# 3D SKYVIEW – A 3D GIS TOOL FOR URBAN CANYON GEOMETRY AND SOLAR ACCESS

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**Abstract** – This paper uses a 3D-GIS environment for simulating a spatial representation of urban canyons in place of many other high cost-equipment methods for determining Sky View Factors (SVF), allowing also the visualization of urban solar access by sunpaths simulation. The sky view factor is an estimation of the visible area of the sky from an earth viewpoint, being defined as the total amount of radiation received from a plane surface and that received from the whole radiant environment. In this way the sky area results from the limits of the urban canyon generated by urban elements, which is basically a result of a tri-dimensional environment. The tool here developed which is called 3D SkyView, aimed the substitution of a camera equipped with a 180º fisheye-lens by an algorithm of calculation and visualization to be applied on a three-dimensional GIS. The 3D SkyView extension was generated in *Avenue* computational language, developed in *ArcView 3.2* software, and used its *3D Analyst* extension. This first version of 3D SkyView calculates a new coordinate system for stereographic and equidistant projections of urban areas on a horizontal plan, and calculates SVF values for any observation point inside urban areas. In addition, the results create an environment suitable for sunpaths analysis and visualization of the whole scene desired in a fish-eye-lens 3D scene representation, as discussed in this paper.

## 1. INTRODUCTION

This paper presents the 3DSkyView extension, which is a tool developed for assessing urban geometry in a 3D-GIS environment, creating an interface suitable for visualization of solar sun-paths in urban canyons. The 3DSkyView extension substitutes the use of a 180º fisheye-lens camera by an algorithm of calculation and visualization developed for enhancing functions of a three-dimensional GIS. The 3DSkyView was conceived in *Avenue* scripting language in an *ArcView GIS 3.2* software environment, accessing its *3D Analyst* extension[1].

Urban climate and its heat islands phenomena are comprehensively studied nowadays. Yet, many topics on this subject remain important issues to be examined. The urban climate has a high variability and it is generally warmer and less windy than rural climate. It depends on many characteristics such as topography, regional wind speed, urban morphology and many other factors. Considering the urban canopy layer, i.e, the air contained within an urban street canyon, its radiation budget depends on thermal characteristics of materials and on the geometry of the surroundings. Buildings trap energy reducing the urban long wave heat loss and generating the urban heat island. Among the main aspects causing the urban heat island are the physical characteristics and the spatial relationships of urban features. They have a direct influence on the thermal performance of buildings. The smaller is the visibility of the sky from a given surface, the slower is its cooling ability. Therefore, a thermal parameter called sky view factor (SVF) is one of the main heat island causes, as once studied by Steyn (1980), Oke (1981), Johnson and Watson (1984), Bärring, Mattsson and Lindqvist (1985), Souza (1996), Ratti and Richens (1999), Chapman (2000), and Chapman *et al.* (2001).

The SVF represents an estimation of the visible area of the sky from an earth viewpoint, being defined as the ratio between the total amount of radiation received from a plane surface and that received from the whole radiant environment. It is thus a dimensionless parameterisation of the quantity of visible sky at a location. In this way the sky area results from the limits of urban canyons generated by the tri-dimensional characteristics of urban elements and their mutual relationships. The SVF when graphically represented by means of stereographic or orthographic projections, allows the overlay of sunpaths diagrams. It is thus way being a suitable way to analyse urban solar access on urban canyons.

To demonstrate the potentiality of the tool here developed for solar access analysis, this paper presents in section 2, after a brief comment about the SVF, the approach used for the development of the 3DSkyView Extension and its context on a 3D-GIS environment. Next an algorithm based on the sun-paths approach of Szokolay (1996) and ABNT (1999) is also applied,

[1] *ArcView GIS, Avenue* and *3D Analyst* are trademarks of ESRI (Environmental Systems Research Institute products)

allowing sun-paths visualization in a resulting view of the 3DSkyView extension.

## 2. THE 3DSKYVIEW EXTENSION

### *2.1 An Overview*

The 3DSkyView extension is mainly a tool to calculate sky view factors of urban canyons, which works in an environment created by *ArcView GIS version 3.2* with its *3D Analyst* extension switched on. *ArcView GIS* is a flexible software GIS package that uses *Avenue* as a scripting language, allowing the development of extensions and plug-ins to enhance its functionality.

