Building-up urban open spaces from shadow range analyses

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This paper explores an alternative approach for the creation of new built forms based on solar access analysis. Consolidated on urban areas under development, the denominated 'inverted' approach is focused on the generation of recreational open spaces based on shadow conditions caused by existing built forms, and as a starting point for the construction of new urban envelopes as possible development areas. Unlike the existing method of the 'solar envelope', the 'inverted' approach shows an alternative procedure for the construction of built forms, based on pedestrian comfort caused by solar access in urban spaces rather than on indoor performance affected by the penetration of sunlight into buildings. As a method for the creation of urban envelopes, this approach attempts to enhance pedestrian comfort according to the study of solar access in urban areas. The 'inverted' approach is based on sun path data and is developed as a generative procedure, where the results of shadow range analyses and the different urban objectives work as input parameters for the generation of urban envelopes. Based on this methodology, two Grasshopper® custom components are developed.

Keywords: *urban open spaces, solar access, shadow range simulation, generative modelling*

INTRODUCTION

Climate is the pattern of variation in precipitation, temperature, humidity, sunshine, wind velocity, phenomena such as fog, frost, and hail storms, and other measures of the weather that occur in a given region over long periods of time [1]. Urban climate refers to climatic conditions in an urban area that differs from the climate of its rural surrounding and is attributed to urban developments. Cities absorb and retain significantly more heat than rural areas (Howard, 1818). This warmth of cities in contrast to their surrounding is known as 'Urban Heat Island' or UHI (Oke, 1976). Urban climate conditions affect how cities will develop in the future, not only because of the impact on the environment or on the energy consumption of buildings, but also on the human comfort in urban spaces. While there is a growing field on bio-climate architecture where knowledge on how to design climate-sensitive indoor environments is increasing, there is still a lot to explore on the construction of the urban open spaces according to microclimatic conditions (Calthorpe, 2011).

With the understanding of urban microclimate and its effects on architecture and urban design, the application of different strategies to control solar access have been fundamental when it comes to designing buildings and urban areas (Erell; Pearlmutter; Williamson, 2011). Therefore, it is important to consider the study of solar exposure where the degree of exposure to solar radiation is one of the main controls on microclimate conditions. These strategies can be divided into two purposes; **the solar access for buildings** and **the solar access for pedestrians** (open public spaces) (Erell; Pearlmutter; Williamson, 2011). The first one is the basis for the 'solar envelope' developed by Ralph L. Knowles. The latter one is related to the outdoor thermal comfort, and is the basis for the 'inverted' approached introduced in this paper.

Outdoor spaces are important for cities as these provide daily pedestrian traffic and different outdoor activities contributing to urban livability and vitality (Chen; Ng, 2011). Promoting the use of streets and outdoor spaces by pedestrians will benefit cities from physical, environmental, economical, and social aspects (Hakim et al., 1998). In this way, ensuring that people are comfortable in outdoor spaces is essential to high-quality urban living. Over the past few decades, making outdoor spaces attractive to people, and ultimately used by them, has been increasingly recognized as a goal in urban planning and design (Chen & Ng, 2011; Gehl & Gemzøe, 2004; Carr, et al., 199) Among many factors that determine the quality of outdoor spaces, the urban microclimate is an important one. Pedestrians are directly exposed to their immediate environment in terms of variations of air temperature, relative humidity, wind speed, and solar radiation. Therefore, people's sensation of thermal comfort is greatly affected by the local microclimate (Chen & Ng, 2011).

The outdoor thermal environment is impacted by the built environment in terms of; anthropogenic heat (Ichinose et al., 1999) ground surface covering (Lin et al., 2007), evaporation and evapotranspiration of plants (Robitu et al., 2006) and shading by trees and man-made objects. The outdoor thermal comfort is generally studied on the urban micro-scale level, which is affected by the Canopy Layer Heat Island (CLHI) (Voogt, 2004; Oke, 1995; Oke, 1976). As shade can block incident solar radiation, some studies have discussed shading effect on thermal environments. For example, street orientation and the height/width (H/W) ratio have been measured to assess the shading levels in some studies (Emmanuel et al., 2007; Johansson, 2006). In the context of urban planning, how outdoor thermal environment influence thermal sensations of people and their behaviour (use of outdoor spaces) is of great interest for designing urban spaces.

