Implementing a Geometry-Related Environmental Indicator in a 3D-GIS

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ABSTRACT: This paper highlights the suitability of applying a 3D GIS to analyze geometry-related environmental indicators. The work starts with a discussion and application of a tool developed to identify sky view factors. Called 3DSKYVIEW extension, this tool was produced as part of a research cooperation effort established between Brazil and Portugal to identify common urban environmental indicators for their medium sized cities. The sky view factor (SVF) is a 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 3DSKYVIEW extension is an algorithm developed by applying the software *ArcView GIS*[1] and its *3D Analyst* extension, allowing an automatic delineation of the visible sky and obstructions. The implementation of this tool in a 3D GIS is useful because it allows straight and quick urban geometry analysis from several points of observation. Furthermore, it can be seen as a single environmental indicator of thermal, lighting and acoustical performance of urban areas, as suggested by the exploratory study conducted in a medium-sized Brazilian city and summarized in this paper.

Conference Topic: Methods and Tools for Design Assistance
Keywords: sky view factors, urban geometry, environmental indicators

1. INTRODUCTION

An immediate consequence of the growing environmental, economic and social problems currently experienced by many cities is the urgent need for methods to keep track and to manage the urban growth process. These methods are essential for promoting a sustainable development and for improving the quality of life of urban citizens. The implementation of strategies aiming this goal must be an outcome of research, careful analysis and critique of the current development stage of the cities, based on indicators which are able to take into account the specific context they belong to. Thus, as part of a research cooperation effort established between Brazil and Portugal to identify common urban environmental indicators for their small and medium sized cities, this work carry out a discussion about an specific parameter that could be applied as an urban indicator.

The focus of the present study is the sky view factor (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

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

results from the limits of urban canyons generated by the tri-dimensional characteristics of urban elements and their mutual relationships. This thermal parameter is one of the main causes of urban heat islands, as once studied by [1], [2], [3], [4], [5], [6], [7] and [8].

There are many methods of estimating SVF values, including mathematical models, fisheye-lens photographs analysis, image processing, diagrams or graphical determination. However, these methods are usually time demanding and the calculation of SVF through them is not straightforward. In addition, there is a common problem of these methods, which 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 [7] should 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.

Therefore, in order to enable further studies with the SVF, a quick and effective determination method was required. Looking for a solution to this problem, the authors implemented an easier way of determining sky view factors in a GIS environment. The estimations of SVF produced with the new tool, which was called 3DSkyView Extension, were validated in an experiment carried out in a Portuguese city, as shown in section 2. After that, the tool was applied in an exploratory study in a Brazilian city. The objective of that application was to look for relationships between the SVF and selected urban environmental characteristics.

2 SKY VIEW FACTORS AND GIS

The proposed tool, named 3DSkyVIew, considers the potentiality of GIS to store and handle geometrical data of cities, as discussed next.

2.1 Linking the SVF and 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. Although 3D GIS is a powerful modelling tool, the applications available are still restricted to some areas. Furthermore, the tri-dimensional capability is more often used for esthetical functions than to represent and to visualize scenes.

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 (also in Figure 1). For the stereonet showed in Figure 1, 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.

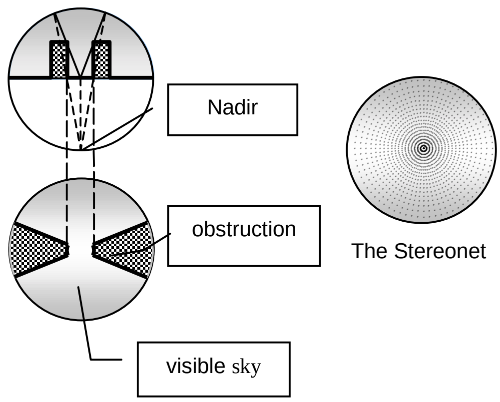


Figure 1: Stereographic Projection of an Urban Canyon and the Stereonet

A 3D GIS is thus a promising tool for such a calculation, since it works as a (X, Y, Z) coordinates database manager.

2.2 About the 3D SkyView extension

The 3DSkyView extension is mainly a tool to calculate sky view factors of urban canyons, which was conceived in *Avenue* scripting language. It works in an environment created by ArcView GIS version 3.2 with its 3D Analyst extension switched on.

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.

