Technical University of Denmark

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Quantitative and creative design tools for urban design in cold and windy climates

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Abstract
In cold and windy climates, the quality of the urban spaces is severely challenged. A design process with a very high level of information regarding wind, sun, daylight and water from the earliest of the design process will help create the most optimized design. For the last couple of years, the Technical University of Denmark has had an initiative to combine the University's existing knowledge, relevant for large scale physical planning, in new ways. Technical-scientific knowledge about traffic and transportation, water-management, snow drift, wind engineering, sun and daylight have prospered in academic 'silos' where little attention has been made in regards to architectural design processes. Simulation tools were developed that can render a larger amount of information available in a short time and thus can keep pace with an ongoing design process in an architectural studio. Bridging the gap between the design processes and the academic knowledge available is a focus area. The effects of climate change and a general higher demand for quantitative assessment of urban planning proposals in hard climatic locations have created a demand for research based design advice. The paper will present these 'design tools' and how they can inform an ongoing design process from the earliest of design phases and afterwards.

1. Introduction

The demand for documented sustainability and safeguarding, in respect to the effects of climate change, have raised the interest for a range of technical – scientific disciplines in the urban and landscape area. Simulation tools, developed to perform analysis of already existing systems and documentation, are now in demand from the earliest stages of the design processes. The researchers receive requests for advice from various actors in the planning sector that have not previously shown interest in simulation tools or quantitative evaluation of design proposals. Due to this new demand, a mapping of the research based tools available was initiated. Design methods for integrating results from simulations have a long record in building design and it is natural to profit from this pool of experience when addressing urban and landscape design. In this paper an outline of the major fields of interest for Arctic conditions and the related research based design tools are presented.

2. Architectural Wind Engineering

2.1 Windtunnels as a design tool

Wind tunnel tests have existed since the 1930's (Addis, 2007). At the Technical University of Denmark (DTU) large facilities for detailed testing are available through a collaboration with Force Technology, a private company associated with DTU. The testing is financially demanding and though Force Technology has actually experienced an increase in inquiries from architectural offices and urban planners, urban design is not their main business area.

At the Department of Civil Engineering, a smaller wind tunnel has been an efficient and popular design tool from the earliest conceptual design phases and onwards in the design process.

Figure 1: Large windtunnel at Force Technology.

In initial design phases, small mock-ups of city-shapes, made of cardboard or polystyrene foam in 1:500 – 1:50, are placed in the wind tunnel.

Figure 2: Shaping the models for the tunnels in foam by means of a hot-wire cutter.

Then, a powder is distributed evenly on the card board model which will erode according to the applied wind speed. Urban spaces with lee and areas with too much wind become immediately visible. The cardboard models can easily be modified to search for solutions to improve the local urban wind climate and hence, the resulting human comfort. Façade design of tall buildings or the effect of hills and mountains near urban settlements can in a similar way be altered to reduce the effect

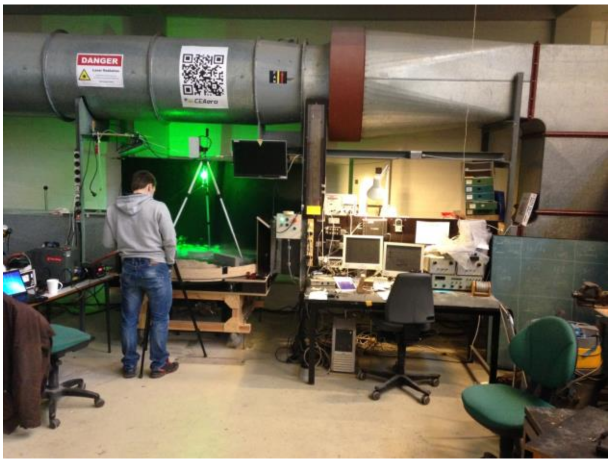


Figure 3: Wind test on foam model.

of 'down wash' – the wind turbulence created by large height differences. For more advanced investigations laser light can expose the actual air movements down a mountain in detail.

