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Computational morphogenesis using environmental simulation tools

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Abstract

A lot of research has been carried out in the relation of structural optimisation and form finding processes of architectural and engineering building projects and only recently the consideration of other performance criteria, such as wind or light, has been included. This research investigates Computational Wind Engineering approaches in relation to the theoretical and methodological framework for morpho-ecological design in architecture. New strategies in computational air flow simulation, physics oriented, and developments in building performance simulation are discussed and analysed on their potential to contribute to the described design and engineering process. Further on the aspect of light can be simulated by various software tools, where the flow of photons and reflections from obstructing surfaces are calculated. Here not only the geometry and opening sizes but also their orientation and materiality play a large role. The materiality is insofar interesting since different materials have different reflection properties. They bounce the photons in various ways but also absorb the energy differently and with that guide the light in its specific way into the the interior. Finally the orientation of openings bears the most design potential for large span structures in order to increase the daylight factor. The above mentioned two exemplary performance criteria will be explained and described in detail within two case studies and it will be discussed how this can lead to new strategies of computational morphogenesis.

Keywords: Computational morphogenesis, architectural design process, performance, computational wind engineering, computational fluid dynamics, daylight studies, parametric design, simulation.

1. Introduction

1.1. Performance

In the Architectural Design Issue of April/March 2008, Versatility and Vicissitude, Performance in Morpho-Ecological Design, guest edited by Michael Hensel and Achim Menges, a new approach towards architectural design is explored. The summary states [3]:

> *The guest-editors inject the meaning of the word "performance'' with an entirely new life. In this context, form is redefined not as the shape of a material-object alone, but as the multitude of effects, a milieu of effects of conditions, modulations and microclimates that emanate from an object's exchange with its specific environment; a dynamic relationship that is perceived and interacted with by a subject.*

A lot of research has been carried out in the relation of structural optimisation and form finding processes of architectural and engineering building projects and only recently the consideration of other performance criteria, such as wind or light, has been included [4][8].

1.2. Computational Morphogenesis

According to the opinion Computational Morphogenesis is an instrumental approach in the design process, making form and function less of a dualism and more of a synergy that aspires to integral design solutions. The summary states:

> *Performance evolves from the synthesis of this dynamic, while morpho-ecological design concerns an instrumental approach, making form and function less of a dualism and more of a synergy that aspires to integral design solutions and an alternative model for sustainability.*

Computational morphogenesis is an instrumental approach linking design theory, the use of computers and software to design, design development and design optimization.

2. Wind

In a case study the link between environmental data, which becomes available through simulation, and the impact it has on the design process is explored. CFD (Computational Fluid Dynamic) simulations, used in CWE (Computational Wind Engineering), provide information on the performance of the configuration and its components.

For wind engineering many definitions are available. In this paper we use the definition on the website of the IAWE, the International Association of Wind Engineering, which states:

> *Wind engineering is best defined as the rational treatment of interactions between wind in the atmospheric boundary layer and man and his works on the surface of Earth.*

In this definition the tension is felt between the design, as an intuitive act and engineering as the rational component. Wind engineering tends to be more analytical than design orientated.

Research in wind engineering is mainly carried out by applying numerical and experimental approaches. In experiments, both experiments in wind tunnels as full scale experiments are used. In this paper, we limit ourselves to a numerical approach.

During the last decade quality assurance of methods and methodologies has been the main concern of wind engineering [5][7]. Studies funded by the European Community COST Action C14 [1], Impact of urban wind on city life & built environment and COST action 732 [2] - Quality assurance of micro scale meteorological models have provided us with internationally accepted best practice guidelines.

2.1. Case study

In this study several steps in the design process are described and analyzed.

The conceptual idea for the configuration of a group of mixed used cylindrical towers Fig. 1. is confronted with the wish to improve the daylight quality around the central towers and a suggestion is made for an improvement, by changing the shape (not the volume) of the four central towers, see Fig. 2. This generates a change in wind climate round the towers and a numerical wind study is performed to generate the general (insight) and quantified (specific) information for pedestrian level. This study tries to point out the benefits of using these kind of simulation tools at an early design stage.

2.1.1. Conceptual Design

The design is an abstraction of an ensemble of 24 mix used towers on a deck, four rows of six towers. In this stage of the project there is not yet a distinction in program between the towers

The height of the towers is 60 meters, the diameter of the towers is 30 meters and the grid spacing of the configuration is 50 meters. The overall dimension of the area considered is 180x280 meters. This ensemble/configuration is north/south (6 rows) orientated.

