

Rodrigues, D.S., L.C.L. Souza, and J.F.G. Mendes, 2004, Enhancing 3DSkyView Extension Performance, In: Van Leeuwen, J.P. and H.J.P. Timmermans (eds.) *Recent Advances in Design & Decision Support Systems in Architecture and Urban Planning*, Dordrecht: Kluwer Academic Publishers, ISBN: 1-4020-2408-8, p. 325-340.

Enhancing 3DSkyView Extension Performance *A Multi-Observer Determination of Sky View Factors*

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Keywords: Sky View Factor, Urban Geometry, GIS Extension, Urban Heat Island.

Abstract: This paper presents a second version of the 3DSkyView extension. The purpose of that extension was to implement a calculation algorithm for assessment and visualization of sky view factors (SVF) by means of tools available in a Geographical Information System (GIS). The sky view factor is a thermal and geometric parameter pointed out in the specialized literature as one of the main causes of urban heat islands. A 3D-GIS is a powerful tool for reaching the goal of this research because it allows the storage, treatment and analysis of tri-dimensional urban data, in addition to a high level of flexibility for incorporating calculation algorithms. The objective in the 3DSkyView extension is to optimize the determination of that factor, not only reducing its demanding calculation and graphical representation time, but also generating a simplified tool for replacing expensive photographic equipment usually applied on this matter. Enhancing functions of *ArcView GIS 3.2*, the first version of that extension showed a very good performance allowing the automatic delineation and determination of SVF. That performance was although limited to a single observer point. The simulation of SVF for several view points in urban canyons was only possible by applying the extension as many times as the number of observers considered. Therefore, this second version was now developed in order to allow simultaneous determination of SVF for many view points. In addition, the 3DSkyView new interface is more flexible, in a way that the user may choose the kind of output wanted (graphical and/or tabular). With this new feature it is then easier to create a continuous SVF map for an entire area.

1. INTRODUCTION

1.1 About the general goals of the tool

The approach of this paper suggests the use of a GIS environment for simulating obstructions that urban canyons can cause to the sky vault. 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. Therefore, the potential of GIS is here explored, showing its potentiality to help not only environment specialists, but also urban architects in deciding shapes and configurations for healthier cities.

In order to achieve this purpose, a tool named 3DSkyView was developed as an extension of a three-dimensional GIS, promoting the calculation and visualization of sky view factors (SVF). The 3DSkyView was conceived in Avenue scripting language in an *ArcView GIS 3.2* software with its *3D Analyst* extension switched on (all ESRI - Environmental Systems Research Institute products).

The first version of that extension (Souza, Rodrigues, et al., 2003) showed a very good performance allowing the automatic delineation and determination of SVF. That was, although, limited to a single observer point. The simulation of SVF for several view points in urban canyons was only possible by applying the extension as many times as the number of observers considered. Enhancing the performance of that tool, in this paper a second release of it is presented. This second version allows simultaneous determination of SVF for many view points. In addition, the 3DSkyView new interface is more flexible, in a way that the user may choose the kind of output wanted (graphical or tabular). With these new features it is then easier to create a continuous SVF map for an entire area.

1.2 Defining Sky View Factors (SVF)

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 parameterization 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. As once studied by Steyn (1980), Oke (1981), Johnson and Watson (1984), Barring, Mattsson, et al. (1985), Souza (1996), Ratti and Richens (1999), Chapman (2000), and

Chapman, Thornes, et al. (2001), the SVF is one of the main causes of the urban heat island phenomenon, therefore required as a parameter for modelling it.

As the sky usually presents lower temperatures than the Earth surface, it has an important role on the energy balance. In the process of the Earth heating loss and its consequent temperature reduction, the sky is an element that receives the long wave radiation from Earth surface. Therefore, the urban radiation loss has a straight relationship with the obstruction buildings or any other urban element can cause to the sky, when considering an Earth viewing point. Long waves are not only trapped by the warm urban surfaces during the day, but also released into the cold sky at night. So, the geometry of urban surfaces influences the radiation exchange between the Earth and the sky.

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 demanding. 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.

