ANALYZING SURFACE MESHES RELATED TO CONSTRUCTIVENESS

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ABSTRACT

Presently amorphous forms are one of the most discussed themes of architecture and civil engineering. These often very imaginative architectural designs comparably fascinates architects, engineers and observers. In connection with the realization several fundamental questions are to answer. The relationship between the "free geometry", the structure and the cladding is one of the most exciting things especially to engineers.

In this context parameterized spatial structures represent an interesting constructive approach. These flexible topologies inform oneself at surface meshes, which are a part in the form finding process. So it is possible, to realize nearly every free form by using members and nodes. Simultaneous the reticulated structure provides an opportunity for using the members as supports for direct structural glazing. Buildings with a high degree of transparency are possible in this way. Due to the parametric character of the structure all the members and nodes can be prefabricated under industrial conditions.

In the structural design process has to be defined all the constructive details of the spatial structure. That's why it is absolutely necessary to know as much as possible about the geometry of the mesh, which describes the free formed structure. The software tool MeshExaminer supports this process. It bases on standard office software and calculates many geometrical parameters of arbitrary surface meshes.

KEY WORDS

architecture, blobs, free form, spatial structures, parameterization, constructiveness

INTRODUCTION

Three main features characterizes architectural free-forms. First the double curvature, which changes as it likes. Second the large dimensions, which makes it essential to split the whole form into comparatively small elements. And third, the unique character of architectural design, which often requires a made-to-order production.

There are in general three ways to find or to define a free form. The first one is the statically mode, which based on a "form follows force"-optimization approach. The second one is the geometrically way. In this approach free formed surfaces are designed under

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stringent constraints of translation and rotation of lines and curves in space [Schober]. The intuitive-artistic way is the third one. Most architects prefer this one in early design phases. It bases on more and more powerful computers and modeling software, which enables them to create arbitrary forms without complex geometrical knowledge.

All the three form finding methods briefly characterized are parts of digital oriented design processes. They uses different meshes for digital describing of architectural free forms. Surface meshes are structures consisting of an any number of edges, connected among each other at nodal points. They compose enclosed meshes. To follow the free form, the edges have to be of different length.

Spatial structures are construction kits made of members and nodes, joint together at the ends of members, like surface meshes do. If the "source code" of the structure is not closed, like in case of standardized space frame systems[4], they can describe arbitrary forms. These structures should be named as parameterized spatial structures. They provide an interesting constructive approach. Firstly their members generates a bearing framework and can be used as supports for structural glazing. Secondly the digital way of form finding provides an direct opportunity for computer aided engineering and manufacturing.

STRUCTURAL DESIGN OF PARAMETERIZED SPATIAL STRUCTURES

BASICS

In the structural design process has to be defined all the constructive details of the spatial structure. Thereby the key problem is the determination of dimensions and shapes of members and nodes as well as their adjustment according to local loads, constraints of structural glazing and last but not least geometry. Specification of the way of joining members and nodes (screwing or welding) is also an important theme. But it is of second priority and that's why it will be neglected in this paper.

ADJUSTMENT OF MEMBERS

In general every member is a support for two adjacent glass panels. Due to the free form all the meshes describing different planes in space. Because there is not a global center or line of reference in the structure, only local geometry parameters can be used for adjustment of members. A meaningful approach, which was used in different projects before[5], is to adjust the members firstly with their up side middle axis at the edges of the surface mesh and secondly with their z-axis at the bisecting line of the adjacent glass panels.