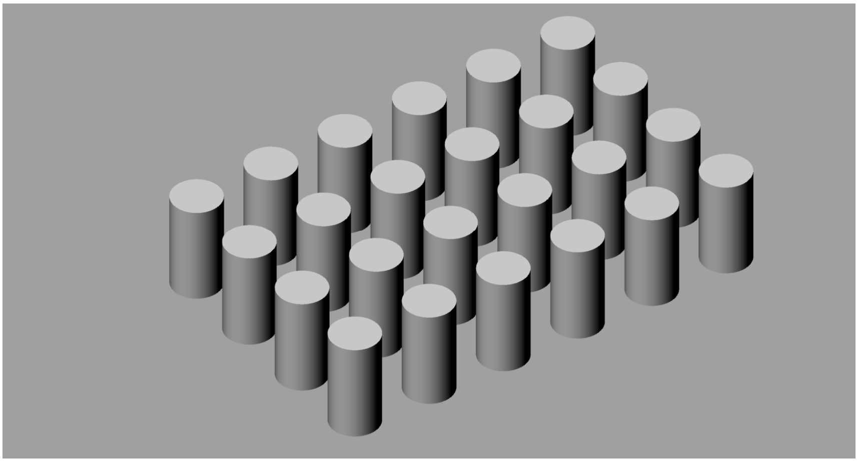

Figure 1: Conceptual stage / Step 1

To improve the light conditions the cylindrical shape of the four central towers is changed into for cones with a double height of 120 meter, see Fig. 2

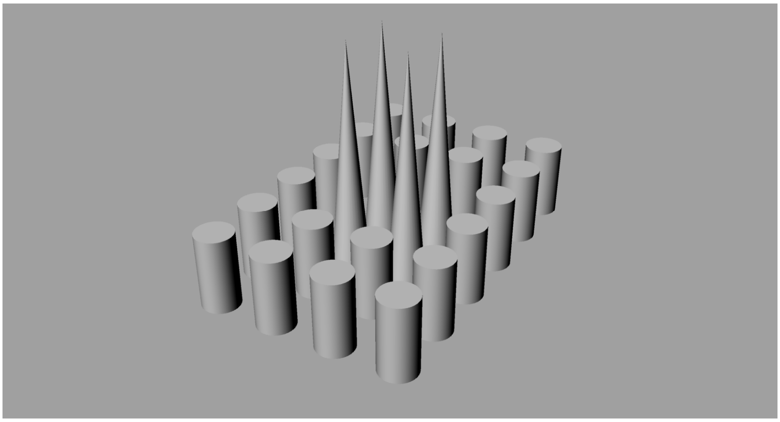

Figure 2: Conceptual stage / Step 2

2.1.2. Simulation setup

The approach in wind engineering is to analyze wind data from 24 directions, in steps of 15 degrees. An extraction from the feedback of the simulation is presented in the Figures. 6-9.

For each individual case a specific computational domain is created. The dimensions of this computational domain relate to the height of the tallest building. In this case the length/ width sizes of the domain are 2 x 15 x 120 meters = 3600 meter (15 times the height of the tallest building in all directions) and the height of the domain is 6 x the height of the tallest building in this case 720 meter, see Fig. 3.

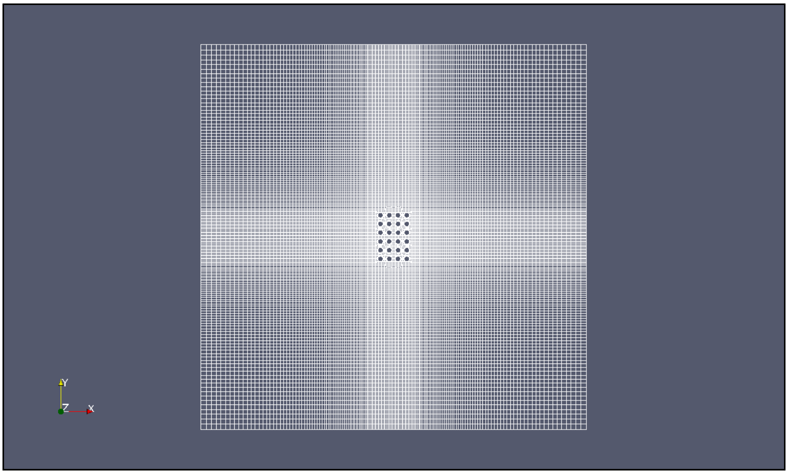

Figure 3: Accuracy Computational Domain and grid resolution

The area of interest, in this case the central core with the four towers, is positioned in the centre of the domain in accordance with the highest grid density, generating the most accurate solutions in reach with desktop (standard) computers.