In practical terms, the aim of the 3DSkyView is to identify a new coordinate system for the tri-dimensional urban elements, so that they could be represented in a stereographic projection on a bi-dimensional plane, in this way allowing the calculation of the SVF parameter. In the 3DSkyView extension the viewing point position is movable for all three dimensions and it can be fixed inside the urban canyon level with its focus point centred on the urban canyon level. The bi-dimensional representation of this view is dependent on the tri-dimensionality of the canyon.

This new coordinate system of a stereographic projection refers to the tri-dimensional relationships in the canyon. There are three important angles in the canyon determining the scene, as it is shown in Figure 1. First is the horizontal angle a created between the viewer North-South axes, on viewer horizontal plane, and the point of interest. Second is the vertical angle ß between the viewer plane and the point of interest. And third, is the Nadir vanishing point angle ? between the vertical plane that contains the Nadir point and the projected line from the point of interest to the vanishing point.

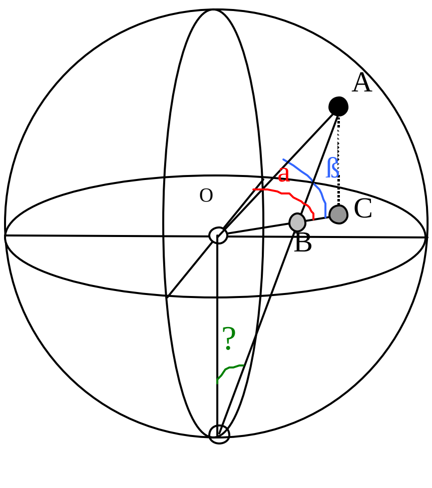


Figure 1 - Stereographic Projection and Angles

Considering that the viewer is in a movable position and regarding the particularities that a should always be related to the vertical plane that contains the viewer (point O in Figure 1) and that ß should always be related to the viewer horizontal plane, those angles are comparable to the azimuth and altitude angles that can be easily determined. The angle ? can be calculated by Equation 1, as it belongs to an isosceles triangle.

$$q = \frac{90 - b}{2} \tag{1}$$

The stereographic projection on the equatorial plane determines a segment ($\overline{OB}$), from the viewing point O to the projected point B on Figure 3, being calculated by Equation 2. The *r* variable is the radius of the circle on the equatorial plane that was considered for the stereographic projection representation.

$$\overline{OB} = r \cdot \tan q \tag{2}$$

The new coordinates can then be expressed by Equations 3 and 4, composing the new coordinate system on a stereographic projection. Here the a angle was submitted to an adjustment in order to have the same origin of the trigonometric relationships. This is done because a was calculated based on the north side corresponding to 0º, while the same angle for trigonometric calculation corresponds to what would be the east side. This rotation is the reason for the subtraction of the a value from 90º in Equations 3 and 4.

$$x = \cos(90 - a).\overline{OB} \tag{3}$$

$$y = \sin(90 - a).\overline{OB} \tag{4}$$

With the new coordinates of the points of interest it is possible to have the stereographic projection by plotting them on the horizontal plane in *ArcView* GIS. The determination of SVF is then just a question of spatial manipulation of layers by overlaying a stereonet of equal radius on the stereographic projection of the scene. The value of SVF is calculated by Equation 5, where *q* is the visible area of the sky and *Q* is the total area of the sky defined by the area of the circle applied on the stereographic projection.

$$j = \frac{q}{Q} \tag{5}$$

### *2.2 Applying the 3D SkyView Extension*

Given a circle radius into which the urban canyon will be projected, one must specify a polygon theme containing height and elevation of urban elements combined in it, in order to start an application. An observer point theme with height and elevation attributes must also be defined (Figure 2). Besides calculating SVF values, the 3DSkyView provides a visualization of a 2D stereographic projection view, a 2D orthographic projection view and a 3D scene view of the urban canyon selected by the user.

The simulation process follows the steps described below:

- Based on the input themes containing the viewer point and urban elements polygons, the XY coordinates of the observer and of the vertices of the polygons are automatically identified;

- According to the observer coordinates, the XY coordinates of the polygons are transformed into a stereographic projection. In addition, they are also transformed into an orthographic projection;
- The projection of the polygons vertices on new coordinates are linked, depending on their original characteristics, shaping a 2D plan of the scene;
- The boundaries resulting from the new projection system are the limits of two new themes for each projection: one represents the obstruction caused to the sky and the other represents the visible sky;
- By applying GIS tools, a stereonet, which is a netpoint of the whole sky, is compared to each one of these new themes, allowing the calculation of their areas and therefore the sky view factor;
- A scene simulating the reflection of the urban canyon on the hemisphere is presented in a 3D environment.