This paper investigates a method for the creation of urban open spaces based on shadow conditions caused by existing built forms, and as a starting point for the construction of new urban envelopes as possible development areas.

'SOLAR ENVELOPE' APPROACH: SOLAR ACCESS FOR BUILDINGS

The referred concept of 'solar rights' is the guarantee of exposure of a building to direct sunlight in a predetermined period in order to meet the requirement for indoor passive solar heating. The building surfaces that must receive the benefits of sunlight are usually vertical and equator-facing. This information, within other requirements of solar access for buildings, leads to establishing limits on height or volume of buildings. Such limits were referred as 'solar envelopes' by Ralph L. Knowles in 1974 as a framework for architecture and urban design to provide solar access needs according to building geometry, and support solar energy for future developments (Knowles; Berry, 1980).

Nowadays there are simple ways and tools to measure sun path movements. The most know is the Stereographic sun-path diagram, which represents annual changes in the path of the Sun through the sky in a single 2D diagram. These diagrams provide a summary of solar position that the designer can refer to when considering shading requirements and design options. Based on this diagram, environmental analysis tools can generate visualizations on how the sunlight affects the built environment. One way to measure this effect is to analyse how shadows are form according to building obstacles. The 'solar envelope' builds-up from this knowledge in order to create a method to avoid shadowing to neighbouring buildings in desirable angles. Recently, the environmental analysis Diva for Rhinoceros® Grasshopper® developed a 'solar envelope component' based on Knowles theory and which "creates the largest build-able volume that will not shade its neighbours for a specified period of time throughout the year" [2].

THE 'INVERTED' APPROACH: SOLAR ACCESS FOR PEDESTRIANS

This paper proposes a method for controlling solar access, like the 'solar envelope', but for avoiding shading in potential recreational open spaces, rather than avoiding shading for neighboring buildings. The method called 'inverted' approach is developed by means of parametric modeling in Rhinoceros® Grasshopper®, where a series of components are developed in order to generate urban envelopes based on the 'inverted' method.

Methodology and application

This methodology is intended for urban areas under development, as the final aim is to create possible areas for future urban densification based on the generation of urban open spaces that enhance pedestrian outdoor comfort. Therefore, the case study for the development of the method was the Thälmann-Park in the centre of the Prenzlauer Berg district in Berlin. Today this area features public houses as well as art galleries and a small theatre at the former administrative building of a previous gas plant. The interest of investors in the area of the Thalmann Parkes increased raplidly and projects for the construction of new living areas are currently under development.

The different procedures explored for the 'inverted' approach method are based on generative and parametric modelling techniques that allow the systematic creation of new urban forms according to different solar access and urban boundaries criteria. According to these criteria, the method is divided into three consecutive parts; (i) delimitation of the development areas, (ii) shadow range generation, and (iii) selection of recreational urban areas. At the end, areas for future building densification are created and extruded in order to generate the fi-

