3D CITY MODELS FOR URBAN POPULATION ESTIMATES

1 Introduction

In order to monitor the spatial dynamics of cities, which keep on growing in a fast and uncontrolled way, and to overcome the lack of updated data on their growth trends, specific methods need to be employed so as to cope with the changes and complexities of the urban environment.

The different daily activities undertaken by the inhabitants of cities worldwide (living, circulation, work, entertainment, etc.) bring about an ongoing transformation of the urban realm. In this way, getting acquainted with the population profile is essential for conceiving and planning urban public policies and actions, making it possible to the local authorities to meet the population demands on housing as well as on infrastructure and services.

The demographic census is the most important tool to characterize the population of a given district, municipality or State. In Brazil, the census is accomplished every ten years by the Brazilian Agency for Geography and Statistics (IBGE) and it requires a huge amount of financial resources and trained personnel for the collection of in-situ data, as well as for their storage in databases and further release (OLIVEIRA; SIMÕES, 2005). Although the census data present detailed information on the urban population, data on land use patterns and urban growth dynamics are still needed to effectively monitor the cities continuous changes.

A feasible solution for acquiring information in inter-census periods is the usage of alternative sources for demographic data assessment. This work is committed to elaborate an alternative method for urban population estimates by means of remote sensing data, such as orbital optical images and laser scanning. The combined use of remote sensing and GIS for population estimates is comparative less costly in relation to traditional survey methods and offers the possibility of continuously updated coverage, i.e. high temporal resolution in the data provision.

According to Liu and Clarke (2002), there are three basic ways to realize demographic surveys: (i) by means of traditional census, (ii) by registers available at County Records Offices, and (iii) through remote sensing data. The use of remote sensing data for population estimates started with Porter in 1956, who counted the total number of houses in the city of Liberia using aerial photographs (HENDERSON; XIA, 1998).

As stated by Lo (1986), cited by Henderson and Xia (1998), there are basically four research methods to estimate population using remotely sensed data: (i) estimates based on the count of individual dwellings; (ii) estimates based on the calculation of the total residential surface; (iii) estimates based on the areas of different land uses; and (iv) estimates based on the spectral information of the pixels individually.

Another way to classify methods to estimate population by means of remote sensing is to consider the scale of analysis (LIU; CLARKE, 2002). In this way, we have:

- global or generalized methods: based on mathematical models that relate a given urban area with its respective population, using orbital images of medium to low spatial resolution;

- semi-detailed methods: which provide occupation standards based on the demographic density at the neighborhood level, using medium spatial resolution images;

- detailed methods: counting of residential units in order to estimate population, using high spatial resolution images.

In a generic form, considering the wide range of research goals, there is a great number of works dealing with urban themes using high spatial resolution images and/or laser scanning. In Brazil, for instance, Centeno and Mitishita (2007); Botelho (2007); Machado (2006); Moura and Loch (2006); Falat (2005); and Tommaselli (2003) are worthy of mention. Abroad, the specific topic of 3D city models is approached by Jacobsen (2006), Schiewe and Ehlers (2005), Vozikis (2005), Gamba (2004), Boccardo et al. (2004), Habib et al. (2004), Oriot and Michel (2004), Jaynes et al. (2003), Baltsavias et al. (2001), Brenner and Haala (1998), Weidner and Förstner (1995), amongst others.

Solely regarding the works dealing with population estimates by remote sensing, we have Reibel (2007), Voss (2007), Li and Weng (2005), Souza (2003), Qiu et al. (2003), Faure et al. (2003), Chen (2002), Harvey (2002), Ikhuoria (1996), Lo (1995), Langford et al. (1991), Manso et al. (1981), Foresti (1978), Kraus and Senger (1974), Murai (1974), and Hsu (1971), just to mention a few examples.

Although there is worldwide a broad spectrum of works approaching the topic of population estimates from remotely sensed data – both in terms of research methods and scale of analysis – the employed methodologies so far have been limited to bidimensional data. The use of 3D models for estimating population is thus innovative. This work is based on the premise that adding the information on height (z coordinate) will enable a refinement of population estimates initially obtained by bidimensional data, for the particular case of cities where high-rise residential buildings are commonly found.