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 [1], 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.

$$\varphi = \frac{q}{Q} \qquad [1]$$

2.3 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. 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 user interface was developed to be easy-to-use by architects, climatologists and engineers, as can be seen in Figure 2. 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. The first version of 3DSkyView is available for download at the ESRI site (www.esri.com).

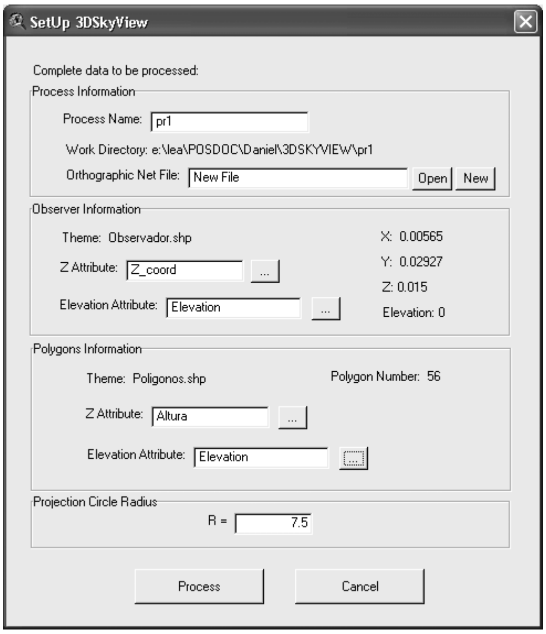


Figure 2: 3DSkyView User Interface

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.

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.

For validating the SVF estimation model, urban canyons in the city of Braga-Portugal were selected as the study area. Sample plans containing the location of the observer and of the buildings of these urban canyons are shown in Figure 3. These correspond to the shapefiles used to start the simulation. The point in the centre of the plans is the observer position. For all urban canyons, the observer was placed on a height of 1 m above ground, point from which the elevation level was also taken for each position.

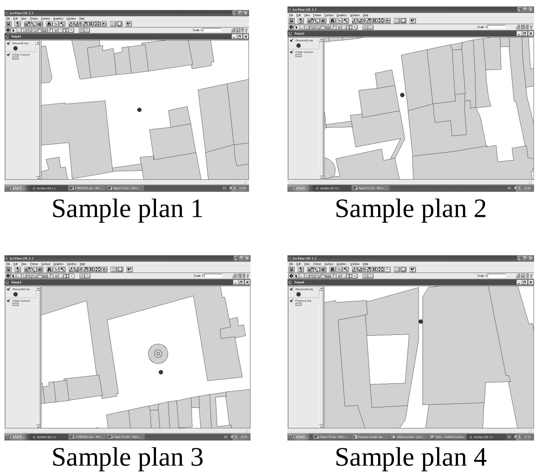


Figure 3: Urban canyons selected in Braga

As aforementioned, both stereographic and orthographic projections are generated by 3DSkyView extension. These projections for sample plan 1 are shown in Figure 4, as an example.

A comparison between real and simulated scenarios was then 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 real values was done with the graphical method suggested by [9]. 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 1 establishes a comparison between field values and software estimation values.

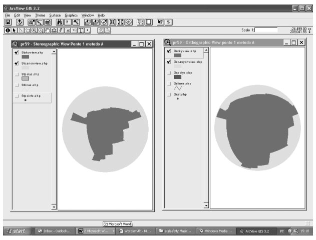
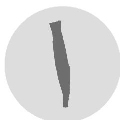
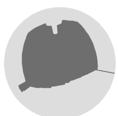


Figure 4: Sample 1 Steregraphic and Orthographic Projections

According to Table 1 results 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 graphical estimation method of [9] assumes “ideal canyons”, which are barely encountered in real world situations. Although both methods are simplified, the 3DSkyView apparently presents the best numerical representation of the actual SVF values.

Table 1: Results obtained for urban canyons in Braga, Portugal

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		

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. In addition, its resulting 3D fish-eye scene (shown in Figure 5) is a new way of learning and understanding how the whole scenario takes place.

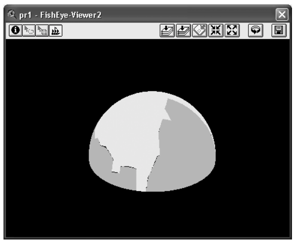


Figure 5: Fish-Eye 3D Scene

3 SVF AS ENVIRONMENTAL INDICATOR: A CASE STUDY IN BRAZIL

For demonstrating the potentiality of the SVF as an environmental indicator at the pedestrian level of an urban canyon, a case study was carried out in São Carlos-SP, a Brazilian medium-sized city.