A more simplified method was although developed and automatized by Souza, Rodrigues, et al. (2003) in the 3DSkyView extension, whose principles are presented in the next section.

2. PRINCIPLES OF THE 3DSKYVIEW EXTENSION

The issue of SVF lies on 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 very useful. 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 hemispherical 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 onto the equatorial plane, creating a stereonet (Figure 2). By 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, determining their ratio (i.e., the SVF).

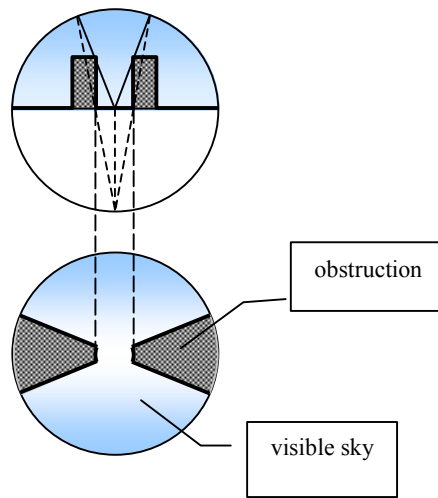


Figure 1. Stereographic Projection

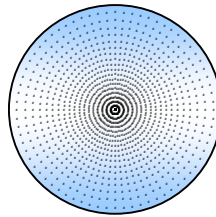


Figure 2. Stereonet

This method of calculation is automatic in the 3DSkyView extension. In practical terms, the aim of the 3DSkyView is to identify a new coordinate system for the tri-dimensional urban elements, so 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 at the urban canyon level. 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.

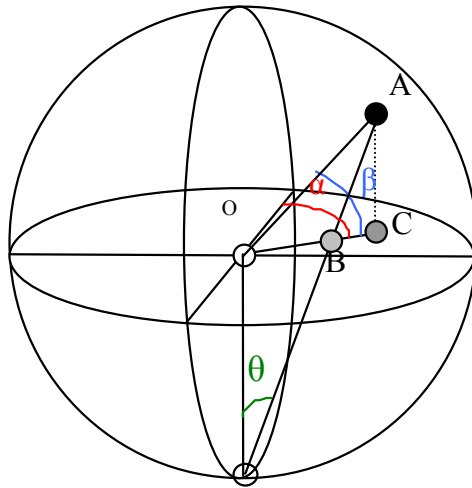


Figure 3. Important angles in the stereographic projection determination

The first one is the horizontal angle α created between the viewer North-South axes, on viewer horizontal plane, and the point of interest. The second one is the vertical angle β between the viewer plane and the point of interest. And the third one is the Nadir vanishing point angle θ between the vertical plane that contains the Nadir point and the line projected from the point of interest to the vanishing point. 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 1) 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.

$$\theta = \frac{90 - \beta}{2} \quad (1)$$

The new coordinates can then be expressed by Equations 2 and 3, which define the new coordinate system on a stereographic projection, where r is the radius adopted for the projection. Here, the 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 0° , while the same angle for trigonometric calculation corresponds to East side. This rotation is the reason for the subtraction of α value from 90° in Equations 2 and 3.

$$x = \cos(90 - \alpha) \cdot r \cdot \tan \theta \quad (2)$$

$$y = \sin(90 - \alpha) \cdot r \cdot \tan \theta \quad (3)$$

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 4, 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.

$$\varphi = \frac{q}{Q} \quad (4)$$

The simulation process of the 3DSkyView 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 identified;
- According to the observer coordinates, the XY coordinates of the polygons are transformed into a stereographic projection. As a side product, they are also transformed into an orthographic projection;
- 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 netpoint of the whole sky stereonet is compared to each one of these new themes, allowing the calculation of their areas and therefore the sky view factor;
- A scene simulating a projection of the urban canyon on the hemisphere is presented in a 3D environment.

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 also generated in that GIS environment.

In Figure 4, the user interface of the first 3DSkyView version is presented.