ADJUSTMENT OF NODES

The adjustment of nodes can also be defined related to local geometrical parameters. It is a very important predefinition with regard to the geometrical-constructive parameters described afterwards. In relevant literature were shown two different approaches [Sischka]

[4] e. g. the MERO-space frame system, patented by Max Mengeringhausen in 1942 and all the imitate systems developed later around the world

[5] e. g. the Roof of the Great Court of the British Museum of London by Foster, Happold, Zenkner & Handel and Waagner-Biro or 'Logo' and 'Vela' at the New Trade Fair in Milan by Fuksas, Schlaich and MERO

[Stephan]. The first one is to generate a nodal axis by summation of scaled vectors of edges which ending at the specified node (Fig. 1, left). Second one is to generate a nodal axis by summation of scaled perpendiculars of the meshes which surrounding the node. (Fig. 1, right)

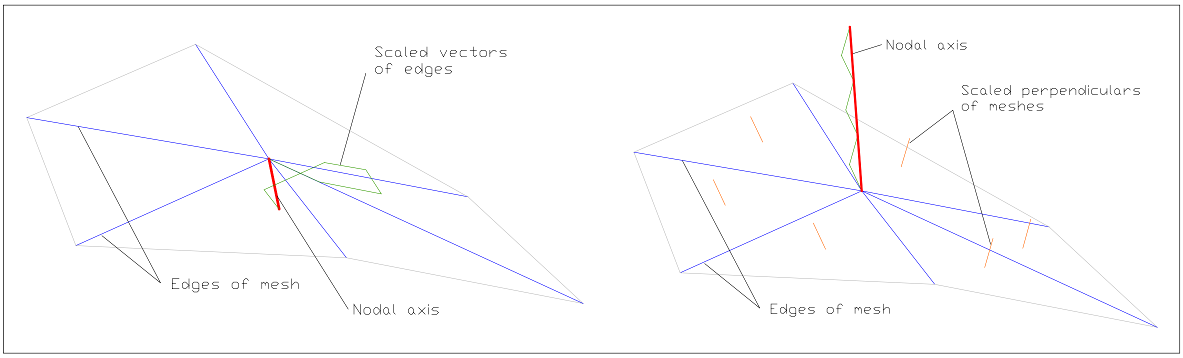

Figure 1: Generating nodal axis

GEOMETRICAL-CONSTRUCTIVE PARAMETERS

According to the adjustment of members and nodes there are different geometrical parameters which describes the local and in sum the global geometry of the mesh respectively the structure.

The length of the edges is the core information of the mesh. To follow the free formed surface the edges of the mesh have to be different length. Related to the shape and dimension of nodes these parameters are directly associated.

Due to the determination of the adjustment of the nodal axis there are three polar angles at each node which are very important regarding to dimensioning and shape.

The first should be named as "nodal axis angle". It can be identified between the nodal axis and the edge of the mesh (Fig. 2, left).

Second angle should be named as "sector angle". It could be identified by projection of the edges to a plane normal to the nodal axis. There is an angle between two adjacent edges. The sum of all the angles at one node is naturally 360°. (Fig. 2, middle)

Third one should be named as "node-member-rotating angle". It could be identified in the cross section plane of the members at the node. The z-axis of each member and the projection of the nodal axis encloses another polar angle, which is shown on Fig. 2, right.