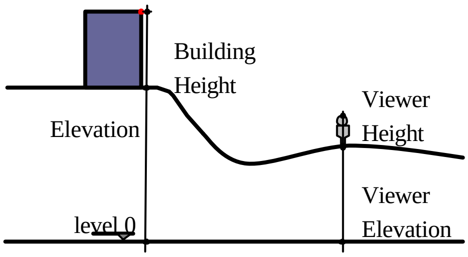


Figure 2 - Height and Elevation Variables

As one can draw from the steps above, shapefiles containing polygons, which represent the buildings in urban areas, are required for the operation to be successful. These files can be either imported from CAD and any other compatible extension accepted by the *ArcView GIS 3.2*, or directly generated in the GIS environment. In Figure 3 a zoom in part of a typical shapefile required is presented. It corresponds to the 'buildings.shp' theme of the figure. This polygon file was prepared in *ArcView GIS*, based on a *dwg CAD* file, which was imported by means of the *Cad Reader Extension* available in *ArcView*. Part of the table of contents with the polygons attributes of the theme measured in meters can be seen in Table 1. Height and elevation of buildings ought to be available among the attributes.

The user interface was developed to be easy-to-use by architects, climatologists and engineers, as can be seen in Figure 4. Once the user is familiar with the *ArcView GIS 3.2* environment, the extension can be downloaded and an icon is automatically created to run the algorithm from the main software interface screen.

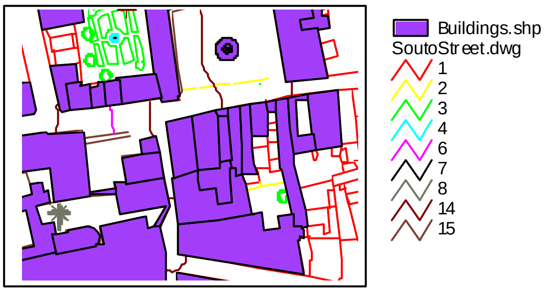


Figure 3 – A typical shapefile required

Table 1 – Attributes of buildings theme shapefile

| Shape | ID | Height | Elevation |
|---|---|---|---|
| Polygon | 0 | 13.0 | 184.0 |
| Polygon | 0 | 11.0 | 185.9 |
| Polygon | 0 | 7.0 | 185.9 |
| Polygon | 0 | 12.0 | 185.9 |
| Polygon | 0 | 6.0 | 185.9 |
| Polygon | 0 | 9.0 | 185.9 |
| Polygon | 0 | 9.0 | 185.9 |
| Polygon | 0 | 10.0 | 185.9 |
| Polygon | 0 | 20.0 | 188.4 |
| Polygon | 0 | 10.0 | 188.0 |
| Polygon | 0 | 10.0 | 187.7 |
| Polygon | 0 | 10.0 | 187.0 |
| Polygon | 0 | 13.0 | 186.0 |
| Polygon | 0 | 13.0 | 186.6 |

There are four kind of information which should be provided by users: process information, observer information, polygons information, projection radius. The process information refers to the file name and file paths. The observer information requires the identification of columns containing observer attributes such as Z coordinate and elevation. As the layer containing the observer should be already selected, the X and Y coordinates of the observer are automatically identified on the user interface window. The polygons information corresponds to the attributes of the buildings under consideration. A pre-selection of the layer containing this theme is also a requirement. The user is prompted to fields, where the columns corresponding to height and elevation attributes of the buildings should be identified. Finally, the radius of the circle adopted to represent the scene in stereographic projection is requested.

The whole process is run through this unique interface window. The resulting windows of this process are: a projection of the urban canyon in a 2D stereographic representation, a projection of the urban canyon in a 2D orthographic representation, a table of contents indicating the SVF value for that urban canyon and a 3D scene representing the reflection of the urban canyon on a hemispherical surface, as a ‘fish eye surface’.

For the hypothetical scenario of Figure 5 an application of 3DSkyView extension results in the projections shown from Figure 6 to Figure 8, where the limits of the visible sky area and buildings area are automatically delineated. Consequently, the sky view factor can be calculated, as shown in Table 2. In the resulting table it is possible to identify the total sky area, which would be available without the obstruction of the buildings. As the canyon obstructing area and the visible sky area are also available, the SVF value is directly determined.

