The Study of Sky View Factor in Urban Morphologies: Computational Tools and Methods of Analysis

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ABSTRACT

Regarding density, many studies confirm that a crowded space cannot be described easily by one single number. Its perception differs from individual to individual, leading to the concept of perceived density. Among the aspects that can influence such perception, the sky view factor (svf) can be highlighted. This paper focuses on the sky view factor and investigates different methods to calculate such parameter in urban design. Several procedures and computational tools were listed and three of them were selected for practical investigation: I) MapInfo and II) Sky View Factor Calculator, both for the analysis of fish eye lens images; and III) DEM (Digital Elevation Model). Three neighbourhoods in Sao Paulo, Brazil, were chosen as case studies for investigation with the selected methods: Cambuci, Bela Vista and República. The results of the case studies and the application of each tool are discussed. As part of the results, unexpectedly lower values of svf were obtained with the DEM analysis in comparison with the fish eye lens methods. DEM allowed for a quick view of the distribution of svf in urban area; nevertheless, it showed lack of accuracy on the representation of irregular surfaces and other obstructions at the pedestrian level such as trees and urban equipment. The fish eye lens methods were more efficient for the analysis of smaller areas with more details; however, its results also depend on the procedure used to calculate the svf. Finally, it was concluded that the efficiency of each method of sky view factor prediction depends on the aim of the specific research; and that the svf is a valid parameter to inform sustainable urban design. Further investigation on the subject is recommended.

1. INTRODUCTION

Many studies confirm that density in urban spaces cannot be described only as a single number (quantity of individuals or buildings divided by area) (Churchman, 1999; Rapoport, 1978). The definition of what is a crowded place can vary from individual to individual, according to their culture, background, location and function. In urban morphologies, additionally to all these aspects, the sky view factor (svf) can be highlighted (Cheng, 2010).

Sky view factor indicates the percentage of visible sky for a specific observer, or, in other words, it indicates the openness of an area (Holmer, Postgard & Eriksson, 2000). The factor varies from 1 to 0, being 1 a completely unobstructed view of the sky and 0 an obstructed view. It is a dimensionless parameter related to two planes: horizontal and vertical. In analyses of urban morphologies, the svf is closely related to the streets’ width and the height of obstructions (such as buildings, monuments, objects, trees).

The sky view factor has already shown its importance in solar availability and natural lighting studies. Many researches were developed to facilitate its identification and analysis through...
computational tools, mathematics, diagrams and graphics, fish eye lens images and image processing tools (Souza, Rodrigues & Mendes, 2003; Ratti & Richens, 2004; Zaksek, Ostir & Kokalj, 2011; Santos, Lima & Assis, 2003).

Aiming to test some of those methods, three case studies were developed in Sao Paulo, Brazil, as part of a major research on building typologies and urban morphology in the city. In the first case, Cambuci, new buildings were proposed and their orientation was analysed for a fixed population density. For the second and third neighbourhoods, Bela Vista and Republica, existing building typologies were studied.

2. COMPUTATIONAL TOOLS FOR SKY VIEW FACTOR ANALYSIS

Three methods involving computational tools were selected for practical investigation regarding the svf: I. DEM (digital elevation model) which was generated by Image J or NIH Image; II. MapInfo; and III. Analysis of fish eye lens images.

2.1. DEM (Digital Elevation Model)

According to Ratti & Richens (2004), DEM is a simplified way to represent urban morphologies. It is visualized in a grayscale plan where each colour determines the height of the pixel. In simple image software such as ImageJ and NIH Image (Ratti & Richens, 2004), it is possible to create a plan and apply different colours to each pixel. The same programs are capable of reading and translating those colours into their corresponding height, turning the 2D plan into a 3D model.

The DEM is an 8-bit .TIFF image in grayscale, with colours varying from 0 to 256. Each plan is created with a lock-up table (LUT) which is similar to a template. It allows the user to attribute a height to each colour. Normally, the grey number 0 is defined as 0m height, grey number 1 equals 1m height, and so on. This makes it easier to change the images’ height without recoloring the entire plan.

It is possible to import images into ImageJ and NIH Image, however, inevitably some colour fixing will be necessary. Both software are able to create macros which allow other types of analysis. Nonetheless, it is also possible to calculate built area through histograms, to create sections of the site and axonometric representations, as well as to visualize the 3D model.