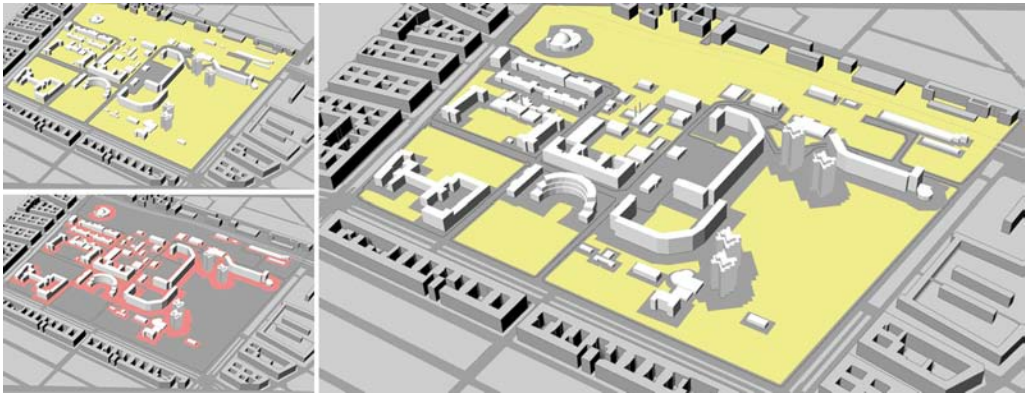


Figure 1
Delimitation of development areas (i).

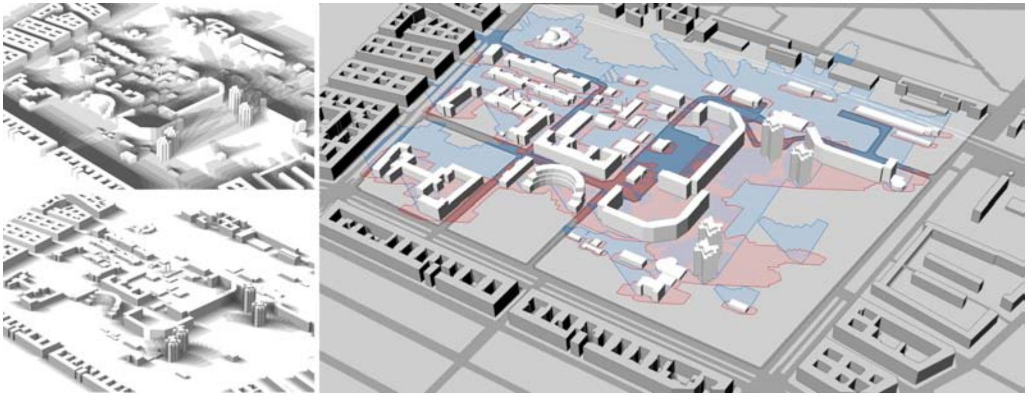


Figure 2
Shadow range generation (ii), (blue) winter solstice shadow range and (red) summer solstice shadow range.

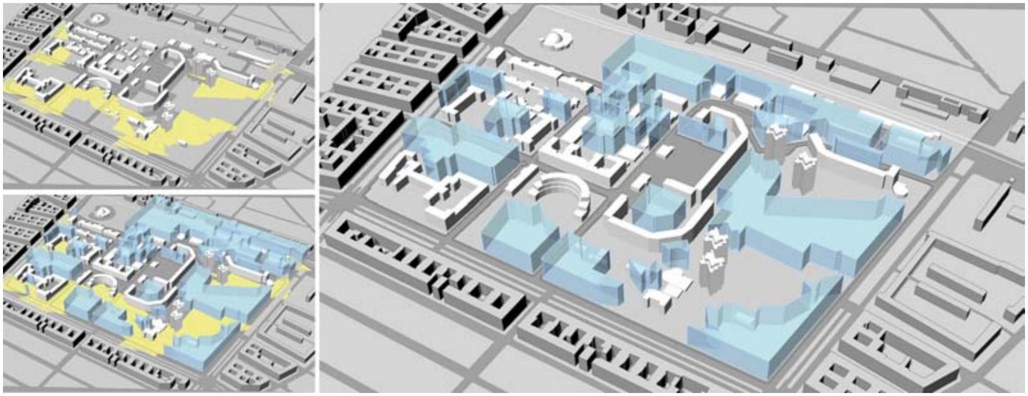
nal building envelopes (possible volumes for building densification).

The first part of the method aims to establish a ground-level geometry of the possible building areas according to the limit distance between buildings and on the urban block boundaries (city normative). This is done first by taking the urban block area as a surface for possible developments. Subsequently, measuring the minimum distance between building (city normative) from the current buildings and extracting this area from the urban block surface. At this point, an area for possible future developments is created as shown in figure 1.