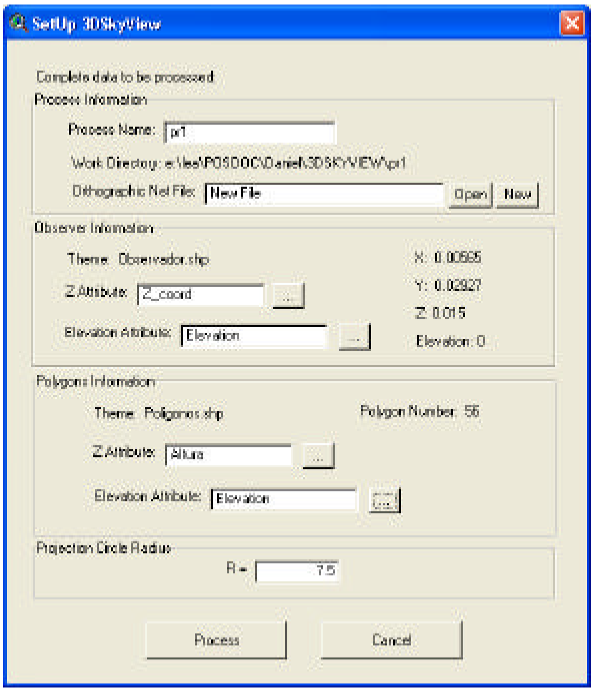


Figure 4 - User interface of the 3DSkyView

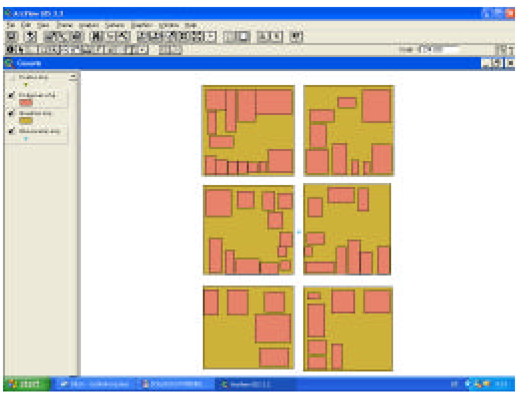

Figure 5 – Hypothetical scenario

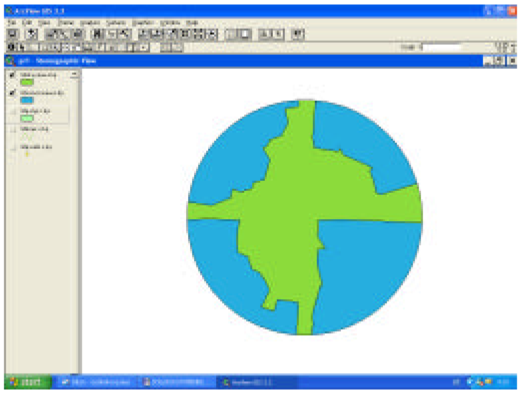

Figure 6 – 2D Scene on Stereographic Projection

The 3D Scene of Figure 8 allows a visualization and understanding of the whole geometric relationship between the observer and the buildings. Changes on the view point of the 3DScene are possible, so the user can interact to get the best angle to analyse the tri-dimensionality of the canyon.

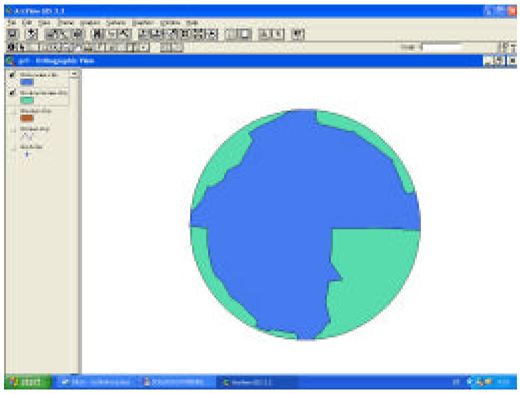

Figure 7 – 2D Scene on Orthographic Projection

Table 2 – SVF value for an urban canyon

| SkyArea | CanyonArea | VisiSky | SVF |
|---|---|---|---|
| 353.2500 | 118.9872 | 234.2627 | 0.6631 |