There were found two macros for DEM analyses. The first one was developed by Ratti & Richens (2004) based on a study on building’s shadows. Their aim was to determine the sky view factor by the shadows created by the obstructions. This macro was written for NIH Image, which only runs on iOS system; due to this fact, and because the only system available for the present research was a Windows, it was adopted the second macro developed by Zaksek, Ostir & Kokalj (2011). The latter was developed in ENVI+IDL in a partnership between the Universities of Hamburgo (Germany) and Ljubljana (Slovenia) with the objective of identifying surfaces’ imperfections in geomorphological studies.

2.2 Fish Eye Lens Images

Fish eye lens allow a physical camera to register a field of view wider than regular lens, close to 180° wide. The resulting image is created in a complex process. Firstly, the obstructions (pedestrians, buildings, objects) are projected in a half-hemisphere, or sky vault, which defines the field of view around the lens. Then, such images are projected again in a horizontal plane (Souza, Rodrigues & Mendes, 2003). For the analysis of the first case study, Cambuci, as the model was already built in Google SketchUp, two digital cameras were adopted to generate the fish eye lens images: VRay for SketchUp and Autodesk Ecotect Analysis. For the latter tool, it was necessary to import the model from SketchUp and rebuild it. In the second and third cases studied (Bela Vista and Republica) the focus was the existing morphology, and thus images were shot with a physical camera.

Computational tools were then used to analyse the obtained images. Generally, such tools divide the sky vault into several parts which are later projected in the horizontal plane. Following, each part is identified as being and obstruction or a part of the sky. The software differ from each other by the way they divide the vault.
Two computational tools were adopted for this phase of the research. The first one was developed by Santos, Lima & Assis (2003) at the Universidade Federal de Minas Gerais and was analysed by MapInfo. The second one, Sky View Factor Calculator, was developed by Lindberg & Holmer (2010).

Other methods were listed; however, due to limitations on time and software availability, it was not possible to assess them all. Among those, it is worth mentioning Souza, Rodrigues & Mendes (2003), which developed a SIG based model created in ArcView. As part of such method, the sky view factor is calculated by an extension called 3DSkyView, which runs together with 3d Analyst, from ArcViewGIS. Once the observer is located, it is possible to generate stereographic and orthographic projections. The obstructions and the visible sky are automatically detected by the extension, which additionally compares the generated image with a stereographic grid of the sky vault, enabling the calculation of the sky view factor. The main reason for not including that method on the present study was the unavailability of a former version of ArcViewGIS, which is required for the 3DSkyView extension to run.

Another tool listed, although not adopted, was CityZoom, developed by SimLab from Universidade Federal do Rio Grande do Sul, in Brazil. This tool is intended for urban design applications (Ely, Lins & Sonza, 2009). As part of the main features, regarding the geometry to be studied, a 3D volume can be drawn directly in the software or a .DXF file can be imported from Autocad. The software can calculate sky view factor by itself without any extensions. It seems to be a fast and friendly tool, but unfortunately it was not available for download by the time this research was ongoing.

2.2.1. Fish Eye Lens Image and MapInfo

Following Santos, Lima & Assis (2003), a fish eye lens image of the area of interest is compared to a template: a grid divided in cells developed by Souza, Rodrigues & Mendes (2003). A number corresponding to a portion of the sky vault is attributed to each cell, as indicated in Fig. 1. The sum of numbers equals 10,000, representing 100% of the visible sky.

![Figure 1. Grid for MapInfo analysis, developed by Souza, Rodrigues & Mendes (2003).](image)

The grid was vectored in Autocad, as well as the fish eye lens image; in the latter case, the obstructed area was separated from the unobstructed one. Using MapInfo (Santos, Lima & Assis, 2003), it was possible to compare the fish eye lens image and the template, resulting in the sky view factor.

2.2.2. Sky View Factor Calculator (Lindberg & Holmer, 2010)

This computational tool was developed in MATLAB, and runs on MATLAB Compiler Runtime (MCR). It can analyse any image file and detect the portion of sky and obstruction automatically. This tool is easier and simpler than the method developed by Santos, Lima & Assis (2003). Once the fish eye lens image is uploaded, the program turns it into a black and white image, where black represents the obstructions and white, the visible sky. Subsequently, the tool can calculate the sky view factor according to two methods.

The first method (Johnson & Watson, 1984) analyses the wall view factor, which is the area...
occupied by the walls that contour the urban canyons. It was originally used for evaluation of long wave radiation exchange within urban canopies.

The second calculation method (Holmer, Postgard & Eriksson, 2000) analyses each pixel of the image and assigns, to each one, a value representing its percentage in the sky vault. Such portion is related to the angular distance from the centre of the vault. In the present study, the results obtained with this calculation method were discharged due to a great discrepancy in comparison with the results of the other methods.

