# A 3D-GIS EXTENSION FOR SKY VIEW FACTORS ASSESSMENT IN URBAN ENVIRONMENT

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**Abstract:** This paper presents a Geographic Information System (GIS) 3D extension that is a tool to simulate the representation of sky view factors (SVF) while calculating their values. The sky view factor (SVF) is a climatological parameter used to characterize radiation properties on urban areas and to express the relationship between the visible area of the sky and the portion of the sky covered by buildings viewed from a specific point of observation. The implementation of this tool in a 3D GIS is useful not only because it allows straight and quick urban geometry analysis from several points of observation, but also because it can help to predict sky view factors due to future buildings without the usual associated costs of cameras and image processing. The algorithm was developed by applying the software *ArcView GIS*[1] and its *3D Analyst* extension, allowing an automatic delineation of the visible sky and obstructions.

**Keywords:** sky view factor, 3D-GIS extension, urban canyon geometry

## 1. INTRODUCTION

As the sky usually presents lower temperatures than earth surface, it has an important role on the energy balance. In the process of the earth heating loss and its consequent earth temperature reduction, the sky is an element that receives long wave radiation oozed up from earth surface. Therefore the urban radiation loss has a straight relationship with the obstruction a building or any other urban element can cause to the sky surface, when considering an earth viewing point. Long waves are not only trapped by the warm earth surfaces, but also released into the cold sky. So, the surfaces relationship due to urban geometry influences the radiation exchange between the Earth and the sky. This relationship can be estimated by a parameter called Sky View Factor (SVF), as once studied by Steyn (1980), Oke (1981), Johnson and Watson (1984), Bärring, Mattsson and Lindqvist (1985),

[1] *ArcView GIS is a trademark of ESRI*

Souza (1996), Ratti and Richens (1999), Chapman (2000), and Chapman *et al.* (2001). The SVF is one of the main causes of the urban heat island phenomena, therefore required as a parameter on its modelling.

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.

There are some software for architectural purposes, as ECOTECT (Ecotect), or decision support system for urban planning, as CITYZOOM (Cityzoom), which deal with the visualization of buildings obstruction on the sky vault in order to simulate solar access or sunlight availability. These tools are centered on buildings performance rather than on urban thermal environment performance, hence not developed for determining SVF values.

On the other hand, there are many methods of estimating SVF values, including mathematical models, fisheye-lens photographs analysis, image processing, diagrams or graphical determination. The calculation is, however, not straightforward and these methods are usually time and money-consuming. In addition, the main problem of these methods is the delineation of the sky from buildings in the graphic representation. This delineation is often a task that has to be done by hand. In this matter, the work of Chapman (2000) must be remarked, since it develops a technique to enable direct calculation from a digital fish-eye image, by delineating sky pixels from the non-pixels in the image.

Besides the facts above mentioned, nowadays the use of Geographical Information Systems (GIS) as a tool to understand and analyze urban areas is wide spread. Based on a technology that allows spatial and non-spatial data storage, analysis and treatment, GIS are able to optimize calculations and tasks, while reducing decision-making time. Achieving successful results is although a technology dependent matter, while also related to the quality of the available data. The latter also shows strong relationship to technology. Therefore, as developing countries sometimes experience a very different technological level than developed ones, it is important to highlight that the following aspects can limit the use of GIS: a lack in equipments and in qualified human workforce. Although, in the last decade even developing *countries* are experiencing advances on GIS matters. That is certainly the case of Brazil. This fact leads to believe that, since information are accessible for researchers and institutions of education its use should be also consolidated in developing countries. Moreover, GIS should constitute as an alternative to substitute tasks that can represent dependence on high-cost technologies and not simply to repeat methodologies and procedures that have been developed for a different reality.

The approach of this paper suggests the use of a GIS environment for simulating a spatial representation of urban canyons obstructions to sky vault, in place of many other high cost-equipment methods for determining Sky View Factors (SVF). The tool here presented, named 3DSkyView, has the purpose of replacing the use of a 180º fisheye-lens camera with an algorithm of calculation and visualization that has been developed by the authors for enhancing functions of a three-dimensional GIS. The 3DSkyView was conceived in *Avenue* scripting language in an *ArcView GIS 3.2* software environment with its *3D Analyst* extension switched on (all ESRI - Environmental Systems Research Institute products). The results here obtained represent a cooperation effort between the São Paulo State University at Bauru, in Brazil, and the University of Minho at Braga, in Portugal.