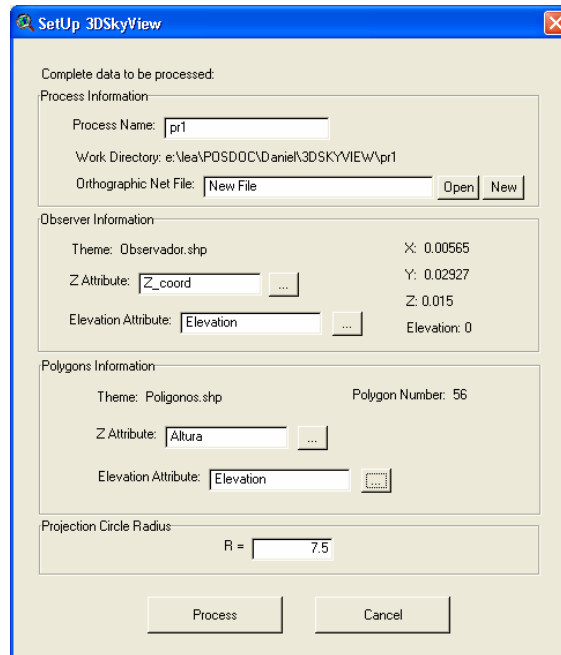


Figure 4. User interface of the 3DSkyView first version

3. 3DSKYVIEW RELEASE 2

3.1 Description and Options

Here the potentiality of the second 3DSkyView version is highlighted, demonstrating its advantages in relation to the first version. The principles of that original version in determining SVF and presented in the previous section are exactly the same. However, the ability of applying the algorithm in a simultaneous and automatic way for multi-observer points is unique. This is the main feature of version 2. The development of this new capability was the aim of the whole process now implemented. Furthermore, in version 2 the simulation time has also been taken care of.

The new users' interface presented in Figure 5 has six input data groups so that the process can be started. They are the process information,

orthographic net data, information about the observer points, polygons information, radius of the circle projection, and the desired outputs.

Figure 5. User Interface of 3DSkyView version 2

The process information refers to the name the user designates the process. The directory, where the resulting data (tables, shapefiles) will be stored, appears automatically next to that field.

For the generation of the skynet (the orthonet) created in this calculation, the user must supply the information about the increment of alpha and beta angles. The values of this increment have influence on the 3D model resolution. The lower the increment, the better the resolution shapes.

As the user should select both, the theme (layer) containing the observer points and the buildings (polygons) theme before running the routine, the software identifies the number of observers and the name of those themes. The observer information group requires the user identification of input data fields in the table of contents of the observers theme. Therefore, the fields on the input data table must include a unique identifier for each observer point. Also the height of the buildings and their elevations (contour line levels) are fields that ought to be available on that table of contents. The identifier will be then associated to the resulting data. For the polygons information group, these requirements are the same, except for the identifier field, which is useless here.

The projection circle radius group allows the user to choose a radius for the graphical representation of the SVF in stereographic and orthographic projections.

At last, the outputs group highlights the flexibility of this new version in allowing the user to make choices of outputs. That means that the user can optimize the time of simulation getting only the outputs of interest. (Note: the interface of 3DSkyView version 2 presented in Figure 6 does not yet allow the generation of the 3D model as a result because this option is still under construction).

These input data, followed by the click on the *Process* button, starts the process without any further user intervention.

The user' *outputs* selection is one of the advantages of version 2. It makes possible, for example, to use the extension only to get tabular results, without the graphical outputs. If the user selects only the *SVF Table* option that will create a table as shown in Figure 6. By means of the identifier number, its structure adds to each observer point the values of the sky area, the obstructed area (*CanyonArea*), and the relative area of visible sky (*SVF*).

It is then important to highlight that the simulation time is dependent on the number of observers in the input data. This happens because the final values are stored point by point in the table. This facet assures the availability of partial results, even if there is any sudden interruption on the process.

<i>ObsID</i>	<i>SkyArea</i>	<i>CanyonArea</i>	<i>VisSky</i>	<i>SVF</i>
3236	353.25000	57.68043	295.56957	0.83671
3294	353.25000	97.82636	255.42364	0.72307
3342	353.25000	43.94293	309.30707	0.87560
2586	353.25000	97.82636	255.42364	0.72307
2595	353.25000	115.06223	238.18777	0.67428

Figure 6. Resulting table with sky view factor values

In comparison to the first 3DSkyView version the other results are basically the same. Only for demonstration purposes, a stereographic projection is presented in Figure 7, in which the visible sky area (*Stsky2586.shp*) and the obstructed area (*Stcanon2586.shp*) can be observed. In addition, Figure 8 shows the stereographically projected points that generated both themes of Figure 7.

