Extracting urban environment quality indicators using georeferenciated data and image processing techniques

Cláudio Carneiro[1], Eugenio Morello[2], Gilles Desthieux[3], François Golay[1]

[1] Geographical Information Systems Laboratory (LASIG), Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland
claudio.carneiro@epfl.ch; francois.golay@epfl.ch
[2] Laboratorio di Simulazione Urbana, DIAP, Politecnico di Milano, Milano, IT
eugenio.morello@polimi.it
[3] Haute Ecole du Paysage, d'Ingénierie et d'Architecture (HEPIA), University of Applied Sciences Western Switzerland (HES-SO)
gilles.desthieux@leea.ch

1. INTRODUCTION

The representation and visualization of more or less detailed 3-D urban scenes can be done using different techniques, from those more conventional (for example, photogrammetry) to the most recent ones (laser scanning). However, the use and application of this kind of data for the study of urban environment quality (UEQ) remains unsettled for the analysis and planning of urban developments.

Several different types of analysis concerning urban morphology, such as solar accessibility, heat transfer and visibility analysis are introduced in this work. The applied methodology is directly related to the extraction of these indicators which are calculated according to the available 2-D and 3-D georeferenciated urban data. The work here presented is part of a larger jointly project between many researchers, experts and end-users around Europe which integrates cross-disciplinary competences, like remote sensing, GIS, image processing, energy, environment, architecture and urban design.

The proposed tools are innovative solutions to apply complex spatial analysis operations to the urban scale, while existing tools on the market are generally implemented at the scale of architecture (buildings as single objects) or at the land use scale.

The ultimate scope of this research is to provide a set of tools finalized to the environmental assessment of cities, thus providing valuable feedback to urban designers and planners. Considering this target, it is very important to scrutinize the right modalities to present results, both in terms of quantifiable indicators and visual representations. On the one hand, quantitative indicators must be significant at the scale of the neighbourhood or city, and should be used for comparative studies among different design schemes; on the other hand, visualizations have to be immediately comprehensive also to the wider audience, thus trying to capture and translate the indicators on the maps in the most efficient way.

2. DATA SOURCES USED

Due to its highest level of accuracy, the use of detailed 2-D vectorial building outlines and, when available, the 2-D projection of building roof outlines existing in 3-D city models (stored in GIS databases) is crucial in order to classify LIDAR points contained within each building and to improve the final result of the different 2.5-DUSM (Digital Urban Surface Model) interpolated and constructed.

According to the algorithm initially presented by Axelsson (1999), raw LIDAR data points corresponding to terrain are classified. Hence, the use of a hybrid approach from raw LIDAR data contained within vector building outlines and roof prints allows respectively, to interpolate two independent 2.5-DUSM:

- 2.5-D urban surface model (DUSM) of building outlines;
- 2.5-D urban surface model (DUSM) of building roofs;

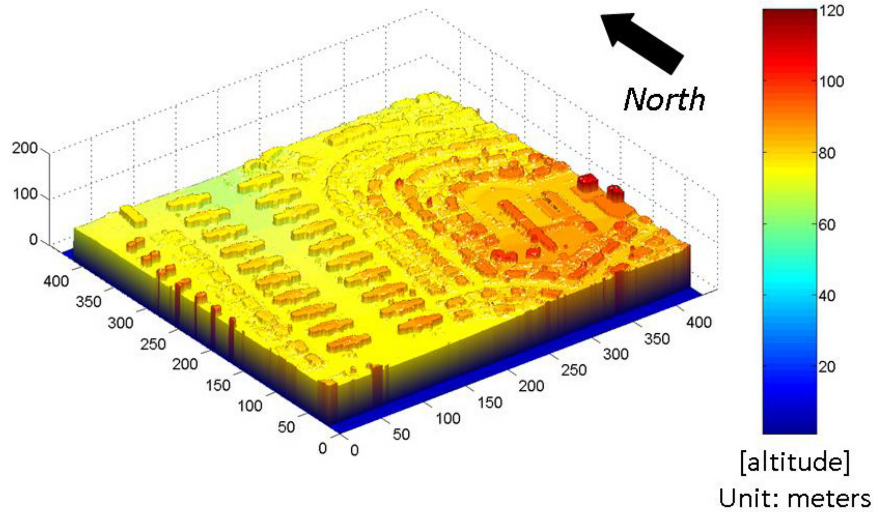

Figure 1. The 2.5-DUSM of a neighborhood of the city of Lisbon, derived from LIDAR data (pixel size 1m X 1m)