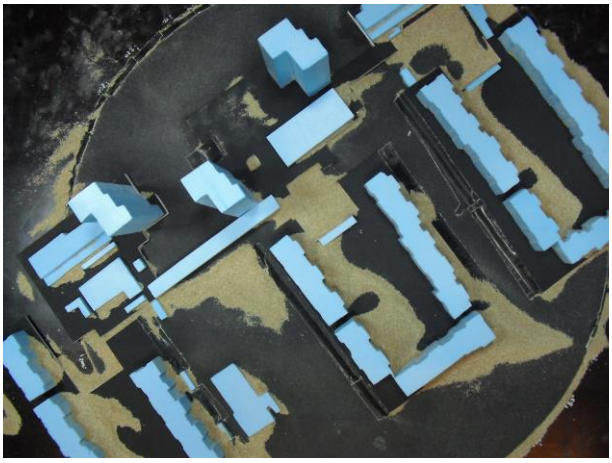


Figure 4: Wind tunnel test of the Brøndby Strand Settlement.

Figure 5: Brøndby Strand at street level.

Figure 6: The international operating Danish architecture firm Bjarke Ingels Group (BIG) designed a new gallery in Greenland. The new building for modern Greenlandic art will be located on a steep hillside near the old colonial harbour close to the sea. The building forms a circle around an inner sculpture garden and follows with a nearly constant elevation height the contour of the rugged landscape (picture: BIG architects, available at: <http://big.dk/press/nuuk_146>).

Another use of the wind tunnel is to predict snow drift. A study of snow drift and accumulation on the planned new National Gallery in Nuuk, Greenland has recently been performed. The approach chosen for this study concentrates on the surface transport process of powdery and granular material scaled to match reference observations from full-scale. Prior to the study of snow accumulation around the new national gallery building, a series of tests with different easily available materials was performed to identify those materials and test conditions that would exhibit the largest similarity to nature. Material transport and accumulation were tested for wind conditions comparable to during and after snowy weather.

The tests clearly revealed different scenarios of possible snow drift and accumulation. The build-up of snow can be influenced through spoilers and significantly reduced near the garden facade. These measures can be further developed for subsequent installation on the building if experience in the future will show major problems with respect to snow accumulation. Apart from the direct results on the National Gallery building, the project demonstrated the potential for investigating snow drift and accumulation issues in a wind tunnel experiment. Further tests will be conducted to refine the simulation technique and to expand the calibration and verification with more systematic observations and measurements in nature.

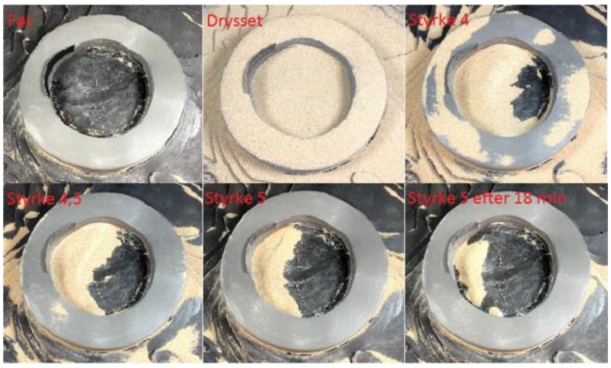


Figure 7: The progression of different phases of a snow drift test (flow approaching from the left) with a wind screen on top of the building. The snow layer starts drifting from the downwind side of the sculpture garden and accumulates over a larger area on the upwind side of the garden.