In other words, this extension now called 3DSkyView2 allows the determination of urban geometry by calculating and representing sky view factors simultaneously viewed from multi-observer points. Thus, as the

outputs are already stored in a GIS software, these data can be handled and plotted to create new databases and maps.

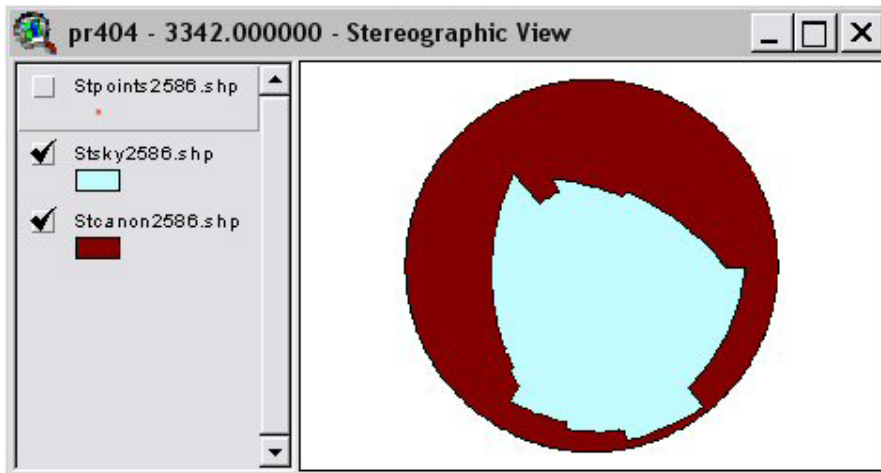


Figure 7. Example of Stereographic Projection

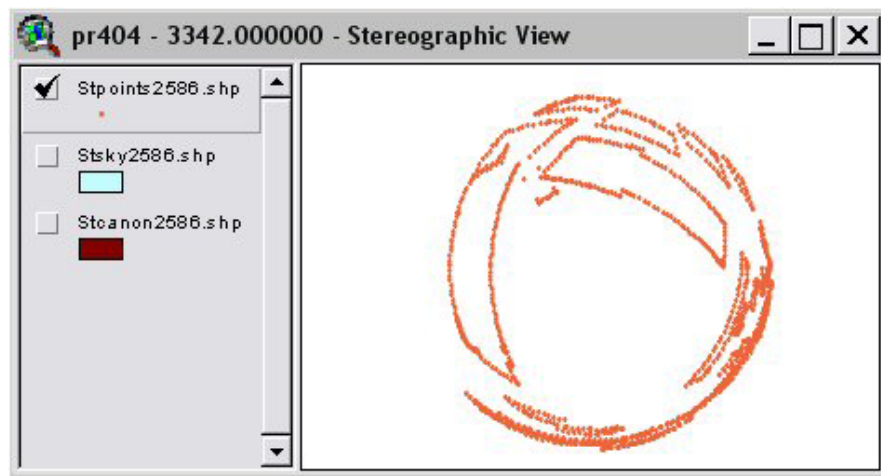


Figure 8. Points stereographically projected that allowed the delineation showed on Figure 7

4. APPLYING AND GETTING RESULTS

An application of the extension has been carried out in order to validate the main feature of 3DSkyView2, which is the multi-observer simultaneous input. This application has taken into account the University of Minho – Campus de Gualtar as the study area. That Campus lays on a peripheral area of the city of Braga, between the east side of the city and the former village of Gualtar. It occupies an area of twelve hectares. The community of the Campus has about 13000 users, with 12000 students, 800 lecturers and 300 staff employees. The buildings support academic activities, congregating Schools and Institutes, three Classroom Complexes and several buildings for services, such as the Library, the Computational Center, the Academic Services, the Sports Complex, and so on. (see Figure 9)



Figure 9. Plan of the University of Minho in Braga – the Gualtar Campus

A campus database was prepared for the simulation process. Two themes (layers) were required as input data, one containing attributes of the observers, and the other containing the attributes of the buildings polygons.

