SATELLITE IMAGERY AND LIDAR DATA FOR EFFICIENTLY DESCRIBING STRUCTURES AND DENSITIES IN RESIDENTIAL URBAN LAND USES CLASSIFICATION

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Commission VI, WG VI/4

KEY WORDS: SPOT, LIDAR, Pixel-based classification, Building density, FAR, BCR

ABSTRACT:

Urban areas are complicated due to the mix of man-made features and natural features. A higher level of structural information plays an important role in land cover/use classification of urban areas. Additional spatial indicators have to be extracted based on structural analysis in order to understand and identify spatial patterns or the spatial organization of features, especially for man-made feature. It's very difficult to extract such spatial patterns by using only pixel-based approaches. Sections of building occupation densities which are integral parts of other uses may be difficult to identify. A lot of public resources have been directed towards seeking to develop a standardized classification system and to provide as much compatibility as possible to ensure the widespread use of such categorized data obtained from remote sensor sources. The definition of "building densities", for example, includes those uses similarly classified.

This paper examines the utility of high-resolution remote sensing image and airborne laser altimetry data for mapping residential land uses within the spatial limits of Barcelona City Council (Spain). It was possible to discriminate different densities of residential development, and to separate these from commercial/industrial and agricultural areas. Difficulties arose in the discrimination of low-density residential areas due to the range of land cover types within this specific land use, and their associated spatial variability. The greater classification errors associated with these low-density developed areas were not unexpected. It was found that these errors could be mitigated somewhat with techniques that consider the mode of training data selection and by incorporation of methods that account for the presence and amount of impervious surfaces.

This paper focuses on a methodology developed based on the pixel-based approach and three dimension analysis of artificial and residential areas. The combination of high spatial resolution airborne LiDAR and SPOT imagery offers great application opportunities, especially in the urban areas. Since residential urban areas are complicated, a comprehensive approach is needed and different setting have to be investigated to cope with different type of urban areas and to different type of cities.

1. INTRODUCTION

Density is a controversial term. Increased density is feared by those who imagine ugly buildings, overshadowed open space, parking problems, and irresponsible residents. It is promoted by those who value urbane streetscapes, efficient infrastructure supply, walkable neighbourhoods, and increased housing options. However, High and dens buildings congested in small place reduce people's quality-of-life. The literature confirms the influence of urban design on many aspects of people's physical and mental health, and social and culture vibrancy. Building density is not only an important issue in urban planning and land management, but also an indicator of a city's evolution, because the buildings constructed in different styles and vary greatly in how the land is used (Ann Forsyth, 2003).

Areas of built form comprise areas of intensive use with much of the land covered by structures. Included in this category are cities, towns, and villages, strip developments along highways, transportation, and areas such as those occupied by industrial and commercial complexes, and institutions that may, in some instances, be isolated from urban areas. Pixel-based image analysis, drawing upon ENVI 4.2, was used to classify SPOT5 images together with data derived from an airborne laser scanner. After the initial classification of different land cover types, a subset only containing buildings was integrated. The study area is defined by physical characteristics such as building density and height, and includes land use.

The capability of remote sensing to support the assessment of construction distribution will be focused on. The up-to-date and area-wide classification of structure characteristics of the physical urban environment from high resolution satellite data provides the basis. How the provision of structural criteria can allow for a distribution of two different types of input data is presented. The methods have the capability to support urban planning or management operations with land-use and built-form information.

This study will examine in a simple way the relation between building site coverage ratio (BCR) and floor area ratio (FAR) to estimate building density of a city from two aspects, the buildings stretching on the surface and growing along the third dimension. A BCR is the ratio of the total occupation area to the total area of the interest area, while a FAR is the ratio of the

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height building area to the total area of the interest area. Manual survey is the traditional method to calculate the aforementioned ratios to obtain the heights and shapes of all buildings. The Light Detection and Ranging (LiDAR) approach is a quick method to collect topographic data, and is also applicable in extraction of urban building forms. Another way is to obtain the building's information from the GIS and the aerial photos. But they are not always affordable (Halla and Walter, 1999).

To specify the ideas and goals this methodology provides answers to the following related points:

1. Can the morphology of a city be meaningfully described by such an urban volume layer in a reproducible manner?
2. Can this study of densities show the rising/decreasing importance of polynuclearity in the city?
3. Can areas of high intensity land use be discovered?

Finally, the objectives of this study are to measure the variation of building density by using BCR and FAR indices in some areas of interest in Barcelona. The method use high resolution satellite images and LiDAR data set for building extraction heights and standing areas. This method is useful in analyzing urban building density in similar regions.

