INTEGRATION OF PARAMETRIC DESIGN – AND ANALYSIS TOOLS

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Summary This paper is about the opportunities and advantages of parametric design and analysis, shown within two practical instances:

1. The adaptive nodes for the renovation of the membrane roof in Masserberg, Germany

2. The material optimized cutting pattern for the membrane roof in Abano Terme, Italy.

1 INTRODUCTION: ADAPTIVE NODES IN MASSERBERG, GERMANY

In 1994 the double layered and insulated membrane roof of the health center in Masserberg, Germany, was finalised. The membrane structure has got 6 high points, which are held up by steel pylons, the membrane edges are anchored through 33 struts, that are connected to the ground with steel cables.

After 30 years of use, the outer membrane reached the end of it's lifespan, due to UV-damage and weathering. Therefore the structure got renovated in 2025. The outer membrane got replaced as well as all the steel nodes and cables.

Figure 1 completed membrane roof in 1994

The aspiration of the renovation was to use the minimum amount of material necessary, for every element, that got changed.

The old outer membrane was made of PVC-coated polyester type VII. The new outer membrane is made of PVC-coated polyester type V, that is thinner and lighter. To allow for the increasing forces at the high points, the membrane got reinforcements through 1-2 additional layers, directly welded to the main membrane[1]. These local reinforcements were possible, because of the progress made in the force evaluation tools during the last decades, in comparison to the first building state.

Building parts, that are even more impactful regarding the load transfer between the membrane and the struts, as well es the visual appearance of the structure, are the steel nodes at every corner of the membrane.

Previously there was a single node, that had many possible connection configurations, which was used at most of the membrane corners. In addition there were special nodes for the entrance area and around the adjacent building called "der Splitter".

These nodes are also treated differently within the renovation. The detailing of the remaining 30 nodes is the focus of the first part of this paper.

2 DESIGN

Previously there was a single master node, that was able to anchor all the different configurations at the 28 positions, that are accentuated in figure 2. The differentiating factors, that classified them as type A, B or C, are the diameter of the adjacent edge cables and the diameter of the anchor rods. The master node had two main connection points, located at the arm of the angle, which held the edge cables. Additionally there were seven connection points in between, which were used to connect to the valley cables and pylon safety cables. At the center of the angle, was the connection to the anchor rod.
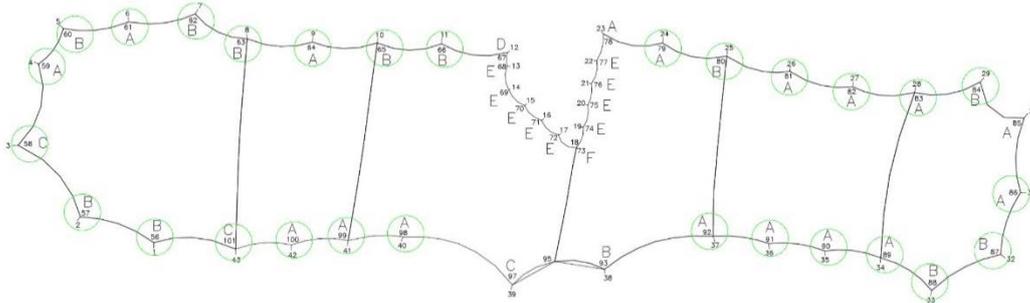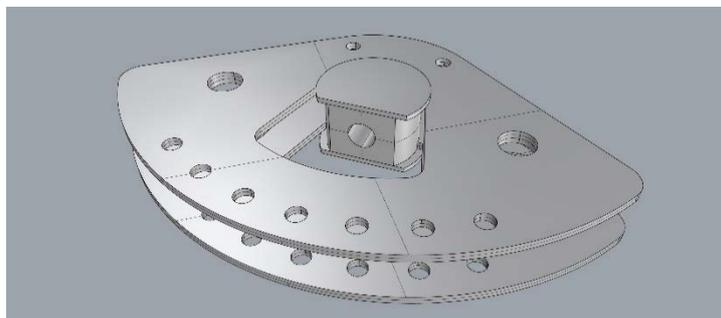

