SKY VIEW FACTORS ESTIMATION USING A 3D-GIS EXTENSION

Léa C.L.Souza,[1], Daniel S. Rodrigues[2], and José F.G. Mendes[2]
[1]São Paulo State University, Bauru, Brazil
[2]University of Minho, Braga, Portugal

ABSTRACT

The sky view factor indicates the relationship between the visible area of the sky and the area covered by urban structures. A method of sky view factors (SVF) estimation for urban analysis was developed and implemented in a Geographical Information System (GIS). In order to validate this tool, this paper presents a comparison of actual SVF with the results obtained by simulating the SVF in particular areas of a medium sized city with the developed tool. The simulation with this tool pointed out many advantages, such as: reliability; flexibility and ability to predict sky view factors in future scenarios.

INTRODUCTION

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 urban street canyon, its radiation budget depends on thermal characteristics of materials and 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 less a surface has visibility to the sky, the slower its cooling ability. Therefore, a thermal parameter called sky view factor (SVF) is one of the main heat island causes. Heat islands present their highest intensity in specific times of the day and they are usually greater in nocturnal than in daytime hours. Urban heat islands have significant influence on cities' energy consumption, however, there are only relatively few works dealing with their relationship. As shown by Santamouris *et al.* (2001) and Williamson and Erell (2001), there is not only a reduction on heating energy consumption, but also an increase on cooling load of buildings related to the spatial distribution of the urban heat island. Hence, this thermal phenomenon cannot be neglected on thermal simulation.

Taking into account those relevant points of the urban thermal environment, a research project named CEU (which in Portuguese stands for "Consumo de Energia Urbano", or Urban Energy Consumption) is being undertaken at the State University of São Paulo in Bauru, Brazil. The CEU Project studies the relevance of urban geometry on the electric energy consumption of medium sized cities, seeking the identification of patterns of urban energy consumption for urban planning proposals. Moreover, the project works in collaboration with another research effort conducted by Silva (2003), which deals with the issue of urban sustainability on medium-sized Brazilian and Portuguese cities (The Urban Sustainability Project). Considering the usual technological limitations of countries in the same stage of development as that of Brazil, CEU Project steps include the development, improvement and application of planning supporting tools, (ST-Module), as shown in Figure 1. One of the main contributions to the Urban Sustainability Project in this case is the identification of common urban environmental indicators for small and medium-sized cities of both countries. In the present stage of the research, a tool that allows an easy and quick way of calculating and representing sky view factors has been created under the CEU Project framework, as described by Souza et al. (2003). That tool, called 3DSkyView Extension, is mainly an algorithm written in *Avenue* to work with *ArcView GIS 3.2* and its *3D Analyst* extension switched on. That tool transforms coordinates of polygons into stereographic and orthographic coordinates to allow sky view factors estimation. As such, it represents an innovation created by the authors, what is here evaluated.

As a result of the ST-Module, the 3DSkyView Extension was developed by researchers of the São Paulo State University in Bauru, Brazil, and of the University of Minho in Braga, Portugal. After several tests with hypothetical examples, the tool described by Souza *et al.* (2003) is here applied in a real city scenario. Its potential as a sky view factor simulator is now evaluated under those conditions.

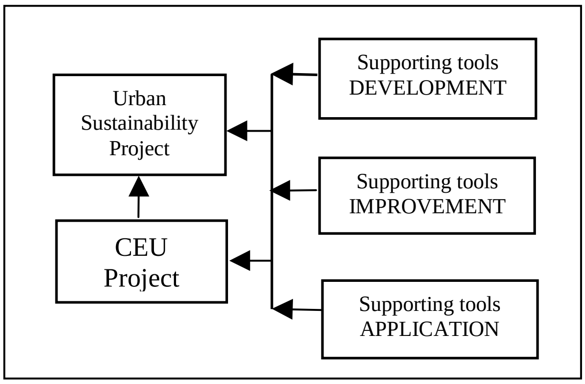


Figure 1 – CEU Project overview

After a brief comment about the SVF, this paper presents the approach used for the development of the 3DSkyView Extension and its context on a 3D-GIS environment. Then, the extension is applied to urban canyons in the city of Braga-Portugal. An overall analysis of the tool as a sky view factor simulator is presented. Finally, its flexibility and advantages are indicated, showing its possibilities to be integrated to other important tools for assessing buildings thermal performance.