2. DATA AND STUDY AREA

The chosen area is Barcelona, which is the regional capital of Catalonia, lying in the north-east of Spain (see Figure 1). The physical limits of Barcelona extend to almost 100 Km2. and the city had a population of some 1,595,110 inhabitants in January 2007 leading to a population density of almost 16,000 inhabitants / Km2 (Campaign, 1991).

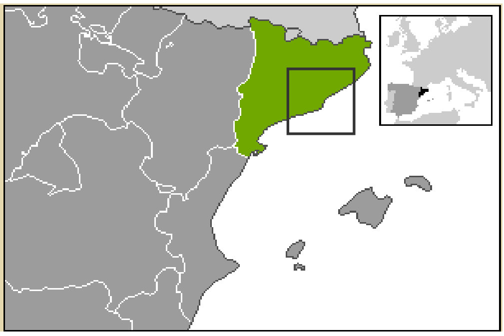

Figure 1: The Autonomous Community of Catalonia.

Two Remote sensing data sets were used for the study. One is subset of an SPOT5 scene, recorded on 2004. It is a fusion product of the four multispectral bands (10m spatial resolution) and the panchromatic band (2.5m spatial resolution), resulting in four multispectral ban with 2.5m spatial resolution. The multispectral bands cover blue, green, red and part of the near-infrared of the electromagnetic spectrum (see Figure 2A, 2B). The second data set is from an airborne laser scanner (ALS), acquired on 23rd July 2002, at flying height above ground of 1325m and average point density of 1 point/m2. From this two different models were generated. One is normalised digital surface model (nDSM), containing height information above ground (see Figure 2C). Building and trees can be clearly seen in this image. The other is a different model between first and last pulses (ΔH_{FL}), which has a height of zero for sealed areas and height similar to that of the nDSM in green areas, thus aiding the identification of trees (Kressler, Steinnocher, 2006).

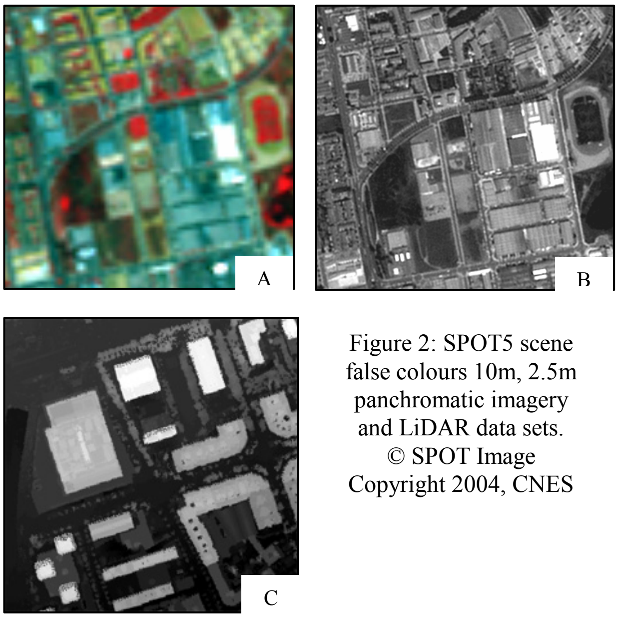

Figure 2: SPOT5 scene false colours 10m, 2.5m panchromatic imagery and LiDAR data sets. © SPOT Image Copyright 2004, CNES

3. METHODOLOGY

For the classification of the satellite image an pixel-based approach as implemented in ENVI 4.2 was used to identify the standing areas of building category to calculate the BCR since most building's standing areas can't be seen clearly from the classification image, the main shape of the building's obtained from applying texture analysis on the panchromatic image adjusted to the real location and shape of the building's foot.
After drawing the building's shape, the next step is to measure the height of buildings. We can calculate the building's height from its shadow but since buildings are densely distributed in some areas and the shadow of one building is usually mixed with the shadows of other building's on the image, some building's height could not estimated directly from the shadows. In this case, airborne laser scanner (ALS) was used to help the calculation. Since the ratios could be calculated from clear buildings form, the heights of unclear form buildings were thus estimated.

3.1 Image Classification and Texture Analysis

An urban land cover classification derived from the high resolution SPOT5 images provides area-wide and up-to-date knowledge on the environment. This product displays the basic information to know "what" is "where". The results were eleven classes mapping the urban morphology – Residential, Industrial, Streets, Forest, Green Open, Irrigated fields, Dry Lands, Shallow water, Deep water and Shadow (see Figure 3).