Figure 2 positions of master node
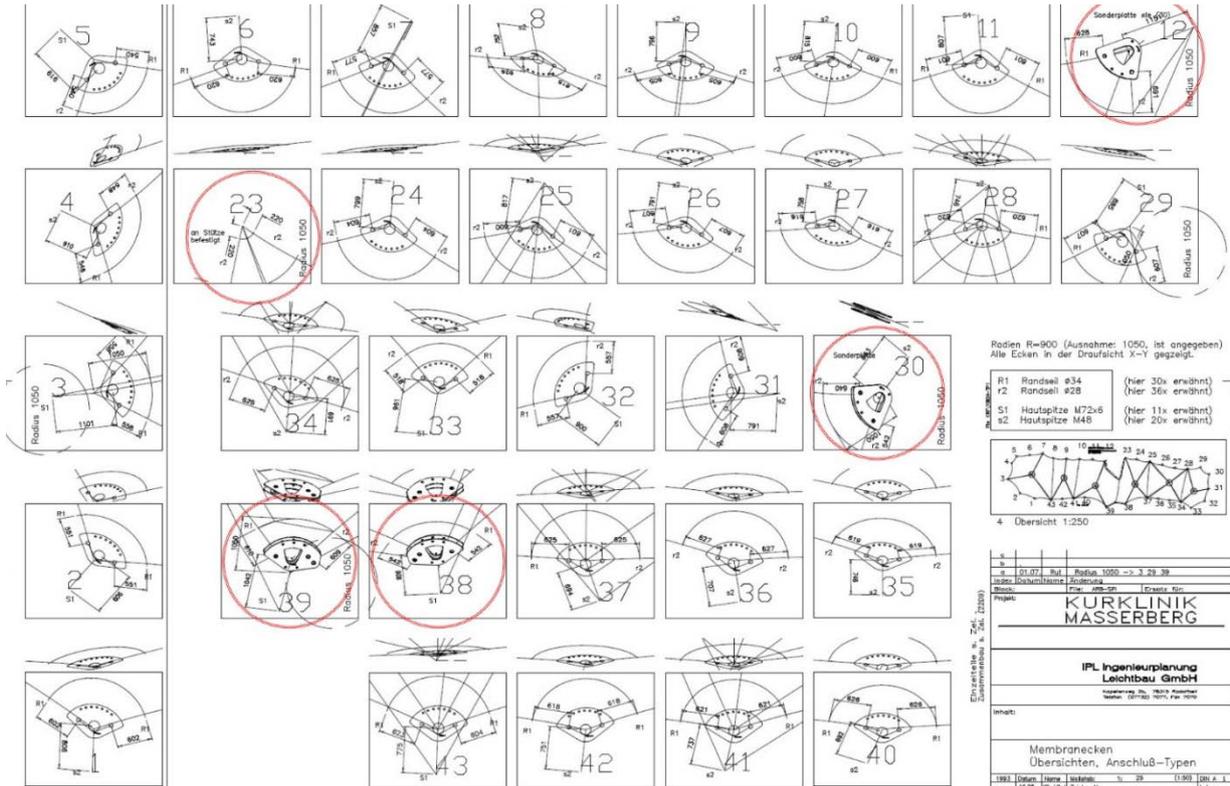

Figure 3 master node – weight: 95.2kg

Figure 4 master node configurations

As displayed in figure 4, the previous master node was able to accommodate up to five cables and an anchor rod. That had the advantage of a highly reduced amount of different parts, that had to be designed and manufactured. But that also meant, there was a lot of dispensable steel incorporated to the structure, as there are multiple locations with just two incoming cables, that often span a tighter angle, than the outer connection points of the master node. So in addition to unnecessary weight, these nodes were not optimized for their specific location, which meant, the load transfer was not optimal in a couple of cases.
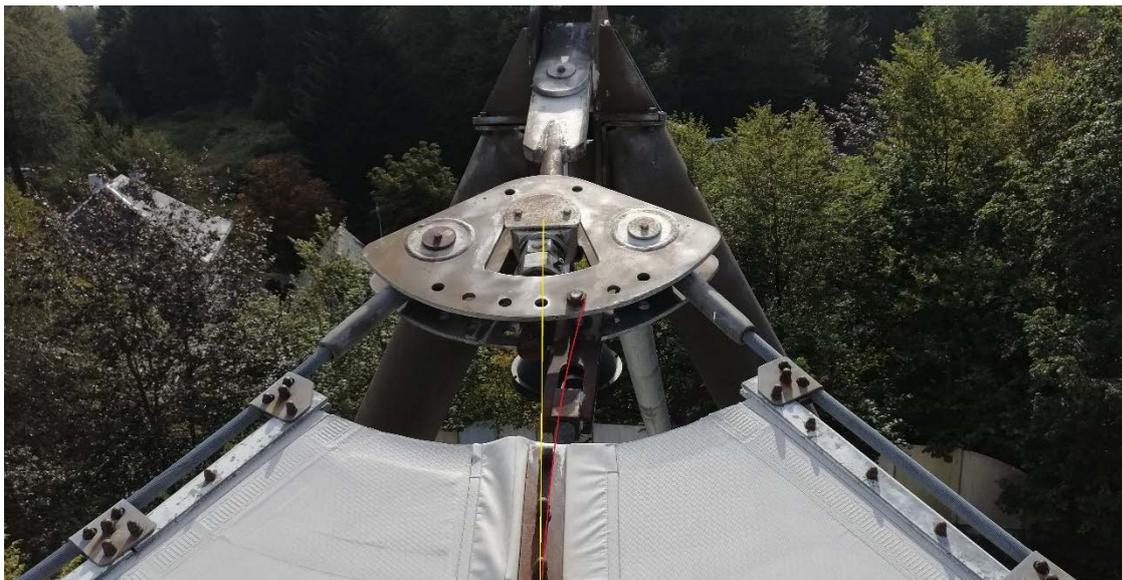