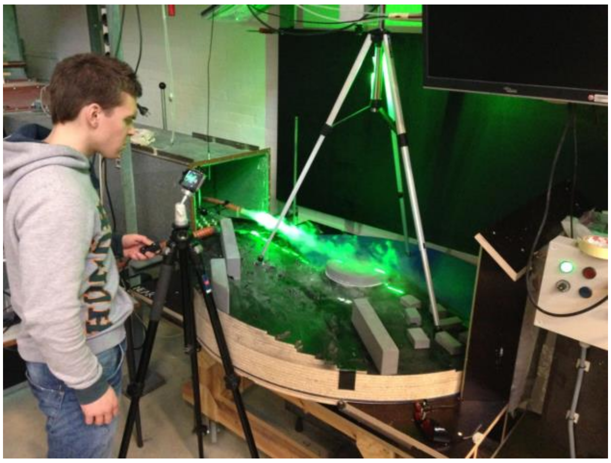


Figure 8: Experimental setup for visualisation of wind flow around the new National Gallery building in the closed-

circuit wind tunnel at DTU Civil Engineering Department.

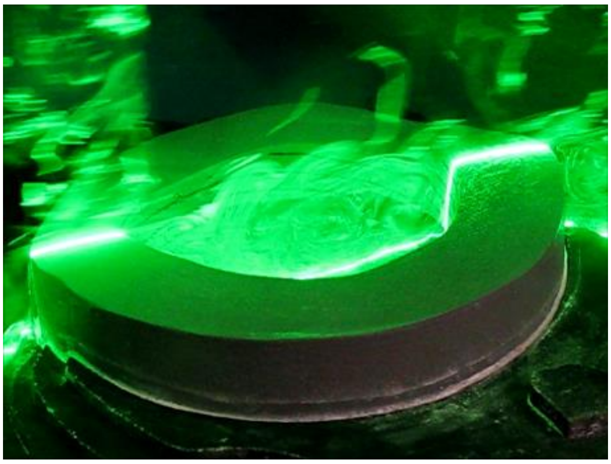


Figure 9: Visualisation of the wind flow over the building of the new National Gallery (flow from left to right) to study the circulating airflow inside the sculpture garden. The visualisation helps understanding the snow drift mechanism and the function of spoilers and wind screens to alter the flow to influence the snow accumulation.

In general, wind tunnel experimentation can be used as an efficient design tool to feed quantitative information into an ongoing design process. Design proposals are fast and easily evaluated and the results are visual and comprehensible to non-specialists in the field of atmospheric flow simulation. Speed, accuracy and visual communication are key words.

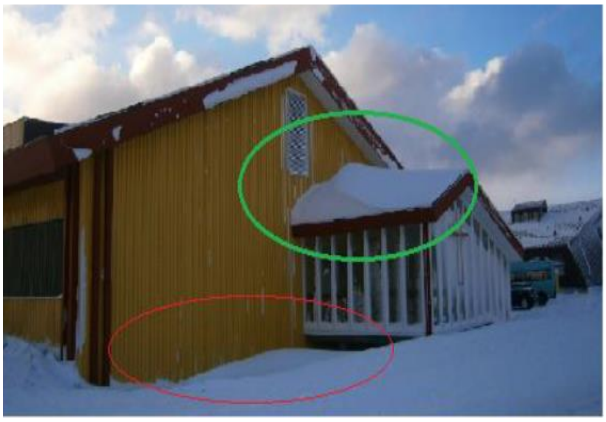


Figure 10: Reference test case to calibrate the snow accumulation simulation on real life observations from Greenland.

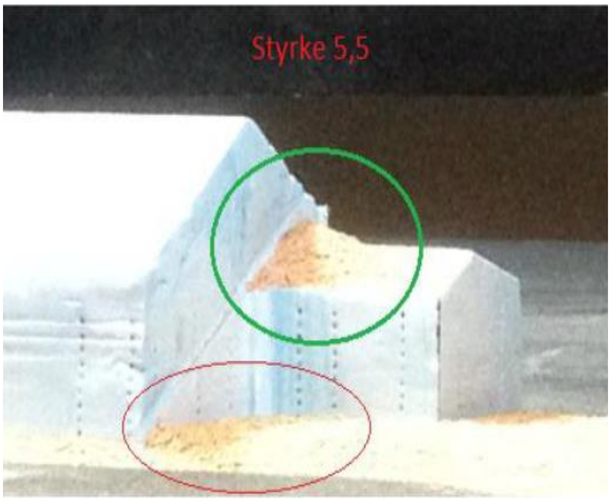


Figure 11: Model of the snow accumulation in Greenland referring to real life observations. Airspeed and material are adjusted to reflect the snow drift mechanism at reduced model scale in the wind tunnel study.