The first theme has been developed by means of a square net with an increment of 5 m, so that a representative cover of observers could be generated. Observer points have then been created on the nodes of this square net. Each node corresponded to an observer point. Finally, all points on this net but outside the Campus area have been removed, as well as those

coincident to existing buildings or with no relevance for the study. It means that remote zones and the boundaries are out of the range of this study. This preparation steps ended up with an observer net of 3502 points, as can be seen in Figure 10. The heights of these observers were constant and corresponded to the pedestrian level of 1.50 m, with their elevation varying according to the correspondent contour line level of their position.

For the polygons representing the buildings, attributes of elevation (ground level) and height have been collected and/or estimated in field. This investigation has brought up the fact that a same building can present different heights. Thus, to have a simulation as nearest to reality as possible, the buildings theme may contain a multi-height building stored as several distinct polygons of different heights.

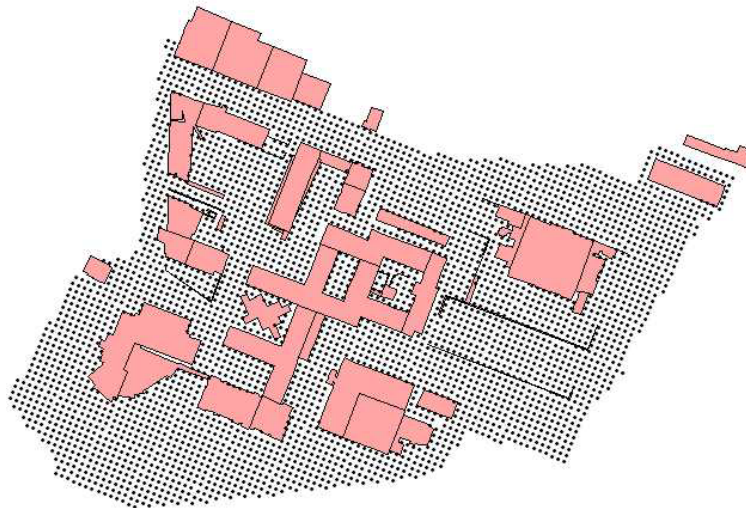


Figure 10. Buildings and Observer points in the Gualtar Campus

Due to the large number of observer points (i.e., 3502) and considering the aim of testing the main facet of version 2, just the SVF table option of the output field was checked in this application. In this way, the routine skips the graphical outputs, which usually represents a significant time-consumption in this method. Nonetheless, for a computer with a 2GHz processing unit the calculation time required for an input of 3205 observer points and 51 building polygons was roughly three days.

Based on the table that resulted from this application, Figure 11 presents the SVF values obtained and plotted in a map. As the results are expressed in percentage values, a continuous scale of colors was applied at

every 10% increment. The colors vary from red to green with red indicating a SVF of 0%, while green indicates a SVF of 100%.



Figure 11. SVF values for all observer point in the Gualtar Campus

An analysis of the results shows that the SVF in this University Campus have high values, pointing out that the distances between buildings are in general well planned. Also their number of stocks is low, in a maximum of four floors. In an environmental analysis, this could indicate the high possibility of solar and natural day lighting access, as well as a high radiation heat exchange. The whole situation contributes to the user thermal and lighting comfort in the Campus. Lower values are although also noticeable. They correspond to the influence of the cover of the pedestrian path structure that links buildings (in the oldest part of the Campus).

For a future investigation, an evaluation of the Campus performance that integrates environmental parameters as solar access, day lighting, sound levels, air temperatures, surface temperatures and radiant temperatures could use the SVF as an environmental quality indicator. In other words, besides evaluating an actual situation this tool can help on future decisions and in predicting the impact of new buildings on sky view factors, before any actual site intervention on the Campus.

Here it is important to highlight that the SVF values plotted in a map help the visualization and create a proper database for integrating other environmental factors. All new information get by the use of this extension is generated in GIS software. Then, a continuing surface of SVF values

based on the resulting table is an easy task to handle. This is what has been done and presented in Figure 12.

