Formfinder Professional
Power Training

SCHEDULE

Introduction
Membrane : Structure : Design Methods
Forces, geometry, element catalogue, building physics, manufacture

Exercise
Formfinder interface, analysis and evaluation

Exercise 1:
- Café Mozart (new: sun and rain shadow analysis)

Exercise 2:
- Schloss Hof (new: background images)

Exercise 3:
- Force : Form
- Analysis of a "Three-Point-Net"
- Analysis of a "Four-Point-Net"

Exercise 4:
- Import, export, EASY, cost estimation

2009 Oct.

INDEX

INTRODUCTION: DESIGN METHODS

Design steps:

a) Definition of the assignment

b) Analysis and evaluation of the assignment

c) Communication with project partners and distribution of responsibilities

d) Preconditions, sketch, model, preliminary draft, design, structural analysis

Five characteristics:

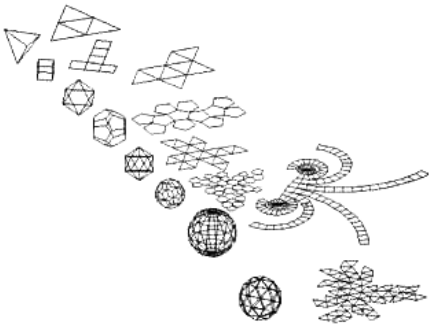
1. **Design with forces** (form-finding, geometry)
2. **Geometry** (typology, dimension, proportion)
3. **Element catalogue** (gestalt, appearance)
4. **Building physics** (climate, acoustic, fire protection)
5. **Manufacture** (erection process, maintenance)

Geometrical properties:

1. **Flat**

   Curvature = 0

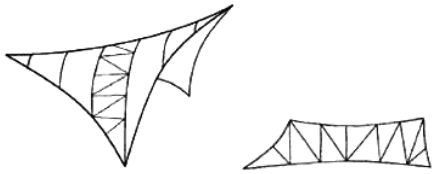
   (unrolled surface free of distortion)



2. **Anticlastic**

   Curvature k = -1

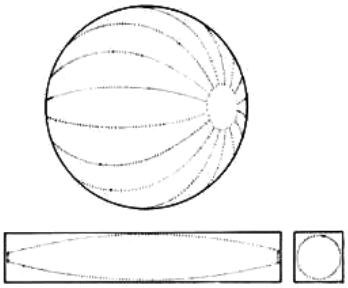
   (unrolled surface will be distorted)



3. **Synclastic (Air supported)**

   Curvature k = +1

   (unrolled surface will be distorted)