Finally, both 2.5-DUSM are independently used for the extraction of several UEQ indicators, such as presented thereafter, in different pilot areas and cities (Geneva, Lausanne, Lisbon, New York, Milano).

3. EXTRACTING URBAN ENVIRONMENT QUALITY (UEQ) INDICATORS

3.1 Solar radiation on building facades and building roofs

These indicators address analysis on solar radiation incident on building roofs and building facades of the urban built environment.

The technique used for the calculation of analysis outputs related to solar radiation is based on the image processing of the 2.5-D DUSM and other input masks that are interpreted as raster images (height values from the DUSM, slope, orientation, roof prints and building and facade labels).

With regards to solar radiation analysis solar geometry formulae allow the derivation of both the beam and the diffuse components of hourly radiations, based on irradiance statistical values for a specific location, for every orientation and inclination of surface starting from the previous mentioned inputs. The shadow casting routine first introduced by Ratti and Richens (2004) is applied to the input images and is used to detect which pixels on roofs and facades are in shadow (cast from buildings or trees in the surrounding environment) and which collect direct sunlight. On this basis, we can assign the global incident solar radiation calculated in W or J /m² for various times scales (hour, aggregation by day, month or year) on facades and roofs.

When roof sections are available (for example, in Geneva), yearly irradiation values (KWh/m2) are aggregated on each roof section to highlight in a synthetic representation which are suitable surfaces for installing solar collectors (Carneiro et al., 2009).

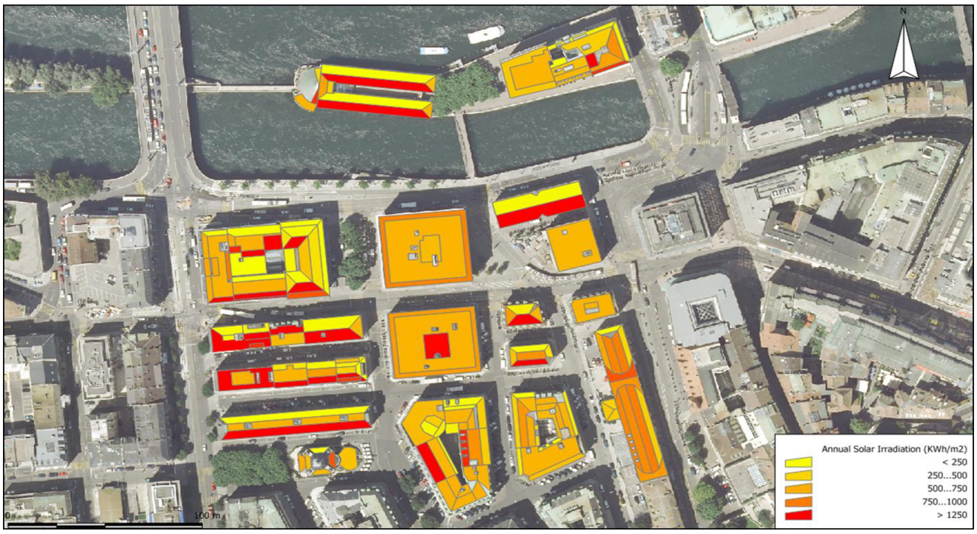

Figure 2. Annual solar irradiation (KWh/m^2) by building roofs' sections for a neighborhood (pilot zone) of the city of Geneva.