The goal of this study is to conduct population estimates for a specific area located downtown of Uberlândia city, State of Minas Gerais, southeastern of Brazil. These estimates will be done by means of 3D city models, generated by optical images alone and by a combination of these images with LIDAR data. In this way, the features of interest in both models are the residential buildings at a generic level of detailing, namely the 3D models are expected to reveal the buildings shape and volume, with no regard to subtle volumetric alterations, like prominences or bays in the façades, as it is shown in Figure 1.1.

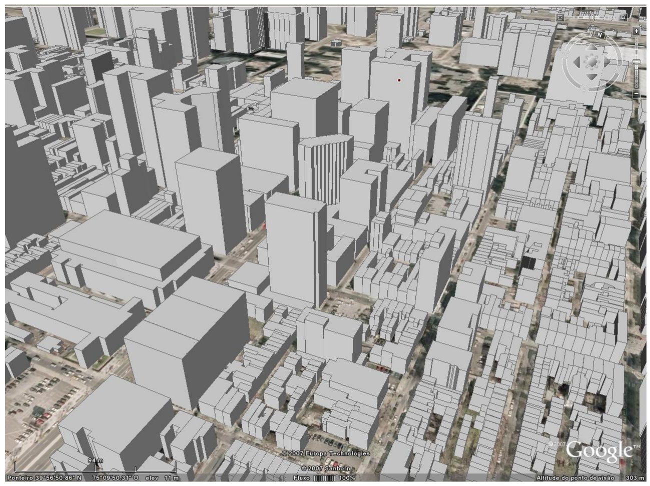

Figure 1.1 – 3D View of the CBD in Philadelphia - USA.
Source: Google Earth (2007).

The proposed method is based on the cumulative residential area, taking into account the relation between the built-up volume (which indirectly expresses the number of pavements) and the population size, derived upon population density coefficients obtained from the literature and/or governmental official publications. Only residential buildings will be considered for analyses. The work involves the following phases: (i) acquisition of 3D data, (ii) detection of buildings footprint and 3D reconstruction, and (iii) population estimates.

With the method based on 3D reconstruction proposed in this work, it will be possible to monitor the population growth, tackling the hindrances represented by the lack of updated data on urban population, and to develop methodologies in a promising scientific area, still at its early stages in Brazil.

2 GENERAL GOAL

Generate 3D city models, obtained by means of active (LIDAR) and passive remote sensors (IKONOS), meant to support the estimates of urban population.

2.1 Specific Goals

- Generate a Digital Surface Model and a Digital Elevation Model from orbital optical images;
- generate a Digital Surface Model and a Digital Elevation Model by means of LIDAR data;
- evaluate the plani-altimetric accuracy of the Digital Models obtained from optical images and LIDAR, using statistical measures;
- accomplish a 3D city reconstruction model by orbital optical images;
- execute a 3D city reconstruction model by the combination of orbital optical images and LIDAR data;

– extract the volume of residential buildings in each of the two models;

– calculate the residential surface (area) upon basis of the volume in each of the two models, and refine both by means of statistical adjustments;

– estimate the urban population living in the study area, considering the residential surface (area) reckoned in each of the two models;

– evaluate the population estimates, obtained in both models, cross-validating the estimates with census districts population data and/or eventually available traditional population estimates or countings.

3 METHODS

3.1 Study Area

The study area is situated in the municipality of Uberlândia, West of Minas Gerais States, in a region named ‘Triângulo Mineiro’. It owns a surface of 4,116 km^2 and is bordered by the municipalties of Tupaciguara, Araguari, Indianópolis, Uberaba, Veríssimo, Prata, and Monte Alegre de Minas. The municipal seat is 550 km away from Minas Gerais State capital – Belo Horizonte – and it is located within the geographic coordinates 18º 55’ 07” S and 48º 16’ 38” W (IBGE, 2007).

According to the Population Estimates of IBGE (2007), the municipality had 608,369 inhabitants in 2007. Table 3.1 shows the population growth in Uberlândia from 1996 to 2007.

Table 3.1 – Population growth in Uberlândia from 1996 to 2007.