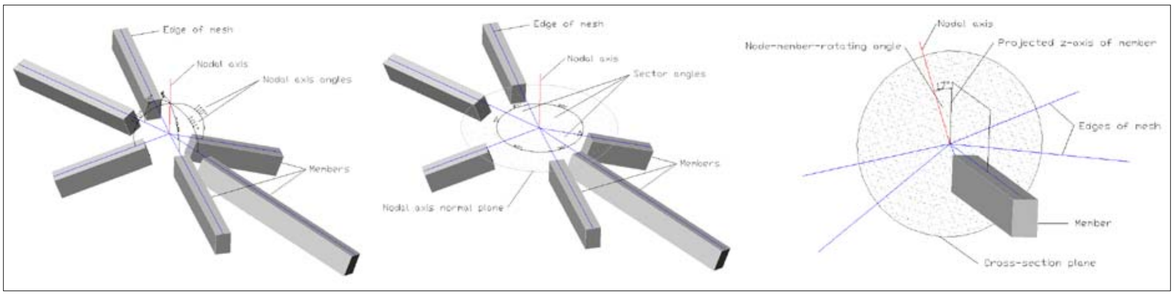

Figure 2: Polar angles at the node

MESHEXAMINER

BASICS

As described in the introduction, two of the commanding features of architectural free formed meshes are their large dimensions and their irregular character. All the constructive elements looking similar but are unique in detail. For structural design it is necessary to know as much as possible about the geometrical parameters of the mesh, such as: where is the longest respectively the shortest member, or on which node are the largest respectively the smallest polar angles as well as where is the mesh with the most respectively the least slope.

Form finding software normally doesn't give any information about the mesh related to constructiveness. The MeshExaminer is a simple software tool which is able to calculate all the described parameters. It bases on Microsoft Excel and uses Visual Basic for Applications. So it is applicable with standard office software. To start the calculation it is only necessary to feed or better to import the following data: co-ordinates of the nodes in the first worksheet named "nodes" and the beginning node as well as the end node of the members in the second worksheet named "members".

WORKING METHODS

Due to the dependence of the polar angles on the adjustment of the nodal axis, it is first and absolutely necessary to determine their way of generating (Fig. 3). Afterwards the calculation starts. All the required information, such as topological references between the members and nodes or between nodes and adjacent meshes are identified by using self programmed scan and filter functions. Software recognizes if the meshes are triangular or quadrilateral and if the mesh is at the edge or not. It has to calculate a lot of geometrical parameters as intermediate data, which here are not further described.

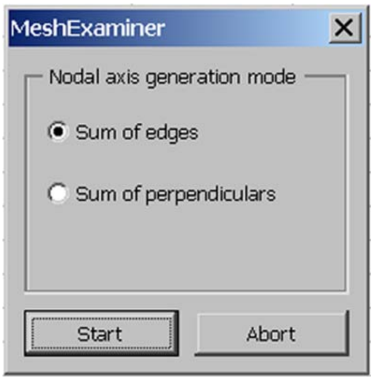

Figure 3: Entry mask MeshExaminer

RESULTS

A lot of data resulting from the analysis of the mesh. These results are written as lists to three different worksheets, which will be automatically generated. Most of the intermediate data also are write out. The mesh regarding results are output to the sheet named "meshes parameters", the member regarding ones, like the length to the "members parameters"-sheet and the nodal axis regarding ones, like all the polar angles to the third sheet named "nodal parameters". All these parameters afterwards can be analyzed related to the maximum or minimum values as well as to each other significant parameters with the functionality Microsoft Excel serially includes.

EXAMPLE

The free formed, concrete made roof shell of the open-air theater in Grötzingen/Germany designed by Heinz Isler and Michael Balz (Fig. 4)was the inspiration for creating a reference project.

Figure 4: Roof shell of the open-air theater Grötzingen/Germany

As a diploma task to a student of our faculty[6] the shape of the roof was re-designed as a free formed mesh, which references a parameterized spatial structure. In the form finding process the software DOMEdesign developed at the Bauhaus-University in Weimar by Christian Tonn was used [Tonn et al.]. (Fig. 5)

As the result of this a hexagonal surface mesh was defined, which looks like a “transparent copy” of the original. Due to constraints of load bearing capacity and structural glazing it was transformed to a triangulated one. These “final mesh” is symmetrical one time. It consists of 223 nodes, 596 members and 374 meshes.