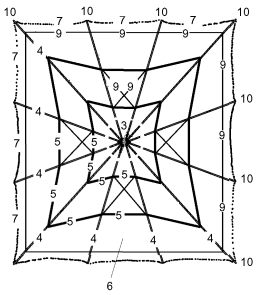


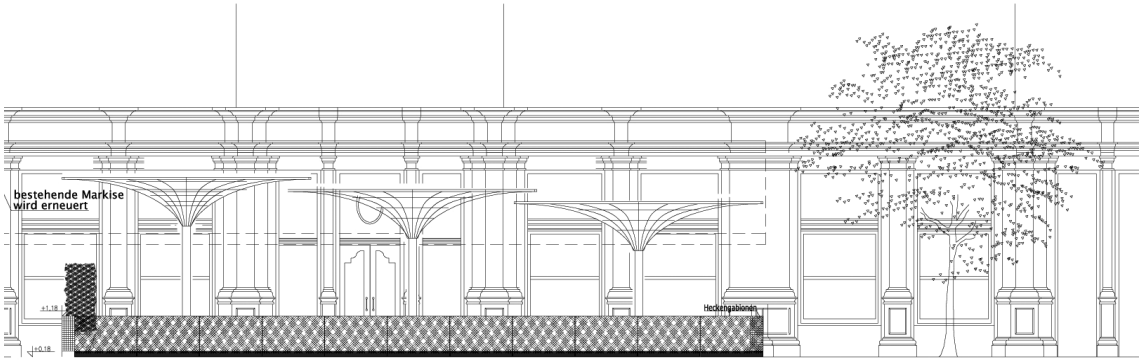
EXERCISES

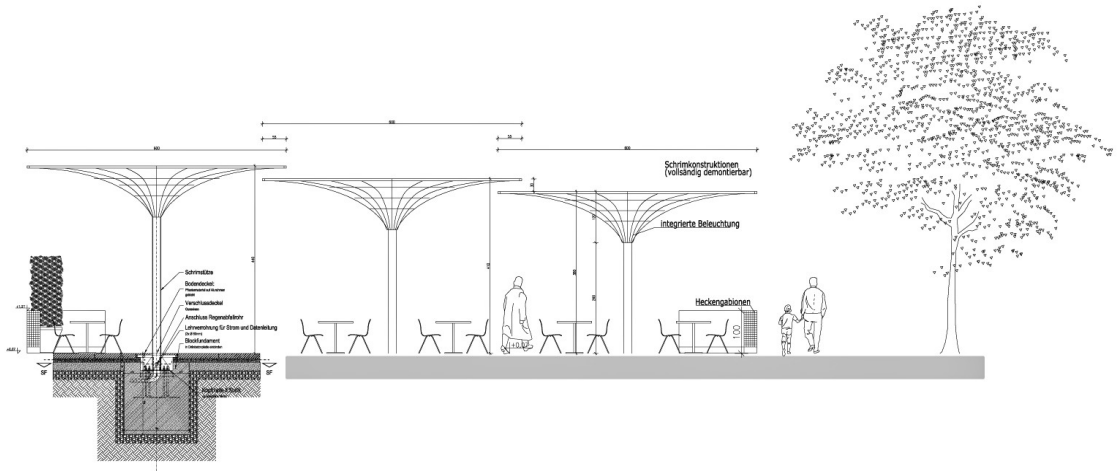
Quickstart

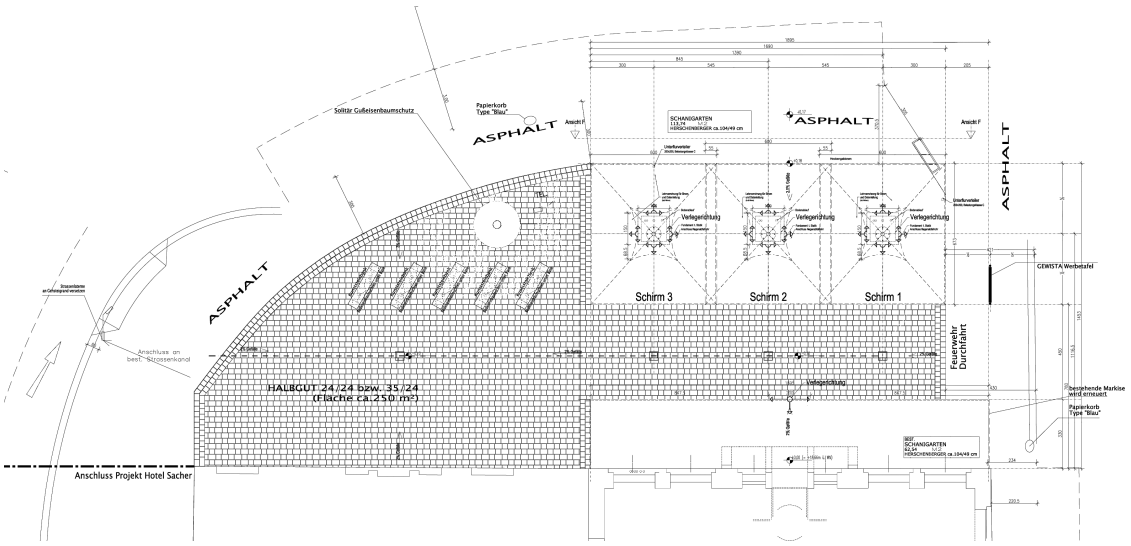
Before starting with the exercise please have a look at the *Quickstart Guide*.

Exercise 1: Café Mozart



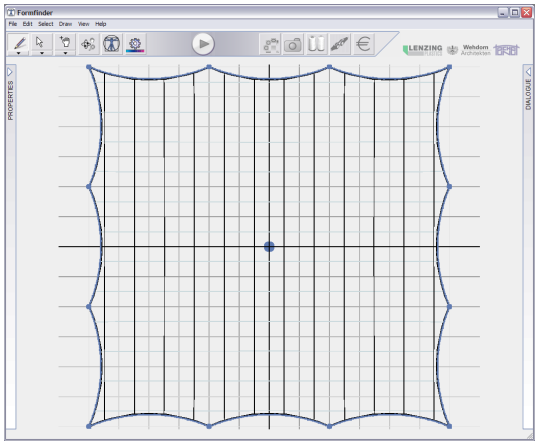






Steps:

Café Mozart



1. Plan shape

(Cafe Mozart 01 - Plan Shape.mem)

Settings to be adjusted:

Edit > Options... > Grid:

Extend: 7 m, *Spacing*: 1 m → press *Set*

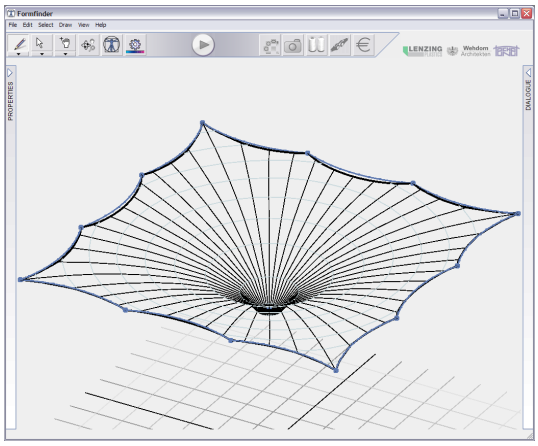
Edit > Options... > Controls:

Activate *Snap* on

Geometry:

Square: 6 x 6 m, Z-Position: 3.8 m,
side subdivision: 2 m

Draw the plan shape using the grid. Then use *Select Points* to mark all points and enter 3.8 for Z in the *Properties Panel* (click on the bar on the left to open).

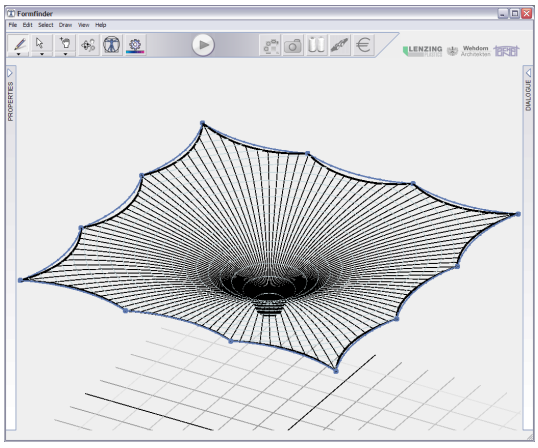


2. Applying curvature

(Cafe Mozart 02 - Low Point.mem)

Low point using a radial net:

Use *Select Anything* and click on the net.
Net type: radial
Center Point: z: 2.6 m
Inner radius: 0.2 m

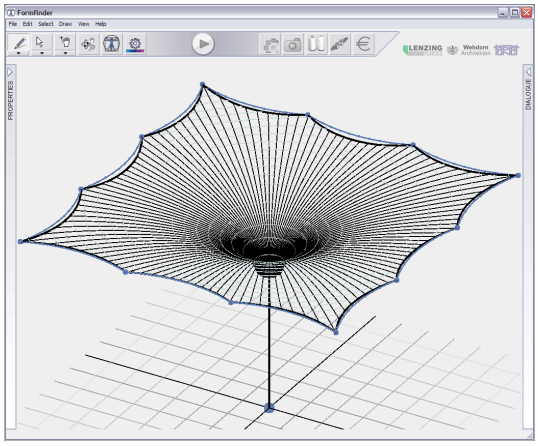


3. Adjust the net

(Cafe Mozart 03 - Finetuning Net.mem)

By adjusting the *Mesh* properties (size, force...) in the *Properties Panel* the shape of the net can be refined.

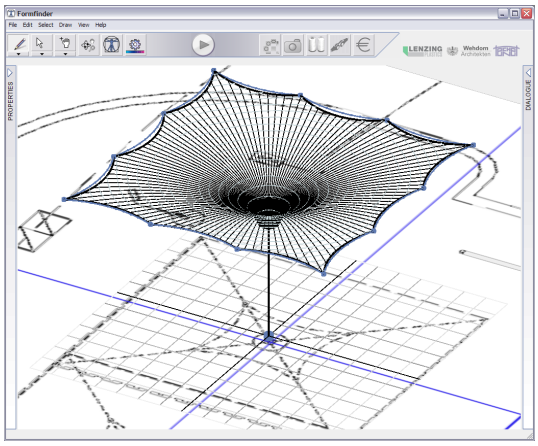
Click on *Finer* until *Size* is:
tangetial = 3 m
radial = 0.2 m
Then adjust *Force* to 0.3 kN.



4. Add the column

(Cafe Mozart 04 - Column Net.mem)

Choose *Rigid Element* from the tool bar. Snap to the low point – if necessary rotate the viewport – and use the grid's centre as end point.



