 3D boundaries generative design template.

Form finding with GSA

1. Define amount of quads /side
2. Define pre-stress in x/y direction

Divide mesh   15
Pre-stress x   1
Pre-stress y   1

Backstay cable distance (x+y)   2
Thickness backstay cables (mm)   20
Thickness edge cables (mm)   10

Column diameter (mm)
114.3

Wall thickness (mm)
8

1. Push scroll button on component
2. Select enable to start GSA analysis

1. Right mousclick on Geometry output
2. Bake

Geometry output

Sag + Elastic link

Sag 1-2   0.040
Sag 2-3   0.040
Sag 3-4   0.040
Sag 4-1   0.040

Angle for elastic links Easy

Angle surface point 1
72.652508

Angle surface point 2
47.736674

Angle surface point 3
73.05856

Angle surface point 4
82.468301

Step 1.   Open elastic link excel   False
Step 2.   Excel read   False
Step 3.   Angle point 1
Step 4.   M10

Elastic link lenght Easy
Double click to

Difference control diagonal B (mm)

Difference (mm)
3.41

Bake for Client

1. Right mousclick on group
2. Select all
3. Push scroll button on mouse
4. Bake

Geo

Output Client (m)

Control diagonals

Control diagonal A
9.0

Control diagonal B
10.22659

Control length between points (3D)

Control line 1-2
9.25

Control line 2-3
7.25

Control line 3-4
7.15

Control line 4-1
4.4

Method of input

3   2-3   2

3-4   B

4   A   1-2

4-1   1

x

y

Diagonal B = control diagonal

Input Client (m)

Diagonals

Diagonal A
9

Diagonal B
10.23

Length between points (3D)

Line 1-2
9.25

Line 2-3
7.25

Line 3-4
7.15

Line 4-1
4.4

Hight points

Point 1
4

Point 2
2.5

Point 3
4

Point 4
2.3

Figure 7. Generative design template developed by the authors

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Step 2. In study 1 the lengths of the connection between column and membrane is calculated.

For the second study, not only the length of the connection detail is calculated but also one is able to define the form finding settings: pre-stress and mesh properties. Besides the form finding settings it is possible to define the geometry and sections of the supporting structure, load cases and desired statical analyzing tasks.

Step 3. In study 1 the 3D output of the tool is exported as DXF from Rhinoceros.

Using the interconnected ssiGSA software in the second case, all the settings are exported automatically towards GSA suite including:

- The geometry.
- Form finding settings.
- Supporting structure with sections and material properties.
- Loads and analysis tasks.

Inside GSA suite the form finding analysis is performed automatically (figure 9) and the form finding imported back inside the generative modelling template, as shown in figure 8. [1]
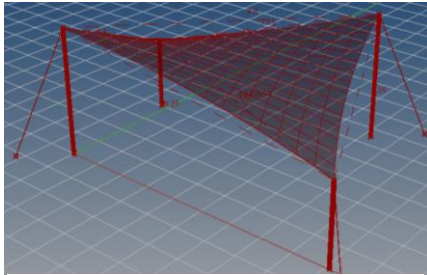

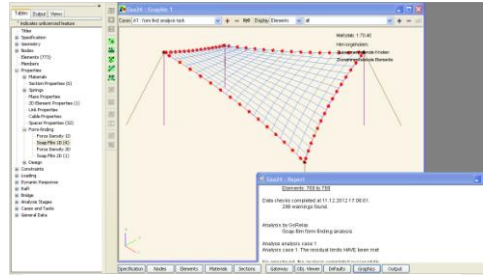*Figure 8. Graphical output including all settings from generative modeling template.*

Figure 9. Automatically import complete structure inside GSA suite.

Step 4. In the case of study 1, the DXF can be imported into EASY and the normal manual processing steps can be performed to get the form finding and supporting structure. To perform a statical analysis, all the settings have to be defined inside EASY.

In case of study 2, the whole structure is already defined into GSA suite. Performing a more detailed statical analysis is a matter of checking the structure and let GSA suite perform the desired analysis. This is also possible to be included in a generative modelling template.

Step 5. After all the required analyses are performed for both studies, the supporting structure of the four point hypar sail has to be detailed. Using generative modelling templates these details also could be parameterized, making the modelling of the details much more efficient and less time intensive.
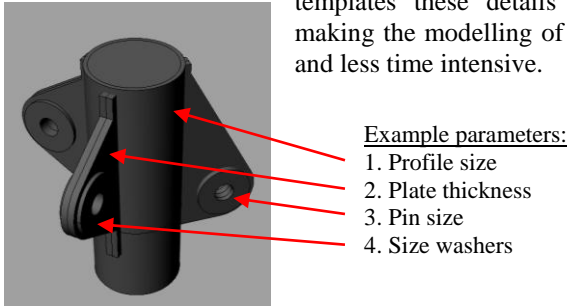
Example parameters:
1. Profile size
2. Plate thickness
3. Pin size
4. Size washers

Figure 10. Parameterized detail of column connection.