São Carlos is located in a hilly region at an average altitude of 854 meters, enjoying favourable wind conditions for its topographical position in relation to the surroundings. It is the highest urban area in the region and therefore is a city with a high urban cooling capacity. Its urban area is sprawled between the geographical co-ordinates of 21^{o}57’ and 22^{o}06’ south latitude and 47^{o}50’ and 48^{o}05’ west longitude. Its total urban population is around 180,000 inhabitants.

In order to investigate the relationship of the SVF with the selected environmental parameters, data of air temperature, surface temperature, day-light illuminance and sound pressure level were collected. The points for measurement were selected according to the following criteria for environmental data acquisition:

- The measurement points should represent different sky view factors samples. The samples should include typical values occurring on the urban fabric associated to points situated at the same kind of land use, building typology, neighbourhood and altitude;
- For the comparison of thermal conditions, the points should represent places with a same orientation in relation to sun and wind incidence. Considering that the experiment would focus on surface temperatures, the same kind of surface should occur in all urban canyons under investigation. Also, the measurement equipment should be positioned with the same orientation in relation to sun and wind. In order to guarantee this similarity, the temperature measurements were taken on the surface of concrete poles used for street lighting;
- The day-light measurements should be carried out under the same sky conditions and positioned at the same distance from the wall surfaces of buildings;
- For the acoustic measurements, the points should represent places with similar background noises and vehicle flows. A sound source of reference was also measured at those points. This source was a car with an equivalent sound pressure level (L_{eq}) smaller than 50 dBA when stopped, and 63 dBA when moving in a constant speed of 40 km/h. At first, the

measurements of both reference values were taken at an open area.

Three points were selected for data collection, having sky view factors of 0.75, 0.83, and 0.94. Only streets settled at the east-west axis were selected for investigation. In these streets the north façades of buildings had solar access, while the south façades remained under shadowed conditions. All equipments used for measurements were kept on the shadowed side of the street for avoiding direct sun radiation. The data observed at those points are represented in Figures 6 to 10.

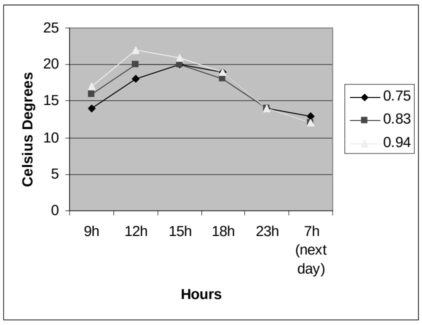


Figure 6: Data of air temperature

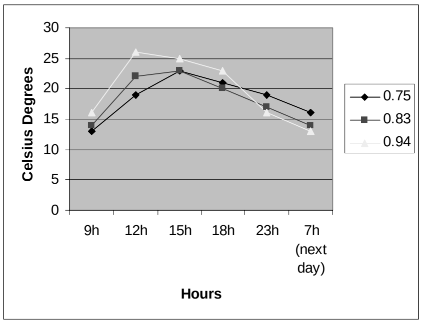


Figure 7: Data of surface temperature

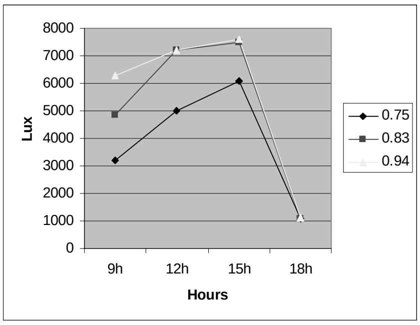


Figure 8: Data of illuminance

As can be seen in Figures 6 to 10 there are some remarkable points to highlight on the results of the exploratory field survey. When comparing the air temperatures collected for the three points it is possible to verify a tendency of two phases in the curve: before 3 p.m. and after 3 p.m. Before 3 p.m. the higher SVF values represent larger solar access and consequently higher air temperatures. After 3 p.m. this behavior begins to reverse, with higher SVF canyons reaching lower temperatures shortly after the sunset. This confirms the urban heat island development, as already widely explored in the literature. In practice, although, this relationship between air temperature and sky view factors is not always easily proved as it was here possible, since many times the air temperature are ruled by other atmospheric dynamics than the simple urban geometry influence.