3. CASE STUDIES: ANALYSIS OF THREE NEIGHBOURHOODS IN SAO PAULO

Sky view factor was predicted and analysed for three neighbourhoods in Sao Paulo: Cambuci, Bela Vista and República. All areas are located in the city centre, have mixed occupation (commercial and residential), urban infrastructure and demonstrate to have potential for an increase in population density.

3.1. Cambuci

The first neighbourhood analysed was Cambuci. A target density was adopted and 16m x 50m buildings were proposed and located in a chosen plot with a minimum distance of 25m between them, according to solar access criteria. For this first essay, the existing buildings, trees and street furniture were discarded. Three scenarios were created and analysed with DEM and fish eye lens images processed with MapInfo method.

For the DEM analysis, the macro was calibrated for a 350 and 250 radius and 180 directions. Each pixel represents 1m distance (Fig. 2).

Since the scenarios were created in Google SketchUp, firstly fish eye lens images were generated by VRay for SketchUp and by Autodesk Ecotect for comparison between the two results, and latter the images were analysed with MapInfo.

Figure 2. Cambuci neighbourhood, scenarios 1 to 3 analysed with DEM (radius=350 / 180 directions).

Figure 3. Cambuci neighbourhood: scenarios 1 to 3 with their points of analysis.
Four points located in the centre of each street around the plot were selected for evaluation (Fig. 3). The results of sky view factor can be seen in Table 1.

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Point of analysis</th>
<th>Scen 1</th>
<th>Scen 2</th>
<th>Scen 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>VRAY Image + MapInfo</td>
<td>0.35</td>
<td>0.40</td>
<td>0.34</td>
</tr>
<tr>
<td>2</td>
<td>Ecotect Image + MapInfo</td>
<td>0.32</td>
<td>0.29</td>
<td>0.32</td>
</tr>
<tr>
<td>3</td>
<td>DEM (radius:350/directions:180)</td>
<td>0.22</td>
<td>0.20</td>
<td>0.21</td>
</tr>
<tr>
<td>4</td>
<td>DEM (radius:250/directions:180)</td>
<td>0.28</td>
<td>0.23</td>
<td>0.29</td>
</tr>
</tbody>
</table>

It is possible to see that, in general, the VRAY image indicated more visible sky than the DEM analyses. However, such lens is more esthetical than technical, and no precise information was found about the type of image generated by this plugin. The results of the fish eye lens images varied from 0.02 to 0.12 in comparison with the DEM evaluation. Despite the different radius adopted for the DEM analysis, the svf results showed some consistency between them and were very similar to the ones obtained with Ecotect + MapInfo.

3.2. Bela Vista

Aiming to study the existing urban morphology, the second neighbourhood analysed was Bela Vista. A block was selected for the investigation and its buildings were catalogued. Fish eye lens pictures were taken directly on site with a camera. Ten points of analysis were selected, comprising all corners of the block and the centre of each surrounding street (Fig. 4). Due to the existence of many trees in the area, it was not possible to determine the svf with the MapInfo method. For this case, it was adopted the Sky View Factor Calculator (Lindberg & Holmer, 2010).

In order to compare results, a DEM was developed for the area (Fig. 5). Since the fish eye lens pictures were taken in pedestrian level (2m from the ground), to build the DEM, the height of the buildings were reduced in 2m. Additionally, the topography in Bela Vista is uneven, and thus its surface was reproduced considering 10cm for each pixel, aiming to improve precision. As a limitation, it was not possible to reproduce trees and other street furniture which are required to accurately represent the area.

Figure 4. Points of analysis in Bela Vista with fish eye lens pictures.
Figure 5. DEM for Bela Vista, at pedestrian level (configuration: radius 380 and 180 directions).

Table 2. Sky View Factor Analysis for Bela Vista.