The second part is focus on the execution of the shadow range analysis for summer and winter periods. For this analyses, the Rhinoceros® Grasshopper® component called Geco is used. Geco is a custom component for Grasshopper® that offers a direct link between Rhinoceros® Grasshopper® models and Autodesk® Ecotect®. Ecotect® is an environmental analyses and simulations software intended for architects to work with highly visual results. It is aimed for early stages of conceptual designs for the exploration of environmental factors and interactions. One of the simulations that can be performed in Ecotect® is the sun-path simulation based on a particular day of the year and hour of the day. This feature can also recreate the shadows of the specific time, furthermore, it can visualise the range of shadows during a predefined day of the year (specifying from which hour until which hour of the day). All of this simulations can be used in Rhinoceros® Grasshopper® through Geco. For this specific case, the shadow range simulations over the solstice of Winter (21st of December) and Summer (21st of June) where generated. The purpose of using the two solstice of the year is to obtain the maximum and the minimum range of shadow during the year in the particular location. An additional purpose is to have the possible shadows for the periods of Winter and Summer in order to make further decisions on the conditions of open spaces during cold and warm periods of the year. After the simulation is conducted for each day, the shadow range result is converted into geometry data in Grasshopper®. These two separate geometries are then combined in order to overlay the information as shown in figure 2 with the blue surfaces as the winter solstice shadow range and red surfaces as the summer solstice shadow range.

As a final step, the third part is based on selecting the specific areas for potential open urban spaces according to pre-defined shadowing conditions. These conditions are based on the desirable characteristics of the urban open spaces for recreational purposes. In this specific case, the conditions are established based on open spaces that have shadows dur-

Figure 3
Selection of recreational urban areas and generation of volumes for future densification (iii).



ing summer but not during winter. In this way, the outdoor thermal comfort will be enhance due to the sunlight penetration in this areas which affect cold and warm periods of the year. In terms of procedure, the two surfaces generated in the previous part (shadow ranges of winter and summer solstice) are overlaid and the segments where the summer shadows without the winter shadows are selected (the red surfaces). Moreover, a buffer zone is created around this surface to prevent future building shadowing. With the combination of the buffer zone and the selected surface, this final area (yellow area in figure 3) is extracted from the urban block surface created in the first part of the method. The final block surface is then denominated as the areas for future development. At the end, this final surface is extruded according to the city normative (maximum high of buildings) and urban volumes are created. These final envelopes are the possible areas for future building densification as shown in light blue in figure 3. The remaining urban spaces are the potential open areas for recreational purposes like parks and urban squares. In this way, these areas enhance the outdoor thermal comfort according to shadow range analyses.

For the first (i) and last (iii) part of this method, two Rhinoceros® Grasshopper® components are developed. These custom components are linked to the Geco components used in the second part (ii) to link the weather data of the specific location and generate the geometry of the shadow range simulation.

Grasshopper components

Both components are named SUD, which stands for "Strategic Urban Densification". The custom component for the first part of the method (i) is called SUD1, and the one for the last part of the method (iii) is called SUD2. The aim for the development of these custom components is to reduce complexity of grasshopper with existing components and to compress and simplify the procedure of the proposed method and make it applicable to other case studies.

The development of SUD1 (figure 4) is based on the first part of the proposed method explained above. The input parameters are:

- Buildings: takes building footprints as a first input parameter.
- Distance: takes the minimum distance between buildings according to the city normative. This second parameter creates an offset of the geometry of the building footprints
- Blocks: takes the urban block perimeter as a third parameter.

SUD1 first performs an offset command according to

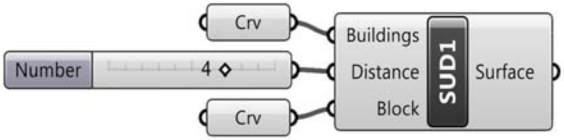


Figure 4
Grasshopper custom component, SUD1 (i).