2.2 Digital wind simulation

Digital simulation of wind/air movement is developing rapidly in these years based on the principles of computational fluid dynamics. The method of computational fluid dynamics (CFD) was developed in the 1990s (Addis). An array of uses was developed including simulation of wind. The benefit of this method is that the accuracy can be very high and the effect of small details in the design can be evaluated using a CFD simulation. Ansys FLUENT is one of the relevant programmes which can also import CAD files (.dwg), which is a main program used for building rendering and modelling.

The CFD simulations using Ansys take a long time to perform- up to several days- and in that respect fail to inform an ongoing design process, where changes in the design take place from hour to hour. The reason for the long simulation time is that the simulation, apart from CFD, is built on finite element methods which calculate the impact on minuscule cells in a mesh. This accounts for the accuracy and the ability to calculate turbulence.

Recently, new digital tools for the early conceptual design phases have been developed, such as Project Vasari Autodesk.

It is also based on CFD but has a low accuracy compared to Ansys. However it allows for digital simulation and evaluation of a design idea within minutes. Wind simulations in Project Vasari are based on an average wind speed which is 'blown' on the digital model. However, it cannot account for elements like turbulence.

In the process, first a digital drawing, made in SketchUp software, is imported in the Vasari programme. Next, coordinates of longitude and latitude are placed. The software will then automatically draw information concerning prevailing wind conditions from the nearest weather station via Google Maps features. The shadow and sun exposure can also be simulated in Vasari.

As mentioned, the accuracy is much lower than when using the wind tunnel, but the speed and direct linkage to computer aided drawing programmes is an advantage.

The wind comfort in urban spaces is decisive for achieving liveable urban developments in the arctic than can enhance social interaction and urban qualities in general.

A conceptual design of landscape based on the analysis described above can help document and secure the outcome in respect to wind. By this the wind load can be predicted, and storm damages or problems with snow drifting can be reduced.

This holds a great potential for design of urban spaces with good thermal comfort in the Arctic region.

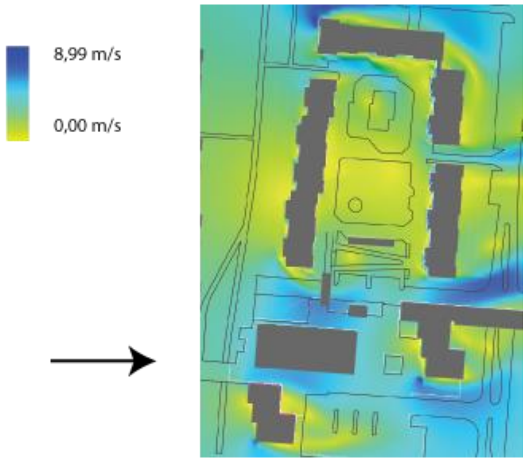
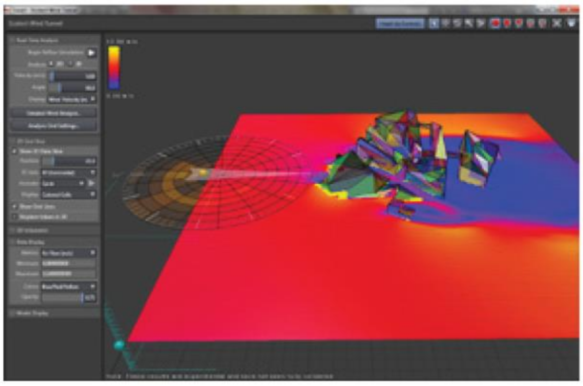


Figure 12: Depiction of Project Vasari from simulation of Brøndby Strand.