THE SKY VIEW FACTOR PARAMETER

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 a building 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. 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 *et al.* (1985), 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, hence 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 plan surface and that available 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 sky view factor from the streets to the sky can be used to predict the maximum heat island intensity using a well-known formula by Oke (1981).

METHODOLOGY FOR SVF ASSESSMENT

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.

Besides the facts above mentioned, nowadays the use of Geographical Information Systems (GIS) as a tool to understand and to 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. The approach of this research suggests the use of a GIS environment for simulating a spatial representation of the urban canyons obstructions to sky vault, in place of many other high cost-equipment methods for determining Sky View Factors (SVF). The 3DSkyView extension, which is an outcome of the ST-Module presented in Figure 1, has the purpose of replacing 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].

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 2. In this way

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

any point on the sphere is projected into the circle representing the sky vault on the plane projection.

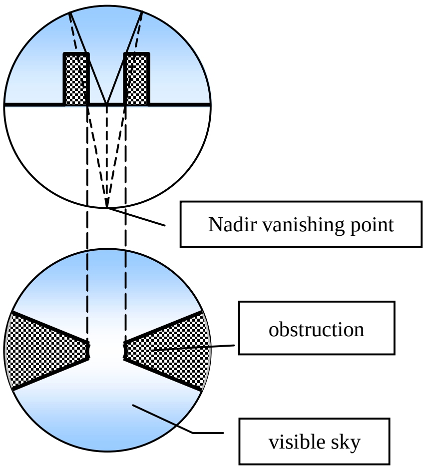


Figure 2 - Stereographic projection of an urban canyon

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 3). By overlaying this stereonet on the equatorial plan 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).

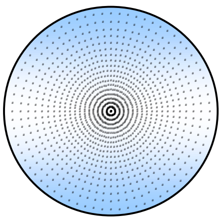


Figure 3 - Stereonet on equatorial plan

In practical terms, the main task 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.

3DSKYVIEW SIMULATION

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 the reflection 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 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.

Figure 4 – 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

The user interface was developed to be easy-to-use by architects, climatologists and engineers, as can be seen in Figure 5. Once the user is familiar to 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.

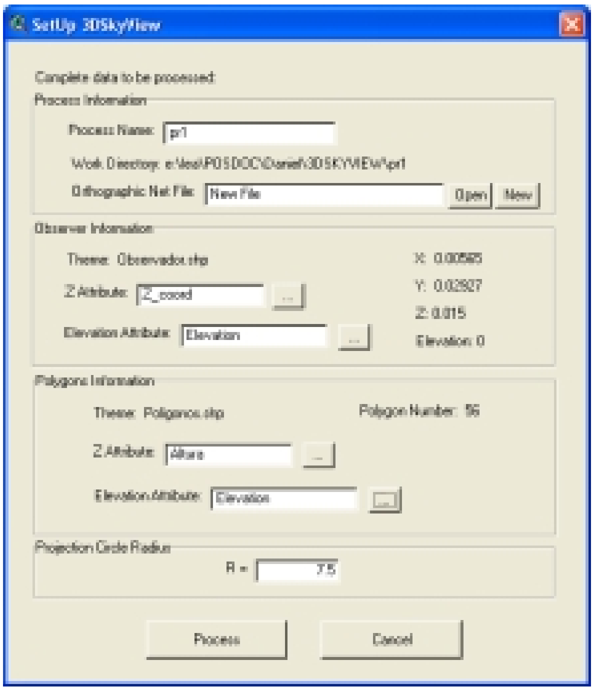


Figure 5 - User interface of the 3DSkyView

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'. These results are exemplified from Figure 6 to Figure 8 and Table 2.

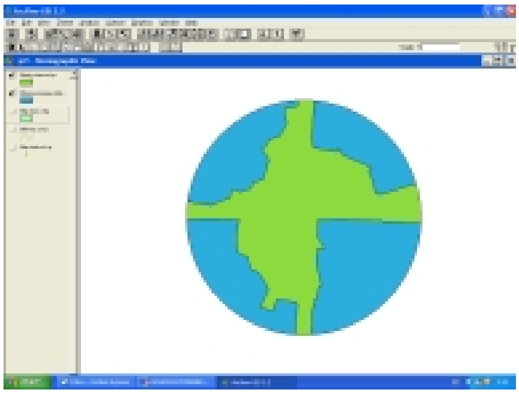


Figure 6 – 2D Scene on Stereographic Projection

In Figure 6 and Figure 7 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.