3.2 Morphological properties of buildings

Considering the image processing techniques described above in section 2, morphological properties of buildings can be calculated (Carneiro et al., 2010). Using the 2.5-DUSM of building roofs, areas of roofs can be calculated and by means of the 2.5-DUSM of building outlines, areas of facades and volumes can also be calculated. Other minor indicators can be then derived:

- General morphological indicators: the total built floor area considering all storey (average height of 3m); the mean height of buildings on the site, total area of roofs (for solar collectors purpose for instance)
- Derived indicators of urban density, as follows: the built volume on the considered urban area (m3/m2); the ground occupation index, i.e. the covered area to the urban area ratio (m2/m2); the floor area ratio (FAR) (m2/m2).

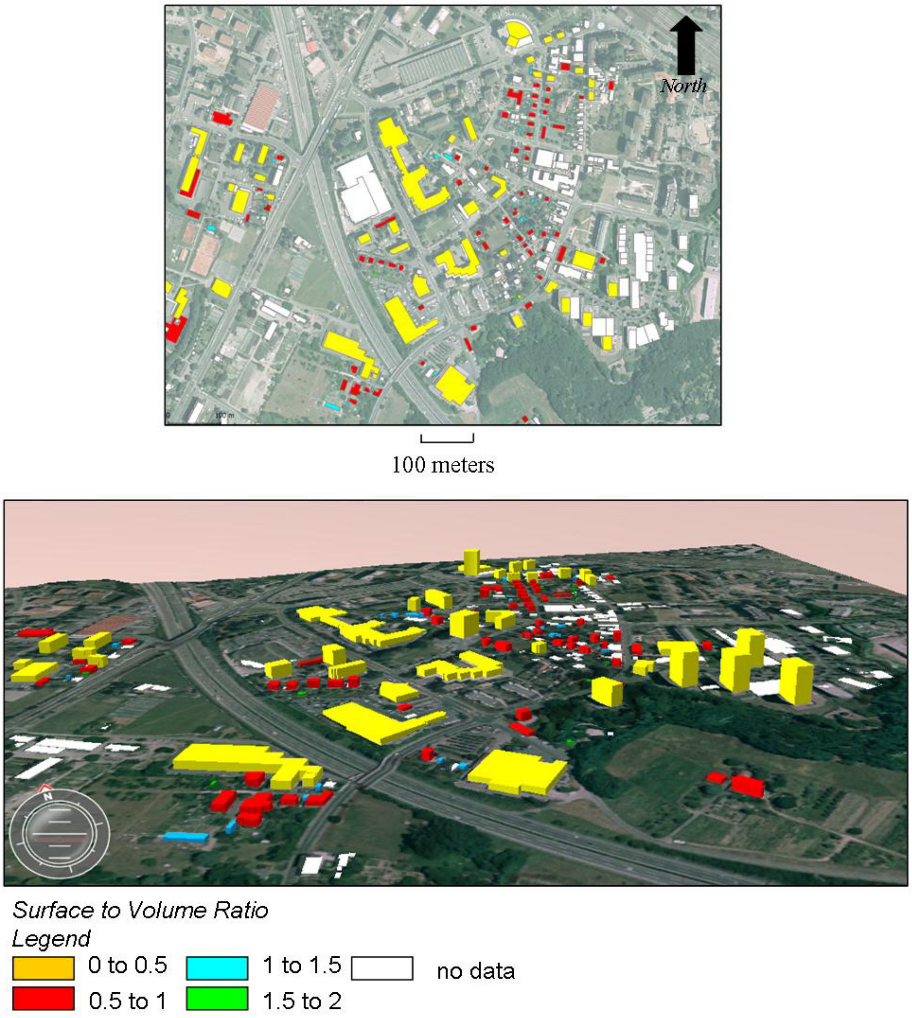

Figure 3. Two maps illustrating the surface to volume ratios visualized in a 2-D (image above) and a 3-D (image below) representation for a neighborhood (pilot zone) of the city of Lausanne.

3.3 Visibility analysis on the urban fabric

The visibility analysis at the urban scale aims to produce maps and qualitative indications about the visual experience through open spaces in the city. We refer to the concept of the isovist, as introduced above in the introduction. All isovists here presented are calculated using the 2.5-DUSM of building outlines plus vegetation higher than 2 meters.