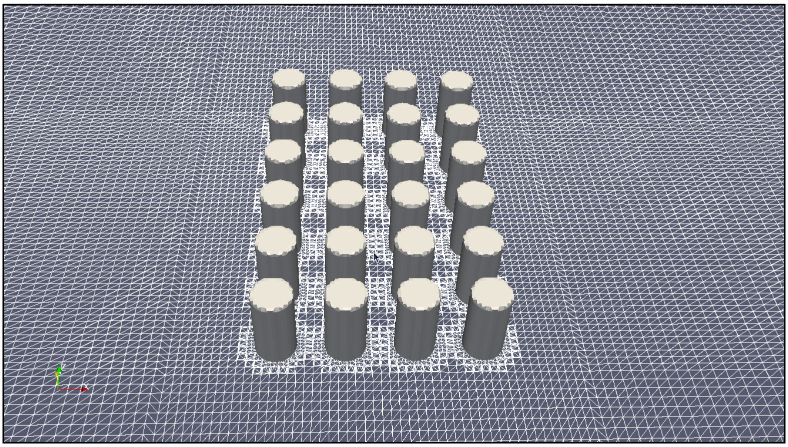

Figure 4: Accuracy. Block mesh and grid resolution

2.1.3. Simulation feedback

The simulation provides more information (see Fig. 5/6) than stated in the research question: What happens at pedestrian level with the wind climate depending on light conditions? In fact in simulations this information is available on all levels. It depends on the way you model this and what the accuracy is on the other levels. The accuracy and quality of the data on other levels depends on the way the meshing is defined. Changes in the meshing, to minimize the amount of cells involved in the calculation, in the different directions determines the accuracy.

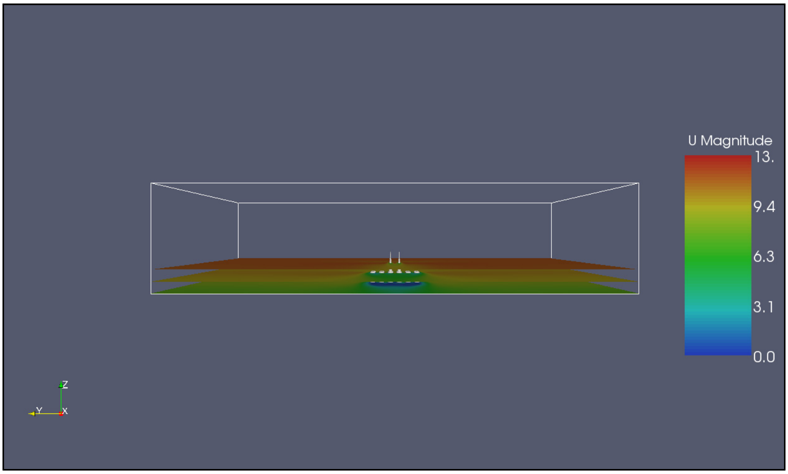

Figure 5: Computational Domain and information available

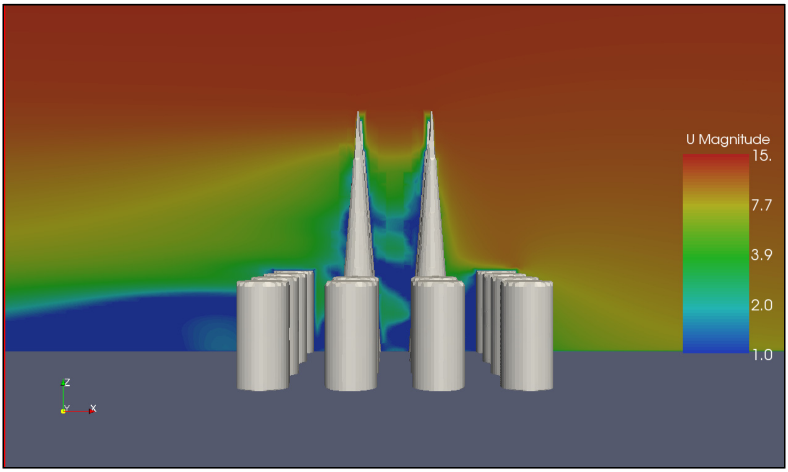

Figure 6: Wind speeds and pattern. Cross section. Wind blowing from the East/right