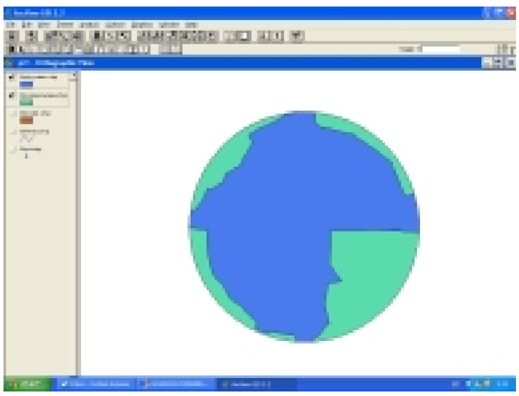


Figure 7 – 2D Scene on Orthographic Projection

Table 2 – SVF value for an urban canyon

SkyArea	CanyonArea	VisiSky	SVF
353.2500	118.9872	234.2627	0.66316

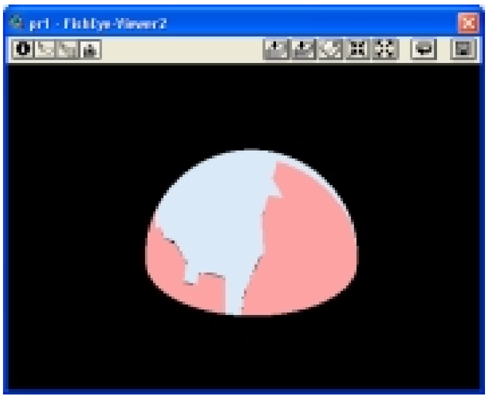


Figure 8 – 'Fish-eye' 3D Scene

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.

EXPERIMENT CONDITIONS

After several tests with hypothetical examples, an experimental survey to collect true sky view factors data was undertaken, as presented in this paper. Central urban canyons in the city of Braga-Portugal were selected as the study area. A comparison of simulated sky view factors and those field data was performed, in order to evaluate the 3DSkyView extension results.

Sample plans containing observer and buildings of these urban canyons are shown from Figure 9 to 12. These correspond to the shapefiles used to start the simulation.

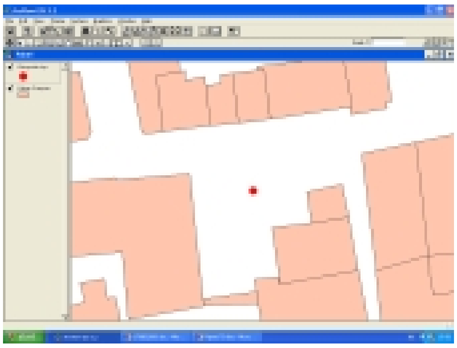


Figure 9 – Sample plan 1

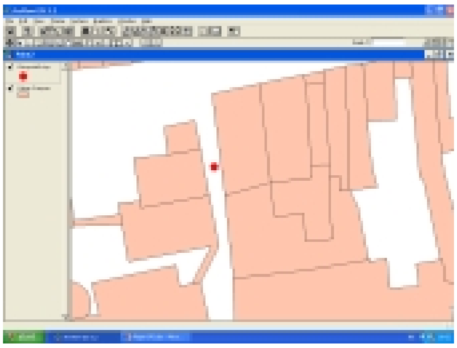


Figure 10 – Sample plan 2

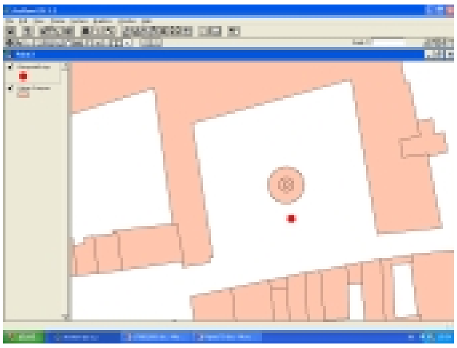


Figure 11 – Sample plan 3

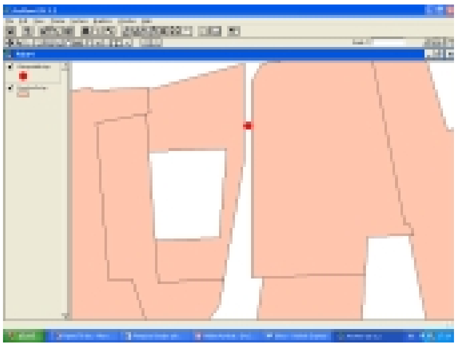


Figure 12 – Sample plan 4

The point highlighted in the centre of the plan is the observer position. For all urban canyons, the observer position was placed on a height of 1 m above ground, from which the elevation level was also taken for each position.