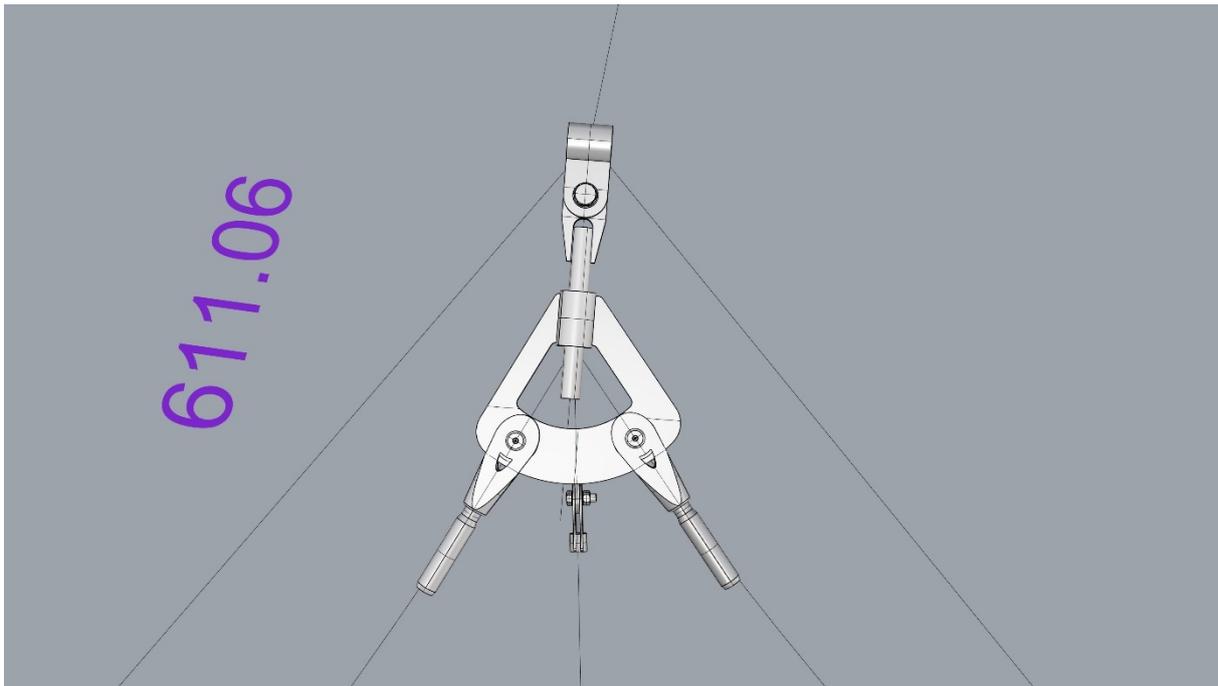*Figure 5 position 611.06 system lines pylon safety cable*

Figure 6 redesigned node at position 611.06

As you can see in figure 5, the system line of the pylon safety cable is tilted to the right side, instead of leading straight into the center of the node. That is, because the anchor rod and the cable fitting would collide there.

Figure 6 displays the redesigned node at position 611.06, which has got a geometry, that is informed by the angles of the two edge cables and the direction of the safety cable. This way the boundary of the node is minimal and the attachment points are precisely oriented, resulting in optimized load transfer and a stream lined appearance.

The goal of the redesign of these nodes was, to reduce the amount of steel as well as creating a case sensitive geometry.

2.1 Workflow

The starting point for the development of the redesigned nodes was a 3d system line model. This model contained the geometry itself attached to numerical attributes regarding the properties of the building parts, for example the type of cable(edge cable type1 or edge cable type 2, valley cable, anchor rod type 1 or type 2, pylon safety cable). That was important, so not only the angle of the node fits the specific boundary, but also the cable fittings could be placed automatically according to the cable type.

Before beginning the Grasshopper analysis, the system points(where all according system lines meet in one node) had to be sorted in the global geometry model. From the start point on the upper edge, the numbers increased clockwise, but they were split into the types 611 and 612. Type 611 meant an anchor rod diameter of 72mm and type 612 an anchor rod diameter of 48mm.
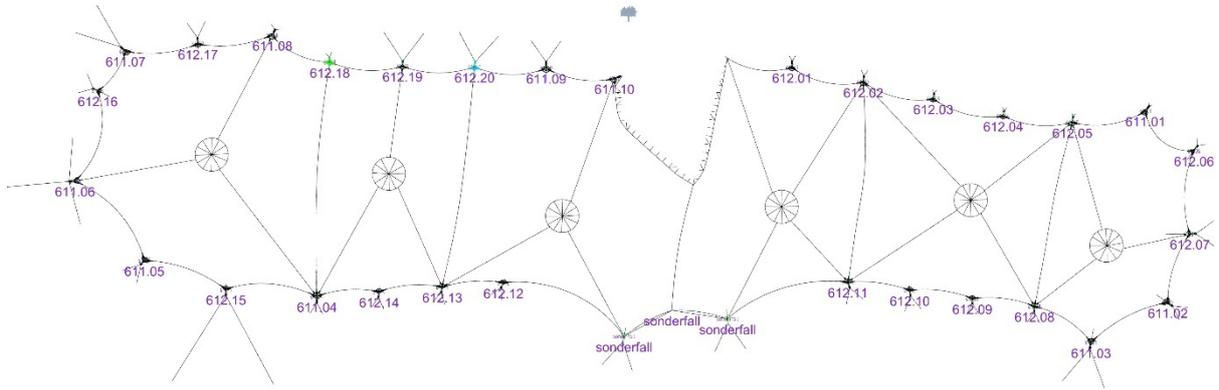
Figure 7 unique position numbers for system points

The Grasshopper script has got two geometry inputs, the (system) points and the (system) lines. Based on the system line attributes, the generated geometry would adjust accordingly. The parameters that were influenced by the attributes were: the hole diameters, the boundary shape, the diameter of the sleeve for the anchor rod and the connection type (hole or bracket). The script analyzed each system point step by step.