In all cases the information of all levels and can be related to vertical cross sections in both directions and the results of the simulations must be related to the wind statistics of the context to become location and time specific.

2.1.4. Wind patterns and wind speed at pedestrian level

Wind speeds up around circular/round bluff bodies. By putting a number of circular/round bluff bodies together you can see that the effect becomes stronger.

Through the change of the central four towers from cylindrical into cones the pattern changes and wind speed diminishes, you can see the effect in the results of the simulation from three directions. North Fig. 7, North/East Fig. 8 and East.Fig. 10.

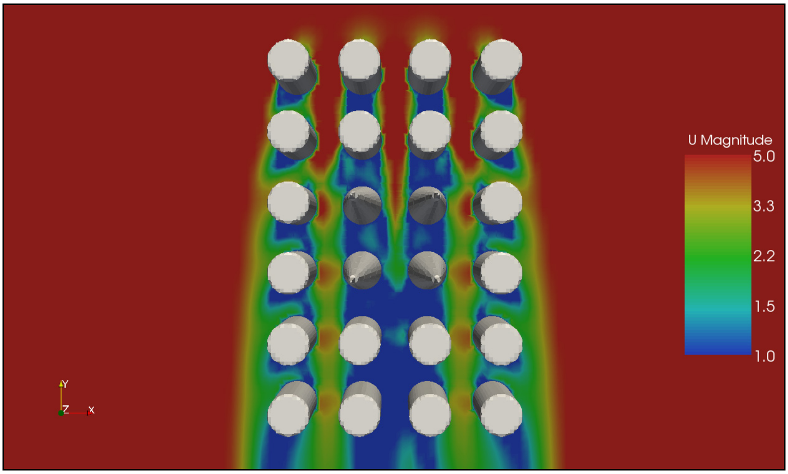

Figure 7: Wind speeds and wind pattern at 2 m. height. Wind blowing from the North/ top

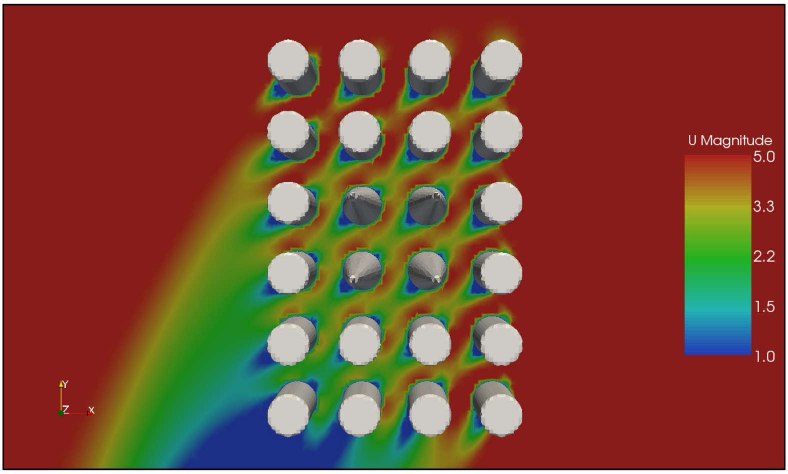

Figure 8: Wind speeds and wind pattern at 2 m. height. Wind blowing from the N-E/ top right

