PRODUCING A BUILDING CHANGE MAP FOR URBAN MANAGEMENT

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ABSTRACT

The high rate of changes in cities requires the existence of matching geographic information in order to enable proper land monitoring and planning. When cartographic information exists, but is out-dated, a change detection procedure using recent geographic data can be applied for map updating. The aim of such an analysis is to highlight those areas where changes have most likely occurred.

The goal of this work is to present an object-oriented methodology that enables outdated large-scale cartography to be updated, using Very-High Resolution (VHR) imagery and Light Detection and Ranging (Lidar) data. The procedure is a two-step method. The remote sensing data is used to map the present land cover situation, and then, based on a change/no-change approach the land information is used for updating the large-scale cartography.

The result is an alarm system that indicates the location of potential changes in the built-up zones. However, in order to be a legally valid document, the mapped objects must comply with the technical specifications of the respective cartographic scale. This is not possible strictly based on an automatic methodology, and requires further human intervention. Therefore, the alarm layer can then be used by the municipal technical staff as the basis for manual editing, following the technical specifications indicated for the desired map scale.

INTRODUCTION

According to a recent survey of how the Portuguese municipalities use and value geographic information, the municipal services require updated geo-data mainly on three themes: “Roads”, “Altimetry”, and “Buildings” (1). Among these classes, buildings are the most relevant elements for municipal activity, because they are involved in daily administrative acts for which updated information is required. Various procedures such as land subdivision into lots, redevelopment and/or modifications to already existing buildings, production of location maps for licensing acts or intervention on buildings, all require municipal permits. In order to grant such permissions, the municipal services need access to updated geo-information. This land use information is also required for municipal tax administration. Therefore, all these activities depend heavily on spatial information in the form of building maps, demanding their regular updating.

Large-scale cartography in order to be used by municipalities must follow the scale-specific technical specifications. Since the specifications are very detailed, the traditional framework based on aerial images, photogrammetry, and fieldwork, is the most common way of producing these maps. Consequently, the whole process of cartographic production is very time-consuming and requires a significant financial effort from the municipalities. These facts have a direct impact on the regularity of municipal official cartography updates. In Portugal, the time lag between available maps is generally 10 years.

To overcome the data update periodicity, a methodology using VHR imagery and Lidar data to detect and identify changes in outdated cartography is proposed. The aim of this analysis is to highlight those areas where changes have most likely occurred. The first step is to produce a LCM from the imagery and altimetric data set, and then to use that information, on a rule-based post-classification procedure, to update the outdated cartography.

Extracting buildings from satellite imagery is a well documented research area in the remote sensing community (2,3,4,5). In addition to the optical images, the inclusion of altimetric data can result in a more accurate extraction (6,7,8,9). Furthermore, approaches based on objects rather than pixels, are better suited for the high heterogeneity found in complex landscapes (10,11). The concept behind GEographic Object Based Image Analysis (GEOBIA) is that information relevant to the interpretation of an image is not represented in single pixels but in meaningful image objects, which reflect real patterns and their mutual relations (12).

In (13) a post-classification method was tested to update the Belgian topographic data base, at 1:1 000 scale, with IKONOS and QuickBird orthorectified imagery. (14) tested the fast updating of 1:10 000 scale land use maps using high-resolution remote sensing imagery and a class-knowledge-oriented change detection technique. (15) used a QuickBird image to update a cadastral GIS, of 1:2 000 scale. The analysis included imagery segmentation and a rule-based system to judge, for every parcel, whether or not change happened comparing to the existing GIS polygons. (16) proposed a GEOBIA methodology to detect changes in buildings, using VHR images, cartographic data and a priori knowledge applied in the form of transition rules.