Isovists can be visualized through different modalities (Morello, Ratti, 2009):

a) 2-D isovist maps.

b) A sequence of 2-D isovists, such as the representation of "a walk through a number of steps".
c) The 2-D isovist field identifies collections of views accumulated at each point in space. It shows what is contained within each isovist at every viewpoint in the space
d) 3-D isovist maps aim to quantify the visual experience in the third dimension.

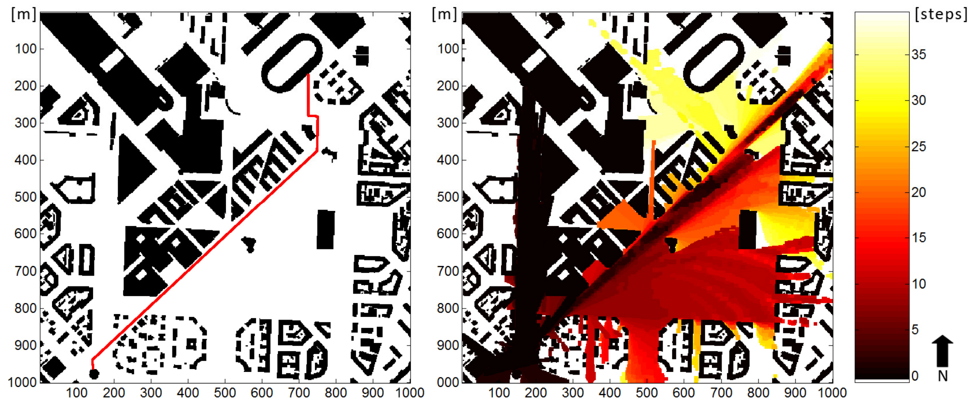

Figure 4. Superimposed isovists (right) along a path (the red line on the left) for a case study in the city of Milan.

4. CONCLUSIONS

This paper introduces several tools that use different data sources in order to analyze UEQ indicators of the built fabric. As emerged, both the accuracy and reliability of some applications are significantly affected by the quality and availability of the source information.

The presented UEQ indicators are the basis for the development of further indicators addressed to various urban applications. For instance, the solar admittance indicator on buildings is rather useful in terms of urban energy planning and environmental policies devising at the level of community: inventory of well irradiated buildings, calculation of thermal and electrical potential for sun collectors, ratio to energy needs and global statistics. The morphological analysis could lead to interesting indicators that may be used by urban planners in order to predict the environmental behavior of different urban textures and the visibility analysis, as we have seen, is very promising in studies related to urban planning.

Future work should provide a common container as to manage different types of input data and to facilitate the computation of further indicators as those mentioned above. Moreover, the improvement of the interfaces among the different software used to read, analyze and reconstruct the models will certainly be fundamental to the increase of the usability of the proposed tools.

BIBLIOGRAPHY

Axelsson P., 1999 Processing of laser scanner data - algorithms and applications. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. 54, pp. 138-147.

Carneiro C., Morello E., Desthieux G., 2009 Assessment of Solar Irradiance on the Urban Fabric for the Production of Renewable Energy using LIDAR Data and Image Processing Techniques. In:

Sester M., Bernard L., Paelke V. (Eds.), Advances in GIS, Proceedings of the 12th AGILE Conference, Springer Berlin Heidelberg, pp. 83-112.

Carneiro C., Morello E., Voegtle T., Golay F., 2010 Digital urban morphometrics: automatic extraction and assessment of morphological properties of buildings. *Transactions in GIS* (accepted but not published).

Morello E., Ratti C., 2009 A Digital Image of the City: 3-D isovists in Lynch's Urban Analysis. *Environment and Planning B: Planning and Design* , Vol. 36, pp. 837-853.

Ratti C., Richens P., 2004 Raster analysis of urban form. *Environment and Planning B: Planning and Design*, Vol. 31(2), pp. 297-309.