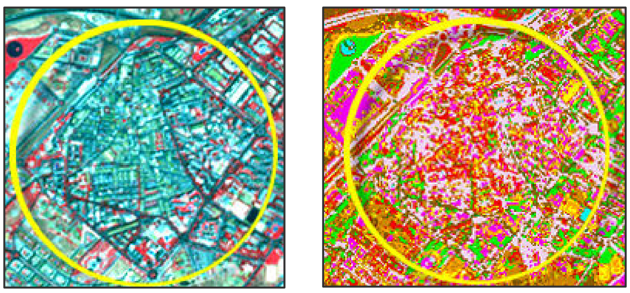

Figure 3: A primarily results of supervised classification with 11 different categories.
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The Pixel-based classification methodology has been presented elsewhere (Alhaddad, Roca, Burns, 2005), showing an accuracy of 85.94% correctly detected buildings. It specifically shows a user accuracy of 86.2% and an 83.8% producer accuracy adapted from 130 randomly distributed sample points. Based upon this result methodologies have been developed to analyse urban structure for regionalization based on homogeneous urban structure features. From the classification result only the identified building objects were used for the integration with airborne laser scanner data. In Figures 4 and 5 texture analysis approach was performed only on the basis of the panchromatic image in uncovered areas by LiDAR data (Alhaddad, Roca, Burns, 2007) and normalised digital surface model (nDSM) data to extract buildings boundary (Zeng, Zhang, Wang, and Lin, Z., 2002).

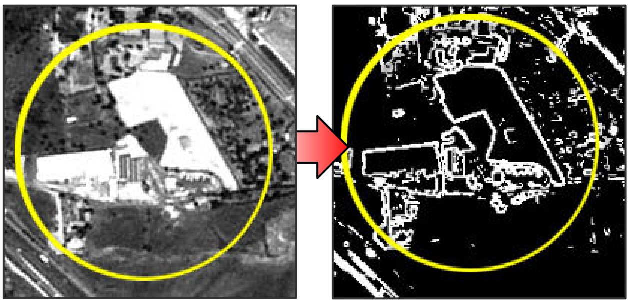

Figure 4: applying texture analysis on the panchromatic image will give clear element boundaries.
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Here LiDAR provides the opportunity to identify land use types such as roads and buildings with high degree of accuracy. The nDSM information greatly improves the differentiation between roads and buildings; the quality being was mainly dependent on the resolution of the data but not on any ambiguity within the data (Priestnalla, Jaafara and Duncanb, 2000).

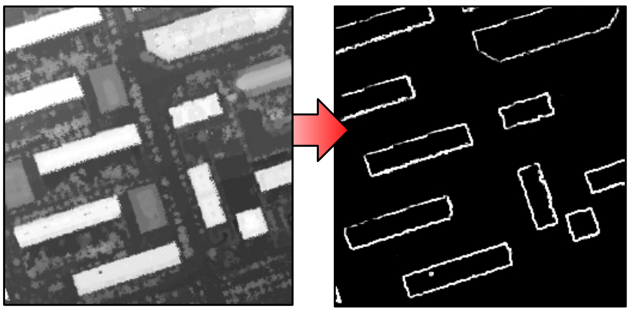

Figure 5: some areas already cover by LiDAR data and by applying texture analysis clear buildings boundaries will show.
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Airborne laser altimetry data and high resolution Panchromatic image offer possibilities for feature extraction and correct classification errors in urban areas (see Figure 6), high classification accuracy will be important for building site coverage ratio (BCR) calculations. Since in particular the texture analysis to detect the building boundaries may contain noisy pixels caused by adjacent vegetation or structures in gardens as shown in Figure 4, it is up to the user or application objectives to decide from which level to extract the outline of the base at ground level (Alhaddad, Roca, Burns, 2007).

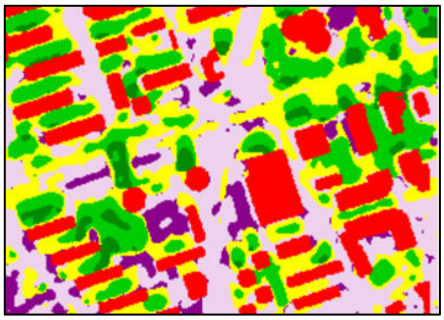

Figure 6: Red class illustrates buildings area. Extracted boundary from ALS and panchromatic image offer possibilities for classification correction results.