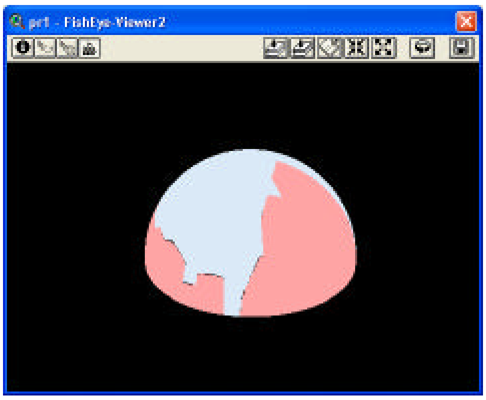


Figure 8 – ‘Fish-eye’ 3D Scene

## 3. THE SOLAR ACCESS VISUALIZATION

Based on the widespread solar equations available in Szokolay (1996) and in ABNT (1999), it is possible to identify the solar declination, altitude and azimute angles at any place of known latitude and longitude, and at any time. These parameters allow then the determination of stereographic and orthographic solar coordinates in ArcView by applying the same equations 3 e 4 described before, considering though that a is now the value of the solar azimute. All these stereographic and orthographic coordinates are then available in an attribute table. So the views resulting from the 3DSkyView Extension can be overlayed with sun-path diagrams for a specific latitude, allowing the analysis of the solar access into the urban canyon.

The steps for the representation of sunpaths in ArcView can then described as:

- Calculation of solar declination, solar azimute and solar altitude, based on latitude and longitude of a location;
- Determination of stereographic and orthographic solar coordinates (X,Y) for each solar position, given a period of 1 hour between two consecutive solar positions. One day in each month of the year was considered for the development of the algorithm;
- Storage of all this information on a table of contents to create a layer corresponding to the monthly sun-path diagrams;
- Creation a theme for each hourly solar position on the year, to be visualized in a 2D view. The theme with the sun-path diagram can be overlayed on the urban canyon stereographic or orthographic projections;
- Representation of a 3DScene corresponding to the solar sunpaths for one day in each month of the year;
- Overlay of the urban canyon and the sun-paths in a 3DScene.

In Figure 9 the hourly solar positions for specific days in each month of the year are plotted.

For the hypothetical scenario of Figure 5, Figures 10 to 12 present the results obtained with that algorithm integrated to the 3DSkyView results.

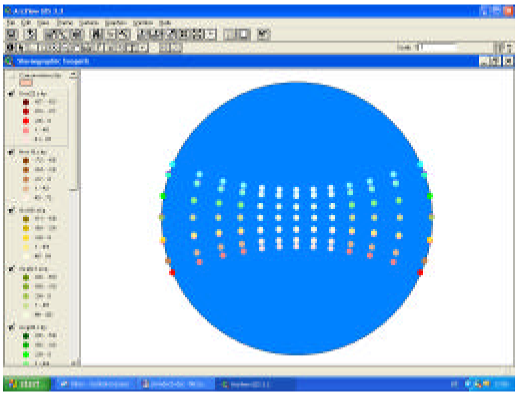

Figura 9 – Visualization of the hourly solar sun-path on the viewer plan, considered a location at 0$^{o}$ latitude in stereographic projection

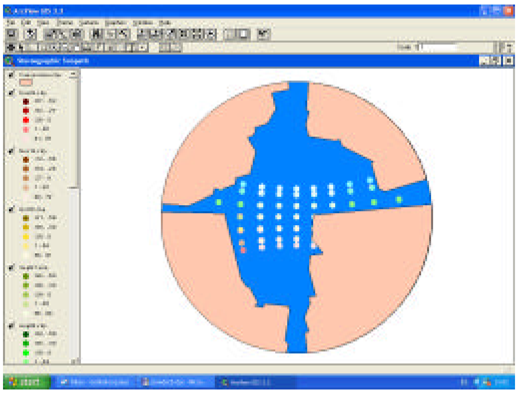

Figura 10 – Integrating the 3DSkyView stereographic projection with the sun-path diagram in a 2D view.