[6] Roman Kramer

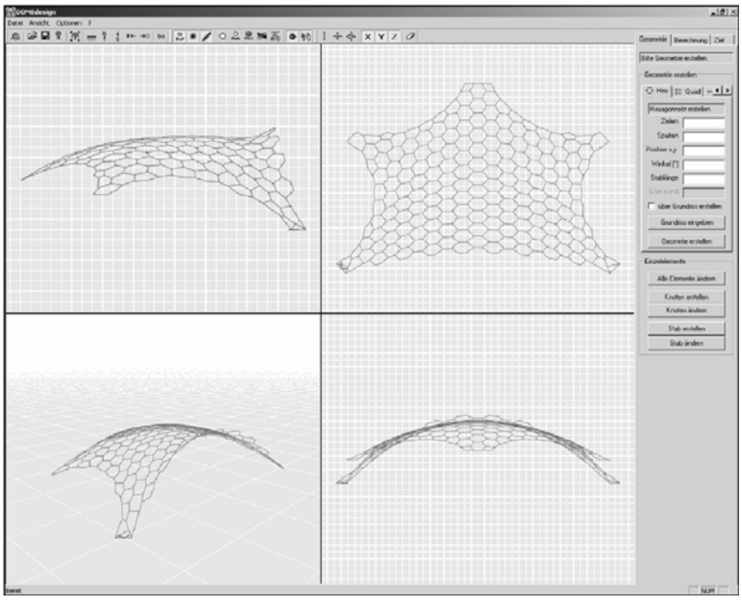

Figure 5: Reticulated Grötzingen-shell as a screenshot of DOMEdesign [Kramer]

Analysis of the mesh by using MeshExaminer indicates several results, shown in fig. 6. The longest members are 298,8 cm long (number 12 and 15) and the shortest 72,2 cm (number 211 and 477). Intermediate length of members amounts 218,3 cm. The nodes with the most unfavorable polar angle between two edges are number 44 and 159. Node number 11 is the one, which sector angles are best-balanced.

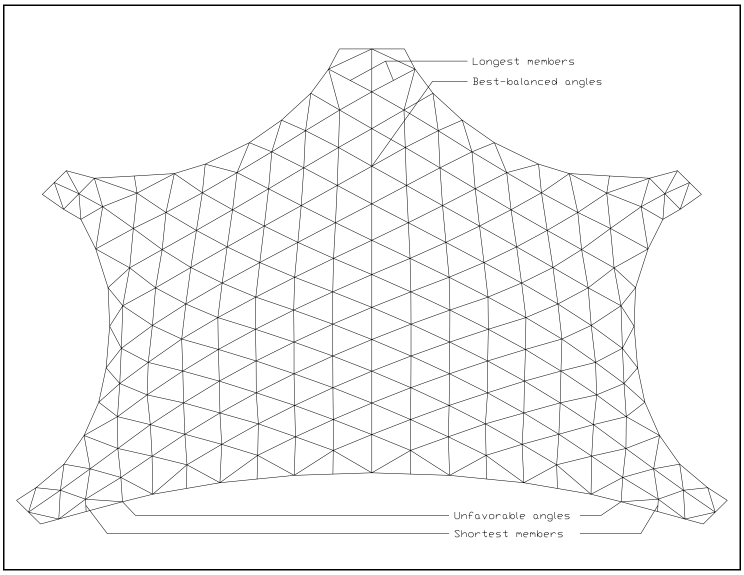

Figure 6: Some special members and nodes of reticulated Grötzingen-shell

CONCLUSIONS

The MeshExaminer tool presenting here is made for analyzing surface meshes which should be used as a reference for a parameterized spatial structures. It calculates a lot of geometrical parameters which are definitely necessary for structural design. The advantages of MeshExaminer are:

- It uses standard office software, and that's why it is practicable by nearly each engineering consultants.
- Only key information of the mesh (co-ordinates of the nodes as well as beginning - and end node of the members) have to feed respectively to import to two worksheets as a list.
- It is easy to start. Only the generating rules for the adjustment of the nodal axis have to be selected.
- The results are written to self-generated worksheets. It can be used all the functionality's Microsoft Excel offers to sort the results concerning to project individual parameters.

Finally should be annotated that the tool introduced before were developed by an engineer. It wasn't optimized related to efficient data processing or data storing. Nevertheless it works fast and robust. Total calculation time directly depends on the size of the mesh.

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