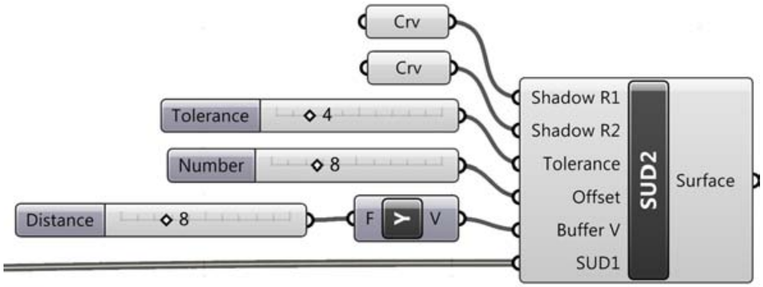


Figure 5
Grasshopper custom component, SUD2 (iii).

the number given by the Distance input. Then it eliminates the overlapping geometry by combining the different curves and taking the perimeter of the result. In this way, a single curve is created for each of the urban blocks.

The output parameter is called surface, but is actually a curve which later needs to be converted into surface. This last output represents the area for possible future developments as shown in figure 1.

The development of SUD2 custom component (figure 5) is based on the third part of the method (iii) and takes as input parameters the results (outputs) of the previous custom component (i) and the Geco definition (ii). The input parameters are:

- Shadow R1 & R2: takes shadow range 1 and shadow range 2 from Geco component after analysis.
- Tolerance: takes tolerance number to reduce line segments in order to simplify geometry.
- Offset: SUD1 takes real number as a second parameter to create offset of buildings.
- Buffer V: Buffer vector. Vector from the generation of Shadows in Geco from Shadow R2. A number is linked to the vector in order to move the geometry to a given distance.
- SUD1: takes resulted surface from the SUD1 component as a parameter.

SUD2 takes input surfaces from Geco component as the shadow range geometries of the two solstice of the year. According to the pre-conditions, the shadows are overlaid and one of the shadows is selected and the overlaid regions created by the second shadow are deleted. Shadow R1 is the selected one and Shadow R2 is the one creating the overlaid region. Eventually Shadow R2 is deleted as well, its purpose is only to created the overlaid region in Shadow R1. Before going into the next step, these surfaces have to me simplified by taking input tolerance to reduce line segments. Until this point, this area created from this curve in the first state of the output (urban open areas for recreation). After the simplification is done, the component makes an offset of the curves and then this offset geometry is moved in the same direction (vector) of the Shadow R2 in order to create a buffer zone to protect the area created by Shadow R1 from future Shadow R2 (in this case, the winter shadows). In a following step, the component creates a union of all curves created until this point as show in yellow in figure 3. An overlapping of the final curve and the input parameter from SUD1 is generated where the region of intersection is deleted from the SUD1 surface.

The output parameter is called surface but, as the output of SUD1, it is actually a curve, which can be converted to a surface. This final output of the SUD2 needs to be extruded with the Grasshopper® existing components in order to create the final volume as shown in light blue in figure 3.

CONCLUSION

As a result, building envelopes are created from solar access analyses in order to explore possible directions for climate-sensitive urban growth. This method can work as a previous process for the 'solar envelope', as the final urban envelopes from the 'inverted' approach can be used for the process of controlling solar access for buildings. In this way, not only the urban spaces but also indoor spaces can benefit form solar access. Eventually, this method can contribute to urban planning practices as a decision-support tool for the construction of climate-sensitive urban forms.

Additionally, the Grasshopper custom components developed for this method can be used to apply the purposed method to other case studies around the world, always taking into consideration the weather data of the specific location. Before applying this method to other urban settlement, it is important to consider that this method is intended for urban areas under development only.

FURTHER WORK

As for the 'solar envelope', different researches have been taking place towards optimizing the different design possibilities, for this particular approach the idea is to use evolutionary algorithms (EAs) for multi-objective optimization (as this shadow range analyses may encounter contradicting criteria) in order to explore different optimal solutions for the construction of new urban envelops.

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