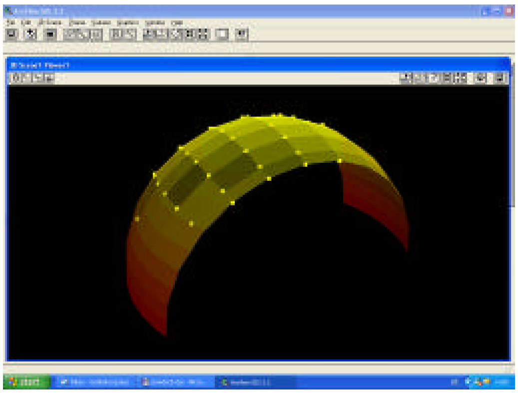

Figura 11 – A 3DScene for the solar sun-path diagram for a location at 0$^{o}$ latitude.

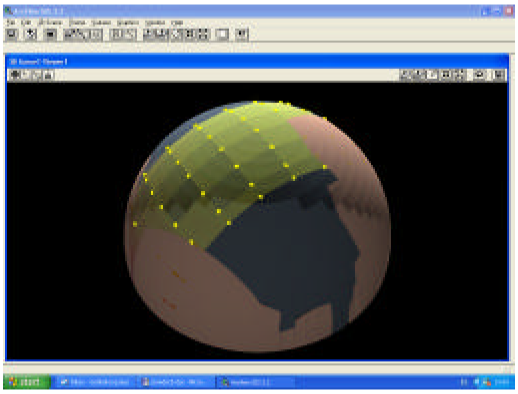

Figura 12 – Overlay of the hypothetical scenario urban canyon to the sun-path in a 3D Scene.

The 3DScene is a good way to visualize the integration between solar sun-paths and urban canyon, therefore allowing analyses of the influence of urban geometry on the solar access.

## 4. CONCLUSIONS

The 3DSkyView extension generates a suitable environment for urban solar access analysis, simplifying the methods usually applied for the determination of sky view factors and sun-path diagrams. It solves one of the main problems of sky view factors determination, which is the delineation of urban and sky areas.

As the extension was developed in a flexible GIS environment, there are several possibilities of integration with other tools, aiming the urban geometry analysis.

Already available at the ESRI site, the 3DSkyView is now under evaluation. One of the improvements in the tool is the consideration of the terrain topography, so that the submission file can have a layer of contour lines.

The tool is proving to be a good alternative for architects and architecture students, due to the quick determination and visualization of the urban geometry that it provides.

## ACKNOWLEDGEMENT

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## REFERENCES

ABNT - Associação Brasileira de Normas Técnicas (1999). Iluminação natural – Parte 2: Procedimentos de cálculo para a estimativa da disponibilidade de luz natural. *Projeto 02:135.02-002*. São Paulo. Available in: //www.labeee.ufsc.br/conforto/normas/index.htm

Bärring, l.; Mattsson, J.O.; Lindqvist, S., (1985). Canyon geometry, street temperatures and urban heat island in Malmö, Sweden. *Journal of Climatology*, 5: 433-444.

Chapman, L., Thornes, J.E.; Bradley, A.V. (2001). Rapid determination of canyon geometry parameters for use in surface radiation budgets. *Theoretical and Applied Climatology*. 69: 81-89. Available in: www.cert.bham.ac.uk/research/urgent/canyongeometry.pdf.

Chapman, Lee, (2000). Improved one dimensional energy balance modeling utilizing sky-view factors determined from digital imagery. *Proceedings of the 10th SIRWEC Conference*, March 2000, Davos-Switzerland. Available in: www.sirwec.org/conferences/ davos2000.html.

Johnson, G.T.; Watson, I.D., (1984). The determination of view-factors in urban canyons. *Journal of Climate and Applied Meteorology*. 23: 329-335.

Oke, T.R. (1981). Canyon geometry and the nocturnal urban heat island: comparison of scale model and field observations. *Journal of Climatology*, 1(1-4): 237-254.

Ratti, C.F.; Richens, P. (1999). Urban texture analysis with image processing techniques. *Proceedings of the CAADFutures 99*, Atlanta, GE. 1999.

Souza, L.C.L. (1996). Influência da geometria urbana na temperatura do ar ao nível do pedestre. *PhD Thesis in Science of Environmental Engineering*, University of São Paulo, Brazil.

Steyn, D.G., (1980). The calculation of view factors from fisheye-lens photographs. *Atmosphere-Ocean*, 18(3):254-258.

Szokolay, Steven. (1996). *Solar Geometry*. Queensland, University of Queensland.

Williamson, T. J. and Erell, E. (2001). Thermal performance simulation and the urban microclimate: measurements and prediction. *Proceedings of 7th IBPSA*, Rio de Janeiro, Brasil: International Building Performance Simulation Association: 159-166.