The aim of this research is to examine the potential of VHR satellite imagery and Lidar data to derive a sub-product with less detailed thematic and geographic information but with a higher temporal resolution. This alarm tool is used for pointing out potential changed areas. This new product can be analyzed by municipal technicians who: (i) will decide, based on analysis of the image and related information, if the marked spot is in fact a changed area (a new urbanization or a built-up object that was demolished), and if so, (ii) digitize the new buildings into the old cartography, or eliminate it, thus producing an updated map, if the alarm layer is accurate enough, or send a topographer to collect it directly. If the spot is considered to be a false detection, then the technician will (iii) eliminate it. All these actions can be done using a GIS interface where the most recent building map is overlaid on the VHR imagery, and where attributes like on-going urban developments or the Constraints Master Plan, can also be seen. Such methodology can be used by the municipality to keep its cartographic data base of urban areas up-to-date between two official map products, with higher thematic and positional accuracy.

STUDY AREA AND DATA SET

The cartographic update was tested in a study area located in the oriental part of the city of Lisbon. The selected area occupies 64 ha (800 m $\times$ 800 m) (Figure 1), and is characterized by a diverse land cover that includes herbaceous vegetation, lawns, trees and agricultural plots, bare soil, single and multi-family housing, a school, industrial properties, as well as roads and rail networks.

The data base includes planimetric, spectral, and altimetric data. The map to be updated is the Lisbon’s Municipal Cartography (Carto98), available at the Lisbon City Hall. This cartography was produced in a vector format, for the year 1998, and has a scale of 1:1 000.

The spectral data is a QuickBird image acquired on April 14, 2005. The image has a spatial resolution of 2.4 m in the multispectral mode (visible and near-infrared bands), a pixel size of 0.6 m in the panchromatic mode, and a radiometric resolution of 11 bits. The image used in this study has an off-Nadir angle of 12.2°.

Furthermore, two altimetric data sets were also explored in this study. One set is derived from a Lidar point cloud, and the other is derived from cartography. From a Lidar flight performed in 2006, a surface image was produced based on the second return, with 1 m resolution. This image represents the Digital Surface Model (DSM) of the study area. From the 1:1 000 scale cartography of 1998, a set of elevation mass points and contours were retrieved.