5. Load the plan as background image

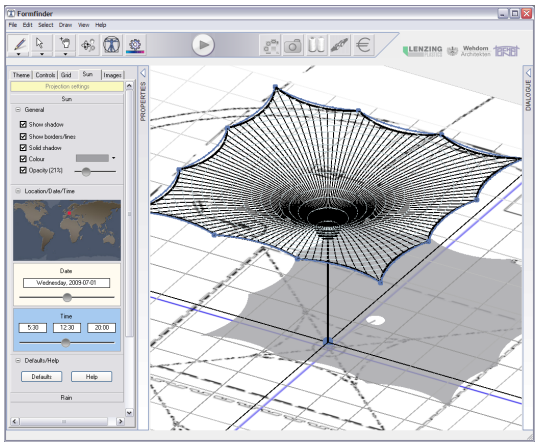
(Cafe Mozart 05 - Plan.mem)

Load the image from the sub folder Images:

Edit > Options... > Images:

Click on *Select image* and load *Plan.gif*
Uniform scale factor: 4.9
X position: -2.1
Y position: -8.8
Z position: -0.1 (in order to see the grid)

North equals +Y and east equals +X.



6. Shadow

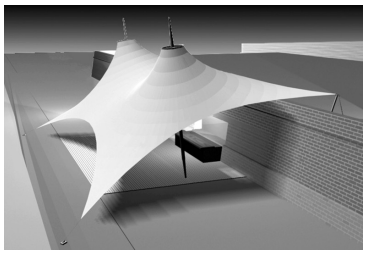
(Cafe Mozart 05 - Plan.mem)

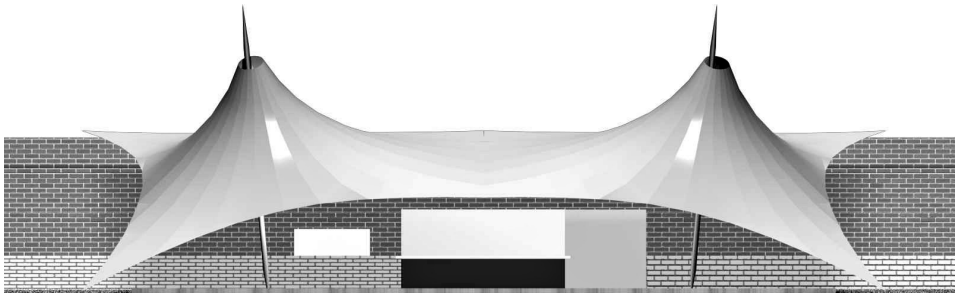
Use the Sun / Rain tool to explore the potential sun and rain protection of the design and its efficiency considering its position on the site plan.

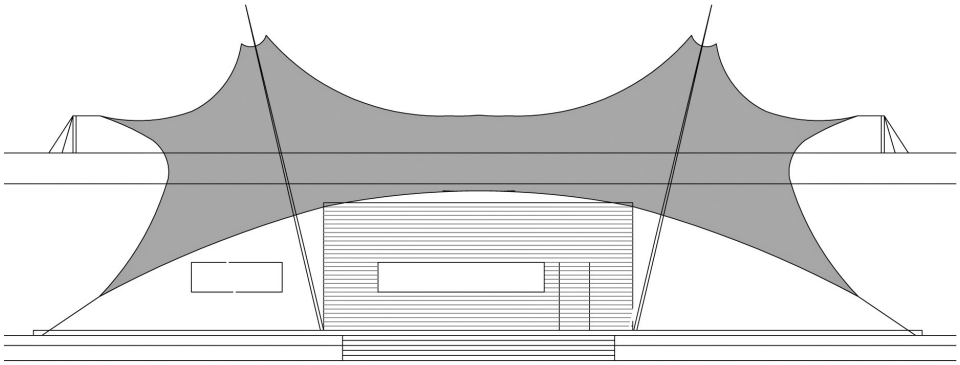
Edit > Options... > Sun:

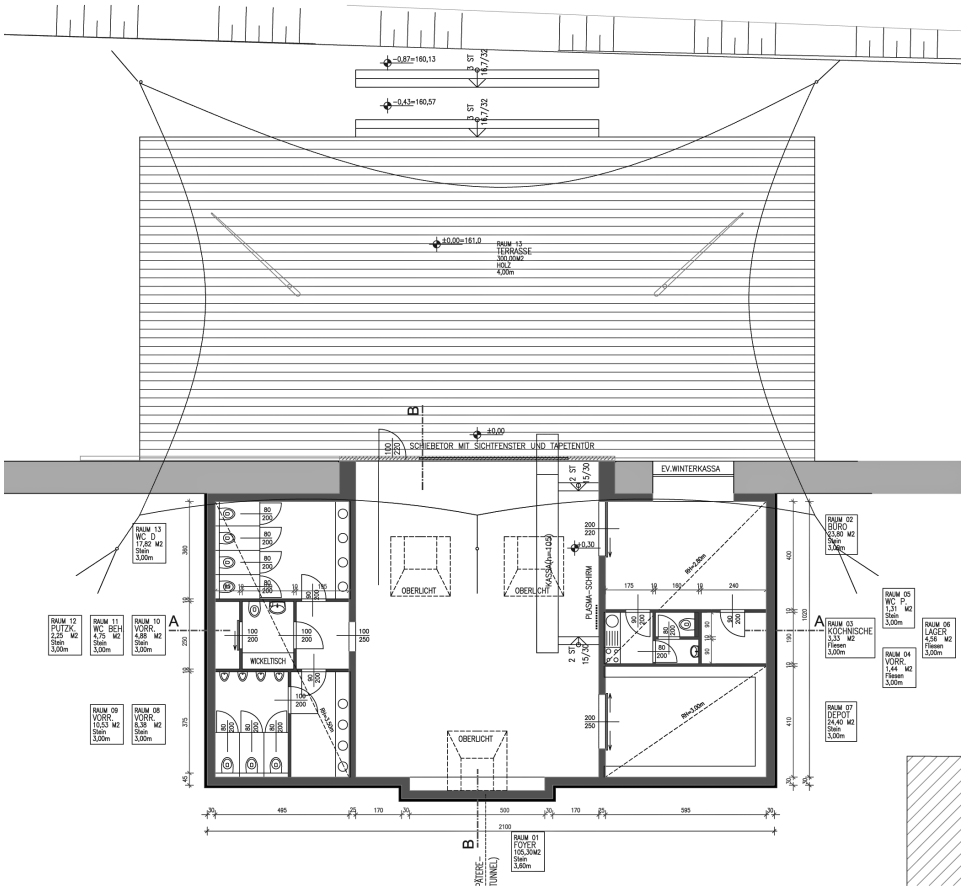
Set the approximate geographical position on the map.
Use the sliders for *Date* and *Time* to determine protected areas at a given time.
Switch to the *Rain* section:
Direction angle: 90 → wind blows from west
Falling angle: 90 → no wind; 60 → windy