To create the node boundary, the system lines adjacent to a specific system point had to be evaluated. Therefore an average plane was created, defined by intersection points of the curves with a sphere, based on the system point. The x-axis of the plane needed to be aligned with the anchor rod, so that every position would share the same angle measuring logic. Afterwards all geometry defining curves had been projected to this average plane. This step is necessary, as the goal was to fabricate the nodes from planar sheet metal, while the incoming cables and rods were never in an exact plane.
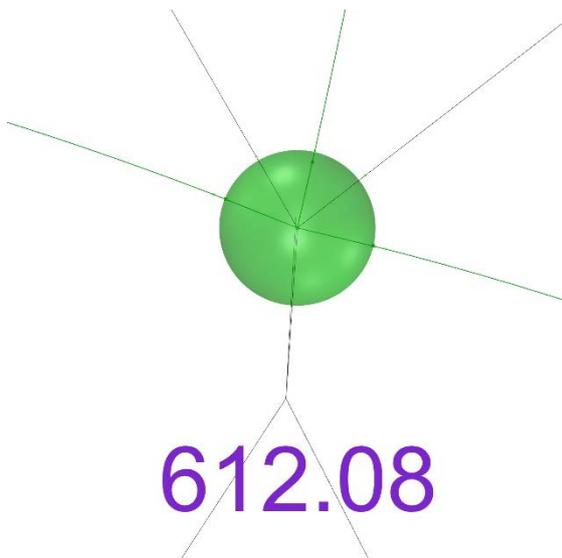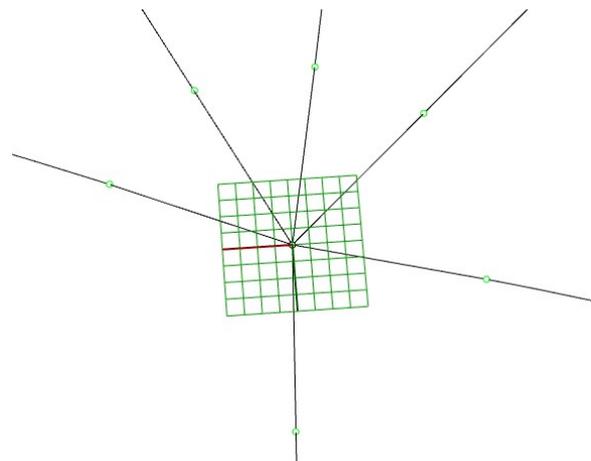

Figure 8 intersection points with sphere
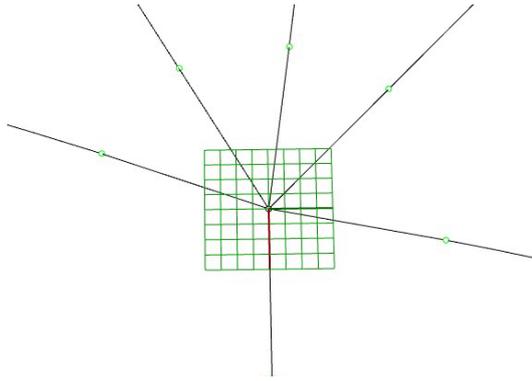

Figure 9 average plane

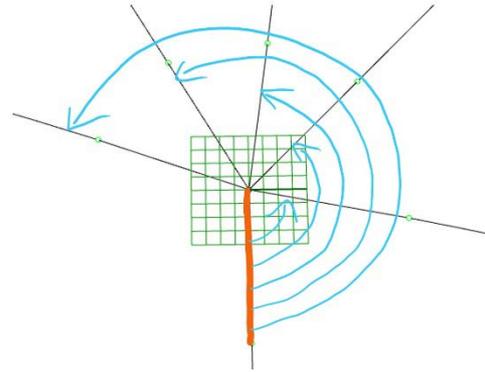*Figure 10 average plane x-axis aligned with anchor rod*

Figure 11 angles between projected curves

Between the anchor rod and every incoming cable system line, the angle got measured in the same direction. These angles, as well as the information about the system line attributes and the properties of the specific plane, got automatically written into an xml file.

So for every node there is an xml file with angle information, system line information, a unique system number and plane coordinates.

Afterwards these text files got imported into Autodesk Inventor, where an adapive master model had been set up. This master model was able to adjust into every possible configuration of inputs from the xml file. As there was a common design logic behind all of these nodes, there were parameters, that could be defined globally. For instance a parallel offset of the edges or the filleting radius of the corners. Based on the system line attributes an according cable fitting was placed automatically in inventor, as well as the correct sleeve based on the diameter of the anchor rod. Inventor created the assemblies at global 0,0,0 with the relative angle information measured in Grasshopper.