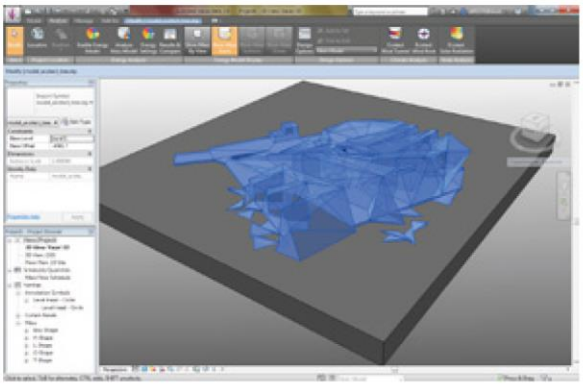


Figure 13: Project Vasari illustrating different variables of a model.

3. Simulation of sun, shade and daylight in urban design

The simulation of a building's exposure to sun and daylight have been thoroughly developed and tested for approximately two decades. Focus on the building's performance in regards to energy demand and indoor climate was important in the development. The aim was to use the information given by the simulations to design buildings with a small energy demand for operating the indoor climate systems: ventilation, lighting, heating, and cooling. The facades' exposure to direct sunlight can reduce energy consumption for heating, due to passive solar heating. On the other hand, the risk of overheating and thus a demand for cooling might arise. The windows in the façade also allows for daylight which is needed in order to reduce the energy demand for electric lighting.

However, the risk of also allowing for direct sunlight and overheating co-exists with a good intake of daylight. To handle these dilemmas accurately, fast and visually simulation tools have become widely available (Jensen et al., 2013).
Research of how to use these tools in a design process have had another parallel development. Urban planning could also draw from this pool of design methodological knowledge.

The innovative part is to use these simulations tools in urban design with the same methodology. In cold climates, the quality of urban spaces is determined not only by wind conditions, but also by the amount of sunlight they achieve. Areas which are not shadowed by objects like adjacent buildings and receive a maximum of sunlight are more used. The general amount of sunlight in an urban space can be estimated in hours of sun per year.

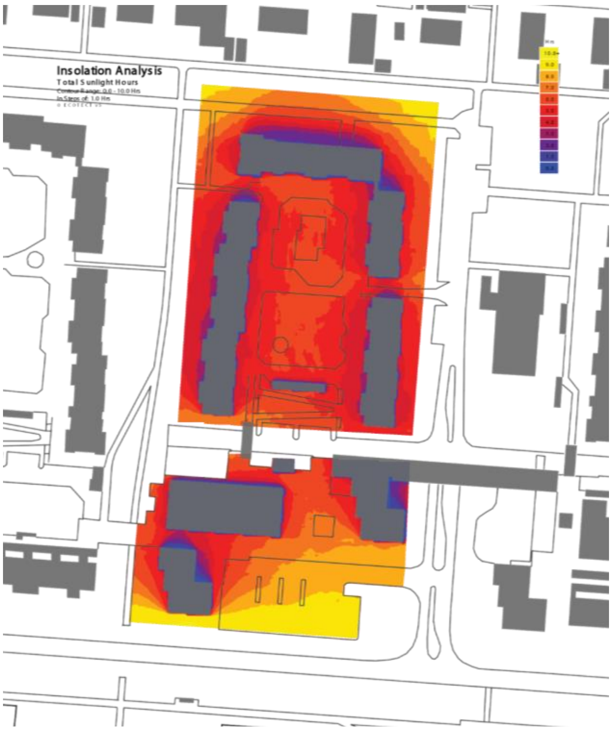


Figure 14: Simulation of average sun hours per year at Brøndby Strand.