Exercise 2: Schloss Hof



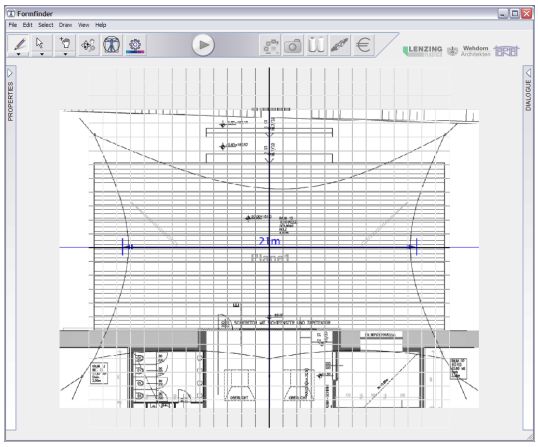






Steps:

Schloss Hof



1. Load the background images

(Schloss Hof 01 - Image Planes.mem)

Settings to be adjusted:

Edit > Options... > Grid:

Extend: 26 m, *Spacing*: 1 m → press *Set*

Edit > Options... > Controls:

Snap to grid points / lines off

Load the image from the sub folder Images:

Edit > Options... > Images:

Click on *Select image* and load *Plan.gif*

Uniform scale factor: 2.7

X position: 0

Y position: -0.8

Z position: -0.1 (in order to see the grid)

Now select *Image plane 2* load *Elevation.gif*

Choose *Front (Y)*

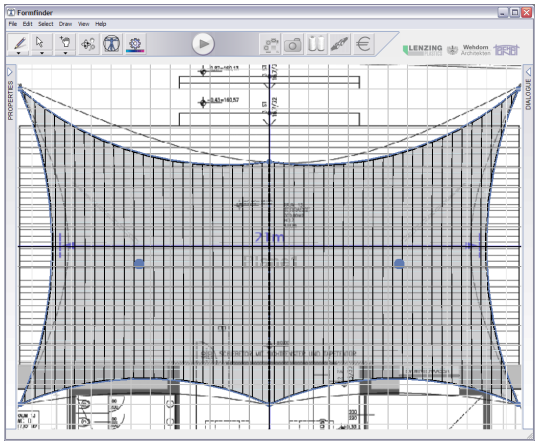
Uniform scale factor: 1.5

X position: 0

Y position: 10

Z position: 5.5

North equals +Y and east equals +X.



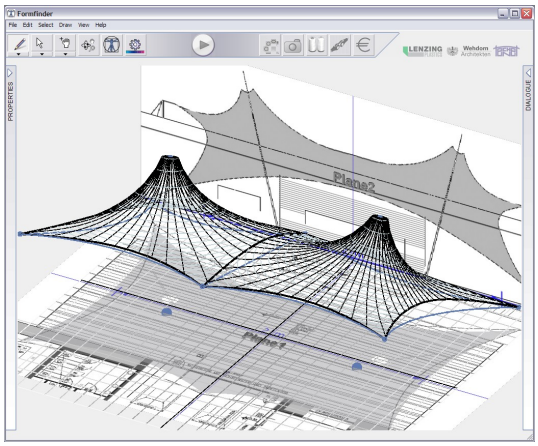
2. Plan shape

(Schloss Hof 02 - Plan Shape.mem)

Draw the shape outlined in the plan.

Then rotate the viewport and lift the points to their approximate position on the z-axis and refine the position in the *Front view.* Alternatively adjust the coordinates in the *Properties Panel.*

Now close your sketch and open the *Schloss Hof 02 - Plan Shape.mem* file to continue with the prepared model parameters for comparable results.



3. Applying curvature

(Schloss Hof 03 - 3D Form.mem)

Left high point using a radial net:

Use *Select Anything* and click on the net.

Net type: radial

Center Point: x: -7.25, y: 0.7, z: 9.8 m

Inner radius: 0.5 m

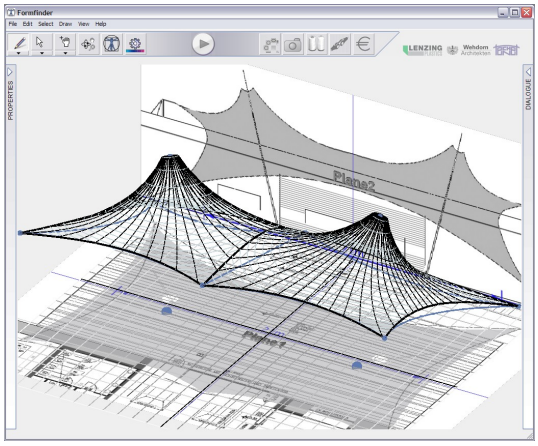
Right high point using a radial net:

Use *Select Anything* and click on the net.

Net type: radial

Center Point: x: 7.25, y: 0.7, z: 9.8 m

Inner radius: 0.5 m

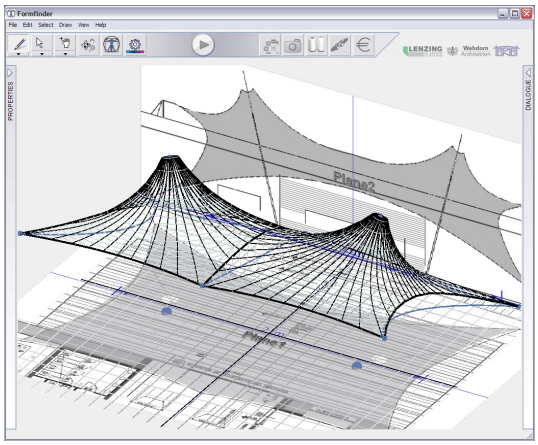


4. Adjust the net

(Schloss Hof 04 - Finetuning Net.mem)

By adjusting the *Mesh* properties (size, force...) in the *Properties Panel* the shape of the net can be refined.

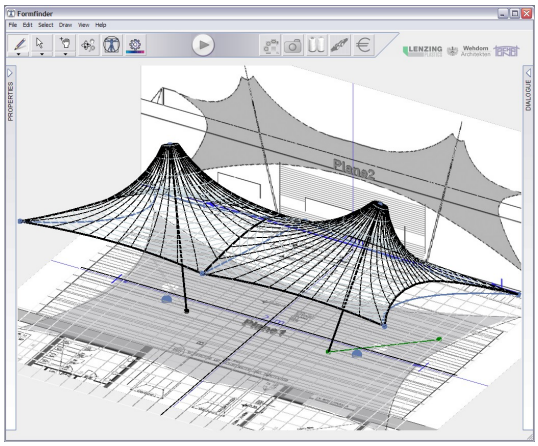
Select left net:
Adjust *Force* to 0.35 kN.
Stress radial: 1.2 kN/m
Go to *View direction of mesh calculation*:
Manual vector: x: -0.3, y: 0.3, z: 1
Repeat for right net with adjusted vector:
Manual vector: x: 0.3, y: 0.3, z: 1



5. Adjust edges

(Schloss Hof 05 - Finetuning Edges.mem)

Refine the shape by adjusting the sag (edge curvature) using the *Move / Lift* tool on the edges.