The 3DSkyView extension is presented in this paper. At first the Sky View Factor (SVF) parameter is discussed, considering its geometrical process of determination. The importance of 3D GIS for this research is also remarked. After pointing out the advantages a 3D GIS could bring to the process of determining SVF, the 3DSkyView extension is described. That topic explains which variables are considered to get a representation and calculation of the SVF in the 3D GIS here used. For demonstration of the 3DSkyView use, results and complementary functions, the extension is applied to a hypothetical scene. Some limitations and conclusions are presented along with suggestions for the future development in the final part of the paper.

## 2. LINKING SKY VIEW FACTORS (SVF) AND 3D GIS

The GIS geo-referencing capability, which is nowadays available in many software GIS packages, each one having its own potentialities and functions, is unique. Among the applications it can be used for are: as a data processing system to visualize maps, as spatial analysis systems, as decision making systems, and so on. In this research the main feature explored is its potentiality as a tri-dimensional geometry tool and as an urban geometry predictor for ends of thermal analysis.

According to Batty (2002) representation in the third dimension is at the cutting edge on GIS research. He adds that there are many reasons why GIS will embrace CAD in the architectural domain, as it has stronger functional power than CAD. There are many potential applications of a 3D GIS suggested by Janosch *et al.* (2000) and also in Ratti *et al*. (1999). In the latter, some urban geometry studies and surface modelling are discussed. On the other hand, although 3D GIS is a powerful modelling tool the applications available are still restricted to some areas. Furthermore, usually the tri-dimensional capability is most used for esthetical functions than to represent and to visualize scenes.

### 2.1 The Issue in Determining SVF

The issue of SVF determination is constituted of an identification of angular dimensions between the observer and the urban element obstructions caused to the sky vault. These angles allow the urban canyon to be projected in a bi-dimensional plane, in a process where the stereographic projection is a very useful tool. The stereographic projection of an urban canyon is an azimuthal projection, in which points of urban elements are projected to the sky vault surface (which is a spherical surface) and then transferred to the equatorial plane of the same sphere. This transference is possible by the union of each point on the upper sphere surface to the Nadir vanishing point, as shown in Figure 1. In this way any point on the sphere is projected into the circle representing the sky vault on the plane projection.

In order to estimate the SVF value, the sphere can be homogeneously divided and its parts projected stereographically to the equatorial plane, creating a stereonet (Figure 2). For the stereonet showed in Figure 2, a regular spacing of 5 degrees for both altitude and latitude angles was kept for the whole sky vault. Next, overlaying this stereonet on the equatorial plane projection of the obstructions, their parts (i.e., sky and obstruction areas) can be compared to the total area of the whole sky available, determining their ratio.

As described above, the determination of SVF is an angular identification issue that takes place in a tri-dimensional environment. A 3D GIS is thus a promising tool for such a calculation, since it works as a (X, Y, Z) coordinates database manager. Therefore, an extension was naturally created in a 3D GIS to visualize and calculate SVF, playing not only the role of a representation tool, but also as a calculation tool.

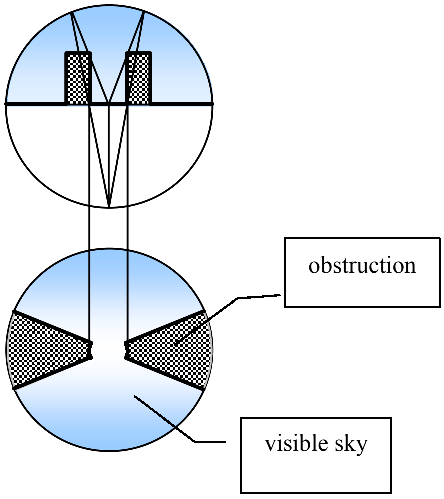


Figure 1 Stereographic Projection of an Urban Canyon

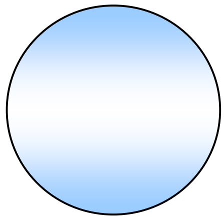

Figure 2 Stereonet on Equatorial Plane

## 3. THE 3DSKYVIEW EXTENSION

### 3.1 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. Here attention is drawn to the fact that the stereographic projection of maps available in *ArcView GIS* does not produce by itself the results desired here. That *ArcView GIS* function was developed to allow two dimension maps representation, in which the viewer is above the earth surface with the focus centred on earth surface. In 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 3. First is the horizontal angle α created between the viewer North-South axes, on viewer horizontal plane, and the point of interest. Second is the vertical angle β between the viewer plane and the point of interest. And third, is the Nadir vanishing point angle θ between the vertical plane that contains the Nadir point and the projected line from the point of interest to the vanishing point.