This way Inventor created 30 unique nodes with the according workshop drawings.
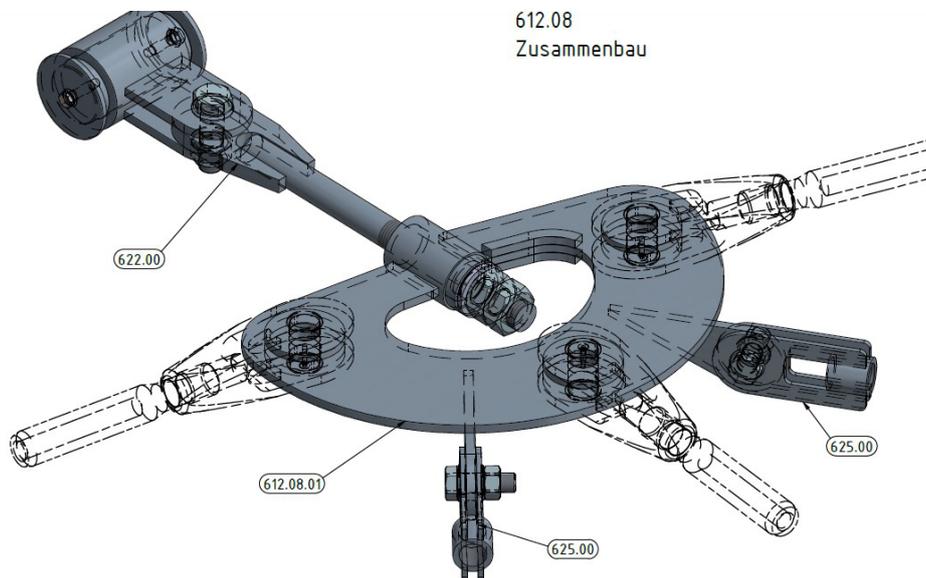
625.00	2	4.273 kg	8,5 kg	
622.00	1	46.133 kg	46,1 kg	
612.08.01	1	44.397 kg	44,4 kg	
Pos.	Quantity	Weight	Total weight	Material

Figure 12 assembly node 612.08 - node weight 44.4kg

In comparison with the previous master node, which had a weight of 95.2kg, the new node 612.08 weighs just 44.4 kg(Figure 12). That is a weight saving of more than 53%.

Before sending the data to the fabrication, we performed a check, by placing the generated node assemblies in the global geometry in Rhino. That step was easy to automate, because the information about the global coordinates was allways present within every node model. This way, we had a visual reference between the created node assemblies and the underlying system lines. For example in figure 13.


Figure 13 placed node assembly 611.04

Figure 14 new node during installation

3   INTRODUCTION: MATERIAL OPTIMIZED CUTTING PATTERN FOR DOUBLE CURVED MEMBRANE ROOF IN ABANO TERME, ITALY

After the design and form finding of a double curved membrane is finished, there is an always reoccuring problem, which is creating a seam pattern, that combines low geometrical distortion with economic utilization of the material width of the membrane roll.

In the following part of the paper, I want to explain this process in the case of the 3 funnel shaped parts of the membrane roof in Abano Terme, Italy.
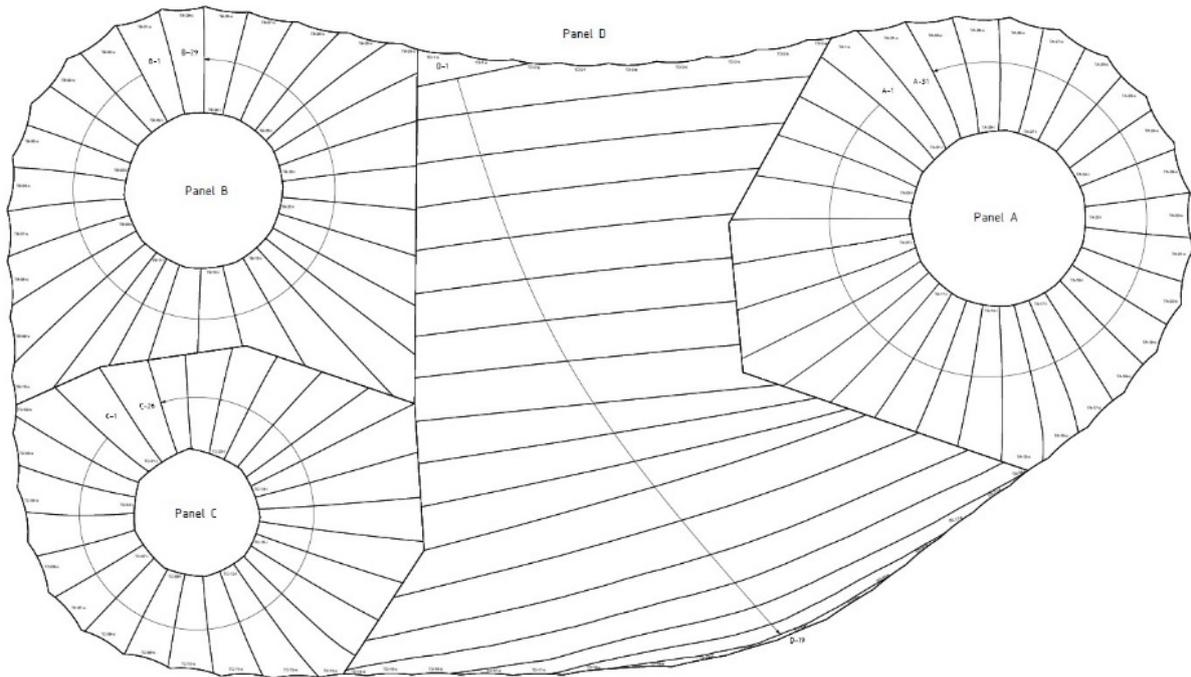
Figure 15 seam pattern membrane roof in Abano Terme, Italy