6. Columns

(Schloss Hof 06 - Mast.mem)

Use the drawing tool *Construction Line* to define the position of the column on the ground plane (by combining plan and elevation).
Draw the column as *Rigid Element* between the point on the ground plane and the high point.

Exercise 3: Force : Form

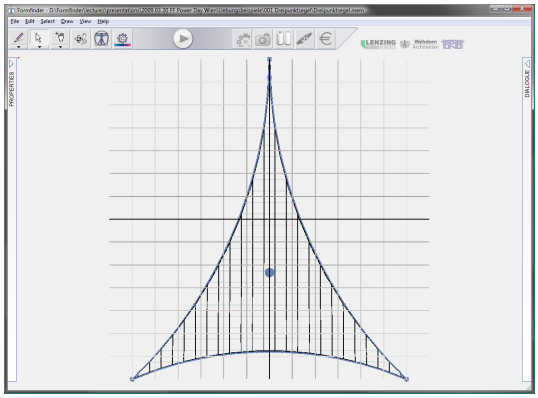
Structural efficiency

Both structural and economic efficiency depend strongly on the chosen form. Therefore form-finding is a key element for a successful membrane design - a form-active structure made of non-rigid material and thus is dependent on prestress to maintain its shape against loads like wind, snow...

The following examples of a tree-point-net and a four-point-net should demonstrate the difference between a design model free of loads (*Formfinder*) and a structural calculation using loads (*EASY Software*) and how the chosen design influences the deformation under load.

Applying this findings during form-finding can substantially increase efficiency during the design process.

Three-Point-Net



1. Formfinder: Plan shape

(3Point 01 - Formfinder.mem)

Settings to be adjusted:

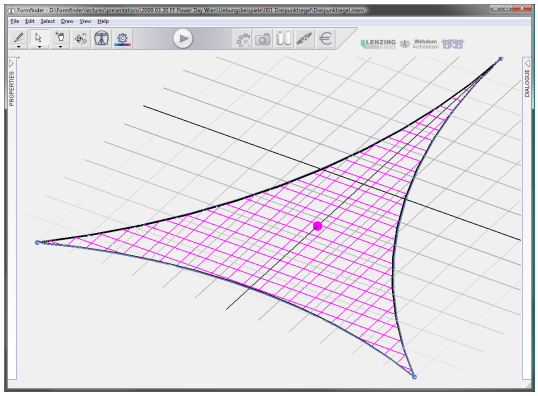
Edit > Options... > Grid:

Extend: 14 m, *Spacing*: 1 m → press *Set*

Edit > Options... > Controls:

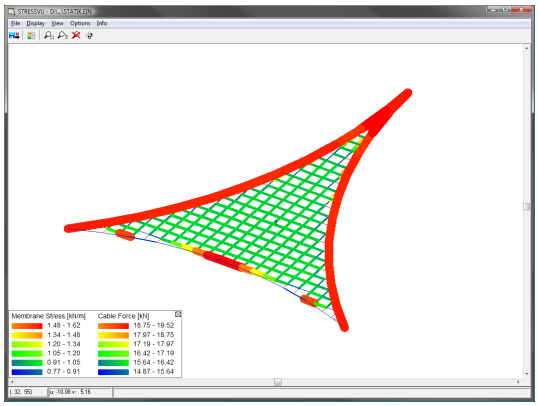
Activate *Snap* on

To create a net at least 3 points have to be defined.



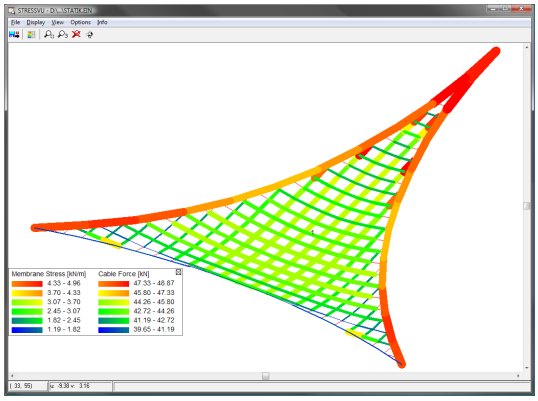
2. Formfinder: Net generation

Formfinder calculates the net within a closed polygon. With the *Edge Controller* (blue line) the calculation can be influenced to match the edges as close as possible to the desired shape. Though it is possible to curve the *Edge Controller* away form the net remember to keep it close to the edge to prevent distortion.



3. EASY: Stress distribution

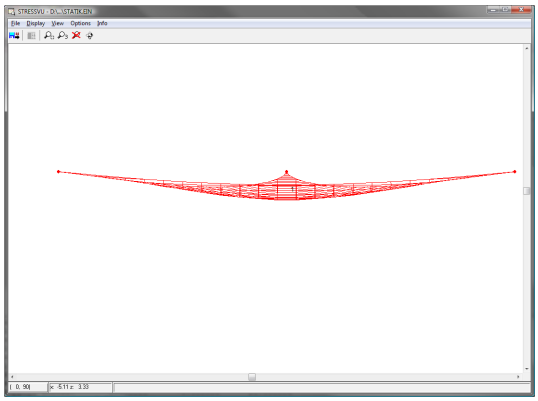
The model created in *Formfinder* is now imported in the EASY Software. The distribution of stress shows the disproportionate strain of the edges compared to the surface.



4. EASY: Dead weight

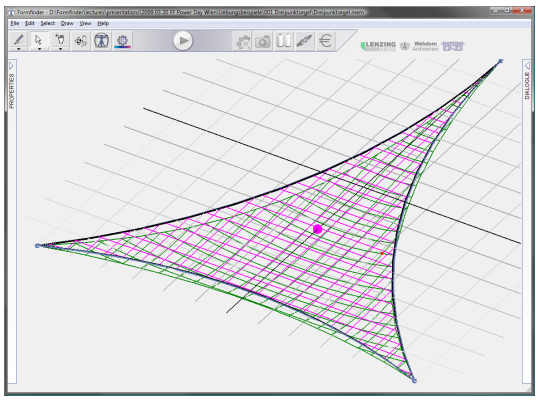
(3Point 02 - EASY.dwg)

Dead weight is used to test the model's behaviour under load. The result is exported to the *3Point 02 – EASY.dwg*.



5. EASY: Deformation

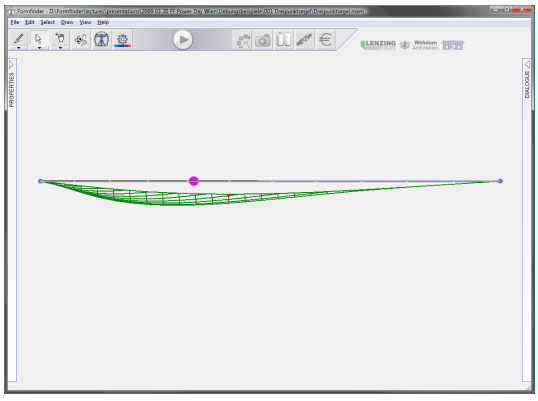
Even minimal strain of the structure causes considerable deformation.