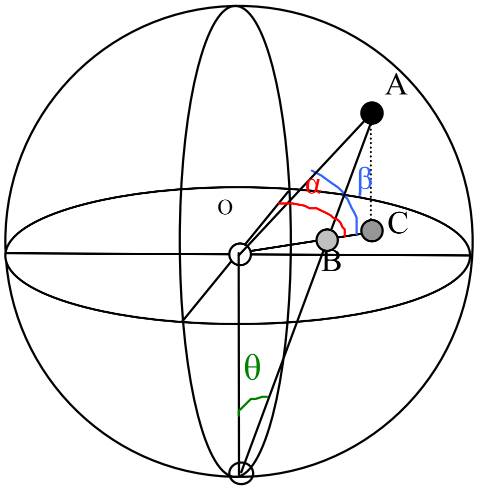


Figure 3 Stereographic Projection and Angles

Considering that the viewer is in a movable position and regarding the particularities that α should always be related to the vertical plane that contains the viewer (point O in Figure 3) and that β 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 θ can be calculated by Equation 1, as it belongs to an isosceles triangle.

$$\theta = \frac{90 - \beta}{2} \tag{1}$$

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.

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

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

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

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

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.

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

### 3.2 Applying the 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 4). 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.

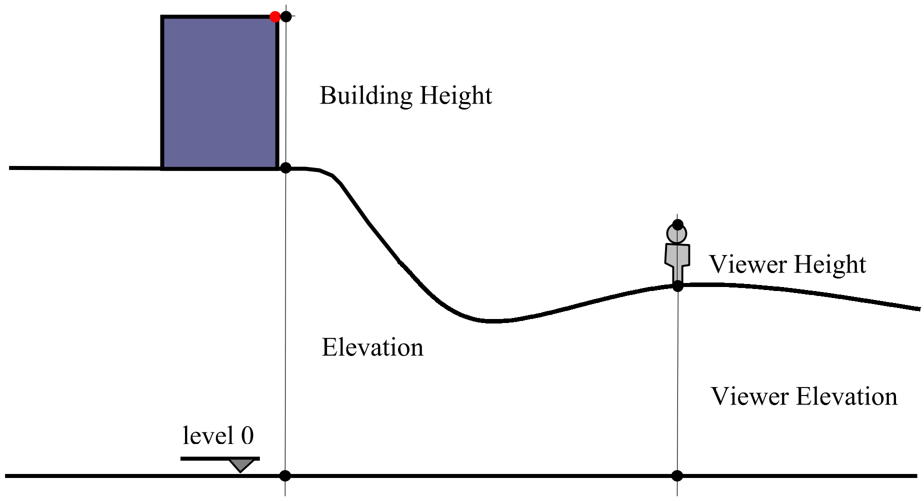


Figure 4 Height and Elevation Variables

The simulation process follows the steps described below:

- Based on the input themes containing the viewer point and urban elements polygon, the XY coordinates of the observer and of the vertices of the polygons are identified;
- According to the observer coordinates, the XY coordinates of the polygons are transformed into stereographic and orthographic projections;
- The new coordinates are unified by arcs or lines, depending on their original characteristics;
- The boundaries resulting from the new projections system are the limits of two new themes for each projection: the first one represents the obstruction caused to the sky, and the second one represents the visible sky;
- By applying GIS tools, a netpoint of the whole sky stereonet is compared to each one of these new themes, allowing the calculation of their areas and the sky view factor;
- A scene simulating the reflection of the urban canyon on the hemisphere is presented

in a 3D environment.

## 4. AN APPLICATION

In order to show the results that can be obtained with the 3DSkyView extension, a hypothetical scenario was created, as shown in Figure 5. This scenario is composed of polygons with different heights representing buildings. These can be visualized on a 3D Scene that was generated just applying common tools of the *3DAnalyst* (Figure 6).