The difficulty is, that there can be a substantial length difference between a planar, projected segmentation and the resulting seam curves on the 3d geometry. Focusing on radial seam patterns - as soon as there is a variation in the length of the pieces, you can not partition the geometry with the same angle. Because the maximum material width would increase in relation to the distance to the origin of the circle. An additional factor is the surface development in the three dimensional space. If the starting point for a cutting pattern is a planar, projected, polar array of curves, there will be a deviation towards the three dimensional counter part. The magnitude of this deviation is dependent on the angle difference of the normal direction between a given point on the flat and the 3d pattern.

That means, the more curvature and more tilt a surface has got, the harder it is to correctly estimate the resulting material width between a pair of seams, that is based on a two dimensional curve input (figure 16). The length differences are significant. The decisive measurement is the distance between the end point of the shorter radial seam to the closest point on the longer radial seam. But not connected through a 2-point-line, instead a curve flowing along the membrane surface. As shown below, the 2d perpendicular line is 226mm shorter than it's 3d counter part.
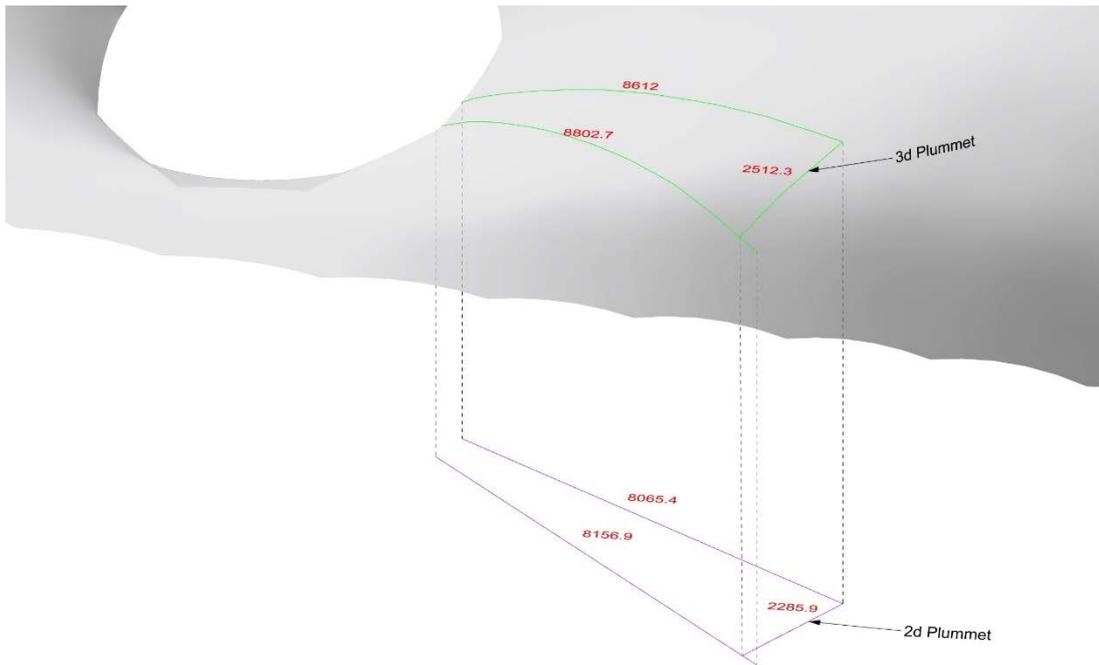
Figure 16 length differences at sub panel C-14

4 WORKFLOW

4.1 Partition into main membrane panels

   The first step was to break down the membrane surface into four main membrane panels (A,B,C,D - see figure 15).

Three of them are funnel shaped and the fourth is similar to a trimmed cylinder.