6. Formfinder: Comparison

(3Point 01 – Formfinder.mem, Import: 3Point 02 - EASY.dwg)

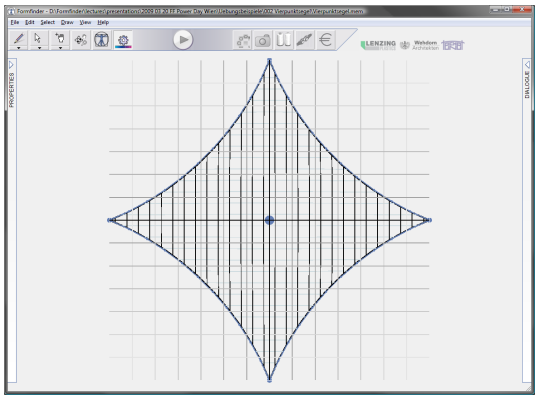
Back in Formfinder the 3Point 02 – EASY.dwg is imported to compare the load free design to it's behaviour under load (green). The deviation between the two forms shows the inefficiency of the design.



7. Formfinder: Conclusion

To compensate the deformations in the surface the edges would have to take disproportionate high prestress. Too high prestress causes problems during assembly and for the durability of the membrane. The inefficiency of the design has a negative impact on the technical and economical feasibility of the project.

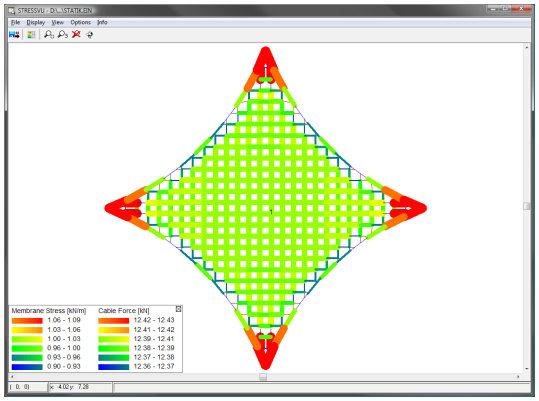
Four-Point-Net



1. Formfinder: Plan shape

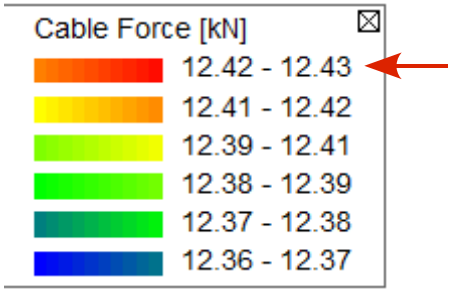
Settings to be adjusted:
Edit > Options... > Grid:
Extend: 14 m, *Spacing*: 1 m → press *Set*
Edit > Options... > Controls:
Activate *Snap* on

First a planar net is generated over a square plan shape.



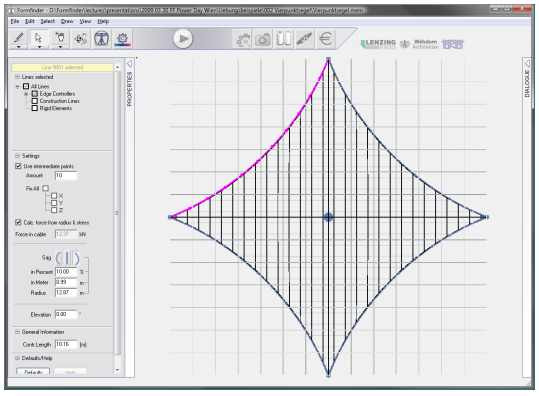
2. EASY: Stress distribution

The model is imported in the *EASY Software*.



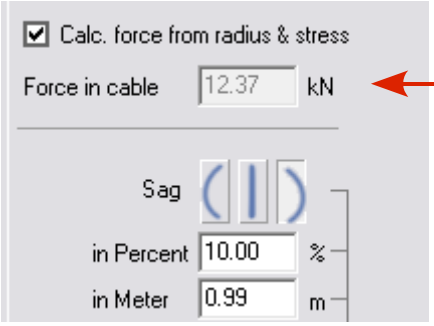
3. EASY: Cable force

Highest cable force: 12.43 kN.

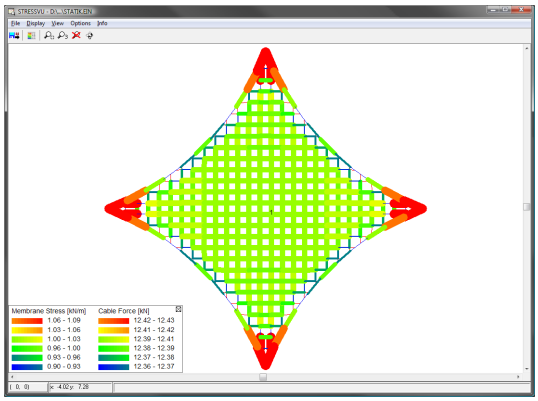


4. Formfinder: Cable force

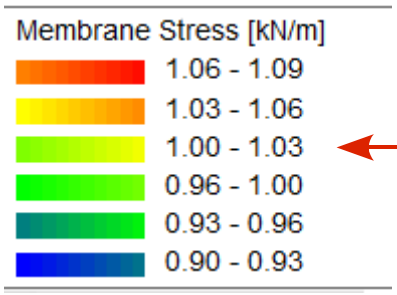
Back in *Formfinder* the cable force is determined by selecting a edge. The value is displayed in the *Properties Panel*.



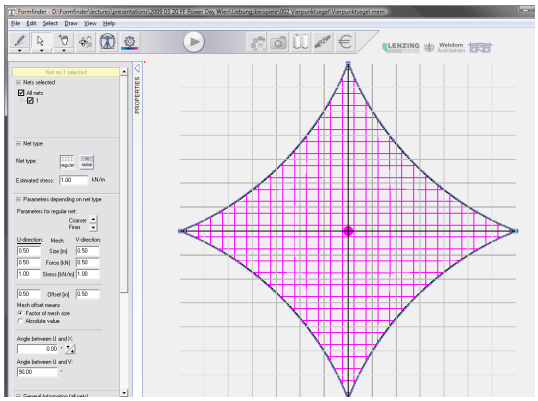
5. Formfinder: Values match
Force in cable: 12.37 kN
compared to 12.43 kN calculated by *EASY Software*.