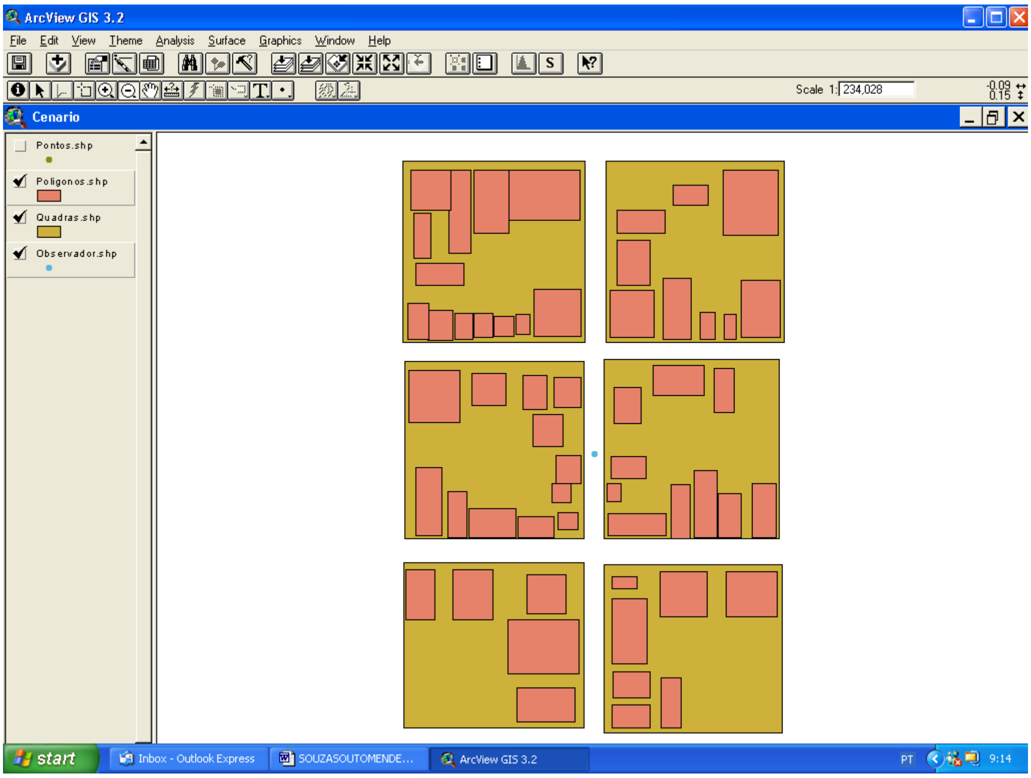


Figure 5 An hypothetical input scenario developed with the observer position

By means of the dialog window of the 3DSkyView extension, which is shown in Figure 7, the 2D view of the stereographic projection in Figure 8 is provided. Next the boundaries of these buildings are delineated in order to edit two themes, the visible sky vault theme and the obstruction buildings theme, as shown in Figure 9. Here is then possible to eliminate the hand delineation of the sky obstruction, often necessary in other methods. So this extension allows a step not previously possible, except from digital image processing.