3DSKYVIEW EVALUATION

As aforementioned, both stereographic and orthographic projections are generated by 3DSkyView extension. These projections for sample plan 1 are shown in figure 13. As expected, the orthographic projection gives an opener image than the stereographic one. This is an inherent characteristic of these kinds of projections. As it is well known, both projections present areas and form distortions near the horizon line, but for the stereographic projection this distortion is slightly reduced. Thus, there is for orthographic projection a poor resolution for buildings situated in low altitudes in relation to the observer position. This happens because the altitudes of equal increments are spaced very close together near the horizon and widely spaced nearer the zenith in this kind of projection.

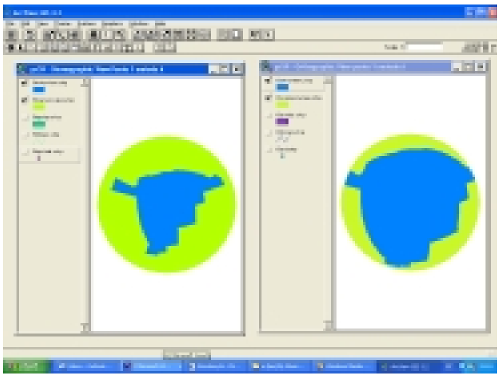


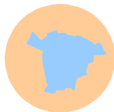
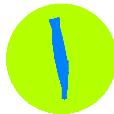
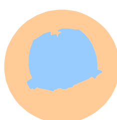
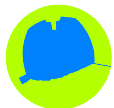
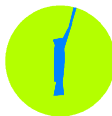
Figure 13 – Stereographic and Orthographic Projections Results for Sample plan 1

The replacement of fish-eye lens photographs, combined with its ability of automatically delineating the visible sky and calculating SVF values is the most important characteristic of the 3DSkyView Extension. One can not forget also its didactical potentiality for architectural purposes. Its resulting 3D fish-eye scene (already shown in Figure 8) is a new way of learning and understanding how the whole scenario takes place.

Despite those qualitative remarks, a quantitative comparison between real and simulated scenarios was carried out. Fish-eye photos of some urban canyons were taken, so that their geometry could be visualized. These pictures were then delineated to highlight the boundaries between visible sky and buildings. The estimation of the SVF values was done with the graphical method suggested by Johnson & Watson (1984). In this way, not only the shape of the urban canyons in a 2D representation could be evaluated, but also the value of SVF. Table 3 establishes a comparison between field values and software estimation values. Here is important to highlight, however, that field values for SVF are always a sort of estimation.The available methods are based on some approximation or simplification of the urban canyon geometry, as one can realize on the detailed description presented by Johnson & Watson (1984).

According to Table 3 it is possible to state that the 3DSkyView has a very good performance, both for SVF values as well as for 2D Scene representation. There were minor differences between the simulated SVF values and the estimated ones. The 3DSkyView is a spatial analysis method with only few simplifications on urban polygons representation, while the Johnson & Watson graphical estimation assumes "ideal canyons", which are barely encountered in real world situations. Although both methods are simplified, the 3DSkyView apparently presents more accurate results than the other method.

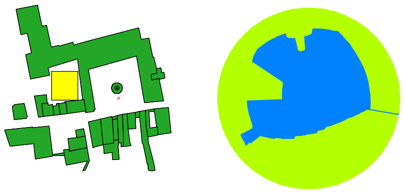
Table 3 – Comparison of field values and software estimation values

Case Nr.	SVF Field Data	3DSky View SVF	Actual urban geometry	3DSkyView 2D Stereographic Scene
1	0.59	0.62		
2	0.24	0.28		
3	0.67	0.70		
4	0.19	0.25		

Despite the good performance shown here, the 3DSkyView is most adequately used for urban elements with constant horizontal sections or narrower sections in the upper parts. As it assumes a simplification of polygons for the automatic delineation of the sky, the 3DSkyView extension will always consider the upper and largest shape of a polygon as a reference. So, if the shape is larger at the top, this might produce a miscalculation of SVF and a representation of a constant section element instead. That might happen, for example, with urban elements like trees.