A correlation of LiDAR with corresponding building height is used to assess building height classes. Nine different height classes (1-3, 3-6… 15 and more floors) were derived. Figure 7 shows an urban land cover classification differentiating the class “buildings” by height. ArcGIS software was used in the 3D simulation.

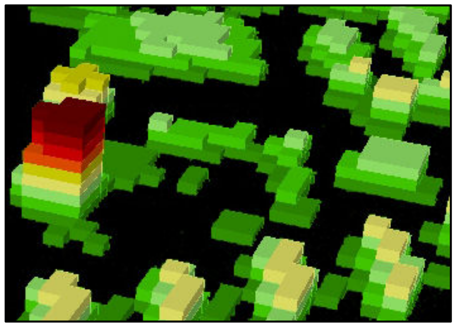

Figure 7: 3D simulation illustrates the building heights from LiDAR data integrated with 10m grid cells.

3.2 Integration and Calculation

For the data integration, only the identified buildings were use. The first involved the integration with specific grid cell data (10m). This allowed for the separation of buildings based on the building site coverage ratio (BCR) in the cell area. The buildings were assigned to one of four classes of cell occupation - complete, high, medium and low BCR ratio. For each building a mean height is available, allowing the calculation of volume. In the research, small area inside Barcelona was selected to measure the BCR, the FAR and the integration between both ratios. After obtaining the building’s height, the BCR and the FAR within an area of interest was calculated from the following equations:

$$BCR = \sum F / A \qquad (1)$$

$$FAR = \sum (H / C * F) / A \qquad (2)$$

Where H is the height of a building, F is the area of the cell occupied by the building at ground level, C is a constant which represents the average height of one storey of all the buildings (C = 2.9m), A is the total area of the cell grid (100m2), FAR and BCR is the floor area ratio and building coverage ratio of a site. A site here refers to a cell area, usually including one cell. There are a number of other potential measures of density, and even more of perceived density (Pan, Zhao, Chen, Liang and Sun, 2008).

4. RESULTS

Both the BCR and the FAR results in a local distribution of building density are shown in Figure 8 and 9. The result is a local distribution of the generalized building densities based on the spatial unit. Diagram 1 presents the statistical results of the FAR and BCR based on the entire grid of all the cells in the selected study area. The results also indicate that the variation of BCR is more than that of FAR. Diagram 1 shows the frequency distribution of FAR and BCR values of all the cells. The Diagram shows that 90% of all cells have FAR value less than 0.0062 (H < 50m), while more than 76% of the cells are between 0.6 and 1 (F between 60m2 and 100m2) for BCR. New development within existing and already developed urban areas of a city generally has a higher BCR and lower FAR. The greater variation in BCR and lesser variation in FAR would suggest that the selected sample area inside Barcelona shows that while the city has already witnessed some change, the prospects of further redevelopment and increased FAR are high. It is suggested that a better planning and management of the urban land is needed (Zhou, Song, Simmers, Cheng, P., 2004).

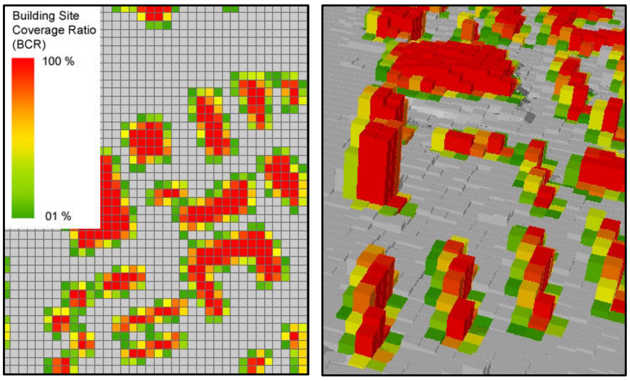

Figure 8: 3D simulation illustrates the frequency distributions for BCR for all cells grid inside the sample area.

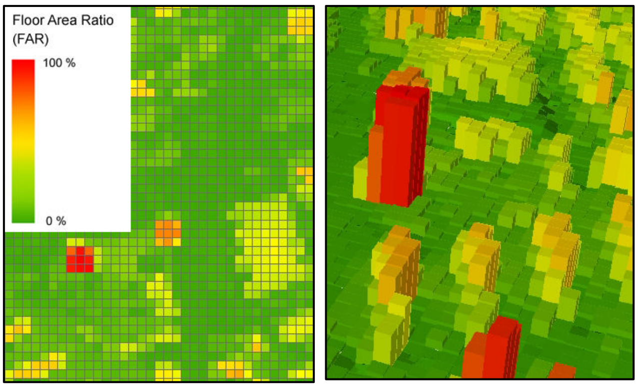

Figure 9: 3D simulation illustrates the frequency distributions for FAR for all cells grid inside the sample area.

