Freeform follows functions

A research dealing with architectural and structural design complexity using a computational intelligent method for the generative design of a freeform non-standard tessellated market hall roof.

Reflection

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§ 1.1. Research process and products

The products of this research are twofold, firstly a couple of parametric and computational models brought together in a generative computer program and secondly a design in a redevelopment setting with a limited program of requirements.

Both computational and structural goals were tested in the single redevelopment design case. Multiple high performing design solutions are results of this case, the Intelligent Design Objects (IDO) method has been applied to identify those high performing designs. The developed computational rigidity tools are on the other hand the most innovative result of this research.

During the application of IDO on the design case the complex nature of design became very manifest. The applied method is able to deal with a vast amount of design objectives. To prove this, initially too many objectives for the design case were chosen. If the method is to be used to its fullest potential more human resources and/or time are necessary.

To work in an interdisciplinary way as one person has proven to be a time-consuming task. To be able to conduct this research a lot of knew knowledge on subjects traditionally not studied in depth during the bachelor and master education at the faculty of Architecture in Delft had to be obtained. For example non-visual programming skills and numerical analysis. For this study the programming languages C# (C sharp), Visual Basic, Python and Matlab were used, next to the mainly used visual programming language Grasshopper. This was necessary to be able to implement numerical analysis for the structural evaluation in the computational model.
From the exact sciences mainly linear algebra has been studied. This to be able to use matrix operations proposed in the method for rigidity calculations used in this thesis. During the application of this method of rigidity analysis in the design case it became apparent that the method lacked a way of computationally interpreting the found mechanisms in non-rigid structures. Therefor the focus on multi-objective optimization shifted towards the development of a usable extension to this method. In collaboration with the Numerical Analysis department of Applied Mathematics finally a way was found to computationally identify the location of mechanisms in structural frameworks. From this point forward this new extension can be extensively tested.

For the analyzed single layer constructions the rigidity analysis only holds for forces in plane, forces out of plane (bending) can still cause problems. Therefor in practice the hinges still need to be fixed.

In parallel, architectural analysis of the design case has been conducted and several parametric generative models have been developed. Due to the necessary shift in focus sadly not enough could be done with the information from the architectural analysis and the implementation of multiple objectives in the overall generative model. The validity of the computational intelligent design method could thus only be partly determined until now.

In general can be concluded that the proposed research method was followed. However the chronological approach of a literature study followed by a design proved unrealistic and during every step of the design additional knowledge had to be obtained. This was mainly due to the broad starting point and the only later found research focus of the project. Until now the last step of the research has not been completed fully, but additionally a, from the start not foreseen, rigidity analysis extension has been largely developed.

§ 1.2. Graduation lab and thesis

The theme of the lab Computation and Performance is: design, computation and digital manufacturing of performative architecture in an exploratory process. The following subjects are the treated subthemes and encompass different, mostly computational, methods:

1. Parametric design techniques to explore and represent design alternatives;
2. Integral 3D digital design and design generation;
3. Digital process interaction between design, analysis, and manufacturing;
4. Computational morphogenesis or the complex relationship between form, force and materials in 3D;
5. The influence of (new) fabrication methods on design processes;
6. Virtual and physical prototyping;
7. The use of new materials and/or new application of materials.¹

¹ From a personal record of the graduation lab website, which is no longer available because the lab has been suspended recently.
The themes cover an interdisciplinary context and as such can be applied on any case related to design. The proposed design of a market hall in a redevelopment setting is not directly related to the graduation lab but stems from a social and political context (see below) and is used to verify the researched computational methods. The subthemes one to four are largely covered in this thesis. Firstly the parametric design approach is used while building a computational program with the software Grasshopper. This application can create design generations, which can be explored using performance evaluation and multi-objective optimization (point 1 and 2). Together they can accomplish the interaction between design and analysis in a digital process (point 3). Due to the shifted focus this link has not been fully accomplished, but an overall software design has been provided in this thesis.

The relations between form and force have been extensively studied by rigidity evaluation using numerical analysis (point 4). The rigidity analysis makes use of a singular value decomposition, which is an interesting approach because it allows to obtain knowledge about the structural performance without knowing the materials used beforehand. This approach can thus be applied earlier on in the design process to find functional design alternatives than regular finite element methods.

The umbrella chair Design Informatics has the aim to apply Information, Communication and Knowledge Technology (ICKT) throughout the entire domain of architectural design. The emphasis is on building technology and the extra focus on structural performance is thus in this light very relevant. Design Informatics bridges the hard aspects of informatics and technology and the soft aspects of design and creativity. Exactly this bridging function is handled using the computational intelligent method IDO.

Another related subject is non-standard architecture. The conceptual idea of the design case is a freeform envelope structure. Blobs like this fall under non-standard design because they are difficult to design and build using traditional methods. In relation to rigidity also non-standard tessellation has been studied, trying to find interesting alternatives to the widely adopted solution of triangulating doubly curved surfaces.

From the start to the end of this research the relevance and relationship to the graduation lab and chair have been apparent.

§ 1.3. The project and the wider social context

The relevance for society is first and foremost the guaranteed quality of a proposed design, which is very desirable due to the present economic fallback, resource scarcity and other environmental concerns.

The design of a market hall is interesting for the European food industry, since due to new European legislation the preparation and sale of food on open-air markets becomes impossible. The internationally proven typology of the market hall is relatively new for The Netherlands and offers a solution that meets the modern hygienic requirements.
Society will benefit from the qualitative local urban improvements associated with the redevelopment of the original market location.

The newly proposed rigidity tool for pin-jointed frameworks allows architects and structural engineers to search for, and identify useful structures with a new architectural expression. It allows for complex envelopes built with different tessellations than basic triangulated doubly curved surfaces.

The non-standard architecture proposed has intrinsic sustainable qualities due to the uniqueness and high performance of the design. This can be explained by the fact that the most sustainable buildings are the buildings that last the longest. This project is embedded in a redesign setting and thus the existing environment is supposed to have a longer life. By creating a non-standard and architectural relative unique project the life expectancy of the complex is even further elongated.