Solar mapping is a term that signifies the mapping of external surfaces' exposure to direct sunlight. It is useful in urban design for several reasons. First of all, it maps the surfaces with the greatest potential for energy production, both in terms of electricity (photo voltaics) and hot water (solar heating).

Solar mapping can also be a tool for designing urban spaces with the greatest possible climatic comfort in cold regions. Spaces with quantified and documented sun and lee can be created.

The geometric layout of building volumes is a determining feature of any urban design. It is from these primary decisions that the quality of the interior spaces of buildings, and the exterior urban spaces, are determined. Research shows that the energy consumption in buildings is also predetermined by the urban layout.

Deciding on the geometry of building volumes and the density of the urban fabric is where the simulation tools of sun and daylight has a large role to play. A high urban density is wanted to create lee and social interaction etc. However, buildings cast shadow and a non-informed design risks creating interior spaces with too little daylight and cold, shadowed outdoor spaces (Strømann-Andersen & Jakob, 2012).

The interaction between the energy consumption for operating buildings and the urban layout is extremely complex, but can be systematically controlled in an ongoing design process. The simulation tools regarding energy and indoor climate – and with this also sun and daylight exposure - are amongst the best developed simulations tools in the industry. Due to this, a Heliodon is rarely used. The knowledge of how to use them in a design process is as mentioned also well researched.

Autodesk Ecotect Analysis is an advanced program which can handle solar radiation, daylight, shadows, reflections and thermal qualities. Additionally, it gives easy to read graphical results, which is very important in the design process (Jørgensen et al., 2011). An even faster assessment of a design proposal, but with less parameters, is to simulate shadows in SketchUp, a drawing program, where shadows in an urban space can be simulated quite accurately, according to location and time of year.

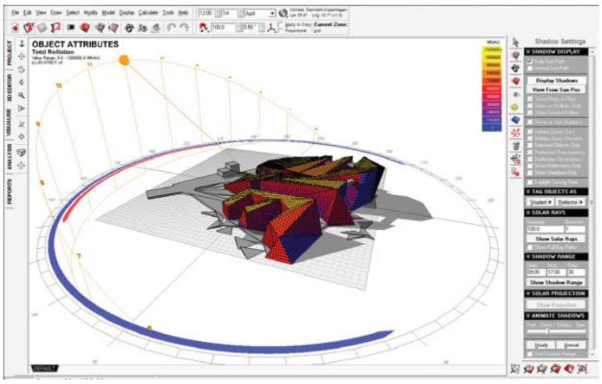


Figure 15: Sun light according to Ecotect.

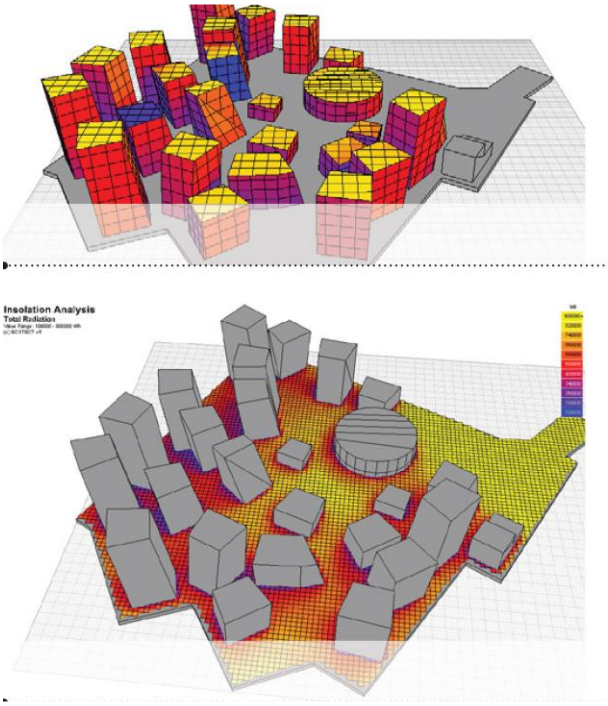


Figure 16: Sunlight on buildings and the street, according to Ecotect.