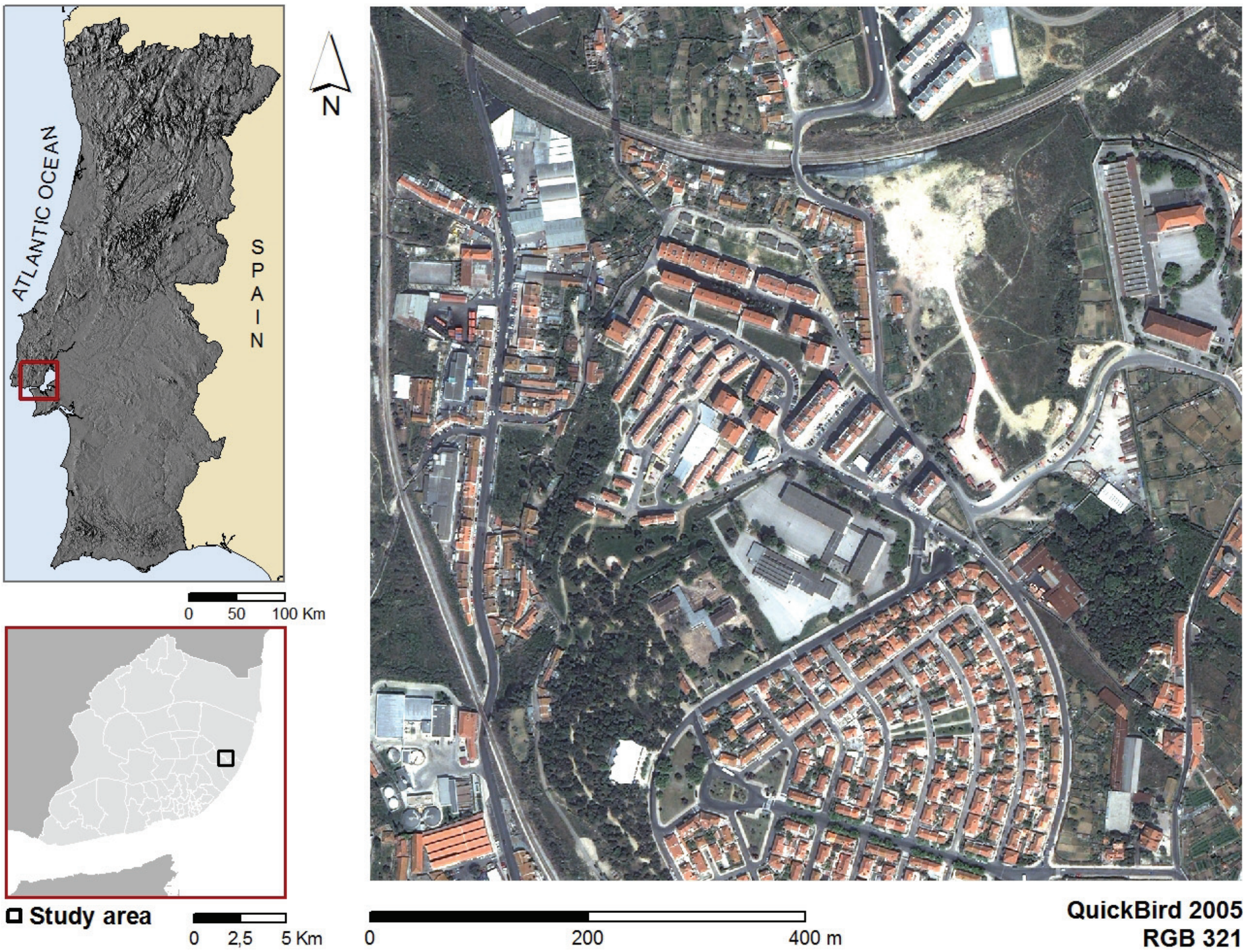

Figure 1: Study area location in the city of Lisbon.

METHODOLOGY

Pre-processing

In this stage, the altimetric data was processed in order to obtain the Digital Terrain Model (DTM). The DTM was then used to orthorectify the QuickBird image and to derive the normalized Digital Surface Model (nDSM). All files were geometrically corrected to attribute a common coordinate system (PT-TM06/ETRS89).

The DTM was obtained from the elevation mass points and contours. Firstly, a Triangulated Irregular Network (TIN) was generated and then converted to a grid with 1 m of resolution. This final file corresponds to the DTM for the study area.

The nDSM was then produced based on the DTM and the DSM. The nDSM was obtained by subtracting the DTM to the DSM image. This raster file stores the height of all elements above and below the terrain (Figure 2).

The QuickBird imagery was orthorectified in order to reduce the geometric distortions introduced by the terrain. Previously, a pansharp image of the multispectral and panchromatic bands was produced for visual benefit. The orthorectification of the multispectral, pan, and pansharp images was performed based on the Rational Polynomial Coefficients (RPCs), available with the image, and a set of 36 ground control points retrieved from the 1:1 000 planimetric and altimetric cartographies of 1998, available from the Lisbon City Hall. For the elevation reference, the DTM, produced as described above, was applied. A 2nd order polynomial was selected for the transformation. To evaluate the process, 40 check points, well distributed across the image, were used. The Root

Mean Square Error (*RMSE*) obtained was less than one pixel. Afterwards, a Normalized Difference Vegetation Index image (*NDVI*) was produced to integrate the data set for feature extraction.

The nDSM and the planimetry were well registered. However, the QuickBird's off-Nadir angle of 12.2º was responsible for the less accurate registration between the imagery and the altimetric and planimetric data sets.