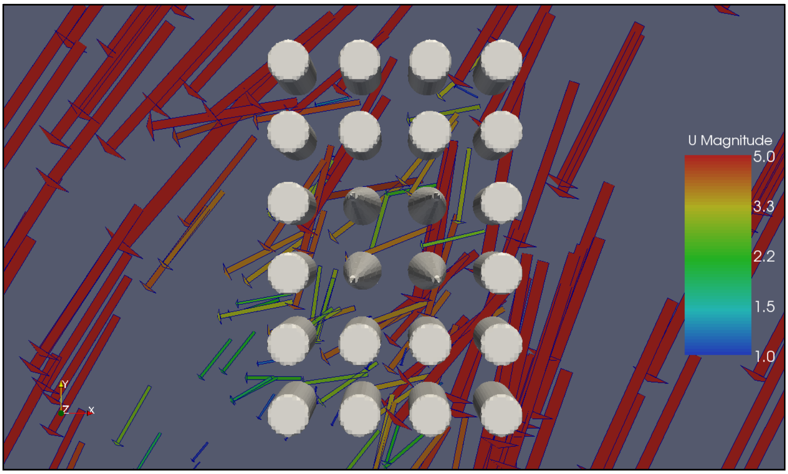

Figure 9: Wind directions and wind pattern at 2 m. height. Wind blowing from the N-E/ top right

The impact is also influenced by the upwind number of rows. The higher wind speeds penetrate the central core more in the case of one row of towers Fig. 8/10 than in the case of two rows of towers Fig 7.

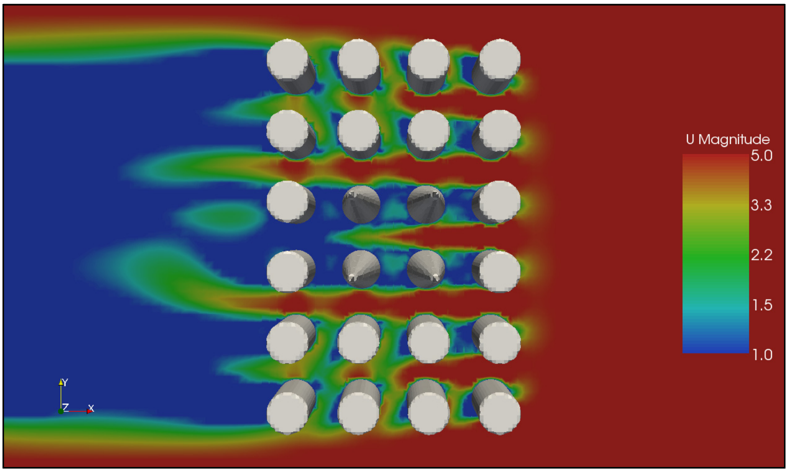

Figure 10: speeds and pattern at 2 m. height Wind blowing from the East/ right

The changes in wind speed on different levels are illustrated in the figures 11/12. The legend shows a range in wind speeds from 0 – 12 meters per second compared with a range on pedestrian level from 0 - 5 meters per second.

And the pattern of wind directions between the towers is completely different.

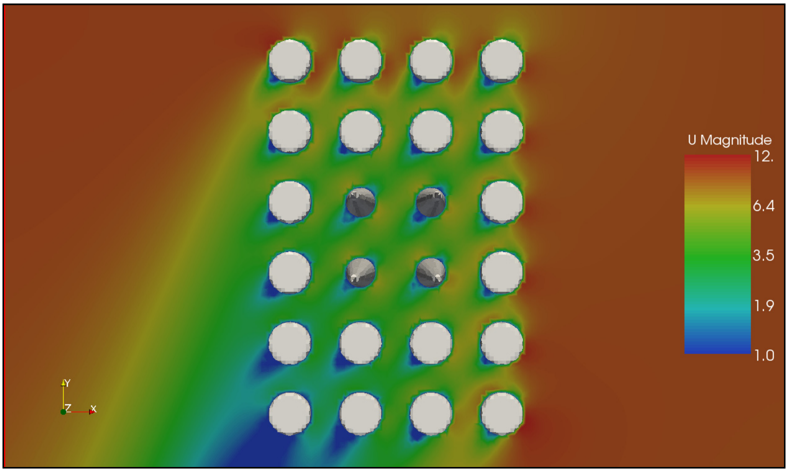

Figure 11: Wind speeds and wind pattern at 55 m. height. Wind blowing from the North/ top