POPULATION									
Area	1996[1]	2000[2]	2001[3]	2002[3]	2003[3]	2004[3]	2005[3]	2006[3]	2007[3]
Urban	431,744	488,982	505,167	521,888	539,162	556,133	570,982	585,719	
Rural	7,242	12,232	12,637	13,055	13,487	13,909	14,280	14,649	
Total	**438,986**	**501,214**	**517,804**	**534,943**	**552,649**	**570,042**	**585,262**	**600,368**	**608,369**

Source: Adapted from PMU / SEPLAMA (2007).
Note: [1] Population Counting – IBGE – 1996
[2] Demographic Census – IBGE – 2000
[3] Population Estimates – IBGE

The city of Uberlândia presents residential high-rise buildings gathered in the central neighborhoods, as it can be observed in Figure 3.1. The selected study area is contained within such area, comprising the neighborhoods Centro and Fundinho, and also part of Tabajaras, Martins, and Osvaldo Rezende neighborhoods (Figure 3.2). As the goal of this work is to use 3D models to refine population estimates previously done with bidimensional data, the study area definition focused on selecting a region with a great number of high-rise buildings.

Figure 3.1 – Study area.
Source: PMU (2007).

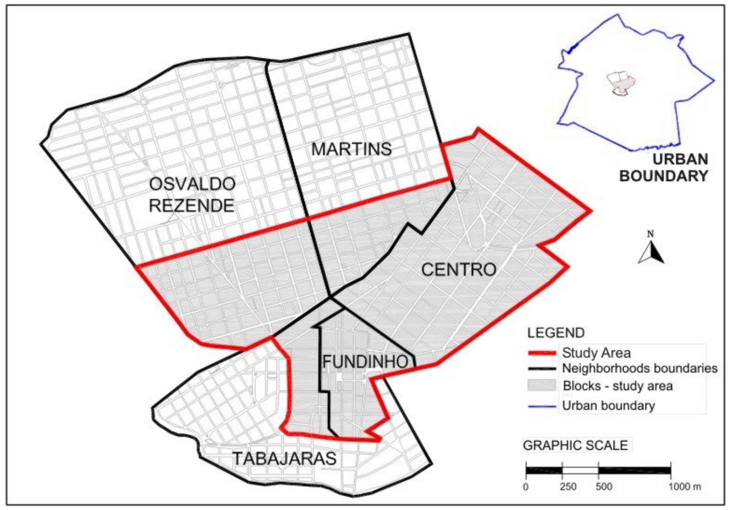

Figure 3.2 – Study area boundaries (in red).
Source: Adapted from PMU / SEPLAMA (2007).

3.2 Input Data

The ‘Esteio Engineering and Survey Company S.A.’ executed an aerial survey of Uberlândia – MG on behalf of the Municipal Government between the years 2003 and 2004. The survey included an aerophotogrammetric survey at a 1:8,000 scale, ground control points, planimetric digital restitution at a 1:2,000 scale, laser scanning, digital ortophotos at a 1:2,000 scale, and in-situ identification and control of photographic details that could not have been interpreted.

The laser scanning was realized with the sensor ALTM 2025, produced by the Canadian company Optech Inc., which offers an altimetric accuracy of 0.15 m (raw data). In Uberlândia, contour lines are available with a 1 m equidistance, and the altimetric accuracy established by the National Cartographic Accuracy Standard (CAS) is of 1/2 equidistance, which corresponds to 0.5 m.

The laser data were donated by Esteio in the form of ‘xyz’ files. These data present the coordinates x, y, and z of the sampled points, which will be further used for the generation of the Digital Terrain Model (DTM) and Digital Surface Model (DSM), as it can be observed in Figure 3.3.

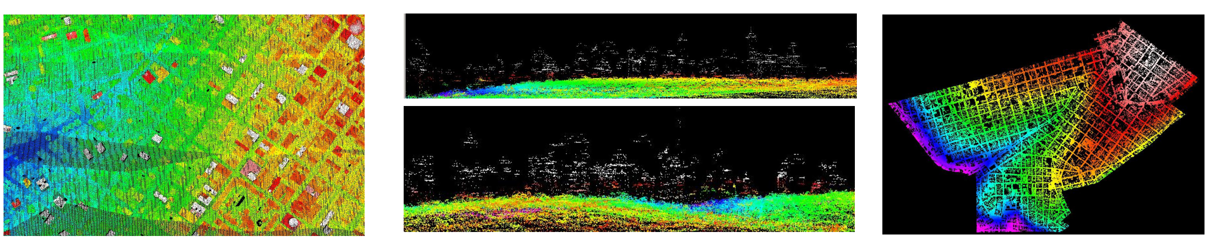

Figure 3.3 – Visualization of the laser data (a) DSM; (b) DSM profiles; (c) DTM.