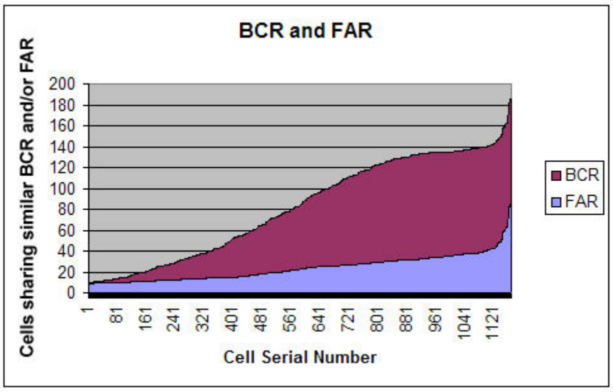

Diagram 1: Cells gave unique serial number; the diagram presents BCR and FAR relation based on entire cells.

In view of the relation between BCR and FAR studied to obtain building densities in the selected study area (see Figure 10), the parameters within the area of interest are calculated from the following formulas:

- When BCR_{high} and FAR_{high} = If F > 50% in A and H > 80% from H_{max} in A = High density
- When (BCR_{high} and FAR_{low}) □ (BCR_{low} and FAR_{high}) = (If F > 50% in A and H < 80% from H_{max} in A) □ (If F < 50% in A and H > 80% from H_{max} in A) = Medium density.
- When BCR_{low} and FAR_{low} = If F < 50% in A and H < 80% from H_{max} in A = Low density

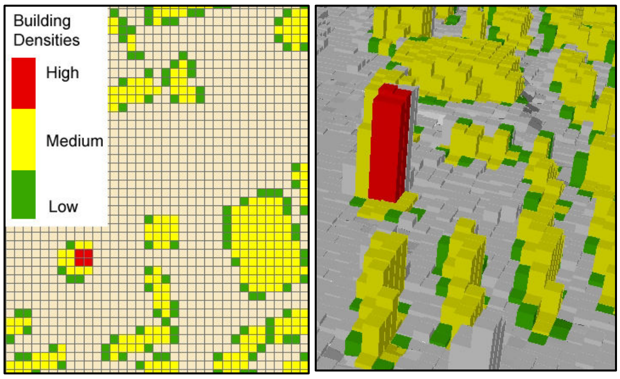

Figure 10: 3D simulation presents the Union between BCR and FAR ratios.

5. CONCLUSION AND DISCUSSION

In this paper the use of LiDAR and pansharpened SPOT data sets allow an easy separation of the basic land cover types present in the study area. LiDAR data are especially beneficial for the separation of flat sealed areas from buildings, while optical data allows a good separation of vegetation and seal areas, then the integration of the classification results with the information provided by LiDAR to extract the building form to be adopted to obtain the BCR with high accuracy results. The methods used to extract buildings information from high resolution satellite images are applicable in this study. However the methods are actually based on some assumptions when measuring the FAR and BCR values. The shape of the buildings could miss part of the information from the classification error or from a texture analysis approach to extract the building's boundaries from the Panchromatic and LiDAR dataset. Obviously this will introduce errors in the calculations.

The most fundamental assumption is that the area of each storey of a building is the same when calculating the FAR. For irregular buildings which have dissimilar floor areas, the calculation of those buildings is very difficult. Some assumptions are required. The aim was the mapping of building data available on a 10m grid basis, not only on the basis of areas covered by the buildings but also on the height of these buildings. The absolute values of the FAR and BCR stated in this article act as a reference, though they are still quite precise in value.

This paper is meant to provide a starting place for examining measures of building densities from their physical base. The method used to extract FAR and BCR values and their integration from the satellite images is more efficient than traditional survey methods. It suggests that a better planning and management of land resources is required for future redevelopment within the wider metropolitan area of Barcelona.

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ACKNOWLEDGEMENTS

The authors of this paper gratefully acknowledge the research funding provided by both the European Commission through the ERDF, by way of the INTERREG IIIB Programme, the Cartographic Institute of Catalonia and the Spanish Ministry of Science and Technology (ref. BIA2003-07176). Thanks to the referees for their help.