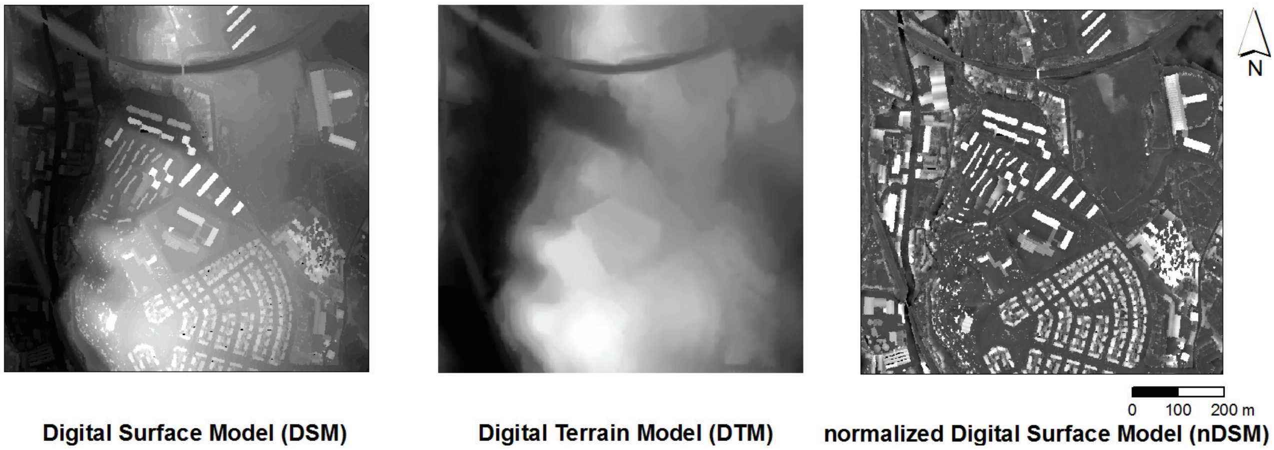

Figure 2. Altimetric data used in the study area.

Land Cover Classification for 2005/06

The first step for updating the 1998 Cartography was to classify the QuickBird image from 2005, using the 2006 nDSM surface for better discrimination of the objects of interest. The goal is to produce a map with the land cover of 2005/06 (LCM).

The class of interest for map updating is the built-up class. Nevertheless, other land cover classes are also considered in the classification system, in order to enable a good extraction. Regarding the buildings' rooftops, three classes were considered: one for the red tile cover, the most common material in the study area; another class for the brighter roof material like light tin; and a class for remaining materials, that include dark tin, dark tile and fibrocement. Regarding the paved areas, three classes were identified: railways, roads and other impermeable surfaces that include streets, sidewalks and other paved material. Although present in the study area, a class for bare soil was not considered in this classification schema, since it did not affect the extraction of the built-up classes.

The nomenclature is organized in three levels of detail. The 1st level includes the classes "Urban" and "Vegetation". On the 2nd level, three classes are defined: "Building", "Pavement", and "Vegetation". On the 3rd level, seven classes are identified: "Building with red tile roof", "Building with bright roofs" and, "Building with other roof", "Road", "Railway" and "Other impermeable surfaces", and "Vegetation" (Table 1).

Table 1: Land cover nomenclature for 2005/06

Land cover classes in 2005/06		
Level 1	Level 2	Level 3
Urban	Building	Building with red tile roof
		Building with bright roof
		Building with other roof
	Pavement	Railway
		Road
		Other impermeable surfaces
Vegetation	Vegetation	Vegetation

Feature extraction was performed in Feature Analyst 4.2 (by VLS) for ArcGIS (ESRI). The classification is based on a supervised approach. The first step is the manual digitizing of training areas for each class, followed by the definition of parameters like the number of bands to be classified, the type of input representation, and aggregation.

For the extraction, several data sets were used simultaneously as input: pansharp and multispectral QuickBird imagery, the *NDVI* grid, and the nDSM layer. The pansharp QuickBird image is of fundamental importance, because it is the main reflectance layer and determines the scale and resolution (spatial detail) where features can be extracted. The approach selected in this work used, in a first stage, the possibility of classifying the study area in two major classes - “Vegetation”, “Urban” - and in the subsequent stages, the level 3 classes were extracted independently. The parameters that produced the best extraction results for each element type are available in (17).

The feature extraction stage was difficult due to the complex morphology and to the spatial heterogeneity of the study area (18). Several iterations took place after the initial training in order to obtain the final classes. Such operations included removing clutter and adding missing data to allow the classifier to learn and produce a better extraction.

After feature generalization, an accuracy assessment of the quality of the LCM was conducted. Since the goal is to update the built-up classes in the 1998 Cartography, the quality assessment of the land cover extracted from the imagery data set was applied only to the LCM level 2 class “Building”. To evaluate the quality of spatial information automatically extracted from images, based on the concept of reference value, it is necessary to measure levels of compliance with information from an independent source. This reference data was a map obtained by visual interpretation of the same source data. All the discernible features belonging to the class of interest were digitized, without limits of size or shape. To assess the overall thematic quality of building extraction, the spatial overlap between classified and reference data is used.