Yet on this evaluation one must consider the ability of *ArcView GIS* of being flexible for incorporation of many algorithms on its environment. This enhances the application of the 3DSkyView extension, because the tool results can always be combined with other algorithms. Moreover, in this specific case, it is possible to process the 3DSkyView simulation several times, for different sections and shapes on the urban element. This would create several layers that could be combined on the *ArcView GIS*. Though that would be a repetitive and time consuming task, a better result for these elements could be reached.

Another important contribution of the 3DSkyView is the possibility of incorporating a new, even hypothetical building, on the original scene, so that a future SVF can be previewed. In sample plan 3, for instance, a hypothetical building was located among the actual buildings for SVF simulation (Figure 14).



Sample plan 3 with a new building inserted

SVF = 0,65

Figure 14 – Incorporating a new building on Sample plan 3 scene.

Yet, analysing the results obtained for the 2D projection, the tool represents an important instrument for environmental architects. Its ability to generate both stereographic and orthographic projections allows future combinations with sun-paths and illumination diagrams, which are often applied for thermal and luminous analysis of buildings. This combination is the next step in development to be incorporated to 3DSkyView extension. For instance, in Figure 15, the sun-path diagram for the city of Braga, although not yet automatically built in this version, was generated in stereographic projection. That allows an analysis of urban solar access, when the sun-paths diagram is overlayed to the stereographic projection of an urban canyon. In Figure 15, the points plotted within the urban canyon are the monthly sun position in 1 hour time intervals. Based on that overlaying, it is possible to verify that, for sample plan 3, in most part of the winter season the sun penetration is blocked by buildings.

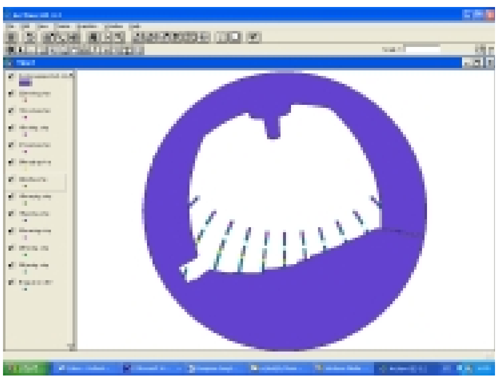


Figure 15 – Stereographic projection of sun-paths on Sample 3 of Braga.

CONCLUSIONS

The main contribution of the 3DSkyView is the automatic delineation of the visible sky. Until now this was usually a hard task, either manually or via image processing determination. Moreover, for urban heat island spatial analysis, the tool may allow direct visualization of urban geometry on many points of a city. That is one of the greatest advantages of working in a GIS environment.

Another important contribution of the tool is the didactical ability in representing the urban canyon reflection on a 3D scene. For tri-dimensional study purposes this is an interesting function that collaborates to better understanding the interactions of urban geometry and climate.

On the other hand, the tool presents a limitation on representing urban elements with different shapes in height. Therefore, the 3DSkyView is most properly applied for constant section elements. However, the GIS environment in which it was developed allows the resulting layers manipulation, which can represent a solution for a better representation of those elements.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the Brazilian agencies CAPES (Post-Graduate Federal Agency), FAPESP (Foundation for the Promotion of Science of the State of São Paulo), and CNPq (Brazilian National Council for Scientific and Technological Development), and to the Portuguese agency ICCTI (International Institute of Scientific and Technological Cooperation), which have supported our efforts on this work.

REFERENCES

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.(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, Davos-Switzerland, March 2000. (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.

Santamouris, M.; Papanikolaou, N.; Livada, I.; Koronakis, I.; Georgakis, C.; Argiriou, A. and Assimakopolous, D.N. (2001), ,,On the impact of urban climate on the energy consumption of buildings”, Solar Energy, 70(3): 201-216.

Silva, A.N.R., (2003) ,,Planejamento Integrado: em busca de desenvolvimento sustentável para cidades de pequeno e médio portes”, Research Report CAPES-ICCTI, Brasil.

Souza, L.C.L.; Rodrigues, D. S; Mendes, J.F.G., (2003). ,,A 3D-GIS extension for sky view factors assessment in urban environment”, Proc. of the 8th International Conference on Computers in Urban Planning and Urban Management, Sendai, 27-29 May, 2003: Japan. (paper awarded with the Sendai Prize for outstanding contributions to the Conference).

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.

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.