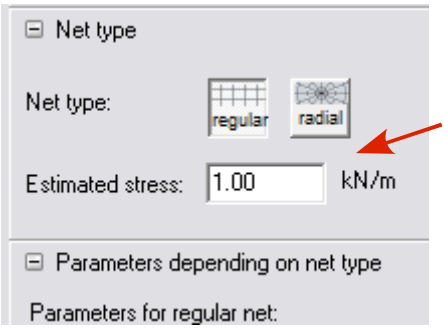
6. EASY: Stress
Comparison of stress.



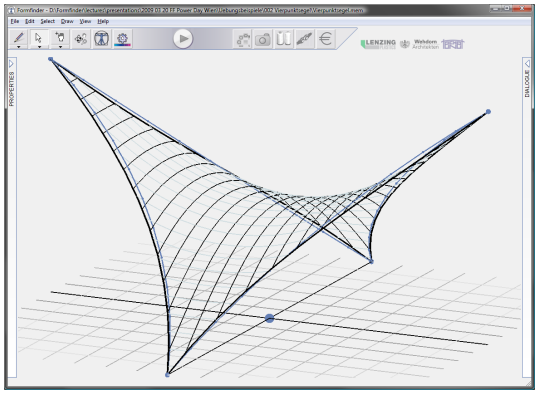
7. EASY: Medium stress
Membrane stress: 1.02 kN/m



8. Formfinder: Stress
Back in *Formfinder* select the net to read the net properties from the *Properties Panel*.



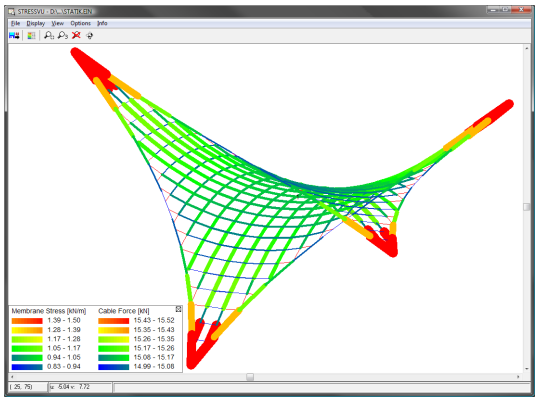
9. Formfinder: Values match
Estimated stress: 1 kN/m
compared to 1.02 kN/m calculated by *EASY Software*.



10. Formfinder: Curved surface

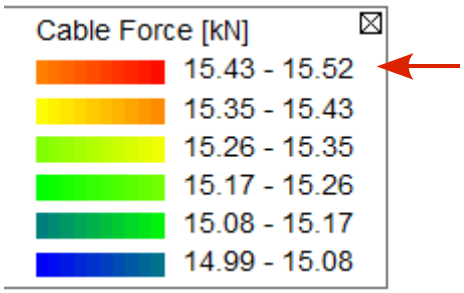
(4Point 01 - Formfinder.mem)

After determining the concordance between *Formfinder* and *EASY Software* using a planar net now a curved structure is tested.



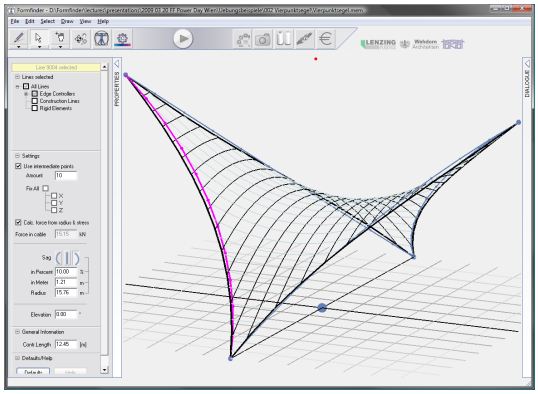
11. EASY: Stress distribution

The model is imported in the *EASY Software*.



12. EASY: Cable force

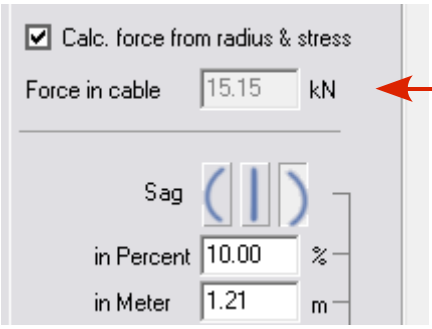
Highest cable force: 15.5 kN



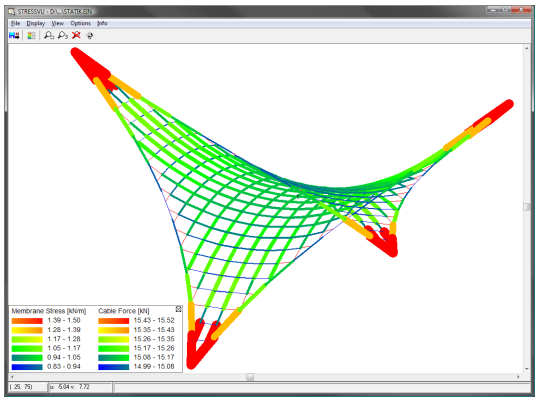
13. Formfinder: Cable force

(4Point 01 - Formfinder.mem)

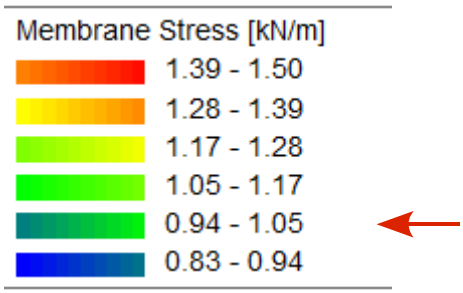
Back in *Formfinder* the cable force is determined by selecting a edge. The value is displayed in the *Properties Panel*.



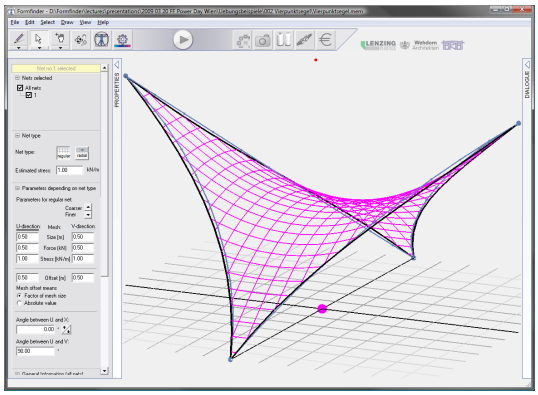
14. Formfinder: Values match
Force in cable: 15.15 kN
compared to 15.5 kN calculated by *EASY Software*.