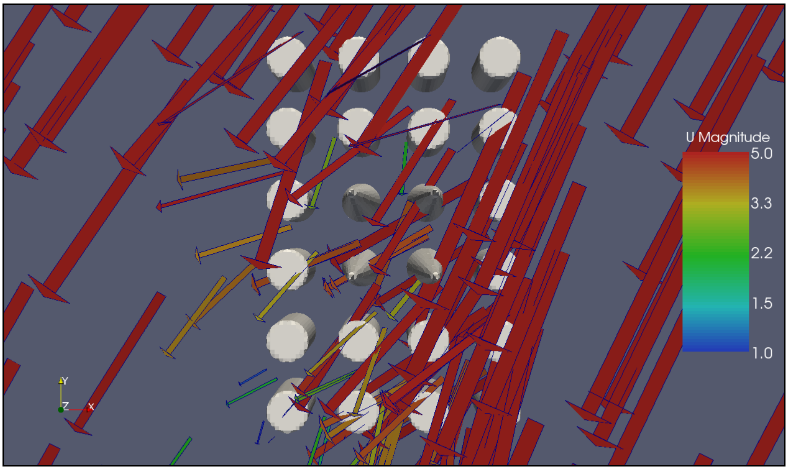

Figure 12: Wind directions and wind pattern at 55 m. height. Wind blowing from the N-E/ top right

This configuration/ ensemble responds to wind as one entity with its own characteristics on every level and in every section. The study illustrates the interaction between building geometry and wind actions.

3. Light

Various software tools are currently at hand which can support the design process in terms of daylighting. Here the distinction has to be made between those which support morphogenetic processes and those which help to assess the results. To support the design task parametric software packages or scripting which are currently used by more design practice are useful tools. The approach is to turn physical parameters into design drivers or 'decision makers', handling the complexity for the designer who determines a set of geometrical/material logical rules within the parametric CAD environment. In terms of daylighting those can be for instance exposure of the skin, daylight factors in the interior or self shading of the skins' aperture.

3.1. Case study 1

Atelier nGai [6] shows for example how the peak radiation on a given surface can become the driver for the population of varying surface components. Here a single nurbs surface modelled in Rhinoceros 3D gets converted into mesh surfaces. Ecotect being an environmental building design tool maps the peak radiation in Wh/m² which the surface receives from the sun with a false colour map on the mesh. In combination with Excel which contains the RGB values of each of the mesh the information is brought back into Rhino where a script places the components with varying apertures, developed in accordance with the peak radiation back on the mesh surface.

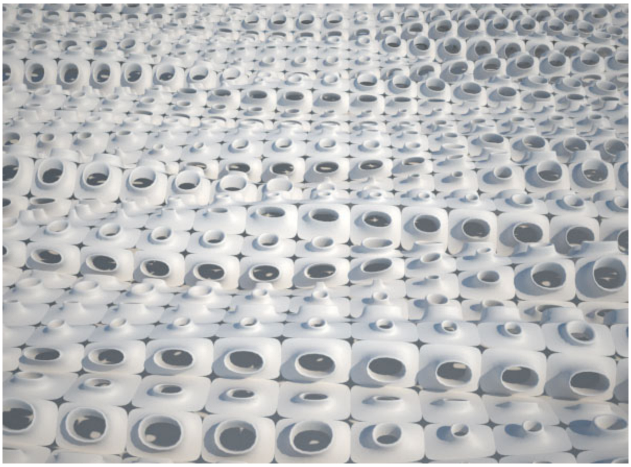

Figure 13: Resulting surface population with varying apertures based on surface peak radiation

3.2. Case study 2

In the authors' example the interior light amount and quality becomes a design driver for a long-span roof structure system. This was done in Grasshopper a parametric plug-in for Rhinoceros 3D CAD software. Within the set up system, a designer is able to manipulate via graph surfaces the aperture of the roof structures components thus changing the daylight factors of the interior. Since the graph surfaces determine the rate of change of the apertures through a set of metric key-values and an interpolated set of in-between values, the interior receives a smooth transition from one light situation into another. The quantitative aspect of the diffuse light received in the interior in form of daylight factors is evaluated with Ecotect.