A stereo pair of high resolution images from IKONOS-2, acquired on 06/27/2008, will be also used (Figure 3.4) as well as vector data of the streets network and of the census districts boundaries, besides non-spatial data, e.g. socioeconomic and demographic data related to the study area.

Figure 3.4 – IKONOS images (stereo pair).

3.3 Methodology

The proposed methodology comprises the following stages:

1) analysis of the available input data and eventual execution of adjustments;

2) preprocessing of IKONOS images;

3) 3D reconstruction using the optical images only – **Model I**;

4) 3D reconstruction using both the optical images the laser scanning data – **Model II**;

5) calculation of the residential buildings volume for both models (I & II);

6) conversion of volume data into cumulative residential surface for each model;

7) population estimates based on the residential surface obtained for each model;

8) cross-validation of results for both models.

The preprocessing of IKONOS images will be executed in the module OrhtoEngine of PCI Geomatics. During this stage, the following tasks will be accomplished: images orientation; detection of homologous points; extraction of spatial coordinates; homologous points heights assessment by spatial intersection; grid generation for surface modeling; interpolation of sampled grid points; generation of the Digital Surface Model; generation of the Digital Elevation Model; orthoimage production.

The buildings extraction consists of two stages: detection and reconstruction. The first one (segmentation and classification) will be done at the Definiens Developer® platform, and the reconstruction (extraction of buildings geometrical features) will be executed in softwares developed at the University of Pavia.

In order to improve the segmentation process, vector data of the study area streets network will be used. And to refine the classification results, data on height extracted from the normalized DSM or 'nDSM' (DSM – DEM) will be employed. The classification aims at identifying all the residential buildings, which is a crucial information for conducting the population estimates.

With the information of the buildings footprint at hand, the information on height derived from the nDSM will be used for the 3D reconstruction model.

Model II will observe the same stages as in Model I. Nevertheless, the buildings height in this case will be obtained from the Digital Surface Model generated from laser scanning.

With the residential volumes estimated in both models, the cumulative residential surface will be calculated, and population estimates will then be conducted for each model. The obtained results will be cross-validated mainly with census districts population data.

Figure 3.5 shows the proposed methodology.