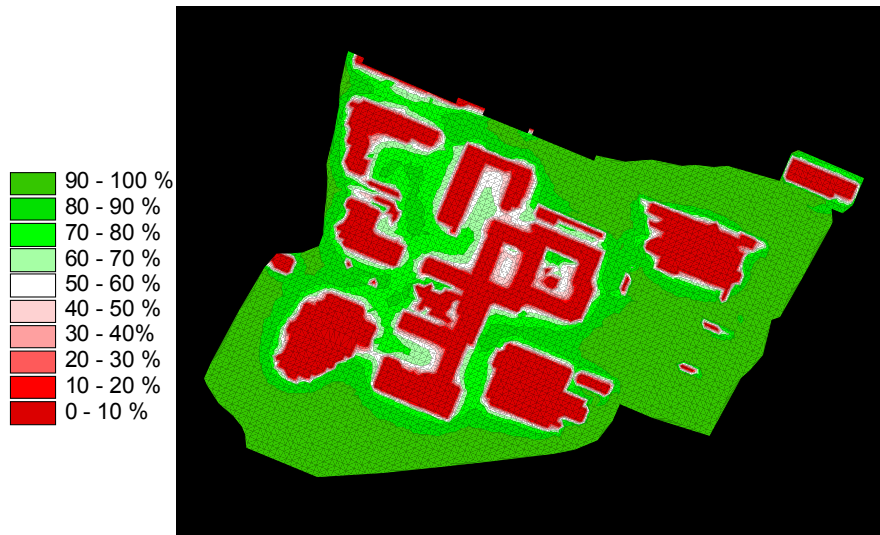


Figure 12. Continuous SVF surface of the Gualtar Campus

On the other hand, also important is the fact not mentioned before that the extension presents a limitation. Considering the inherent performance of the ArcView 3.2, the developed routine does not allow a good calculation and representation of trees or any urban element that should be represented by polygon with bottom section plans narrower than the top plans. These kinds of polygons (or buildings) are right now considered as elements with homogeneous section plans, which are simulated by their largest section. Consequently, for places with this kind of feature SVF values lower than the real ones are determined by running 3DSkyView2. On the contrary, when polygons have larger sections on their lower parts than on their upper parts, this is not verified. As a consequence, for this application on the University Campus the presence of trees was ignored.

5. CONCLUSIONS

The 3DSkyView2 integrated to other tools is a powerful software for a decision making process focusing on environmental aspects.

Both versions of 3DSkyView emphasize the potential of GIS as an important supporting tool in urban thermal analysis. Specifically for this new

extension, the automatic determination of sky view factors for several observers simultaneously is its main point. Before, with the first version, it was only possible to do that by running the extension as many times as the number of observers considered. Now, the data are presented in a unique table that associates the results for each observer.

For the application here conducted on a University Campus, the tool demonstrated its ability and potentiality as a decision support tool. Adopting a dense net with an increment of 5 meters it was possible to extrapolate an analysis from an individual point of view to a general analysis of the whole Campus.

Future efforts are being directed to new outputs, such as solar diagrams or integrating ground level contour lines as part of the scenarios. The latter could reduce the time demanded to prepare the input data.

Furthermore, the software *ArcView GIS 3.2* itself has offered some limitations during the development of the extension and, moreover, there is already another version for this software. This new family, now *ArcView 8.x* and *9.x*, does not apply any more the *Avenue* programming language. That implies that a translation to the actual code of Visual-Basic for Applications should be studied in the near future in order to make the extensions also available to the more recent versions of *Arcview*.

ACKNOWLEDGEMENTS

The authors would like to demonstrate their gratitude to the Brazilian agencies CAPES (Post-Graduate Federal Agency), FAPESP (Foundation for the Promotion of Science of the State of São Paulo), CNPq (Brazilian National Council for Scientific and Technological Development), and FUNDUNESP (Foundation for the Development of the State University of São Paulo), and to the Portuguese agency GRICES (Directorate General in the Ministry of Science and Higher Education) for their cooperation in different phases of this research.

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