The analysis indicated an Overall Accuracy of 73%. A Commission Error of 6% was obtained. The Omission Error was 24% and occurred mainly in places where roofs were in the shadow, or were in different states of conservation, or where elevator shafts were present.

Map Updating

Map updating begins by selecting the classes of interest from the 1998 Cartography - “Buildings”, “Annexes” and “Shacks” (BAS) - and then evaluating their status based on two data sets: the nDSM from 2006 and the Land Cover Map from 2005/06 (LCM). The nDSM is used to characterize the average height of every element above ground. From the LCM, only three classes are used: the level 1 classes “Urban” and “Vegetation”, and the level 2 class “Building”. This option is due to the fact that the remaining level 2 class “Pavement” only achieved a moderate overall accuracy of 65% (1), making it not reliable enough for map updating.

The update is based on a change\no-change approach. Since built-up classes are being analysed, only three classes are possible in 2005/06: “No-Change” (the class in 2005/06 is the same as in 1998), “Change to Vegetation” (removed features) or “Change to New Building” (built-up features):

- If an object is labelled as “No-Change”, then its class and geometry are the same as in the original 1998 Cartography;
- If an object is labelled as “Change”, then two classes are possible, “Vegetation” or “New Building”. The built-up objects of 1998 identified as “Vegetation” in the LCM, maintain their geometry and receive a new classification. The objects identified as “New Building”, have their geometry based on the LCM.

The update is carried out using map algebra operations over the available data sets, and follows four hierarchic rules:

- Rule 1 – every object identified as “Buildings”, “Annexes” or “Shacks” in 1998, and having a height above 3 m in 2006, is labelled as No-Change T1 (FromBAS ToBAS);
- Rule 2 – every object identified as “Buildings”, “Annexes” or “Shacks” in 1998, shorter than or equal to 3 m in 2006, and classified as “Urban” in LCM, is labelled as No-Change T2 (FromBAS ToBAS);

- Rule 3 – every object identified as “Buildings”, “Annexes” or “Shacks” in 1998, but classified as “Vegetation” in LCM, is labelled as Change T1 (FromBAS ToVegetation);
- Rule 4 – every object not identified as “Buildings”, “Annexes” or “Shacks” in 1998, but greater than 1 m in 2006, and classified as “Buildings” in LCM, is labelled as Change T2 (ToNewBuilding).

The final map of the study area, updated for 2005/06 (MapUp) according to the previous schema, has three classes: “No-Change”, “Change to Vegetation” and “Change to New Building” (Figure 3).