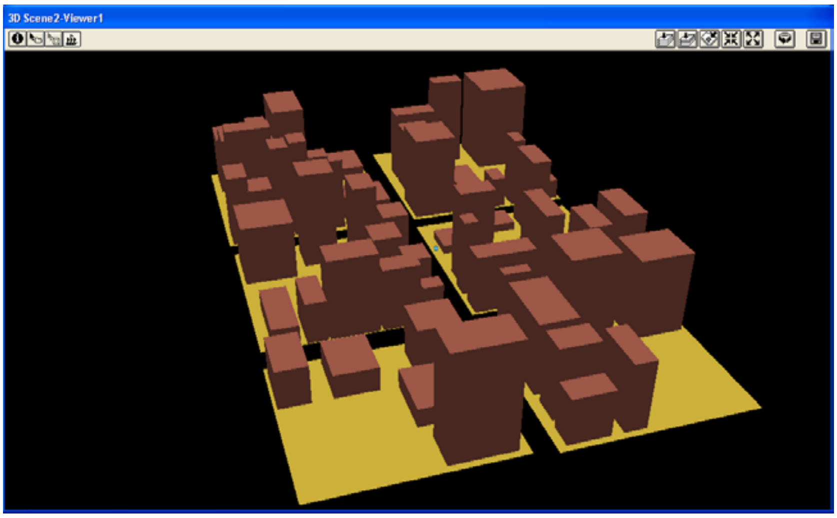

Figure 6 The hypothetical scenario in a 3D Scene of the *3D Analyst*

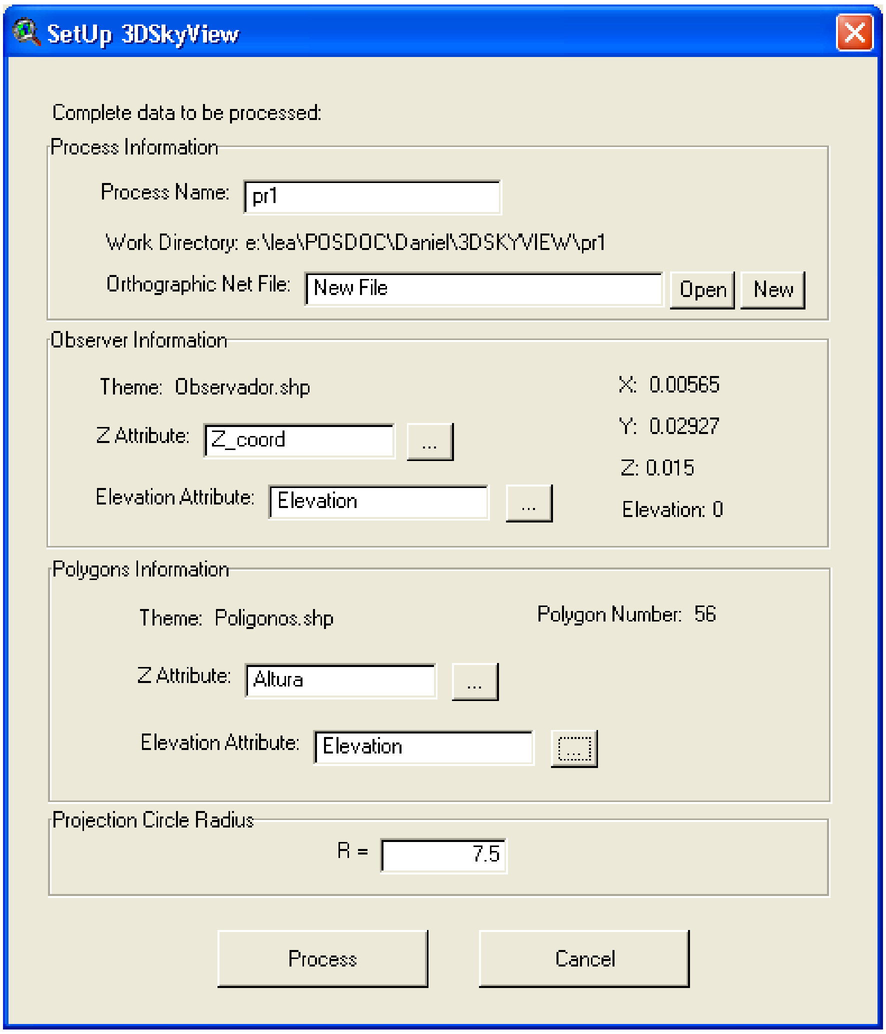


Figure 7 The dialog window of the 3DSkyView Extension

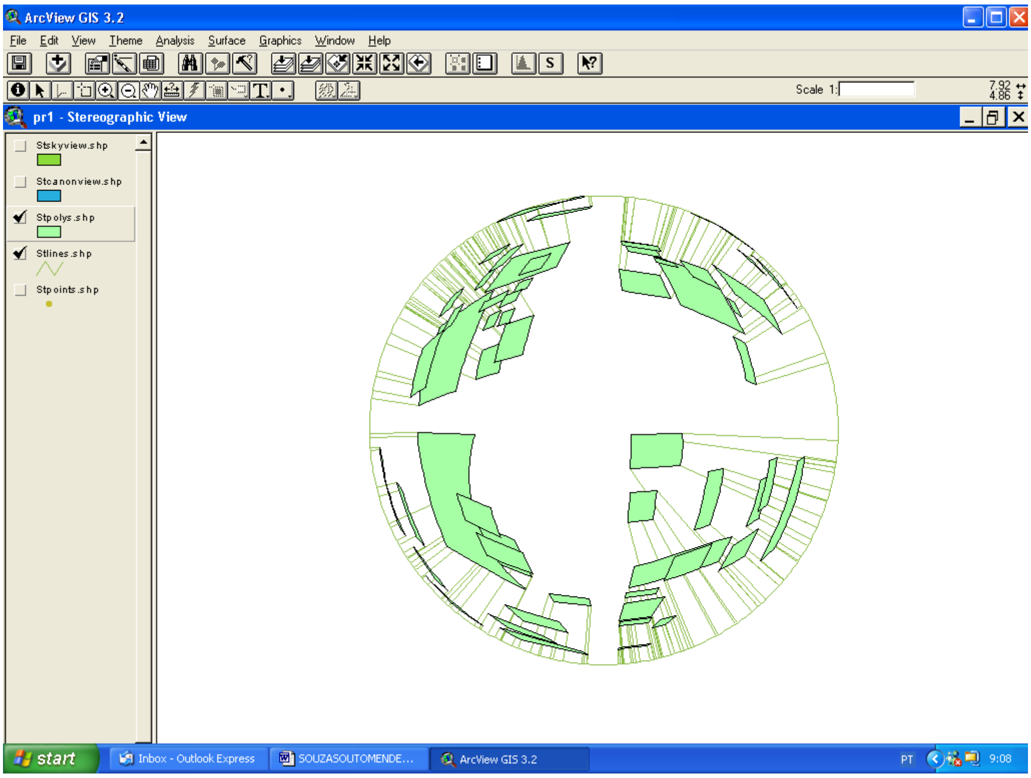


Figure 8 The 2D Stereographic Projection Result

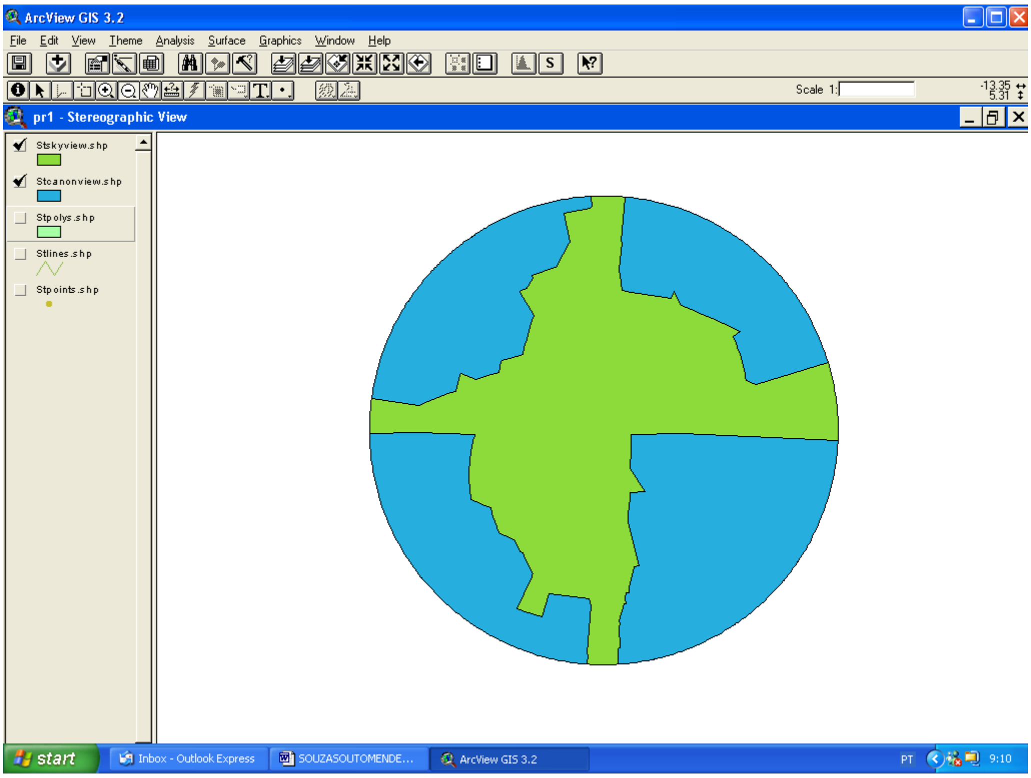


Figure 9 The resulting polygon themes of visible sky and obstructions

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Complementary, the same kind of result of a 2D view on the observer plan is obtained for orthographic projection, as one can see in Figure 10. Although the results of SVF values obtained with the 3DSkyView method are based on the stereographic projection, which is the most widely used projection for this purpose, orthographic projection is a side result also available. We remark here that a comparison between those two projections (Figures 9 and 10) reveals that for the orthographic projection there is a poor resolution for buildings situated in low altitudes in relation to the observer position. This happens because in this kind of projection, altitude of equal increments are spaced very close together near the horizon and widely spaced nearer the zenith.