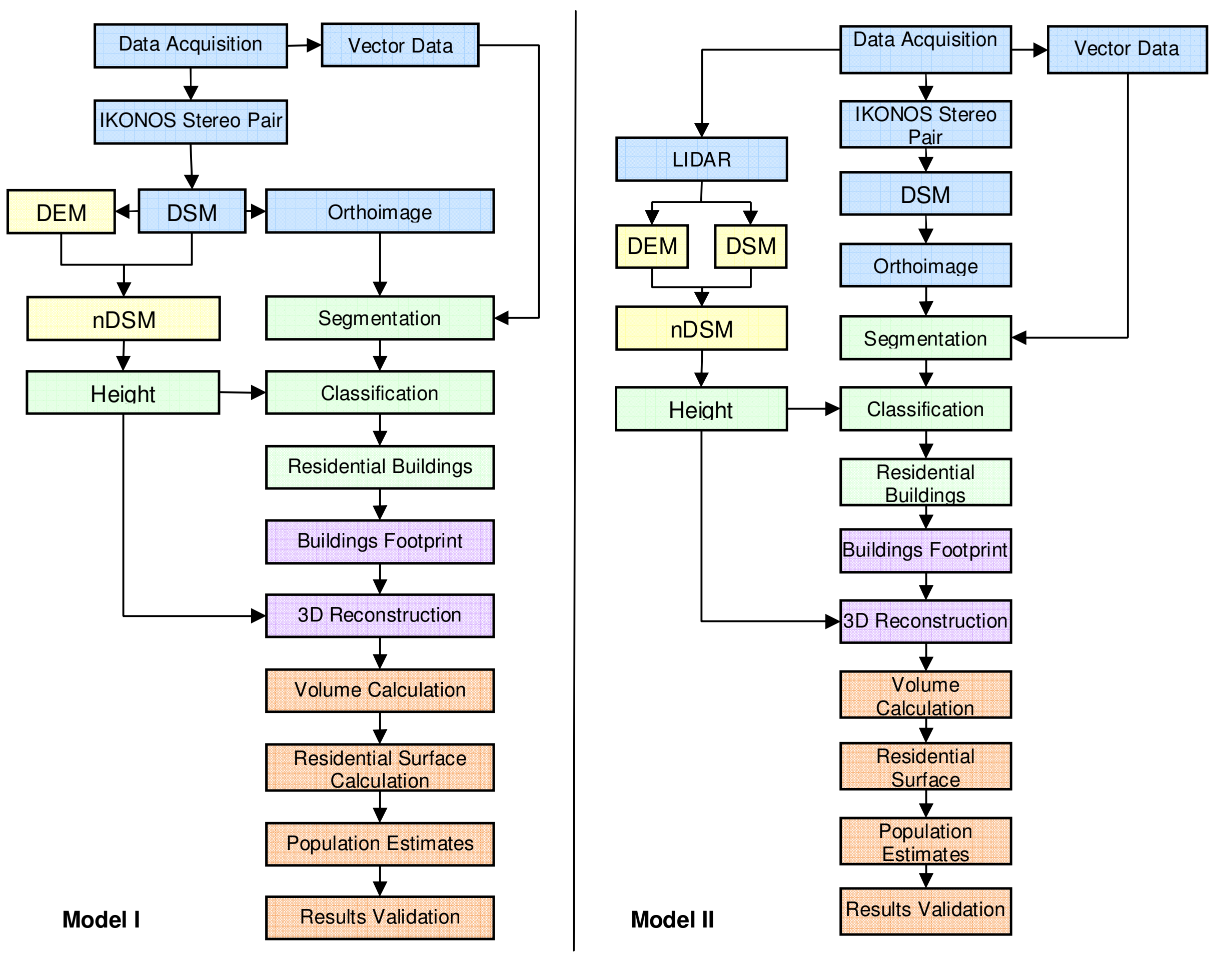

Figure 3.5 – Proposed Methodology.

4 ACTIVITIES TIMETABLE

Activities	**2007**		**2008**				**2009**				**2010**
	Trimesters										
	3	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**
Literature Review	X	X	X	X	X	X	X	X	X	X	
Data Acquisition		X	X	X							
Construction of Database				X	X						
Field Work						X					
Data Processing					X	X	X	X	X		
Analyses and Discussion of Results								X	X	X	
Thesis Elaboration									X	X	X
Thesis Defense											X

5 AGENDA OF ACTIVITIES AT THE UNIVERSITY OF PAVIA

The Department of Electronics of the University of Pavia shelters different research groups and presents a long tradition in the field of remote sensing of urban areas. They are regarded as a leading international reference in this area and have been since 2001 organizing a series of conferences on ‘Urban Remote Sensing’, known as *URBAN*, which gather a great number of experts and scientists from different countries all over the world, aiming at the exchange of experience and knowledge. These conferences were held in Rome – Italy (2001), Berlin – Germany (2003), Tempe – USA (2005), and in Paris - France (2007).

Besides its long-term experience in the scope of ‘Remote Sensing of Urban Areas’, this Department owns the necessary infrastructure for the achievement of the envisaged work, within the deadlines established in the activities timetable.

All the procedures related to the 3D reconstruction of the study area shall be carried out at the University of Pavia, employing the routines developed by the researchers of the Department of Electronics. Upon basis of the 3D reconstruction model, the volume of residential buildings will be calculated, and a method to convert the volume data into residential surface shall be developed. The reconstruction consists in a crucial stage for the success of the population estimates, since the height and volumetric accuracy of high-rise residential buildings impact the assessment of the total cumulative residential area derived from these two measures. These activities will be developed from February 01st to July 31st, 2009.

As previously stated, Brazilian research groups in this field are still incipient, and the possibility of close cooperation with the experienced team from Pavia will certainly promote and develop new research initiatives in this area, strengthening the linkages between Pavia and INPE and laying the path for further exchange of students and researchers between these two institutions.

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