Reflection

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Research proposal

In the research proposal the methods to be used are described. These methods will be described here as well.

Approach and methodology

Literature study

The whole research will be done within the field of structural mechanics. For this reason, the literature to be studied is mainly in the field of structural mechanics. To get the research started, a literature study on several subjects needs to be done. Part of these subjects are studied already. The following subjects will be studied:

- Complementary energy method
- Arches and thrust lines
- Graphic statics in arches
- Hoop forces
- Split in surfaces
- Curvature

Method development

From the literature study hypotheses will emerge. From these hypotheses a method to calculate shell structures will be developed.

Design computational algorithm

The found method will be translated into a computational algorithm. For this algorithm, the 3D program Rhino will be used, with the Grasshopper-plugin.

Validate method

The computational algorithm will be compared to FEM calculations for several case studies. Differences in results from these calculations will show whether or not the method is valid.

Relevance

Societal relevance

This research aims to provide in a tool for designers which gives them earlier in the design process insight in the structural performance of a shell structure. This will lead to a less time-consuming

design process, but also to a more direct feedback on the design changes. It will probably lead to more efficient structural design, in which less material can be used for a similar performance.

Scientific relevance

Currently it is still unknown what the mechanics are behind shell structures. This research aims to give more insight in these mechanics.

Methods during the research

During the research, some of the research was conducted as planned but not all of it. This section will reflect on how these methods worked out.

Literature study

All the subjects in the literature study were researched extensively. However, alongside this study, the first hypotheses emerged. Some of the topics studied turned out to be less relevant to the hypotheses which were to be tested.

Method development

The method development turned out to be a bit less structured then imagined in the first instance. Even though from the literature study some ideas emerged, only when the first calculations are done, you really understand how the theories work. This results in constantly changing of ideas of what might work and how to test it. Some hypotheses could be tested quite quickly (in a day or two) and if they didn't seem to work out, they were not included in any report.

Design computational algorithm

The design of the algorithm was done before the theory was proven, making it more of a research tool than a final product.

Validate method

The theories that seemed to be promising were always compared to a FEM calculation to see whether it was accurate or not.

Results

These methods resulted in several products:

- A summary of some of the methods to calculate the bending energy in arches (chapter 2 and section 3.4.1)
- An equation for calculating the energy due to normal forces
- An equation for directly calculating the thrust line using the equal area method
- An algorithm using the equal area equation
- FEM calculations compared to the algorithm, which prove that the equal area method is not valid for a lot of situations
- A proof of the equal area method for one situation in which it is valid, the situation in which the thrust line coincides with the structure
- A hypothesis on how to calculate the correct thrust line, by only minimizing the bending energy

- An equation using the minimizing of bending energy to find the correct thrust line for three-bar structures

Conclusions

As can be seen from the results, the methods were adequate for this type of research. The aim of the research however is not fully achieved, finding a method to calculate shells. It turned out that for arches, there was still so much to be discovered that the step to shells could not be made in this time frame. This results for instance in some of the subjects (*curvature* and *hoop forces*) which are included in the literature study but not in the final report, since they mainly deal with shell structures. The process might have been more efficiently if the literature study was more fragmented, by studying arch related literature first, conducting that part of the research after that and wait with the second part of the literature study until the problem is solved for arches.

Since the equal area method is proven to be invalid, the second and third product in the list are less relevant than they would have been if it turned out to be valid. This inefficiency could have been prevented if some more extensive calculations were done on this subject. This way the theory would probably have been proven wrong earlier in the process, making sure that less time was spent on trying to prove this subject.

Apart from these two inefficiencies, the methods turned out to fit the problem quite well. Even though the scope of the research was during the process limited to arches, the methods could be applied to this part of the subject as well.