4. Simulation of flooding in an ongoing design process

Extreme rainfall, periodical effects of melted snow and changes in sea and riverbed level causes flooding that future urban design in the Arctic should take precautions against. At the same time, rain is a resource and urban planning regulations ask for reuse of rainwater for flushing toilets and for clothes washing in the design proposals.

The digital simulation of the effects of rainfall, or melted snow in a location is complex. Information regarding sewage systems, topology and the ability of the terrain to absorb water are parameters. MikeURBANflood is a simulation tool that accurately can simulate the effect of rainfall on a location. However, the program cannot import drawings and the build-up of the digital model is complex and time consuming. This makes MikeURBANflood more an analytical tool or a tool for documentation of finished design proposals.

Miljø-GIS is a Danish software that can take information from an overall GIS map. However, it can only simulate water flows in the existing – and thus GIS mapped –urban fabric. In other words, it cannot asses design ideas for future landscapes and urban spaces.

Rules of thumbs and a careful study of topological maps of the landscape can take the design process a long way in the right direction. Combined with simple algorithms, the flooding of a digital topological model of a landscape, have proved to be a relevant design tool. Such a model can help asses urban and landscape design in terms of flooding and thus, designs that allows for the water to periodical flood certain areas and have a natural flow through the landscape without causing problems.

Another option is the Rhino – Grasshopper combination. Rhino is a digital drawing /modelling programme that can link to Grashopper, where algorithms for volume, area and soil quality (percolation) can be set up.

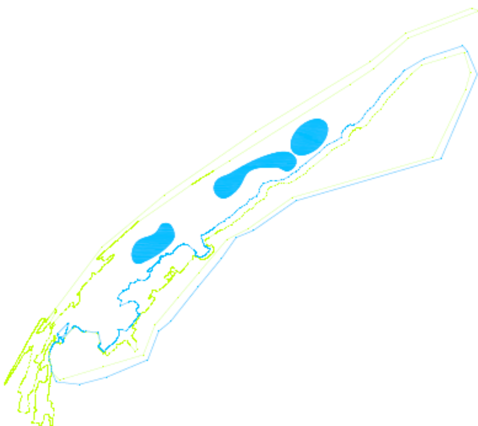


Figure 17: Digital map of the Nørrebro area.

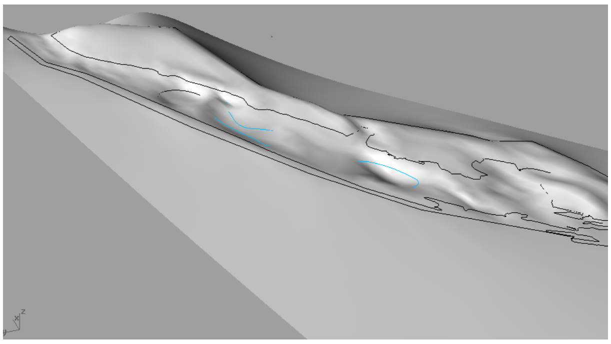


Figure 18: Rhino model of the Nørrebro area.

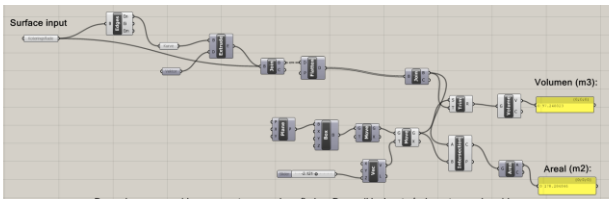


Figure 19: Grasshopper model of the Nørrebro area.