The shared division curve of the two funnels on the left side is purposely not straight or centered, because that way we could reduce the possibilities of two opposing membrane strips overlapping at the same welding spot, while remaining a consistent, economic cutting logic.
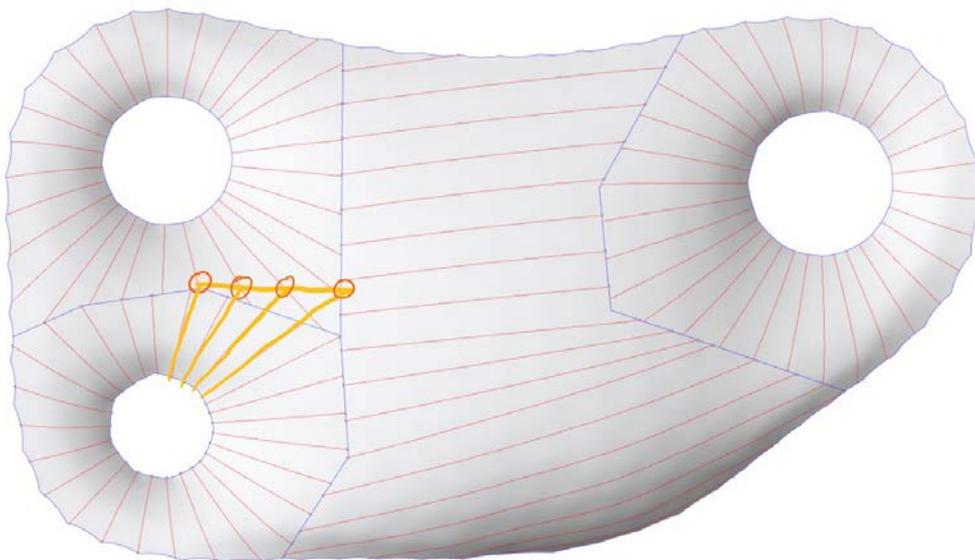

Figure 17 reason for asymmetric panel border

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When creating a radial seam pattern of a funnel geometry, the two neighbouring radial seams are most often of different length. If waste reduction can be of a higher priority, than a symmetrical influence during compensation, the individual membrane sub-panels can be aligned with their longest edge oriented along the warp direction of the membrane (figure 18). This is the underlying concept of the material optimization in this project.
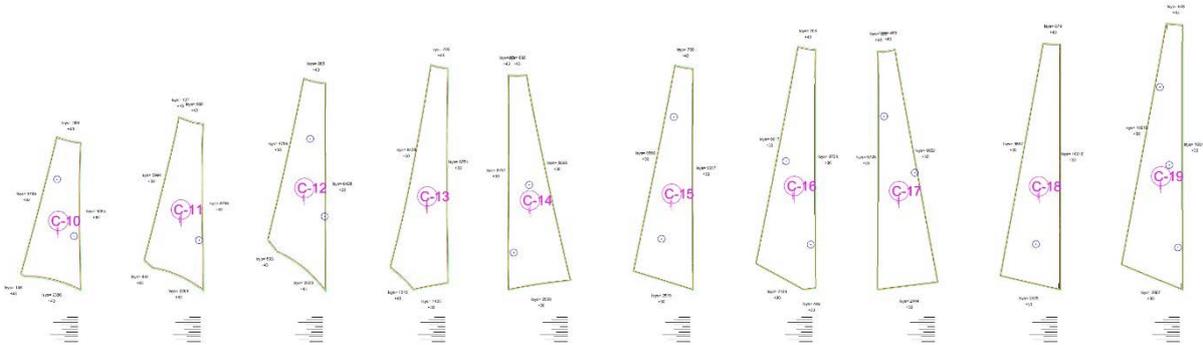

Figure 18 excerpt of the cutting data for panel C

4.2 Automation per membrane funnel

1. extract the membrane edges
2. project the membrane edges to xy-plane
3. split into inner and outer edge
4. use inner edge to get a centroid
5. define a starting point for the solver on outer edge
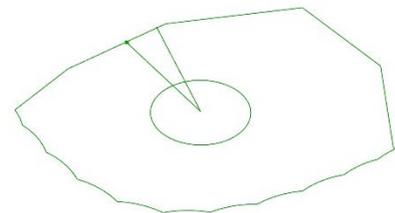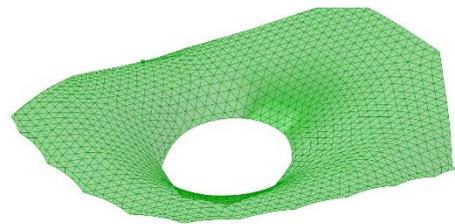6. define a goal material width
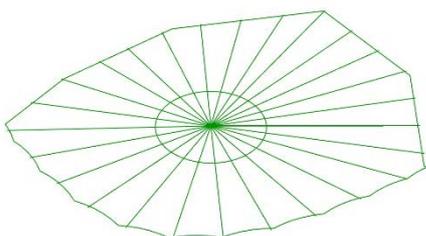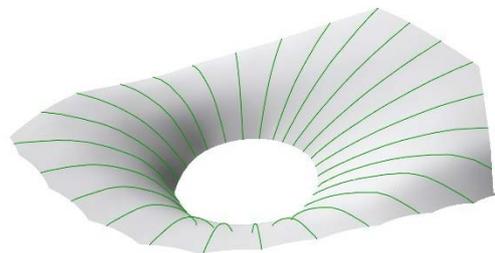7. run the custom solver