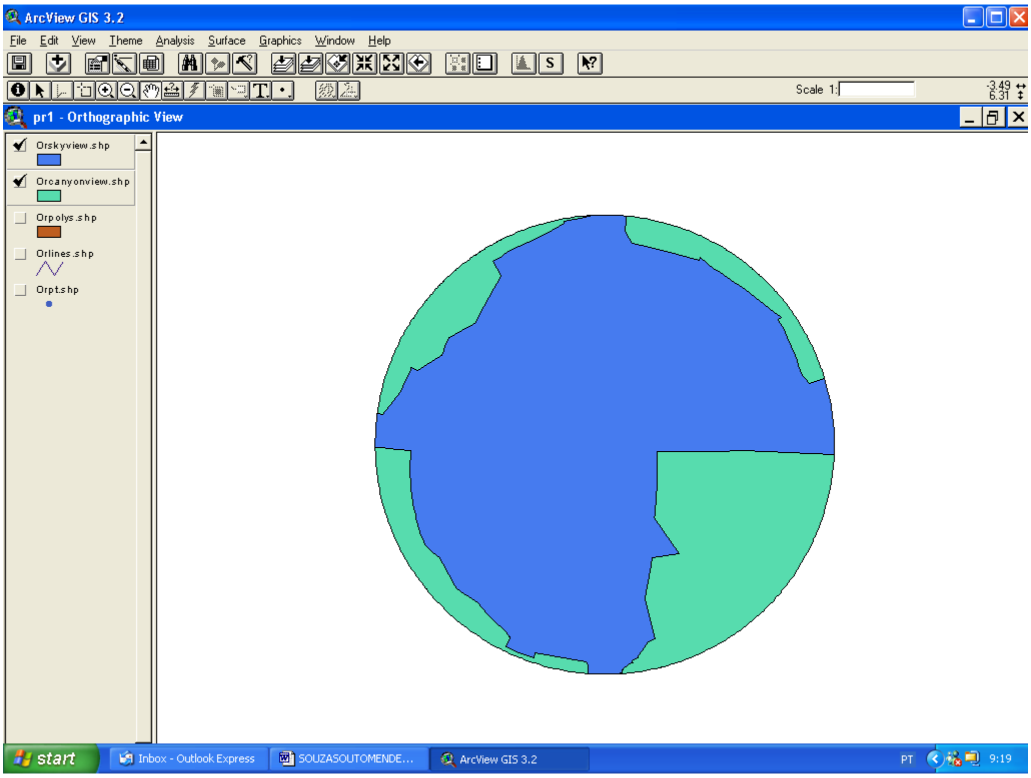


Figure 10 The resulting polygons theme for an orthographic projection

The internal overlaying of stereonet and stereographic projection of the scenario allows the spatial calculation of the sky area and obstruction areas. In this example, the resulting SVF value is equal to 66%, as shown below by the following table produced by the software for the example under consideration (Table 1). Units are dependent on the units the user adopts for the projection.

Table 1 Resulting table generated by the 3DSkyView extension

| SKYAREA | CANYONAREA | VISISKY | SVF |
|---|---|---|---|
| 353.25000 | 118.98723 | 234.26277 | 0.66316 |

Finally, as an additional means, the 3DSkyView Extension generates the 3D scene presented in Figure 11 for better understanding of the whole scene. This is a simulation of the reflection of the urban canyon on a hemispherical surface. Depending on the radius used for this representation, this hemispherical scene can be plotted together with the whole scenario in a 3D representation, what gives an idea of the urban geometry around the viewer.