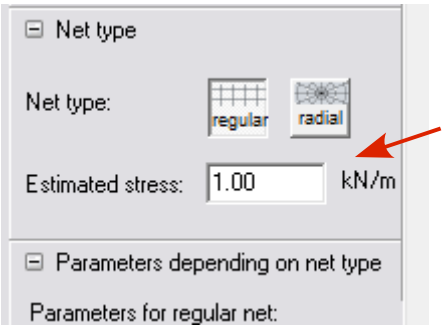
15. EASY: Stress
Comparison of stress.



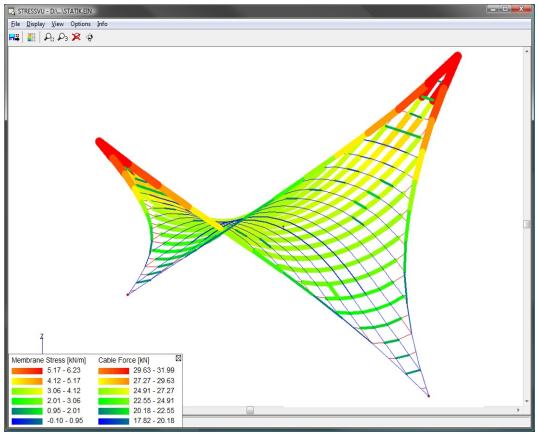
16. EASY: Medium stress
Membrane stress: 1.05 kN/m



17. Formfinder: Stress
(4Point 01 - Formfinder.mem)
Back in *Formfinder* select the net to read the net properties from the *Properties Panel*.



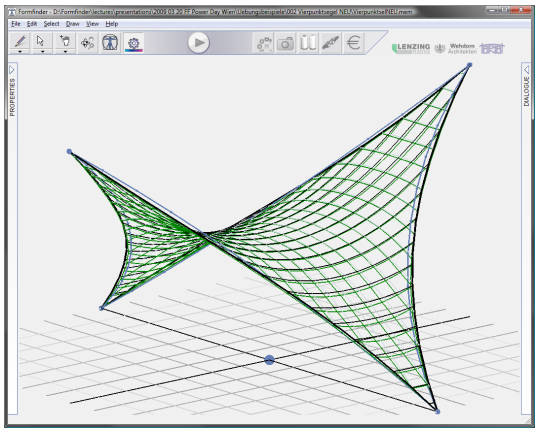
18. Formfinder: Values match
Estimated stress: 1 kN/m
compared to 1.05 kN/m calculated by *EASY Software*.



19. EASY: Dead weight

(4Point 02 - EASY.dwg)

Finally to be able to determine the behaviour of the doubly curved structure under load the deformation is exported to *4Point 02 - EASY.dwg*.



20. Formfinder: Conclusion

(4Point 01 - Formfinder.mem, Import: 4Point 02 - EASY.dwg)

The *4Point 02 - EASY.dwg* is imported in Formfinder. The comparison between the net generated by Formfinder and the imported behaviour under load (green) shows only minimal deviations.
An efficient design assures that the design shape can be maintained under load.

FURTHER INFORMATION

For further information please visit www.formfinder.at.

A collection of frequently asked questions and answers is available at www.formfinder.at/main/faq.

CONTACT

Robert Wehdorn-Roithmayr
Dipl.-Ing. Dr. techn.

Formfinder Software GmbH
Vienna Schlossgasse 22
Austria - 1050 Wien
Tax Number ATU 62944933
Commercial Register Number FN 284970 z
Austrian Federal Economic
Chamber Number 737298

Tel.: +43(1)5440644 40
Fax: +43(1)5444650
Mail: mail@formfinder.at
Web: www.formfinder.at

LEGEND

[Esc]	Characters in brackets define keystrokes.
Net	Words in italic refer to a term used in the application.

APPENDIX

Geodätische Linie

Eine geodätische Linie eine Verbindung zweier Punkte entlang einer Oberfläche. Einer der ersten Wissenschafter, die sich mit dem Problem der kürzesten Verbindung zweier Punkte auf Körperoberflächen auseinandersetzte, war der in Braunschweig geborene Mathematiker CARL FRIEDRICH GAUSS. Er erkannte, dass es bei der Konstruktion dieser Verbindungen, auch Geodäten genannt, zwei unterschiedliche Klassen von Körpern gibt, die hier differenzierter betrachtet werden müssen.

Es gibt sogenannte abwickelbare Körper, wie zum Beispiel Zylinder und Kegel. Bei diesen besteht die Möglichkeit, die Oberfläche in eine Ebene "abzurollen", in der die kürzeste Verbindung durch eine Strecke dargestellt wird. Kehrt man den Prozess um, so erhält man die Geodäte, die die Form einer Spirale, auch Schraubenbahn oder Helix genannt, besitzen. Auch bei Polyederoberflächen können Geodäten mit ähnlichem Verfahren konstruiert werden.

Neben der Gruppe der abwickelbaren Körper unterscheidet man die sogenannten nicht abwickelbaren Körper, wie zum Beispiel die Kugel. Die Oberflächen dieser Körper lassen sich nicht verzerrungsfrei in eine Ebene abbilden. Der Beweis hierfür wurde von Gauß erbracht. Er führte die sogenannte Gaußsche Krümmung ein; diese beträgt bei der Kugel 1 / r 2. Um die Kugel winkel- und flächentreu auf die Ebene abzubilden, müsste diese Krümmung in jedem Punkt diesen Wert annehmen; dies ist natürlich für kein r möglich, somit ist auch einsichtig, warum es keine vollkommenen Karten der Erde geben kann. Dennoch kann man die Geodäten auf einer Kugeloberfläche konstruieren. Hierbei geht man wie folgt vor:

Man erzeugt einen Schnitt der sogenannten Großkreisebene und der Kugel, in dem die Geodäte enthalten ist. Die Großkreisebene wird bestimmt durch die beiden vorgegebenen Punkte und den Kugelmittelpunkt. Ihr Name resultiert daraus, dass der Schnitt der Großkreisebene mit der Kugel den Kreis mit größtmöglichem Umfang erzeugt. Da die Gaußsche Krümmung des Großkreises am kleinsten ist, ergibt sich hier die kürzeste Verbindung der beiden Punkte, die Geodäte.

Krümmungen einer Kurve in der Ebene

Das Krümmungsmaß ändert sich von Punkt zu Punkt. Um die Krümmung im Punkt P zu bestimmen, sucht man den Kreis, der in P dieselbe Tangente hat wie die Kurve und sich ihr optimal anschmiegt. Dieser Schmiegkreis wird definiert durch den Punkt P und zwei Punkte P1 und P2 in seiner Nähe. Je näher diese an P heranrücken, desto genauer repräsentiert die Krümmung des Kreises die Krümmung der Kurve. Das Krümmungsmaß k wird nun durch den Radius r des Kreises beschrieben; es beträgt 1 / r (je stärker die Krümmung, desto kleiner der Radius).

Quelle: Robert Roithmayr, Diplomarbeit TU Wien 2001, Seite 124