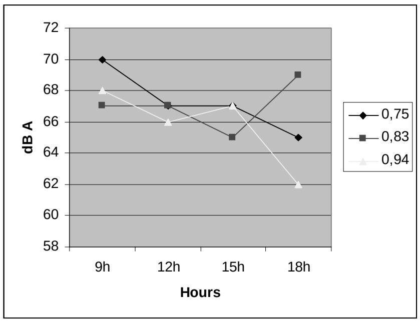


Figure 9: Data of sound pressure level for an average vehicle flow of 10 to 12 cars per minute

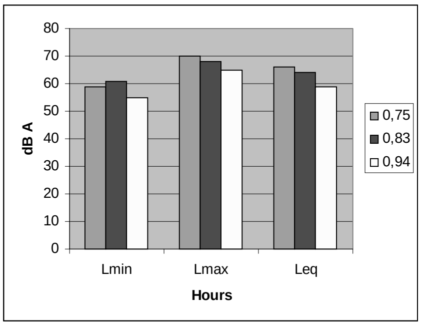


Figure 10: Data of sound pressure level for a selected sound source (i.e., a car moving at 40 km/h)

Yet, for surfaces temperature the inverse is true, as it is often possible to identify the effect of view factors on the storage and cooling capacities of buildings. This was also the case of the results here reached. As one can see, again there were two phases on the curves presented in Figure 7. The higher surface temperatures were directly related to higher SVF values before 3 p.m. After that the trend began to reverse and the cooling ability of the surfaces was reduced for the smaller SVF values surfaces.

Apart from the common application of the SVF as a thermal urban indicator, there is also its influence on the day-lighting availability at a place. Usually day-lighting is studied for internal lighting performance of rooms, many times by means of simulation models. But light at the pedestrian urban environment is one of the main characteristics that create the urban ambience. As the sky is a natural light source during day time, the higher an urban canyon has visibility to the sky, the greater the illuminance of a point within the urban canyon.

For the day-lighting results obtained in São Carlos urban canyons, Figure 8 indicates that there were significant differences of illuminance in relation to the sky view factor values. Considering the clear sky conditions under which the measurements were carried out, the lowest sky view factor urban canyon represented the smallest availability of natural light for the pedestrian level. Therefore, this is another factor that underlines the importance of sky view factors as an urban environmental indicator.

Finally, integrating another important environmental parameter for pedestrian ambience and urban quality, the acoustics characteristics of an urban canyon should not be neglected. Therefore, this work also looked for a relationship between sky view factors and sound level pressure. This hypothesis is based on the fact that lower sky view factors reveals larger and taller surfaces of buildings, which would consequently generate more sound reflection and sound intensity to the pedestrian environment.

Although there is yet a need to increase the number of observations on this sound issue before drawing any definitive conclusion, the preliminary results pointed out on Figure 9 and 10 were quite interesting.

In Figure 9 it is possible to observe the sound pressure level at different times of the day for the three points analyzed. Here, although not having an evenly distribution of the curves, the urban canyon with a sky view factor of 0.75 always presented the highest sound levels, except for the 6 p.m. data. As there is a high variability of car types passing by, and consequently different noise sources happen to be measured, another kind of analysis was necessary. That is what Figure 10 presents. Considering only a specific car as a known noise source passing alone by those canyons on a very low vehicle flow conditions observed in a holiday, the minimum, the maximum and the equivalent sound pressure level were registered. Again the values in the graph showed that for urban canyons with lower sky view factors, higher sound pressure levels were observed.

4 CONCLUSIONS

The 3DSkyView extension generates a suitable environment for urban solar and lighting access analysis, simplifying the methods usually applied for the determination of sky view factors. 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.

Based on the exploratory investigation here conducted, there are enough reasons to believe that the SVF can be taken as a single indicator of many environmental parameters. Further research is undoubtedly needed to confirm this hypothesis, but that was now made easy by the 3DSkyView extension for estimating the SVF values discussed here.

ACKNOWLEDGEMENT

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), CNPq (Brazilian National Council for Scientific and Technological Development), and FUNDUNESP (Foundation for the Development of UNESP), and to the Portuguese agency ICCTI (International Institute of Scientific and Technological Cooperation).

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