<table>
<thead>
<tr>
<th>Point of analysis</th>
<th>Fish Eye Len Pictures + Sky View Factor Calculator</th>
<th>DEM at pedestrian level (radius:380/ directions:180)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.52</td>
<td>0.46</td>
</tr>
<tr>
<td>2</td>
<td>0.37</td>
<td>0.43</td>
</tr>
<tr>
<td>3</td>
<td>0.22</td>
<td>0.40</td>
</tr>
<tr>
<td>4</td>
<td>0.45</td>
<td>0.45</td>
</tr>
<tr>
<td>5</td>
<td>0.30</td>
<td>0.33</td>
</tr>
<tr>
<td>6</td>
<td>0.47</td>
<td>0.42</td>
</tr>
<tr>
<td>7</td>
<td>0.37</td>
<td>0.31</td>
</tr>
<tr>
<td>8</td>
<td>0.42</td>
<td>0.41</td>
</tr>
<tr>
<td>9</td>
<td>0.50</td>
<td>0.38</td>
</tr>
<tr>
<td>10</td>
<td>0.25</td>
<td>0.32</td>
</tr>
</tbody>
</table>

Regarding the fact that the DEM did not consider the obstruction caused by trees, it was expected to present higher svf results than the ones from the fish eye lens images (Table 2). Nevertheless, some of the results were similar (see points 4, 5 and 8) and can be justified by: I. The difficulty to calibrate the Sky View Factor Calculator for the representation of the transparency of the trees; II. The lack of precision in DEM, as the 3D model was generated by a city plan provided by the City Hall website; and III. The difficulty to precisely identify in DEM the same points analysed with the fish eye lens.

3.3. República

The method of analysis adopted for the República neighbourhood is similar to the one adopted in Bela Vista. An urban block was selected and eight points of analysis were chosen (Fig. 5). The buildings were catalogued and fish eye lens pictures were taken in loco at pedestrian level with a physical camera. Those pictures were analysed with Sky View Factor Calculator (Lindberg & Holmer, 2010).

Figure 6. Points of analysis in República neighbourhood.

The urban surface in República is more even than the one in Bela Vista, thus the terrain did not need to be reproduced. A DEM at pedestrian level was also generated for that case and compared to the fish eye lens pictures (Fig. 5 and Table 3).
Once again, there was a considerable difference between the results obtained by fish eye lens pictures + Sky View Factor Calculator method and DEM. One should expect DEM to show higher levels of visible sky than the former method, since it does not consider street furniture and vegetation, although this theory proved not to be true in both neighbourhoods.

### 4. CONCLUSION

During the development of this study, the fish eye lens pictures and the Ecotect lens showed svf with more visible sky than the DEM method. It was unexpected due to the fact that DEM ignores vegetation and street furniture as obstructions, and therefore higher results of svf were expected.

Despite the differences among the results, one advantage of the DEM method for svf analysis is the possibility to obtain a general view of an urban area in opposition to a punctual analysis.

Regarding the results of this research, by analysing the existing morphologies in Bela Vista and República, the average sky view factors were:

- **Bela Vista:** 0.39
- **República:** 0.25

Thus, based on the perceived density concept (CHENG, 2010), the República neighbourhood can be said to be perceived by its users as a denser area than Bela Vista. Such result was already expected and it is probably due to the fact that the buildings in the first neighbourhood are placed directly on the front part of the lot, aligned with the street and close to each other. On the other hand, the buildings in the second neighbourhood are placed in the middle of the plot and most of them have gardens in the front part. The streets in Bela Vista were also wider and had plenty of trees, which according to Cheng (2010), helps reducing the perceived density.

Regarding this research, the method used to analyse sky view factor in areas with considerable amount of trees needs to be improved.

In the Cambuci area, the average sky view factor was:

- Scenarios 1 to 3, fish eye lens image from VRay: 0.30
- Scenarios 1 to 3, fish eye lens image from Ecotect: 0.28
Scenarios 1 to 3, DEM analysis: 0.21

For that neighbourhood, the DEM method showed the lower results. However, for this specific research, related to the analysis of the perceived density, a simplification is suitable and thus the results could be considered as similar, leading to the conclusion that the perceived density in that area is higher than in Bela Vista, but lower than the density perceived in República.

Regarding limitations of the study, glare occurred in the fish eye lens pictures taken with physical camera in Bela Vista and República, which led the software to consider some parts of buildings and trees as part of the sky. The same issue occurred in the buildings covered by glass façades, which reflected solar radiation. How does this fact effectively affect the perception of density?

Some unsolved questions remain for a future research, such as the reasons why there were differences between the results obtained in the different methods and aspects of the DEM calibration. Another important issue is the search for methods to analyse the sky view factor in areas covered with vegetation. It was not possible to include trees in the DEM analysis, and the fish eye lens study demonstrated lack of precision.

The sky view factor is a parameter that influences many analyses, such as acoustics, thermic, ventilation and solar radiation (Cheng, 2010). For this reason, it can be emphasised the relevance of understanding the theoretical concepts and relationships among the variables involved in the subject of svf in order to analyse it with more precisely, combining both hypothetical models and existing areas which present multiple types of obstruction.

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