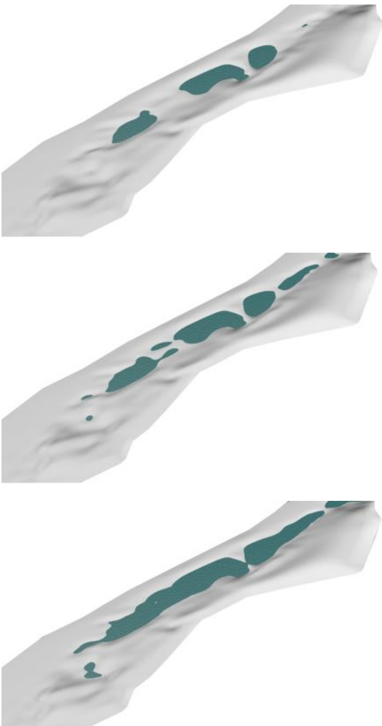


Figure 20: Simulation of flooding in the Nørrebro area, using the Rhino-Grasshopper combination.

The fast process of importing maps into Rhino and adding 'rules' (volume, area, percolation) by means of the Grasshopper program allows for the assessment of different design proposals. Since Rhino is a drawing/modelling program new landscape and urban designs can by tested quickly and quite accurately concerning the effect of water on the design: rainfall, melted snow, changes in sea and river bed levels.

5. Simulation of traffic

Transport modelling has developed since the 1950s from the need to predict the demand for new infrastructure links in large scale environments and networks. It is maybe not highly relevant for the Arctic but should be presented as it belongs to the set of tools available for informing urban and landscape design.

Features of the urban spaces have often provided inputs to the estimation of the demand for travel by mode without spatially explicit treatment of design and design decisions at the urban district level. With improvements in spatial data qualities, transport models are becoming increasingly detailed towards including local networks and paths, including e.g. qualities of cycling networks - which may then be evaluated for their effects.

Within urban districts and especially in critical locations, such as intersections, computational fluid dynamics and social forces also provide the basis for traffic simulation tools such as VISSIM. However, the traffic simulation programs are much faster than software simulating airflow.

A digital model of a road layout is made in the software and then exposed to traffic of a certain intensity, moving at a defined pace. Observation of the forming of events like traffic jam is visually perceivable. Design alterations can be easily transferred to model and a new simulation can be performed.

The optimal traffic simulation would link simulation to demand modelling for an assessment of transport by mode and spatial performance in combination.

Urban design's effects travel demand by car, public transport or non-motorized modes through networks, walking distances, connectivity, transit and parking provisions within the district. These features are increasingly explicitly treated in urban development projects but weakly linked to simulation capacities and options. Qualifying the links between the design decisions within urban districts, travel demand and spatial behaviours should be an area for further works in sustainable urban design.

6. Sustainability assessment of urban areas

For decades, buildings have been assessed and certified according to sustainability assessment systems. Deutche Gesellschaft für Nachhaltiges Bauen (DGNB) is a sustainability certification system with a special version addressing the sustainability certification of urban spaces. There are 55 criteria which each have a detailed description of how the criteria should be evaluated. In some of the criteria, the evaluation can be a simulation. Simulations are ranked higher and give a higher score for the specific criteria than other evaluation methods.

DGNB urban districts have the potential for becoming a documentation required by regulation authorities in the near future. Using simulations as assessment of design solutions will then become an integrated part of any design process.

7. Conclusions

Wind, sun, daylight, rain and traffic are phenomenon that all urban designers handle in their design proposals. Simulation tools that condense technical-scientific knowledge into a fast yet accurate and visual feature will not revolutionize urban design, but it will allow for more precise decisions and avoidance of severe failures in the design in extreme climates.

In the Arctic areas, growing urbanization is a trend and the focus is on social qualities in the city. The quality of urban spaces is closely linked to climatic comfort. The climatic comfort in the urban spaces can be addressed in a precise manner by means of quantitative evaluation of early design proposals by means of simulation tools. This could lead to new arctic urban spaces tailored for the specific conditions of the location.

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