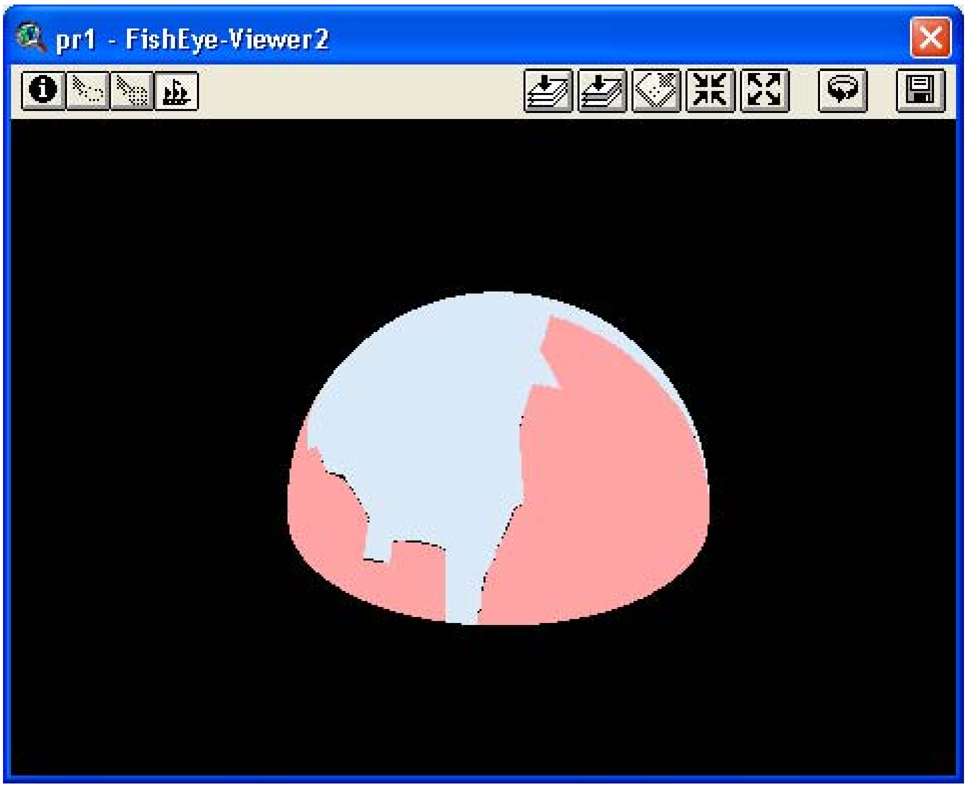


Figure 11 The scenario reflected on a 3D hemispherical surface

The 3DSkyView extension can also work as a simulator tool for future urban canyon geometries and SVF values. So, new buildings design could be tested in their future location before the actual implementation of the building takes place, therefore allowing the verification of its influence on their obstruction to the sky. This is then a way to gather information about the urban thermal environment, which together with many other urban heat island data that can be available as attributes in the input file, indicates the suitability of a new building on particular urban areas. So, the method here developed might enable the incorporation of the SVF as a parameter in an urban thermal model.

## 5. CONCLUSIONS AND FUTURE DEVELOPMENTS

One of the main contributions of this work is the automatic delineation of the visible sky and obstructions, not previously possible except from image processing methods.

This version of 3DSkyView can be a useful tool for developing countries, while working as an alternative solution for the estimation of SVF. Once an urban basis with information about the third dimension is available, it results in optimization of time for the estimation of SVF. It has here the advantage of being a low cost tool, if compared to some photographical accessories usually applied for the same purpose.

On the other hand, the representation and calculation of SVF values are strongly related to the quality of the geometrical basis of the input file. For trees, for instance, a good simulation of the SVF would probably lead to a file of numerous points, so that the tree canopy could be more realistic represented.

This 3DSkyView is the first version implemented on *ArcView GIS*, what suggests that the tool can still be improved. One of the improvements already in process is the provision of sun-paths diagrams and solar variables information. Also in the 3D visualization a complementary south hemisphere containing the information under the viewer plan - the ground view - is another module to be incorporated to the 3DSkyView extension. Other important improvement is the development of this extension in a new recent version of *ArcView GIS*.

The quality of the *ArcView GIS* environment working nearly as an open GIS gives it the possibility of its application for many environmental analyses purposes. Taking this advantage of *ArcView GIS* and the possibilities of the 3DSkyView Extension into account, one might now incorporate the SVF as a parameter in an urban thermal model, by applying the model in an *ArcView GIS* environment.

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## REFERENCES

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

Batty, Michel; Dodge, Martin; Jiang, Bin; Smith, Andy. (1999) Geographical information systems and urban design, in Stillwell, J.; Geertman, S; Openshaw, S. (eds.) **Geographical Information and Planning**. Berlin, Springer. 43-65.

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**, **Vol. 69, 81-89**. (www.cert.bham.ac.uk/research/urgent/canyongeometry.pdf).

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

CityZoom. (no date) Cityzoom: Ambiente de apoio a decisão em projetos de arqutietura e urbanismo. <http://www.cityzoom.net>

ECOTECT. (no date) Ecotect – Design & Analysis v4 http://www.squ1.com/site.html.

Janosch, U.; Coors, V.; Kretschmer, U. (no date) Applications of 3D-GIS. (http://www.giscience.org/GIScience2000/posters/125-Jasnoch.pdf).

Johnson, G.T.; Watson, I.D. (1984) The determination of view-factors in urban canyons. **Journal of Climate and Applied Meteorology, Vol. 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**, **Vol.1, No.1-4,** 237-254.

Ratti , C.; Di Sabatino, S; Britter, R.; Brown, M.; Caton, F.; Burian, S. (1999) **Analysis of 3-D Urban databases with respect to pollution dispersion for a number of European and American cities.** (www.dmu.dk/AtmosphericEnvironment/ trapos/abstracts/CERC_2.pdf).

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, São Carlos, Brazil.

Steyn, D.G. (1980) The calculation of view factors from fisheye-lens photographs. **Atmosphere-Ocean**, **Vol. 18, No. 3**, 254-258.