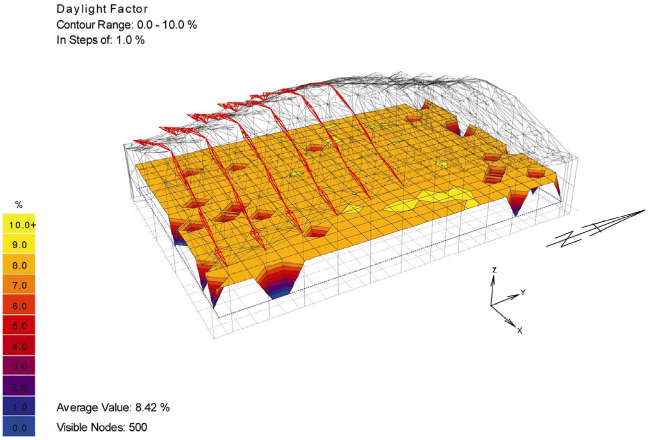

Figure 14: Evaluation of daylight factors in %

The evaluation of the interior light situation in terms of quality and spatial outcome is done with Radiance. Both sets of results are taken back into the parametric design system to further fine tune the relation between the overall roof shape, the surface graph as the design interface and the interior lighting result.

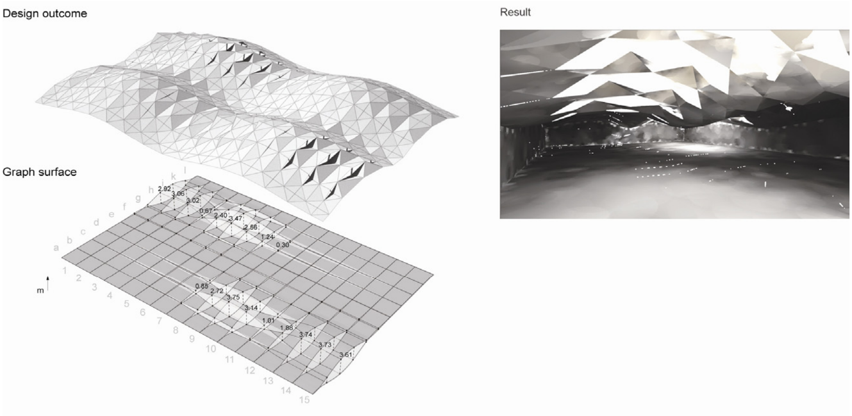

Figure 15: surface in relation to roof formulation and interior lighting quality

3.3. Case study 3

The third example shows how self-shading effects can be achieved via parametric design tools. Here the same roof structure system as shown above gets an additional shading extension in order to shade the interior through certain periods of the year depending on the locations' climatic condition. The programmatic need for a certain daylight quality resulting in the apertures within the roof structure is combined with a sun-vector. Based on changes in outside temperature a date is picked. The resulting sun vector is intersected with the highest and lowest point of each single aperture. As a result the parametric design system calculates and draws each individual shading extension. Through changes in the orientation of the overall geometry or within the graph surface the parametric design system responds to the changing boundary conditions instantaneous and updates the geometry.

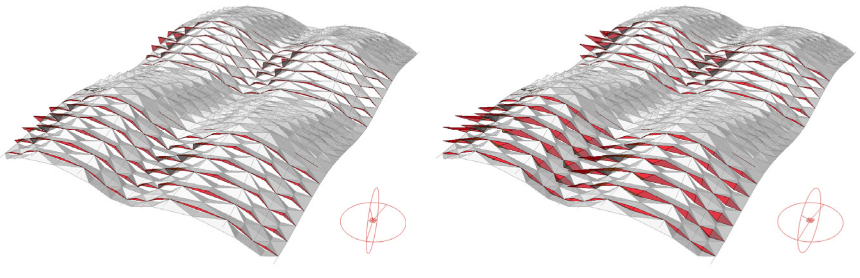

Figure 16: Shading extensions, left Amsterdam operating from the 15.05, right Abu Dhabi operating the whole year

3. Conclusion

Architectural design theory explores the integration of design and engineering. Software visualizes the environmental conditions. The amount of data//information provided by this software enables the architect and engineer to develop new approaches for the design in total and for its components. The lack of computer power gives us at this moment only a glimpse of what will be possible in the near future. Design simulation will fundamentally change the architects design approach and raise the quality of the performance of architecture.

Parametric design provides helpful tools to handle the complexities of free-form designs or like in this example long-span structures while considering environmental driving factors. Through the complexities none the less it becomes inevitable to give the design parameters or drivers a certain hierarchy amongst each other in order to get valid results and enable the designer to understand how certain decisions lead to a specific morphogenetic outcome. It is also necessary to evaluate these outcomes in terms of their performance in order to understand the design intention and the produced effects in a causal way.

The described examples show the possible impact of environmental design drivers and also the possible use of these simulation tools as supporting instruments for the architectural and engineering design process in the near future.

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