Figure 11. Generative modeling template of detail column connection.

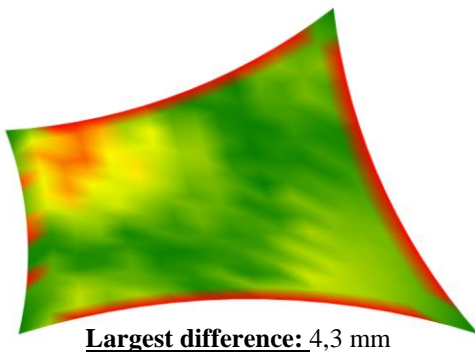# 5 Comparison case study

Largest difference: 4,3 mm

Figure 12. Graphical difference form finding output EASY & GSA suite.

After all the steps of both studies are researched, a comparison is made. The first one is between the two different simulation tools: EASY and GSA suite. In figure 12 the graphical difference between both tools is shown.

The second comparison concerns the time. This is done between the two studies and the design process without the use of generative modelling and interconnected software packages.

8

Estimation of time comparison

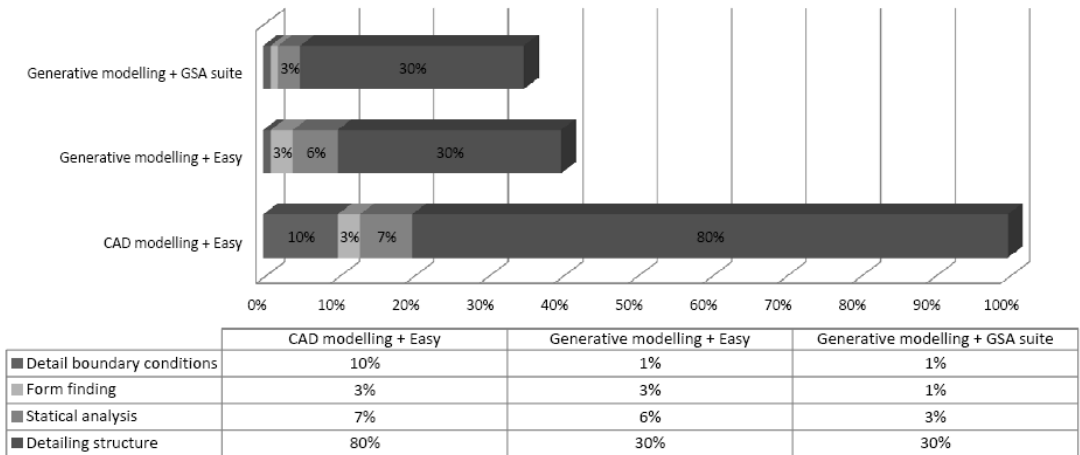|	CAD modelling + Easy	Generative modelling + Easy	Generative modelling + GSA suite
Detail boundary conditions	10%	1%	1%
Form finding	3%	3%	1%
Statical analysis	7%	6%	3%
Detailing structure	80%	30%	30%

Figure 13. Time estimation of studies. (Note: when having experience with the software)

6   Conclusion

The comparison of the two optimized design approaches and the standard design approach for a standardized four point hypar sail shows significant difference in time duration. By using a generative modelling design template an improvement in the time duration of the design process and better controllable precision of the geometric output is achieved. It is not only possible to find the geometry much faster but also to parameterize standardized membrane details. Hereby the advantage of this optimisation saves 50% of the time needed to detail the supporting structure.

Using Grasshopper for generative modelling one is able to create design templates even without having knowledge of scripting. Whereas working with generative modelling in other software packages this scripting knowledge is normally required. Building these design templates, one should consider creating the actual template requires some investment of time.

Combining Grasshopper with simulation software using interconnected tools like ssiGSA shows an optimisation of the whole design process. The connection between Grasshopper and GSA creates a total parametric design approach. On the other hand the combination of Grasshopper and EASY also achieves significant time improvements.

All together these new design processes save a lot of time for each project. The most optimizations are reached by standardized membrane shapes. However, further investigation could lead to new improvements for more complex shapes and forms.

7 Acknowledgement

References

[1] BROK, W., *Application of optimization and form finding tools in a parametric 3D modelling and simulation environment.,* TEUFFEL ENGINEERING CONSULTANTS, Stuttgart, 2012.

[2] TU Graz, *generative modeling*, http:// http://www.generative-modeling.org/, 25-04-2012.