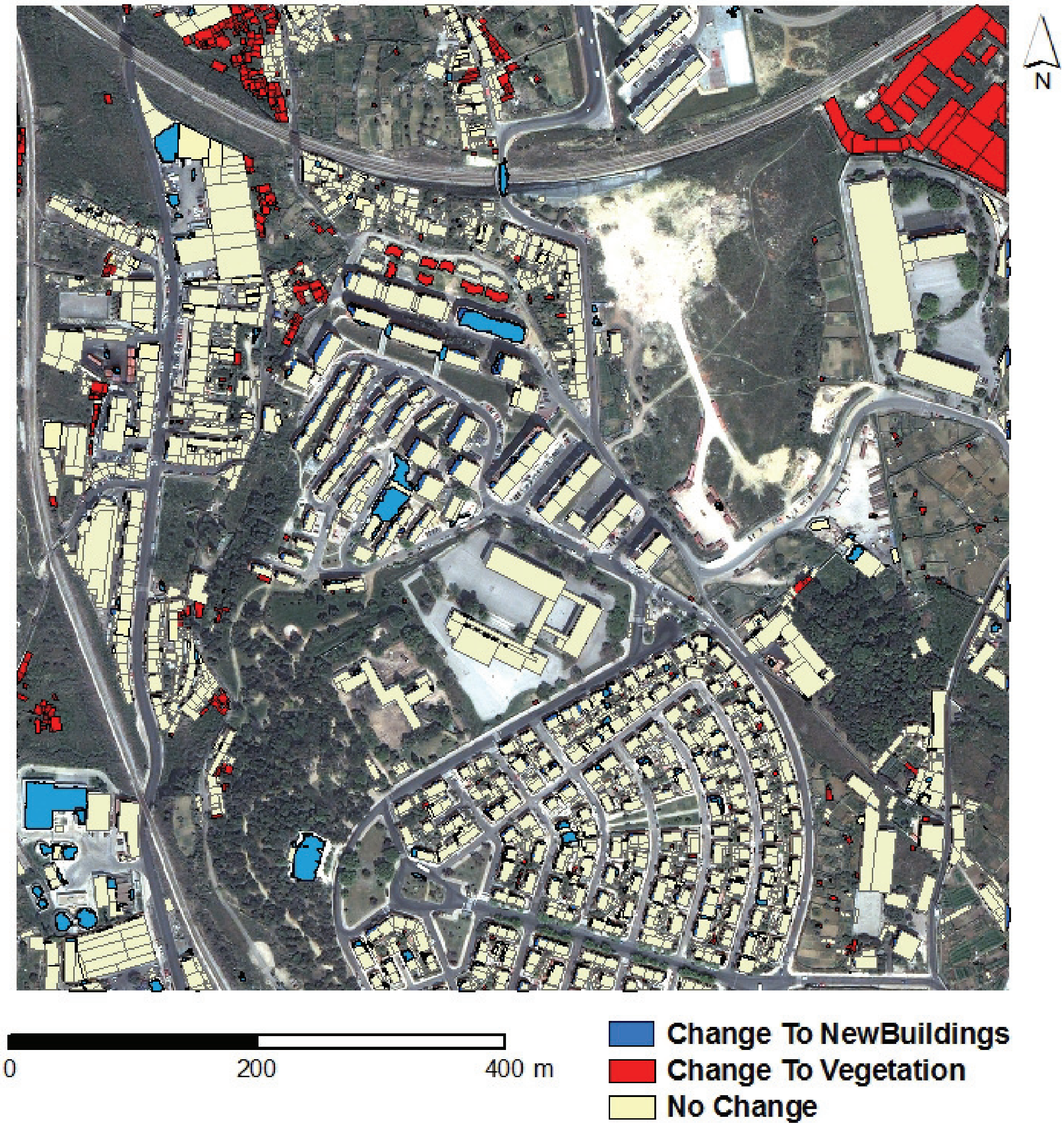

Figure 3: Buildings updated for 2005/2006 (MapUp).

In the period under analysis – 1998 to 2005/06 – the main types of change identified in the study area were: shacks’ eradication and building demolitions (industrial properties), newly built industrial sites (e.g., the wastewater treatment plant, located in the bottom left corner of the map), as well as new residential housing (e.g., two multi-family houses).

Quality of Detection of Building Change

After map updating, its quality was evaluated based on visual interpretation. A census, instead of sampling approach, was conducted in order to fill the error matrix. Two analyses were performed:

one for all objects with an area greater than 20 m^2, and another for all objects with an area greater than 10 m^2 and less than or equal to 20 m^2. This segmentation is intended for evaluating the impact of smaller features in the map's quality. Objects of 10 m^2 or smaller were not evaluated, since many of them are errors introduced by the misregistration between the QuickBird imagery and the nDSM and 1998 Cartography.

Among all objects with an area larger than 20 m^2 that were visually inspected (1239 objects), nine were excluded from the validation, because the final class could not be confirmed with a sufficient level of confidence. From this analysis, it was confirmed that the class "Change To Vegetation" was well mapped. Only three features that were under trees were incorrectly classified as "Change". The "Change To New Building" was also very accurate, with no mistakes. The class "No-Change" was also well mapped, but had 15 misclassified features. From these, 13 objects were in fact demolished buildings that changed to road/pavement in 2005/06.