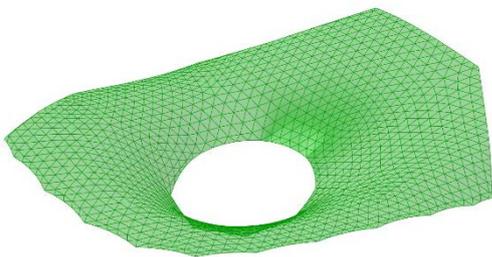*Figure 19 input for custom solver*
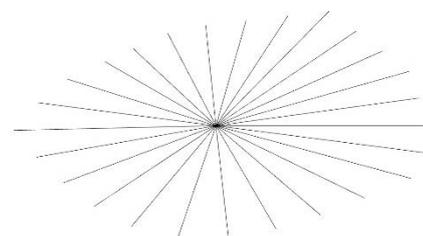

Figure 20 result of custom solver

Figure 21 projected array on membrane surface

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The result of the solver is a planar, polar array of lines, that is optimized based on the length of the 3d-plummet curves. After projecting this array onto the membrane surface, the next step is using their endpoints to create geodesic curves on the surface. There can be a slight deviation between the length of the 3d-plummet between the curves before creating the geodesic curves and afterwards. In case there is an obviously visible difference when comparing the two iterations, exceeding the goal material width, a solution would be adjusting the starting point of the solver or making a local adjustment. For the membrane roof in Abano Terme this automation process created useful results.
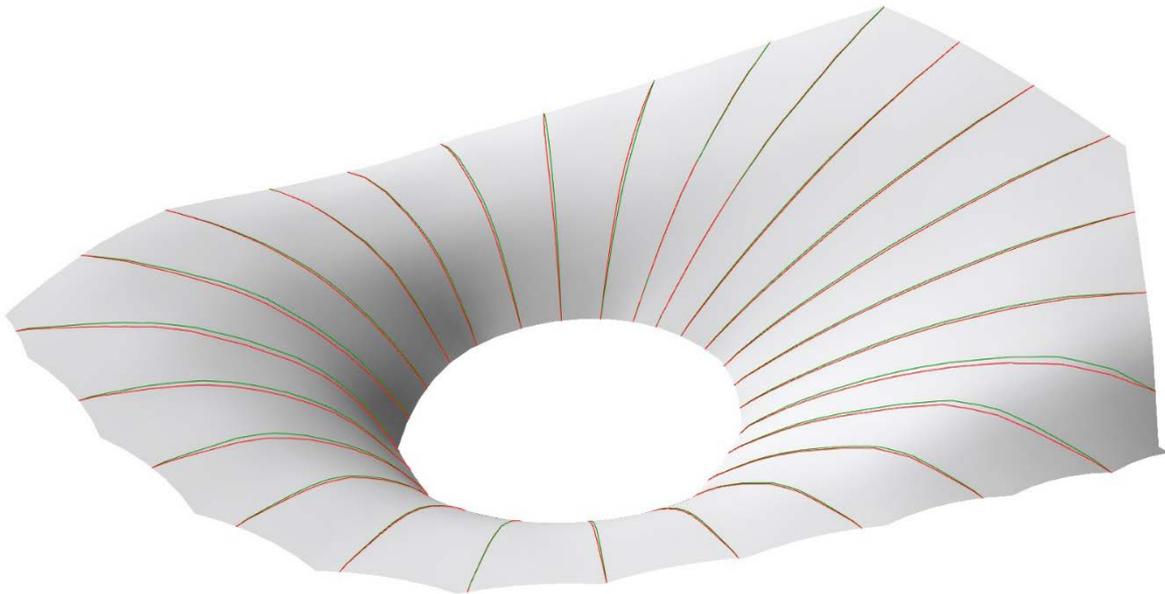
Figure 22 geodesic curve (red) / projected curve (green)

Because we are using mesh geometry for form finding in the office, we could not just refer to the native geodesic function of Rhino inside our python solver. Instead we used the Kangaroo solver to iteratively find the geodesic curves on the membrane geometry (mesh).

5 CONCLUSION

5.1 Masserberg

We used the redesigning process of the steel nodes as an opportunity to create a new workflow by using the strength of the geometry analysis capabilities of Grasshopper and combining it with the output of detailed workshop drawings from Inventor. The challenge was to generate a seamless communication between these applications. The automated production of XML-files was our solution. As the system line geometry got adjusted again, after the initial batch of nodes was created, the automated process was extremely valuable, because we were able to update all the nodes within an hour, which would have taken a week otherwise.

5.2 Abano Terme

Though programming a custom solver for reducing material waste took some time, it was a valuable tool for creating a visually appealing and economic membrane structure. For future improvement, it would be interesting to create the geodesic curves directly through the solver, that would reduce the working steps and increase the accuracy of the output, as the optimization would run on geodesics not only on projected curves on the mesh geometry.

6 PICTURE CREDITS

Figure 1, 4: IPL/ formTL GmbH
Figure 5: Canobbio Textile Engineering Srl
Remaining Figures: formTL GmbH

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[1] B. Stimpfle, "Erhalten durch Mordernisierung, Membrandächer refreshed" , Stahlbau 93(2024), Heft 8 (Sonderdruck) (P. 559-560)
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