For further analysis, the results of the validation were grouped into two classes – "Change" and "No-Change" - and an error matrix was populated (Table 2). Several indices were calculated to assess the quality of the objects larger than 20 m^2. The analysis indicates that the updated map has an Overall Accuracy of 99% and a KHAT statistic of 95%.

Table 2: Error matrix for the Change and No-Change objects with areas larger than 20 m^2

Reference / Map	Change (objects)	No-Change (objects)	Total row
Change	198	3	201
No-Change	15	1014	1029
Total column	213	1017	1230
Overall Accuracy = 99%, KHAT = 95%			

The same evaluation was made for those objects with an area larger than 10 m^2 and smaller than or equal to 20 m^2. From the total of 688 objects analysed, 30 were rejected from the validation, because the final land cover class could not be visually confirmed. From the 116 objects classified as "Change To Vegetation", 14 were false changes located under trees. The accuracy of class "Change To New Building" was not very satisfactory, with 41 errors among the 69 validated objects. The "No-Change" class was well mapped, but several errors occurred, once more, in features that had changed to pavement. From the error matrix, the thematic accuracy indices were calculated (Table 3). The results indicate that the quality of the update for small objects is lower than that for objects larger than 20 m^2, but still very high, with an Overall Accuracy of 89% and a KHAT statistic of 70%.

Table 3: Error matrix for the Change and No-Change objects with areas larger than 10 m^2 and smaller than or equal to 20 m^2.

Reference / Map	Change (objects)	No-Change (objects)	Total row
Change	130	55	185
No-Change	19	454	473
Total column	149	509	584
Overall Accuracy = 89%, KHAT = 70%			

CONCLUSIONS

The accuracy of the building change layer was very high. However, in this extracting experience with VHR imagery and Lidar data, several problems were detected. Complex shapes and multilevel structures could not be well identified. Differentiating between building extensions was a difficult task to perform in this semi-automatic environment. The presence of different roof covers and structures in the same building also contributed to a poor identification and delineation of those features. This situation compromised the applicability of the extracted features to directly update larger-scale municipal cartography without further human intervention. Similar conclusions have been reported by other authors (18,19,20). It is obvious that automatic methods gain in speed and cost, but lose in quality. One must choose to slightly compromise the quality and gain in speed, or maintain quality and sacrifice the cost and speed, depending on use. This fact is also present in other studies that deal with the building extraction issue (21,22,3).

The contribution of altimetric data along with spectral data allowed the mapping quality to be improved. In fact, the inclusion of Lidar data was crucial to separate features with different height values, allowing transition rules to be set up for potential changes.

The proposed methodology is based on a semi-automatic verification and update of existing large-scale cartography, available in a GIS format, using recent image data as reference information. The goal was not to provide cartographic data ready for being integrated in the municipal data bases but, to a certain extent, assist the process of map updating.

The advantage of the developed system is that it reduces the manual efforts of a human operator, saving time and, probably, costs, concentrating attention only on those changed areas, and consequently, making it a more efficient process. Furthermore, the semi-automatic system contributes to a more effective decision-making process, through the production of new information on a regular basis. The developed change detection method enables: areas of land cover change to be identified and the type/direction of change to be indicated, and the degree of cartographic outdatedness to be monitored.

For municipal planning, and according to the technical specifications of large-scale cartography (1:5 000 scale and higher), map production based on VHR images and photogrammetry is still necessary to guarantee that each uniquely identified feature is well delineated and stored in the data base as a geometric entity together with a list of attributes. Nevertheless, all land information requires periodical updates. This task involves searching for small areas of change within an image. Using digital photogrammetric workstations and extremely high resolution aerial photography for this change detection process takes up valuable resources (19). In this context, semi-automatic classification of VHR images can make a great contribution by speeding up the change detection process, and alert the technicians for those areas where potential land changes have occurred, thus combining automatic change detection and human-computer interaction.

ACKNOWLEDGEMENTS

This work was performed under the framework of project GeoSat - Methodologies to extract large-scale GEOgraphical information from very high resolution SATellite images, funded by the Foundation for Science and Technology (PTDC/GEO/64826/2006).

The authors would like to thank Logica for the opportunity of using the Lidar data set.

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